NONRESIDENT
TRAINING
COURSE

Aviation Electronics Technician - Basic

NAVEDTRA 14028

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PREFACE

About this course:

This is a self-study course. By studying this course, you can improve your professional/military knowledge, as well as prepare for the Navywide advancement-in-rate examination. It contains subject matter about day-to-day occupational knowledge and skill requirements and includes text, tables, and illustrations to help you understand the information. An additional important feature of this course is its references to useful information to be found in other publications. The well-prepared Sailor will take the time to look up the additional information.

History of the course:

- *Jun 1991: Original edition released.*
- *Mar 2003: Minor revision released.*

Published by
NAVAL EDUCATION AND TRAINING
PROFESSIONAL DEVELOPMENT
AND TECHNOLOGY CENTER

NAVSUP Logistics Tracking Number
0504-LP-022-3690

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CHAPTER 1

PHYSICS

As a Navy technician, you deal with complex machines and equipment. You are expected to understand, operate, service, and maintain these machines and equipment and to instruct new personnel. No matter how complex a machine or item of equipment, its action is based on the application of a few basic principles of physics. To understand, maintain, and repair the equipment and machinery necessary to operate ships and aircraft, you must understand these basic principles.

The physicist finds and defines problems and searches for their solutions. Studying physics teaches a person to be curious about the physical world and provides a means of satisfying that curiosity. The principles of physics apply to the other sciences. Physics is a basic branch of science and deals with matter, motion, force, and energy. It deals with the phenomena that arise because matter moves, exerts force, and possesses energy, and it is the foundation for the laws governing these phenomena. Physics is closely associated with chemistry and depends heavily upon mathematics for many of its theories and explanations.

BASIC CONCEPTS

In the study of physics, specific words and terms have specific meanings that must be understood. If you don't understand the exact meaning of a particular term, you won't understand the principles involved in the use of that term. Once the term is understood, however, you can understand many principles. The first part of this chapter defines some of the physical terms and briefly discusses some of the particular principles that concern technical personnel.

MEASUREMENT

Learning Objective: *Identify units of measurement for magnitude, direction, and time.*

Measurement is an important consideration in all branches of science. To evaluate results, you must often answer the questions "how much, how far, how many, how often, or in what direction." As scientific investigations become more complex, measurements must become more accurate, and new methods must be developed to measure new things.

Measurements may be classed in three broad categories—magnitude, direction, and time. These categories are broken down into several types, each with its own standard units of measurement. Measurements of direction and time are fairly well standardized and have few subdivisions. Magnitude, on the other hand, is an extremely complex measurement category having many classes and subdivisions.

The unit of measurement is just as important as the number that precedes it, and both are necessary to give an accurate description. The two units of measurement most commonly used are the metric and the English. Metric units are usually used to express scientific observations, where the basic unit of distance is the meter (m), the mass is the kilogram (kg), and of time is the second (s). This is called the *meter-kilogram-second* (mks) system. Another widely used metric system uses the centimeter (cm) as the basic unit of distance, the gram (g) as the basic unit of mass, and the second (s) as the basic unit of time, and is called the *centimeter-gram-second* (cgs) system. The English system uses the foot for distance, the pound avoirdupois (weight) for

mass, and the second for time, and is called the *foot-pound-second* (fps) system. Refer to table 1-1 for other frequently used units of measurement.

Q1. What are the three broad categories of measurement?

Q2. What unit of measurement is used to express scientific measurements?

Units of Distance

As an aviation electronics technician, you will use both the English and the metric systems of measurement. For example, radar range is usually expressed in the English system as yards or miles, while wavelength is most often expressed in the metric system, with the meter as the basic unit.

METRIC UNITS OF LENGTH.— Metric units of length are based on the standard meter. In 1960, the 11th General Conference on Weights and Measures adopted an atomic standard for the meter: The meter is the length equal to 1,650,763.73 wavelengths in a vacuum of the radiation corresponding to the transition between the levels $2p_{10}$ and $5d_5$ of an atom of krypton 86.

When large distances are measured, use the kilometer (km), which is 1,000 meters (m) (1 kilometer = 1,000 meters). For smaller measurements, the meter is divided into smaller units. One meter equals 100 centimeters (1 m = 100 cm), and 1 centimeter equals 10 millimeters (1 cm = 10 mm), so 1 meter equals 1,000 millimeters (1 m = 1,000 mm). The table in appendix 3 lists other prefixes used with basic units.

The micrometer (pm) is smaller than the millimeter. It is often the unit used to state the wavelength of light. The micrometer is one-thousandth of a millimeter or one-millionth of a meter, the nanometer is one-thousandth of a micrometer, and picometer is one-thousandth of a nanometer or one-millionth of a micrometer.

Table 1-1.-Frequently Used Units of Measurement

ENGLISH SYSTEM	METRIC SYSTEM	GENERAL
acre	angstrom	ELECTRICAL
Btu (British thermal unit)	calorie	ampere
bushel	dyne	coulomb
dram	erg	decibel
foot	gram	farad
gallon	hectare	henry
hertz	hertz	mho (siemens)
horsepower	hour	ohm
hour	joule	volt
inch	liter	watt
knot	meter	LIGHT
mil	metric ton (1 ,000 kg)	candle
mile	micrometer	candela
minute	micron	lambert
ounce	minute	lumen
peck	newton	MAGNETIC
pint	quintal	gauss
pound	second	gilbert
quart	stere	maxwell
second		rel
slug		
ton (short, 2,000 lb long, 2,240 lb)		
yard		

ENGLISH UNITS OF LENGTH.— The common units of distance in the English system of measurement are inches, feet, yards, and miles, where 1 foot equals 12 inches (1 ft = 12 in.), 1 yard equals 3 feet (1 yd = 3 ft = 36 in.), and 1 mile equals 1,760 yards (1 mile = 1,760 yd = 5,280 ft = 63,360 in.). The nautical mile is 6,076.115 feet. The mil is one-thousandth of an inch.

In 1866 the United States, by an act of Congress, defined the yard to be 3600/3937 part of a standard meter, or in decimal form approximately 0.9144 meter. Therefore, you can make conversions between the other systems by properly multiplying or dividing. Some approximate conversions are listed in table 1-2.

Q3. Match the element being measured with the metric term used to express the measurement.

1. Distance	*a. Kilogram*
2. Time	*b. Second*
3. Mass	*c. Meter*

Q4. What is the English equivalent of 1 meter?

Units of Mass, Weight, and Force

The measure of the quantity of matter that a body contains is called *mass.* The mass of a body does not change. It may be compressed to a smaller volume or expanded by heat, but the quantity of matter remains the same.

The metric unit of mass is based on the gram, since it is equal to the mass of 1 cubic centimeter of pure water at a temperature of 4° Celsius. For practical purposes, this is correct. The U.S. Bureau of Standards has one iridium cylinder, which is identical to the standard kilogram (1,000 gram) cylinder of platinum preserved at the International Bureau of Weights and Measures, near Paris. The standard pound (lb) is the mass equal to 0.4536 kilogram or 453.6 grams.

The mass of a body is constant no matter where the body is located. The *weight* of a body is the force with which it is attracted toward the earth. The body's weight is slightly higher at the poles than at the equator, and becomes less as the body moves away from the earth's surface.

Grams, kilograms, and pounds are used as units of mass. These units are also used to describe the weight of a body by comparing the body's weight to the weight of a standard mass unit. Normally, when an object is described as weighing 1 pound, it means the object has the same pull of gravity that amass of 1 pound would have near the earth's surface at sea level. At sea level, the numerical values of weight and mass of a given object are equal, when expressed in the same units.

Sometimes, the slug is used as the unit of mass. This is the mass that weights 32 pounds at sea level. At sea level, a mass of 1 gram exerts a downward force of 980 dynes because of gravity, and 1 kilogram exerts a downward force of 9.8 newtons. Since 1 kg = 1,000 g, a kilogram exerts a force of 1,000 x 980 dynes, or 980,000 dynes,

Table 1-2.-Conversion Factors for Units of Length

	km	m	cm	mm	in.	ft	yd	mile
1 km =	1	1,000	100,000	$1 \times 10^{+6}$	39,370	3,280.83	1,093.61	0.621369
1 m =	0.001	1	100	1,000	39.37	3.28083	1.09361	6.214×10^{-4}
1 cm =	1×10^{-5}	0.01	1	10	0.3937	0.032808	1.094×10^{-2}	6.214×10^{-6}
1 mm =	1×10^{-6}	1×10^{-3}	0.1	1	0.03937	3.28×10^{-3}	1.094×10^{-3}	6.214×10^{-7}
1 in. =	2.54×10^{-5}	2.54×10^{-2}	2.54	25.4	1	0.08333	0.02777	1.58×10^{-5}
1 ft =	3.048×10^{-4}	0.3048	30.48	304.8	12	1	0.33333	1.89×10^{-4}
1 yd =	9.144×10^{-4}	0.9144	91.44	914.4	36	3	1	5.68×10^{-4}
1 mile =	1.60934	1,609.34	160,934	1,609,340	63,360	5,280	1,760	1

NOTE: When a number is multiplied by a power of ten, the decimal point is moved the number of places represented by the power. A negative power moves the decimal point to the left; a positive power moves it to the right. Thus, 84 x 10^{-2} = .84, and 84 x 10^{2} = 8,400. Simply stated, a power of ten merely moves the decimal point left or right.

which is equal to 9.8 newtons. Therefore, 1 newton equals 100,000 dynes.

The newton can be equated to the English system as follows: 1 newton equals 0.2247 pound-force, or 1 pound-force equals 4.448 newtons.

Its easy to convert between the weight units of the metric system since you only have to move the decimal point through a conversion of 1000:1. For example, 1,000 mg = 1.000 g, 1,000 g = 1.000 kg, and 1,000 kg = 1.000 metric ton. Its harder to convert between weight units of the English system since the pound is divided into 16 ounces and the ounce into 16 drams. The short ton is 2,000 pounds, while the long ton is 2,240 pounds. (Note: The metric ton is fairly close to the long ton; it converts to 2,205 pounds.)

Q5. What is the difference between the mass of a body and the weight of a body?

Q6. What is meant when a person is described as weighing 195 pounds?

Derived Units

Units based on combinations of two or three fundamental units are sometimes expressed as some combination of these units. The watt (unit of power) can be written as the joule (unit of work) per second. The joule could be expressed as newtons (force) times meters (distance), and the watt then becomes newton-meters per second. Likewise, the unit of horsepower could be expressed in foot-pounds per second. **Although there are conversion factors between derived units of the English system and the metric system, fundamental units of the two systems are not combined.** For example, if force is given in pounds and distance in meters, one or the other must be changed before combining them to get work units.

SPEED AND VELOCITY.— One example of a derived unit is the knot, a unit of speed. This unit combines the nautical mile as the unit of distance and the hour as the unit of time. It is derived by dividing the distance traveled by the time required for that travel. For example, if a ship traveled at a constant rate for 15 minutes (0.25 hr) and moved a distance of 6 nautical miles, its speed would be 6/0.25 or 24 knots (kn). The rate of travel (speed) may also be used to solve for distance traveled when time is known. If the above ship traveled 24 knots for 3 hours, it would move 72 nautical miles. Likewise, the time required for moving a certain distance may be determined when the speed is known. A movement of 36 nautical miles by a ship traveling at 24 knots would require 1 hour and 30 minutes (36/24 = 1.5 hr, or or hr 30 min).

Speed is often expressed as two fundamental units such as miles per hour; kilometers per hour; or feet, inches, meters or centimeters per minute or per second. Conversion is a matter of replacing one unit by its equivalent in another unit. For example, a speed of 60 miles per hour (60 mph) is converted to feet per second by replacing the mile with 5,280 feet and the hour with 3,600 seconds. Therefore, a speed of 60 mph = 60 (5,280 ft/3,600 s) = 88 feet per second.

Table 1-3 gives the conversion factors between meters per second (m/s), feet per second (ft/s),

ANSWERS FOR REVIEW QUESTIONS Q1. THROUGH Q4.

A1. a. Magnitude
b. Direction
c. Time

A2. Metric unit of measurement

A3.

ELEMENT	*METRIC TERM*
1. Distance	*c. Meters*
2. Time	*a. Seconds*
3. Mass	*c. Kilograms*

A4. Approximately 1 yard

kilometers per hour (km/hr), miles per hour (mi/hr), and knots.

The terms *speed* and *velocity* are sometimes interchanged. However, velocity is a vector quantity; that is, it is speed in a given direction. For example, a car may move around a circular path with a constant speed while its velocity is continuously changing. When a body moves with constant speed along a straight line whose direction is specified, it is customary to speak of its velocity (which is numerically equal to its speed). When a body moves along a curved path or along a straight path with no reference being made to direction, it is proper to speak of its speed.

WORK AND ENERGY.— Units of work and energy, also derived units, are the product of the units of force and distance. In the cgs system, the *erg* is the work done by a force of 1 dyne acting through a distance of 1 centimeter. The *joule* is the unit of work in the mks system where 1 newton acts through a distance of 1 meter. Since 1 newton equals 100,000 dynes and 1 meter equals 100 centimeters, the joule is equal to 10 million ergs.

In the English system, the unit *foot-pound* is defined as *the work done in lifting 1 pound a distance of 1 foot against the force of gravity.* For example, the work done in lifting a mass of 5 pounds vertically 4 feet is 20 foot-pounds (5 lb x 4 fg = 20 ft-lb). (Do not confuse this foot-pound with the one used to measure torque.) Since 1 pound-force equals 4.448 newtons, and 1 foot equals 0.3048 meter, 1 foot-pound is approximately 1.356 joules.

The calorie is the heat energy required to raise the temperature of 1 gram of water 10 Celsius. The British thermal unit (Btu) is the heat energy required to raise the temperature of 1 pound of water 10 Fahrenheit, and it is equivalent to 252 calories (and, incidentally, to 777.8 foot-pounds of mechanical energy).

POWER.— All units of power include measurements of force, distance, and time because power equals work (which is force times distance) divided by time. The watt is the unit of power frequently used with electrical units, and it is also the rate of doing 1 joule of work in 1 second. Therefore, if a force of 5 newtons acts through a distance of 12 meters in 3 seconds, the power required is 20 watts, or

$$P = \frac{5 \times 12}{3} = 20.$$

If the same work is done in 2 seconds, 30 watts are required.

The horsepower is a larger unit of power. It is equal to 550 foot-pounds per second, or 746 watts; therefore, 1 foot-pound per second is 746/550 watts. or about 1.356 watts.

OTHER UNITS.— Magnitude measurement is complex. Consider a few examples of measurement dealing with magnitude: weight, distance, temperature, voltage, size, loudness, and brightness. Then consider measurements based on combinations of magnitude: density (weight per unit volume), pressure (force per unit area), thermal expansion (increase in size per degree change in temperature), and so forth. Also, measurements combine categories. The flow of liquids is measured in volume per unit of time, speed is measured in distance per unit of time, rotation is measured in revolutions per units of time (second, minute, etc.), and frequency is expressed in cycles per second (hertz).

The importance of measurement and the selection of the proper unit of measurement cannot be overemphasized. Several systems of measurement further complicate matters. For example, distance may be measured in feet or in meters; weight, in pounds or in kilograms; capacity, in quarts or in liters; temperature, in

Table 1-3.-Conversion Factors for Speed and Velocity

Speed	m/s	ft/s	km/hr	mi/hr	knots
1 m/s =	1	3.281	3.6	2.24	1.94
1 ft/s =	0.3048	1	1.0973	0.6818	0.5921
1 km/hr =	0.27778	0.9113	1	0.6214	0.5396
1 mi/hr =	0.44704	1.4667	1.6093	1	0.8684
1 knot =	0.5148	1.689	1.853	1.152	1

degrees Fahrenheit, Celsius, or Rankine, or in Kelvin units; density, in pounds per cubic foot or in grams per cubic centimeter; and angles, in degrees or in radians.

Q7. How are derived units constructed?

Q8. Speed and velocity are sometimes used us if they meant the same thing. What is the difference between speed and velocity?

Q9. What term is defined as the work done in lifting 1 pound a distance of 1 foot against the force of gravity?

Q10. List the measurements included in the units of power.

MATTER AND ENERGY

Learning Objective: *Identify general physics laws and general properties of matter, density and specific gravity, pressure and total force, and kinetic energy.*

Matter is defined as *anything that occupies space and has weight or mass.* In its natural state, matter is a solid, a liquid, or a gas. All matter is composed of small particles called *molecules and atoms.* Matter may be changed or combined by various methods—physical, chemical, or nuclear. Matter has many properties; properties possessed by all forms of matter are called *general properties,* while those properties possessed only by certain classes of matter are referred to as *special properties.*

Energy is defined as *the capacity for doing work.* It is classified in many ways; but in this training manual (TRAMAN), energy is classified as mechanical, chemical, radiant, heat, light, sound, electrical, or magnetic. Energy is constantly being exchanged from one object to another and from one form to another.

Law of Conservation

Matter may be converted from one form to another with no change in the total amount of matter. Energy may also be changed in form with no resultant change in the total quantity of energy. In addition, *although the total amount of matter and energy remains constant, matter can be converted into energy or energy into matter.* This statement is known as *the law of conservation for energy and matter.* The basic mathematical equation that shows the relationship between matter and energy is $E = mc^2$, where E represents energy, m represents mass, and c represents the velocity of light.

From this equation, you can see that the destruction of matter creates energy, and that the creation of matter requires expenditure of energy. You can also see that a given quantity of matter is the equivalent of some amount of energy. In common usage it is usually stated that matter possesses energy.

General Properties of Matter

All forms of matter possess certain properties. In the basic definition, matter occupies space and has mass (inertia). Those terms represent most, if not all, of the general properties of matter.

SPACE.— The amount of space occupied by, or enclosed within, the bounding surfaces of a body is called *volume.* In the study of physics, this concept is modified somewhat to be completely accurate. You know that matter is a solid, a liquid, or a gas, and each has its own special properties. Liquids and solids tend to retain their volume when physically moved from one container to another, while gases tend to assume the volume of the container.

All matter is composed of atoms and molecules. These particles are composed of still smaller particles separated from each other by empty

ANSWERS FOR REVIEW QUESTIONS A5. AND A6.

A5. The mass of the body is the measure of the quantity of matter that the body contains, and it does not change. The weight of a body is the force that attracts toward earth.

A6. The person has the same pull of gravity that a mass of 195 would have when located near sea level.

space. This idea is used to explain two general properties of matter—impenetrability and porosity.

Two objects cannot occupy the same space at the same time; this is known as the *impenetrability of matter.* The actual space occupied by the individual subatomic particles cannot be occupied by any other matter. The impenetrability of matter may, at first glance, seem invalid when a cup of salt is poured into a cup of water, as the result is considerably less than two cups of salt water. However, matter has an additional general property called *porosity,* which explains this apparent loss of volume: The water simply occupies space between particles of salt. Porosity is present in all material, but to a wide range or degree. Generally, gases are extremely porous and liquids only slightly so; solids vary over a wide range, from the sponge to the steel ball.

INERTIA.— Every object tends to maintain a uniform state of motion. A body at rest never starts to move by itself; a body in motion will maintain its speed and direction unless it is caused to change. To cause a body to change from its condition of uniform motion, a push or a pull must be exerted on it. This requirement is due to that general property of all matter known as *inertia.* The greater the tendency of a body to maintain uniform motion, the greater its inertia. The quantitative measure of inertia is the mass of the body.

Acceleration.— Any change in the state of motion of a body is known as *acceleration.* In other words, acceleration is the rate of change in the motion of a body and may represent either an increase or a decrease in speed and/or a change in the direction of motion.

The amount of acceleration is stated as the change of velocity divided by the time required to make the change. For example, if a car traveling 15 mph increased its speed to 45 mph in 4 seconds, the 30-mph increase divided by 4 seconds gives 7.5 miles per hour per second as its acceleration. By converting the 30 mph to 44 feet per second, you could express the acceleration as 11 feet per second per second or as $11 ft/s^2$.

Force.— Force is the action or effect on a body that tends to change the state of motion of the body acted upon. A force tends to move a body at rest; it tends to increase or decrease the speed of a moving body; or it tends to change the body's direction of motion. The application of a force to a body does not necessarily result in a change in the state of motion; it may only **tend** to cause such a change.

A force is any push or pull that acts on a body. Water in a can exerts a force on the sides and bottom of the can. A tugboat exerts a push or a pull (force) on a barge. A man leaning against a bulkhead exerts a force on the bulkhead. In these examples, a physical object is exerting the force and is in direct contact with the body upon which the force is being exerted. Forces of this type are called *contact forces.*

Other forces act through empty space without having contact and, at times, without seeming to have any mass associated with them. The force of gravity exerted on a body by the earth *(weight)* is an example of a force acting on a body through empty space. Such a force is known as an *action-at-a-distance force.* Electric and magnetic forces are other examples of action-at-a-distance forces. The space through which these action-at-a-distance forces are effective is called a *force field.*

Force is a vector quantity; that is, it has both direction and magnitude. A force is completely described when its magnitude, direction, and point of application are given. In a force vector diagram, the starting point of the line represents the point of application of the force.

Any given body, at any given time, is subjected to many forces. In many cases, all of these forces may be combined into a single **resultant** force that is used to determine the total effect on the body. Because of its extremely large mass, the earth exerts such a large gravitational attraction that it is practical to ignore all other attractions and use the earth's gravitational attraction as the resultant.

Gravitational attraction is exerted by each body on the other. When there is a great difference in the mass of two bodies, we think of the force as being exerted by the larger mass on the smaller mass. Therefore, it is commonly stated that the earth exerts a gravitational force of attraction on a body. The gravitational attraction exerted by the earth is called *gravity.*

The gravitational force exerted by the earth on an object is called the *weight* of that object and is expressed in force units. In the English system, force is expressed in pounds. If an object is attracted by a gravitational force of 160 pounds, the object weighs 160 pounds. The gravitational force between two objects decreases as the distance between them increases; therefore, an object weighs less a mile above the surface of the

ocean than it weighs at sea level, and it weighs more a mile below sea level.

Q11. What relationship is defined by the equation $E = mc^2$?

Q12. Name the concept of the statement "Two objects can't occupy the same space at the same time."

Q13. What action must be applied to an object to overcome inertia?

Q14. What is meant by the term acceleration?

Q15. Why is force considered a vector quantity?

Q16. In the English system of measurement, what force is expressed in pounds?

Density and Specific Gravity

The density of a substance is its weight per unit volume. A cubic foot of water weighs 62.4 pounds; the density of water is 62.4 pounds per cubic foot. (In the metric system, the density of water is 1 gram per cubic centimeter.)

The **specific gravity** (sp gr) of a substance is the ratio of the density of the substance to the density of water and is expressed by the equation

$$\text{specific gravity} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}.$$

Specific gravity is not expressed in units of measurement, but as a pure number. For example, if a substance has a specific gravity of 4, 1 cubic foot of the substance weighs 4 times as much as a cubic foot of water, 62.4 times 4 = 249.6 pounds. In metric units, 1 cubic centimeter of a substance with a specific gravity of 4 weighs 1 times 4, or 4 grams. (Note that in the metric system of units, the specific gravity of a substance has the same numerical value as its density.)

Specific gravity and density are independent of the size of the sample under consideration and depend only upon the substance of the sample. See table 1-4 for typical values of specific gravity for various substances.

Table 1-4.-Typical Values of Specific Gravity

SUBSTANCE	SPECIFIC GRAVITY
Aluminum	2.7
Brass	8.6
Copper	8.9
Gold	19.3
Ice	0.92
Iron	7.8
Lead	11.3
Platinum	21.3
Silver	10.5
Steel	7.8
Mercury	13.6
Ethyl alcohol	0.81
Water	1.00

ANSWERS FOR REVIEW QUESTIONS Q7. THROUGH Q10.

A7. They are based on combinations of two or three fundamental units expressed as some combination of these units. For example, the watt could be written as a joule per second.

A8. Velocity is a vector quantity; it is speed in a given direction, while speed is a body moving along a path with no reference being made to direction.

A9. Foot-pound

A10. a. Force
b. Distance
c. Time

A great deal of ingenuity is often needed to measure the volume of irregularly shaped bodies. Sometimes it is practical to divide a body into a series of regularly shaped parts, then apply the rule that the total volume is equal to the sum of the volumes of all individual parts. Figure 1-1 shows another method of measuring the volume of small irregular bodies. The volume of water displaced by a body submerged in water is equal to the volume of the body.

A somewhat similar consideration is possible for floating bodies. A floating body displaces its own weight of liquid. This statement may be proved by filling a container to the brim with liquid, then gently lowering the body to the surface of the liquid and catching the liquid that flows over the brim. Weigh the liquid displaced and the original body and prove the truth of the statement.

Pressure and Total Force

Pressure and force, while related topics, are not the same thing. A weight of 10 pounds resting on a table exerts a force of 10 pounds. However, the shape of the weight determines the effect of the weight. If the weight consists of a thin sheet of steel resting on a flat surface, the effect is quite different from the effect of the same sheet of steel resting on a sharp corner.

Pressure is the distribution of a force with respect to the area over which that force is distributed. Pressure is defined as the force per unit of area, or P = F/A. A flat pan of water with a bottom area of 24 square inches and a total weight of 72 pounds exerts a total force of 72 pounds, or a pressure of 72/24 or 3 pounds per square inch, on a flat table. If the pan is balanced on a block with a surface area of 1 square inch, the pressure is 72/1 or 72 pounds per square inch.

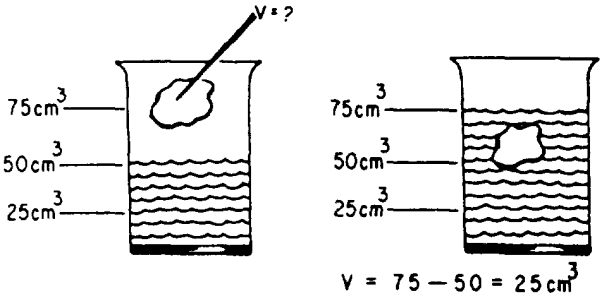


Figure 1-1.-Measuring the volume of an irregular object.

An aluminum pan with a thin bottom is suitable for use on a flat surface, but may be damaged if placed on the small block.

This concept explains why a sharp knife cuts more easily than a dull one. The smaller area concentrates the applied force (increases the pressure) and penetrates more easily. For hydraulic applications, the relationship between pressure and force is the basic principle of operation. In enclosed liquids under pressure, the pressure is equal at every point on the surfaces of the enclosing container; therefore, the force on a given surface is dependent on the area.

Kinetic Energy

Moving bodies possess energy because they are capable of doing work. The energy of mass in motion is called *kinetic* energy, and may be expressed by the equation

$$\text{kinetic energy} = 1/2\ mv^2$$

where m represents the mass of the body, and v is the velocity of its motion.

When the moving body is stopped, it loses its kinetic energy. The energy is not destroyed, but is merely converted into other forms of energy, such as **heat** and **potential** energy. Remember, bodies at rest also possess energy by virtue of their position. You will learn more about **kinetic** energy and **potential** energy later in this chapter.

Q17. How is the density of a substance described?

Q18. How is the specific gravity of a substance described?

Q19. Moving bodies have energy because they can do work. What term describes the energy of mass in motion?

STRUCTURE OF MATTER

Learning Objective: *Identify the various elements, compounds, and states of matter as they affect the structure of matter.*

All matter is composed of atoms, and atoms are composed of smaller subatomic particles. The subatomic particles of major interest in elementary physics are the electron, the proton,

and the neutron. They may be considered electrical in nature, with the proton representing a positive charge, the electron representing a negative charge, and the neutron being neutral (neither positive nor negative). The composition of matter follows a consistent pattern for all atoms; however, the detailed arrangement of subatomic particles is different for each distinct substance. The combination and the arrangement of the subatomic particles determine the distinguishing chemical and physical characteristics of a substance.

The protons and the neutrons of an atom are closely packed together in the atom's nucleus (core), and the electrons revolve around the nucleus. Atoms are normally considered to be electrically neutral; that is, they normally contain an equal number of electrons and protons. This condition is not present all the time. Atoms that contain an equal number of electrons and protons are called *balanced* atoms; those with an excess (too many) or a deficiency (too few) of electrons are called *negative and positive ions.*

The proton and the neutron have approximately the same mass, approximately 1,836 times the mass of an electron. In any atom, nearly all the mass is contained in the nucleus. Normally, any change in the composition of the atom involves a change in the number or arrangement of the electrons (due to their smaller mass, electrons are more easily repositioned than protons). A most notable exception is in the field of nuclear physics, or nucleonics. In chemistry and in general physics (including electricity and electronics), the electron complement is usually dealt with.

Q20. What gives a substance its distinguishing characteristics?

Q21. List the three subatomic particles of the atom.

Q22. What is a balanced atom?

ELEMENTS

The word *element* means any of about 100 substances that make up the basic substances of all matter. Two or more elements may combine chemically to form a *compound,* and any combination that does not result in a chemical

ANSWERS FOR REVIEW QUESTIONS Q11. THROUGH Q19.

A11. The law of conservation for energy and matter which states that "Although the total amount of matter and energy remains constant, matter can be converted into energy or energy into matter."

A12. Impenetrability of matter.

A13. A push or pull that exerts a force on the body.

A14. An increase or decrease in speed and/or a change in direction of motion.

A15. Because it has both direction and magnitude.

A16. The gravitational force exerted by the earth on the body, known as weight of that body, expressed in force units.

A17. It is its weight per unit volume.

A18. It is the ratio of the density of the substance to the density of water.

A19. Kinetic energy.

reaction between the different elements is called a *mixture.* The atom is the smallest unit that exhibits the distinguishing characteristics of an element. An atom of any one element differs from an atom of any other element in the number of protons in the nucleus. All atoms of a given element contain the same number of protons. Therefore, the number of protons in the nucleus determines the type of matter. Elements are frequently tabulated according to the number of protons they contain. The number of protons in the nucleus of the atom is referred to as the *atomic number* of the element.

Nucleus

The study of the nucleus of the atom, known as *nucleonics* or *nuclear physics,* is the subject of extensive modern investigation. Experiments usually involve the bombardment of the nucleus of an atom, using various types of nuclear particles. By doing this, the composition of the nucleus is changed, usually resulting in the release of energy. The change to the nucleus may occur as an increase or a decrease in the number of protons and/or neutrons.

If the number of protons is changed, the atom has become an atom of a different element. This process, called transmutation, is the process sought by the alchemists of the Middle Ages in their attempts to change various metals into gold. Scientists of that period believed transmutation could be accomplished by chemical means, giving impetus to the development of chemistry.

If, on the other hand, only the number of neutrons in the nucleus is changed, the atom remains an atom of the same element. Although all of the atoms of any particular element have the same number of protons (atomic number), atoms of certain elements may contain various numbers of neutrons. Normally, an atom of hydrogen (the sole exception to the rule that all atoms are composed of three kinds of subatomic particles) contains a single proton and a single electron, but no neutrons. However, some hydrogen atoms **do** contain a neutron. Such atoms (although they are atoms of hydrogen) are known as *deuterium, or heavy hydrogen.* (They are called **heavy** because the addition of the neutron has approximately doubled the weight of the atom.) The atomic weight of an atom is an indication of the total number of protons and neutrons in the atomic nucleus.

Atoms of the same element but with different atomic weights are called *isotopes.* Nearly all elements have several isotopes; some are common, and some are rare. A few of the isotopes occurring naturally and most of those produced by nuclear bombardment are radioactive or have unstable nuclei. These unstable isotopes undergo a spontaneous nuclear bombardment, which eventually results in either a new element or a different isotope of the same element. The rate of spontaneous radioactive decay is measured by *half-life.* Half-life is the time required for one-half the atoms of a sample of radioactive material to change (by spontaneous radioactive decay) into a different substance. Uranium, after a few billion years and several substance changes, becomes lead.

Electron Shells

The physical and chemical characteristics of an element are determined by the number and distribution of electrons in the atoms of that element. The electrons are arranged in successive groups of electron shells around the nucleus. Each shell can contain no more than a specific number of electrons. An **inert** element (one of the few gas elements that do not combine chemically with any other element) is a substance in which the outer electron shell of each atom is completely filled. In all other elements, one or more electrons are missing from the outer shell. An atom with only one or two electrons in its outer shell can be made to give up those electrons. An atom whose outer shell needs only one or two electrons to be completely filled can accept electrons from another element that has one or two **extras.**

The concept of *needed* or *extra* electrons arises from the basic fact that all atoms have a tendency toward filling their outer shell. An atom whose outer shell has only two electrons may have to collect six additional ones (no easy task, from an energy standpoint) to have the eight required for that shell to be full. Or, and this is easier from an energy standpoint, the two electrons in the outer shell can be given up, and the full shell next to it serves as the new outer shell. In chemical terminology, this concept is called *valence,* which is the prime determining factor in predicting chemical combinations.

Q23. How is the atomic number of an element determined?

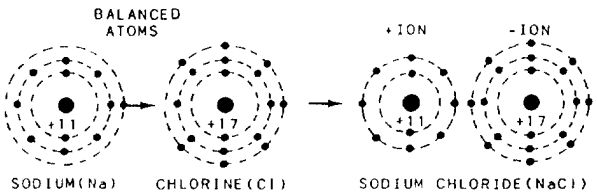
Q24. How is the atomic weight of an element determined?

Q25. The outer electron shell of each atom of an element is completely filled. What type of element is this?

COMPOUNDS AND MIXTURES

Under certain conditions, two or more elements are brought together and united chemically to form a **compound.** The resulting substance may differ widely from its component elements. For example, ordinary drinking water is formed by the chemical union of two gases—hydrogen and oxygen. When a compound is produced, two or more atoms of the combining elements join chemically to form the molecule that is typical of the new compound. The molecule is the smallest unit that exhibits the distinguishing characteristics of a compound.

The combination of sodium and chlorine to form the chemical compound sodium chloride (common table salt) is a typical example of the formation of molecules. Sodium is a highly caustic, poisonous metal whose atom contains 11 electrons. Its outer shell consists of one electron (a valence of +1). Chlorine is a highly poisonous gas whose atom has 17 electrons, but it lacks a single electron (a valence of –1) to fill its outer shell. When the atom of sodium gives up its extra electron, it becomes a positively charged ion. (It has lost a unit of negative charge.) The chlorine atom, having taken on this unit of negative charge (electron) to fill its outer shell, becomes a negative ion. Since opposite electric charges attract, the ions stick together to form a molecule of the compound sodium chloride.



Common Table Salt

NOTE: The attracting force that holds the ions together in the molecular form is known as the *valence bond,* a term that is frequently encountered in the study of transistors.

In the chemical combination of sodium chloride, there is no change in the nucleus of either atom; the only change is in the distribution of electrons between the outer shells of the atoms. Also, the total number of electrons has not changed, although there has been a slight redistribution. Therefore, the molecule is electrically neutral and has no resultant electrical charge.

ANSWERS FOR REVIEW QUESTIONS Q20. THROUGH Q25.

A20. The combination and arrangement of the subatomic particles.

A21. Electron, proton, and neutron.

A22. An atom that contains an equal number of protons and neutrons.

A23. By the number of protons in its nucleus.

A24. By the number of protons and neutrons in its nucleus.

A25. Inert.

Not all chemical combinations of atoms are on a one-for-one basis. In the case of drinking water, two atoms of hydrogen (each with a valence of +1) combine with a single atom of oxygen (valence of –2) to form a single molecule of water. Some of the more complex chemical compounds consist of many elements, with various numbers of atoms of each. All molecules, like all atoms, are normally considered to be electrically neutral. There are some exceptions to this rule, however, specific cases of interest are the chemical activity in batteries.

Elements or compounds may be physically combined without necessarily undergoing any chemical change. Grains of finely powdered iron and sulfur stirred and shaken together retain their own identity as iron or sulfur. Salt dissolved in water is not a compound; it is merely salt dissolved in water. Each chemical substance retains its chemical identity, even though it may undergo a physical change. This is the typical characteristic of a *mixture*.

Q26. Name the smallest unit that exhibits the distinguishing characteristics of a compound.

Q27. In forming a compound, what part of the atom changes?

STATES OF MATTER

Matter is classified and grouped in many ways. One such classification is according to their natural state—solid, liquid, or gas. This classification is important because of the common characteristics possessed by substances in one group that distinguish them from substances in the other groups. However, the usefulness of the classification is limited because most substances can assume any of the three forms.

The molecules of all matter are in constant motion; this motion determines the state of matter. The moving molecular particles in all matter possess kinetic energy of motion. The total of kinetic energy is considered the equivalent of the quantity of heat in a sample of the substance. When heat is added, the energy level is increased, and molecular agitation (motion) is increased. When heat is removed, the energy level decreases, and molecular motion diminishes.

In solids, the molecular motion is restricted by the rigidity of the crystalline structure of the material. In liquids, molecular motion is somewhat less restricted, and the substance as a whole is permitted to **flow.** In gases, molecular motion is almost entirely random; the molecules are free to move in any direction and are almost constantly colliding with each other and the surfaces of the container.

Solids

A solid tends to retain its size and shape. Any change in these values requires the exchange of energy. The common properties of a solid are cohesion and adhesion, tensile strength, ductility, malleability, hardness, brittleness, and elasticity. Ductility is a measure of the ease with which the material can be drawn into a wire. Malleability refers to the ability of some materials to assume new shape when pounded. Hardness and brittleness are self-explanatory terms. The remaining properties are discussed in the following paragraphs.

COHESION AND ADHESION.— Cohesion is the molecular attraction between like particles throughout a body, or the force that holds any substance or body together. Adhesion is the molecular attraction existing between surfaces of bodies in contact, or the force that causes unlike materials to stick together.

Different materials possess different degrees of cohesion and adhesion. In general, solid bodies are highly cohesive but only slightly adhesive. Fluids (liquids and gases) are usually highly adhesive but only slightly cohesive. Generally, a material having one of these properties to a high degree will possess the other property to a relatively low degree.

TENSILE STRENGTH.— The cohesion between the molecules of a solid explains the property called *tensile strength.* This is a measure of the resistance of a solid to being pulled apart. Steel possesses this property to a high degree and is very useful in structural work. When a break does occur, the pieces of the solid cannot be stuck back together because pressing them together does not bring the molecules into close enough contact to restore the molecular force of cohesion. However, melting the edges of the break (welding) allows the molecules on both sides of the break to flow together. This brings them once again into the close contact required for cohesion.

ELASTICITY.— If a substance will spring back to its original form after being deformed,

it has the property of elasticity. This property is desirable in materials to be used as springs. Steel and bronze are examples of materials that exhibit this property.

All solids, liquids, and gases have elasticity of compression to some degree. The closeness of the molecules in solids and liquids makes them hard to compress, but gases are easily compressed because the molecules are farther apart.

Liquids

The outstanding characteristic of a liquid is its tendency to retain its own volume while assuming the shape of its container, A liquid is considered almost completely flexible and highly fluid.

Liquids are practically incompressible. Applied pressure is transmitted through them instantaneously, equally, and undiminished to all points on the enclosing surfaces. The hydraulic system is an example of liquids used in aircraft. The system is used to increase or decrease input forces, providing an action similar to that of mechanical advantage in mechanical systems. The fluidity of the hydraulic liquid permits placement of the component parts of the system at widely separated points when necessary. A hydraulic power unit can transmit energy around corners and bends without the use of complicated gears and levers. The system operates with a minimum of slack and friction, which are often excessive in mechanical linkages. Uniform action is obtained without vibration, and the operation of the system remains largely unaffected by variations in load.

Gases

The most notable characteristics of a gas are its tendency to assume not only the shape but also the volume of its container, and the definite relationship that exists between the volume, pressure, and temperature of a confined gas.

The ability of a gas to assume the shape and volume of its container is the result of its extremely active molecular particles, which are free to move in any direction. Cohesion between gas molecules is extremely small, so the molecules tend to separate and distribute themselves uniformly throughout the volume of the container. In an unpressurized container of liquid, pressure is exerted on the bottom and the sides of the container up to the level of the liquid. In a container of gas, however, the pressure is also exerted against the top surface, and the pressure is equal at all points on the enclosing surfaces.

The relationship of the volume, pressure, and temperature of confined gas is explained by Boyle's law, Charles' law, and the general law for gases.

Many laboratory experiments based on these laws make use of the ideas of *standard pressure* and *standard temperature.* These are not natural standards, but are standard values selected for convenience in laboratory usage. Standard values are generally used at the beginning of an experiment or when a temperature or a pressure is to be held constant. Standard temperature is 0°C, the temperature at which pure ice melts. Standard pressure is the pressure exerted by a column of mercury 760 millimeters high. In many practical uses, these standards must be changed to other systems of measurement.

All calculations based on the laws of gases make use of *absolute* temperature and pressure. These topics require a somewhat more detailed explanation.

GAS PRESSURE.— Gas pressure is indicated in either of two ways—absolute pressure or gauge pressure. Since the pressure of an absolute vacuum is zero, any pressure measured with respect to this reference is referred to as *absolute pressure.* In this TRAMAN, this value represents the actual pressure exerted by the confined gas.

At sea level the average atmospheric pressure is approximately 14.7 pounds per square inch

ANSWERS FOR REVIEW QUESTIONS Q26. AND Q27.

A26. Molecule.

A27. The electron outer shell only. There is no change in the nucleus of either atom, and the total number of electron 's hasn't changed, they've been rearranged.

(psi). This pressure would, in a mercurial barometer, support a column of mercury 760 millimeters in height. Normal atmospheric pressure is the standard pressure. However, the actual pressure at sea level varies considerably; and the pressure at any given altitude may differ from that at sea level. Therefore, it is necessary to take into consideration the actual atmospheric pressure when converting absolute pressure to gauge pressure (or vice versa).

When a pressure is expressed as the difference between its absolute value and that of the local atmospheric pressure, the measurement is designated *gauge* pressure and is usually expressed in pounds **per square inch gauge (psig).** Gauge pressure is converted to absolute pressure by adding the local atmospheric pressure to the gauge pressure.

ABSOLUTE ZERO.— Absolute zero, one of the fundamental constants of physics, is usually expressed as –273°C. It is used to study the kinetic theory of gases. According to kinetic theory, if the heat energy of a given gas sample were progressively reduced, molecular motion would cease at some temperature. If accurately determined, this temperature could then be taken as a natural reference, or **a true absolute zero value.**

Experiments with hydrogen indicate that if a gas were cooled to –273.16°C (use -273°C for most calculations), all molecular motion would cease and no additional heat could be extracted from the substance. At this point, both the volume and the pressure of gas would shrink to zero. When temperatures are measured with respect to the absolute zero reference, they are expressed in the absolute, or Kelvin, scale. Therefore, absolute zero may be expressed either as OK or as –273°C.

BOYLE'S LAW.— The English scientist, Robert Boyle, was among the first to study what he called the *springiness of air.* By direct measurement, he discovered that when the temperature of an enclosed sample of gas was kept constant and the pressure was doubled, the volume was reduced to half the former value. Conversely, when the applied pressure was decreased, the volume was increased. From these observations, he concluded that *for a constant temperature, the product of the volume and pressure of an enclosed gas remains constant.* Boyle's law (fig. 1-2, view A) is normally stated: "The volume of an enclosed dry gas varies inversely with its pressure, provided the temperature remains constant."

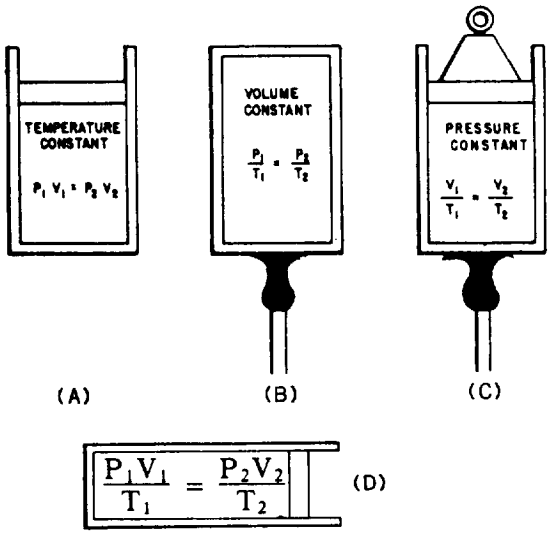


Figure 1-2.-The general gas law.

CHARLES' LAW.— The French scientist, Jacques Charles, provided the foundation for the modern kinetic theory of gases. He found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant (fig. 1-2, view B).

Any change in the temperature of a gas causes a corresponding change in volume; therefore, if a given sample of a gas were heated while confined within a given volume, the pressure would increase. In actual experiments, the increase in pressure was approximately 1/273 of the 0°C pressure for each 1°C increase. Because of this fact, it is normal practice to state this relationship in terms of absolute temperature. The equation (fig. 1-2, view C) means that with a constant volume, the absolute pressure of a gas varies directly with the absolute temperature.

GENERAL GAS LAW.— Look at figure 1-2. The facts about gases covered in the preceding sections are summed up and shown in this figure. Boyle's law is shown in view A of the figure, while the effects of temperature changes on pressure and volume (Charles' law) are shown in views B and C, respectively.

By combining Boyle's and Charles' laws, you can derive a single expression that states all the information contained in both laws. This

expression is the *general gas equation* (fig. 1-2, view D).

NOTE: The capital P and T signify absolute pressure and temperature, respectively.

Refer to figure 1-2 again. Here, you can see that the three equations are special cases of the general equation. If the temperature remains constant, T_1 equals T_2, and both are eliminated from the general formula, it reduces to the form shown in view A. When the volume remains constant, V_1 equals V_2, thereby reducing the general equation to the form given in view B. Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in view C.

The general gas law applies only when one of the three measurements remains constant. When a gas is compressed, the work of compression is done upon the gas. Work energy is converted to heat energy in the gas so that dynamic heating of the gas takes place. Experiments show that when air at 0°C is compressed in a nonconducting cylinder to half its original volume, its rise in temperature is 90°C, and when compressed to one-tenth, its rise is 429°C.

The general gas law applies with exactness only to ideal gases in which the molecules are assumed to be perfectly elastic. However, it describes the behavior of actual gases with sufficient accuracy for most practical purposes.

Q28. List the states of matter.

Q29. List the common properties of solids.

Q30. List the advantages of liquids as applied to aviation.

Q31. What is one of the main uses of absolute zero?

Q32. List the absolute zero points on the Kelvin and Celsius scales.

Q33. Name the person who formulated the following conclusion: "For a constant temperature, the product of the volume and pressure of an enclosed gas remains constant."

Q34. Charles' law states that _____.

MECHANICS

Learning Objective: *Identify terms and recognize concepts involved with the mechanics of force, mass, and motion.*

Mechanics is the branch of physics that deals with the ideas of force, mass, and motion. Normally considered the fundamental branch of physics, it deals with matter. Many of its principles and ideas may be seen, measured, and tested. All of the other branches of physics are also concerned with force, mass, and motion; so if you understand this section, you will understand later sections of this chapter.

FORCE, MASS, AND MOTION

Each particle in a body is acted upon by gravitational force. In every body, there is one point at which a single force, equal to the gravitational force and directed upward, would sustain the body in a condition of rest. This point is known as the *center of gravity* (cg). It represents the point at which the entire mass of the body appears to be concentrated. The gravitational effect is measured from the center of gravity. In symmetrical objects of uniform mass, this is the geometrical center. In the case of the earth, the center of gravity is near the center of the earth.

When considering the motion of a body, the path followed by the center of gravity is "described." The natural tendency of a moving body is to move so that the center of gravity travels in a straight line. Movement of this type is called *linear* motion. However, some moving bodies do not move in a straight line, but move in an arc or a circular path. Circular motion falls into two general classes—rotation and revolution.

Objects come in many different shapes, and to discuss rotary and revolutionary motion, the location of the center of gravity with respect to the body must be considered. As you read the following section, refer to figure 1-3.

In view A, the center of gravity of a ball coincides with the physical center of the ball. In the flat washer (view B), the center of gravity does not coincide with any part of the object but is located at the center of the hollow space inside the ring. In irregularly shaped bodies, the center of gravity may be difficult to locate exactly.

Look at figure 1-4. If the body is completely free to rotate, the center of rotation coincides with the center of gravity. However, the body may be restricted so that rotation is about some point

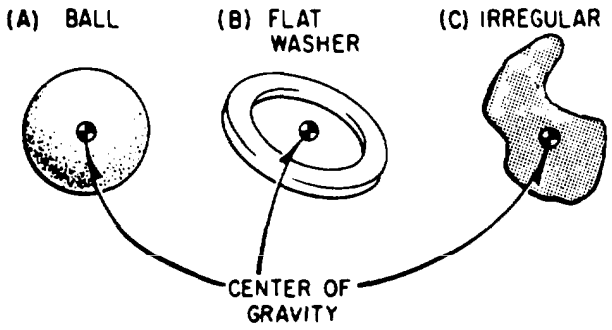


Figure 1-3.-Center of gravity in various bodies.

other than the center of gravity. In this event, the center of gravity revolves around the center of rotation. The gyro rotor (view A) rotates about its axis, and the ball (view B) revolves about a point at the center of its path.

Q35. Name the branch of physics that deals with force, mass, and motion.

Q36. Describe the point of an object that is its center of gravity.

Q37. List the two classes of circular motion.

Q38. Generally, a gyro rotor (a) revolves or (b) rotates about its axis.

MASSES IN MOTION

Learning Objective: *Identify factors that affect masses in motion.*

Motion is defined as *the act or process of changing place or position.* The *state of motion* refers to the amount and the type of motion possessed by a body at some definite instant (or during some interval of time). A body at rest is not changing in place or position; it is said to have zero motion, or to be motionless.

The natural tendency of any body at rest is to remain at rest. A moving body tends to continue moving in a straight line with no change in speed or direction. A body that obeys this natural tendency is said to be in uniform motion.

Any change in the speed or direction of motion of a body is known as *acceleration* and requires the application of some force. The acceleration of a body is directly proportional to the force causing that acceleration; acceleration depends also upon the mass of the body. The greater mass of a lead ball makes it harder to move than a wood ball of the same diameter. A wood ball moves farther with the same push.

These observations indicate a connection between force, mass, and acceleration. They indicate that the acceleration of a body is directly proportional to the force exerted on that body and inversely proportional to the mass of that body. In mathematical form, this relationship may be expressed as

$$a = \frac{F}{m}$$

or, as it is more commonly stated: "Force is equal to the product of the mass and acceleration ($F = ma$)."

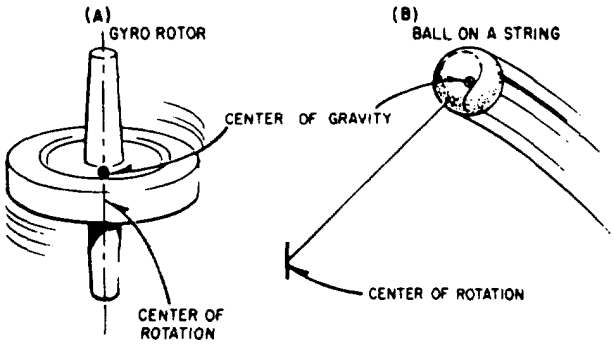


Figure 1-4.-Center of gravity and center of rotation.

Acceleration Due to Gravity

The small letter g represents the acceleration of a body in free fall, neglecting any friction. This can happen only in a vacuum. At sea level near the equator, g has the approximate values of $32\ ft/s^2$ in the fps system, $980\ cm/s^2$ in the cgs system, and $9.8\ m/s^2$ in the mks system. The absolute units of mass of a body may be determined when its weight is known. To solve for m in the formula W = mg, you transpose the formula so

$$m = \frac{W}{g}.$$

When you use the formula stated in Newton's second law of motion (force equals mass times acceleration [F = ma]) to find what force is

needed to give a 1-ton car an acceleration of 8 ft/s^2,

substitute $\frac{W}{g}$ for mass, so

$$\text{force} = \frac{2{,}000 \text{ lb}}{32 \text{ ft/s}^2} \times 8 \text{ ft/s}^2 = 500 \text{ pounds.}$$

In the metric system, the newton is the force that causes a mass of 1 kg to be accelerated 1 m/s^2. Since g = 9.8 m/s^2, a 1-kg mass exerts a force of 9.8 newtons due to gravity. A newton is equal to 0.224 lb.

The dyne is the force that causes a mass of 1 g to be accelerated 1 cm/s^2. Therefore, a mass of 1 g exerts a force of 980 dynes due to gravity.

An accelerating force applied to the center of gravity to accelerate a body with no rotation is called a *translational* force. The force applied to cause a body to rotate about a point is called a *torque* force,

Laws of Motion

Among the most important discoveries in theoretical physics are the three fundamental laws

ANSWERS FOR REVIEW QUESTIONS Q28. THROUGH Q38.

A28. a. Solid
b. Liquid
c. Gas

A29. a. Cohesion and adhesion
b. Tensile strength
c. Ductility
d. Malleability
e. Hardness
f. Brittleness
g. Elasticity

A30. a. Component parts of a system can be placed at separated points
b. Hydraulic energy is transmitted around corners without gears and levers

A31. To study the kinetic theory of gases.

A32. a. 0 Kelvin
b. -273° Celsius

A33. Boyle.

A34. "All gases expand and contract in direct proportion to the change in the absolute temperature, pro vialed the pressure is held constant."

A35. Mechanics.

A36. The point where a single force, equal to the gravitational force and directed up, sustains the body at rest.

A37. Rotation and revolution.

A38. Rotates about its axis.

of motion attributed to Newton. These laws have been used to explain topics earlier in this chapter. In this section, they are restated and consolidated to clarify and summarize the discussion regarding mechanical physics.

1. Every body tends to maintain a state of uniform motion unless a force is applied to change the speed or direction of motion.

2. The acceleration of a body is directly proportional to the magnitude of the applied force and inversely proportional to the mass of the body; acceleration is in the direction of the applied force.

3. For every force applied to a body, the body exerts an equal force in the opposite direction.

Momentum

Every moving body tends to maintain uniform motion. Quantitative measurement of this tendency is proportional to the mass of the body, and also to its velocity (momentum = mass x velocity). This explains why heavy objects in motion at a given speed are harder to stop than lighter objects. It also explains why it is easier to stop a body moving at low speed than it is to stop the same body moving at high speed.

Q39. What type of force is an accelerating force applied to the center of gravity of a body so that the body is accelerated with no rotation?

WORK, POWER, AND ENERGY

Learning Objective: *Perform calculations involving kinetic energy, work, power, and mechanical advantage.*

As defined earlier, **energy** is the capacity for doing work. In mechanical physics, work involves the idea of a mass in motion, and is usually regarded as the product of the applied force and the distance through which the mass is moved (work = force x distance). For example, if a man raises a weight of 100 pounds to a height of 10 feet, he accomplishes 1,000 foot-pounds of work. The amount of work accomplished is the same regardless of the time involved. However, the rate of doing the work may vary.

The rate of doing work (called *power)* is defined as the work accomplished per unit of time (power = work/time). In the example cited above, if the work is accomplished in 10 seconds, power is being expended at the rate of 100 foot-pounds per second; if it takes 5 minutes (300 seconds), the rate is approximately 3.3 foot-pounds per second.

$$P = \frac{\text{work}}{\text{time}} = \frac{1{,}000 \text{ foot-pounds}}{10 \text{ sec}} = \frac{100 \text{ foot-pounds}}{\text{sec}}$$

In the English system of measurements, the unit of mechanical power is called *horsepower,* and is the equivalent of 33,000 foot-pounds per minute, or 550 foot-pounds per second. Since energy converts from one form to another, the work and power measurements based on the conversion of energy must also be readily convertible. For example, the electrical unit of power is the watt. Electrical energy may be converted into mechanical energy; therefore, electrical power must be convertible into mechanical power. One horsepower is the mechanical equivalent of 746 watts of electrical power and is capable of doing the same amount of work in the same time.

Doing work always involves a change in the type of energy, but does **not** change the total quantity of energy. Thus, energy applied to an object may produce work, changing the composition of the energy possessed by the object.

Potential Energy

A body has *potential energy* if it is able to do work. A wound clock spring and a cylinder of compressed gas both possess potential energy since they can do work in returning to their uncompressed condition. Also, a weight raised above the earth has potential energy since it can do work by returning to the ground. Potential energy results when work has been done against a restoring force. The water in a reservoir above a hydroelectric plant has potential energy, regardless of whether the water was placed there by work applied via a pump or by the work done by the sun to lift moisture from the sea and place it in the reservoir as rain.

Kinetic Energy

The ability of a body to do work through its motion is called its *kinetic* energy. A rotating wheel on a machine has kinetic energy of rotation. A car moving along the highway has kinetic energy of translation.

For a given mass (m) moving in a straight line wit h a velocity (v), the kinetic energy is determined by

$$\text{kinetic energy} = \frac{1}{2}mv^2 \begin{cases} \text{in ergs when} \begin{cases} \text{m is in grams} \\ \text{v is in cm/s} \end{cases} \\ \text{in ft-lbs when} \begin{cases} \text{m is in slugs} \\ \text{v is in ft/s} \end{cases} \end{cases}$$

For example; The kinetic energy of a 3,200-lb car traveling at 30 miles per hour can be found by expressing the 3,200 lb as 100 slugs and the 30 mph as 44 feet per second. Inserting these values into the formula gives

kinetic energy = ½ x 100 x 44 x 44= 96,800 foot-pounds of

energy. This amount of kinetic energy is the result of applying 96,800 foot-pounds of work (plus that to overcome friction) to the car to get it traveling at the rate of 44 feet per second. The same amount of energy could do the work of lifting the 3,200 pounds vertically a distance of 30.25 feet; it could have been potential energy if the car had been at rest on an incline and then allowed to coast to a point which is vertically 30.25 feet below its starting point (again neglecting friction).

Efficiency

If there is no change in the quantity of matter, energy is convertible with no gain or loss. However, the energy resulting from a given action may not be in the desired form; it may not even be usable in its resultant form. In all branches of physics, this concept is known as efficiency.

Energy expended is always greater than energy recovered. An automobile in motion possesses a quantity of kinetic energy that depends on its mass and velocity. To stop the car, this energy is converted into potential energy. When the car stops, its potential energy is less than the kinetic energy it possessed while in motion. The difference, or the **energy used,** was converted into heat by the brakes. The heat serves no useful purpose, so the recovered energy is less than the expended energy; therefore, the system is less than 100-percent efficient in converting kinetic to potential energy.

Normally, the term *efficiency* is used in connection with work and power considerations to show the ratio of the input to the output work, power, or energy, It is always expressed as a decimal or as a percentage less than unity.

Friction

In mechanical physics, the most common cause for the loss of efficiency is **friction.** Whenever one object is slid or rolled over another, irregularities in the contacting surfaces interlock and cause an opposition to the force being exerted. Even rubbing two smooth pieces of ice together produces friction. Friction also exists in the contact of air with all exposed parts of an aircraft in flight.

When a nail is struck with a hammer, the energy of the hammer is transferred to the nail, and the nail is driven into a board. The depth of penetration depends on the momentum of the hammer, the size and shape of the nail, and the hardness of the wood. The larger or fuller the nail and the harder the wood, the greater the friction; therefore, the lower the efficiency and the lesser the depth of penetration, but the greater the heating of the nail.

Friction is always present in moving machinery, which is why the useful work done by the machine is never as great as the energy applied. Work accomplished in overcoming friction is usually not recoverable. Friction is minimized by decreasing the number of contacting points, by making the contacting areas as small and as smooth as possible, by the use of bearings, or by the use of lubricants.

There are two kinds of friction—sliding and rolling, with rolling friction usually of lower magnitude. Therefore, most machines are built so rolling friction is present rather than sliding

ANSWER FOR REVIEW QUESTION Q39.

A39. A translational force.

friction. The ball bearing and the roller bearing are used to replace sliding friction with rolling friction. The common (or friction) bearing uses lubricants applied to surfaces that areas smooth as possible. Many new types of machines use self-lubricating bearings to minimize friction and maximize efficiency.

Q40. How much power is being expended if a man lifts 50 pounds 5 feet to put it on a shelf in 15 *seconds?*

Q41. When does an object have potential energy?

Q42. What is lost whenever energy is expended?

Q43. What is the most common reason for efficiency loss in mechanical physics?

Q44. What type of bearing is used in many types of machinery to minimize friction and maximize efficiency?

Mechanical Advantage

The concept of mechanical advantage is one of the great discoveries of science. It permits an increase in force through a distance and represents the basic principle involved in levers, block-and-tackle systems, screws, hydraulic mechanisms, and other work-saving devices. Actually, these devices do not save work; they just let humans do tasks that are beyond their capability. For example, normally, a human couldn't lift the rear end of a truck to change a tire; but with a jack, block and tackle, or lever, the human can do the job.

Mechanical advantage is usually considered with respect to work. Work represents the application of a force through a distance to move an object through a distance. Therefore, you can see that two forces are involved, each with an appropriate distance. This is shown by the simple lever (fig. 1-5).

If there is perfect efficiency, the work input $(F_1 D_1)$ is equal to the work output $(F_2 D_2)$. If distances D_1 and D_2 are equal, a force of 10 pounds must be applied at the source to counteract a weight of 10 pounds at the load.

When the fulcrum is moved nearer the load, less force is required to balance the same load. **This is a mechanical advantage of force.** If the force is applied to raise the load 1 foot, the source must be moved through a distance greater than 1 foot. Therefore, the mechanical advantage of force represents a mechanical disadvantage of distance. When the fulcrum is moved nearer the source, these conditions are reversed.

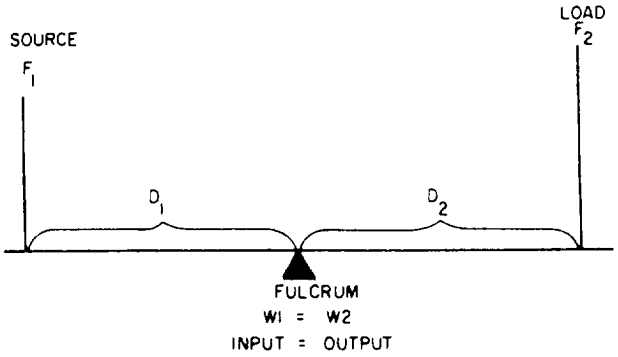


Figure 1-5.-Mechanical advantage.

Since the input work equals the output work (assuming no losses), the mechanical advantage may be stated as a ratio of the force or of the distances. Actually, friction results in energy loss and decreased efficiency, thereby requiring an even greater input to do the same work.

REVOLVING BODIES

Learning Objective: *Recognize the mechanics involved in revolving bodies and identify the forces that act on such bodies.*

Revolving bodies represent masses in motion; therefore, they possess all the characteristics (and obey all the laws) associated with moving bodies. Since they possess a specific type of motion, they have special properties and factors.

Revolving bodies travel in a constantly changing direction, so they must be constantly subjected to an accelerating force. Momentum tends to produce linear motion, but this is prevented by application of a force that restrains the object. The force that prevents the object from continuing in a straight line is known as *centripetal* force. According to Newton's third law of motion, the centripetal force is opposed by an equal force that tends to produce linear motion. This second force is known as *centrifugal* force.

The two forces, their relationships, and their effects are shown in figure 1-6.

The forces involved in revolving bodies may be demonstrated by using a ball and string. Tie a slip knot in the center of a 10-foot length of string to shorten the line to 5 feet. Then, attach a rubber ball to one end of the string. Holding the other end of the string, whirl the ball slowly in a circle. At this point in the experiment, you can tell that the ball exerts a force against your hand (through the string). As you keep the ball in its circular path, your hand exerts a force (through the string) on the ball. As you revolve the ball at a higher speed, the forces increase, but the ball continues in a circular path.

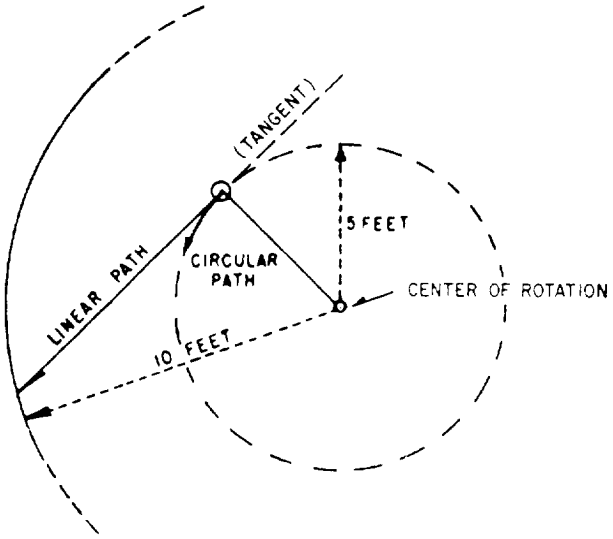


Figure 1-6.-Forces on revolving bodies.

At some rotational speed, the forces are enough to overcome inertial friction, and the knot slips. At this time, stabilize the velocity of rotation (keep the rotational velocity constant). Let's analyze what has happened. When the knot slips, the ball is temporarily unrestrained and is free to assume linear motion in the direction of travel at that instant (tangent to the circle at the instantaneous position, which is shown in fig. 1-6). The ball travels in a straight line until the string reaches its full length. During this time, no force is exerted on or by the hand. As soon as all the slack is taken up, there is a sharp jerk; an accelerating force is exerted to change the direction of motion from its linear path into a circular rotation. The ball again assumes rotational motion, but with an increase in radius.

The ball does not make as many revolutions in the same time (rotational velocity is decreased), but it does maintain its former linear velocity. (The kinetic energy and the momentum of the ball have not changed.) Since the change in direction is less abrupt with a large radius than with a small one, less accelerating force is required, and the hand will feel less force. Accelerate the ball to the same rotational velocity it had just before the knot slipped. The linear velocity of the ball becomes much greater than before; the centripetal and centrifugal forces are much greater, also,

In this experiment, your hand is fixed at a point that represents the center of rotation. This

ANSWERS FOR REVIEW QUESTIONS Q40. THROUGH Q44.

A40. a. First, solve for amount of work being done:
work = force x *distance, or*
work = 50 x *5 = 225 foot-pounds of work*
b. Next, solve for power expanded to do the work:
power = work/time, or
power = 225/15 = 15 foot-pounds per second

A41. When it can do work, such as a wound clock spring or a cylinder of compressed gas.

A42. Efficiency.

A43. Friction.

A44. Self-lubricating bearings.

assumption, while not exactly correct, does not affect the general conclusions you can draw from the experiment. For practical purposes, the two forces are equal at all points along the string at any given time, and the magnitude of each force is equal at all points along the string.

The above example and explanation can be summarized by the following mathematical relationship:

$$\text{force} = \frac{\text{mass x velocity}^2}{\text{radius}}$$

where velocity represents the linear velocity of the ball.

This relationship describes the following facts about forces acting on revolving bodies:

- The centripetal and the centrifugal forces are equal in magnitude and opposite in direction.
- Each force is directly proportional to the mass of the body and inversely proportional to the radius of rotation.
- Each force is also proportional to the square of the velocity.

In revolving or rotating bodies, all particles of matter not on the axis of rotation are subjected to the forces just described. The statement is true whether the motion is through a complete circle, or merely around a curve. An aircraft tends to skid when changing course, and an automobile tends to take curves on two wheels. The sharper the curve (smaller radius) or the higher the velocity, the greater the tendency to skid.

Q45. Name the principle that allows man to accomplish work that he normally could not do.

Q46. What force prevents a revolving object from continuing along a straight line?

Q47. When an object is revolving, what force tries to oppose centripetal force?

WAVE PARAMETERS

Learning Objectives: *Identify the factors involved in wave motion and recognize various types of waves to include transverse waves, waves in water, and standing waves. Identify the terms used to describe wave parameters. Recognize the properties that affect reflection, refraction, and diffraction. Identify the applications of the Doppler effect.*

The term *wave parameter is* a general term, and it applies to all types of waves—water, radio, sound, light, and heat. All types of waves exhibit some common characteristics, such as transmission, reflection, refraction, and absorption.

TERMS USED IN WAVE PARAMETERS

Before you read the section on wave parameters, its helpful to understand the terminology used in the discussion. The terms included in this section will help you as you read about wave parameters.

Propagation. A travel of waves through or along a medium.

Velocity. The velocity of propagation is the rate at which the disturbance transverses the medium, or the velocity with which the crest of the wave moves along. The velocity of the wave must not be confused with the speed of a particle, which is always less than the velocity of the wave. The velocity of the wave depends both on the type of wave and the nature of the medium.

Frequency. The frequency of any periodic motion is the number of complete variations per unit of time. With waves, the time unit is the second, and the frequency unit is the hertz (Hz). A hertz is the number of complete cycles per second; therefore, it is the number of complete waves that pass a given point each second.

Period. The period of a wave is the time required to complete a full cycle. Therefore, the period and the frequency of a given wave are reciprocals of each other. The period of a wave can be expressed mathematically as follows:

$$\text{period} = \frac{1}{\text{frequency}}, \text{ and } \text{frequency} = \frac{1}{\text{period}}.$$

If a sound wave has a frequency of 400 Hz, its period is 1/400, or 0.0025 second. If successive crests of a water wave pass a given point each 5 seconds, the frequency of the wave is 1/5 or 0.2 Hz.

Wavelength. Wavelength, shown by the symbol λ (Greek lambda), is the distance, along the direction of propagation of the wave, between two successive points in the medium that are at precisely the same state of disturbance. In a water wave, this is the distance between two adjacent

crests. Wavelength depends on both the frequency of the wave and the velocity of propagation of the wave in a given medium. Wavelength is expressed mathematically as follows:

$$\text{wavelength} = \frac{\text{velocity}}{\text{frequency}}.$$

Wavelength must be given in **compatible units;** which means that if frequency is in waves per second (in hertz), then velocity must be in distance units per second (feet per second or meters per second). Also, if velocity is given in feet per second, wavelength is given in feet; if velocity is given in meters per second, wavelength is given in meters.

WAVE MOTION

Energy is transferred progressively from point to point in a medium by a disturbance that may have the form of an elastic deformation, a variation of pressure, electric or magnetic intensity, electric potential, or temperature. This disturbance advances with a finite velocity through a medium. Energy is transferred from one point to another without the passage of matter between the two points (although in some cases particles of matter do move to and fro around their equilibrium position). A single disturbance induced into the medium is called a wave *pulse,* and a series of waves produced by continuous variations is called a *train of waves* or wave *train.*

Transverse Waves

In the description of any periodic wave, the wave is a *transverse* wave if the disturbance takes place at right angles to the direction of propagation. You can see this motion by fastening one end of a hemp line to a stanchion, and moving its free end up and down with a simple periodic motion. The motion of the waves will be along the length of the line, but each particle of the line moves at right angles to its length.

Electromagnetic waves do not involve moving particles of matter; they rely on electric and magnetic force fields. The variations of these fields are also at right angles to the direction of wave movement; therefore, electromagnetic waves are transverse waves. Also, the variations of electric-field intensity and those of magnetic-field intensity are at right angles to each other as well as to the direction of propagation of the wave. For example, if an electromagnetic wave is moving toward the north and is horizontally polarized, the variations of the electric-field intensity are east-west horizontal to the earth's surface, while variations in the magnetic-field intensity are vertical. Electromagnetic waves are known as *radio waves, heat rays, light rays,* etc., depending on their frequency.

Longitudinal Waves

Longitudinal waves are waves in which the disturbance takes place in the direction of propagation. The compressional waves that constitute sound, such as those set up in air by a vibrating tuning fork, are longitudinal waves. As you read this section, look at figure 1-7. When struck, the tuning fork sets up a vibrating motion. As the tine moves in an outward direction, the air immediately in front of the tine is compressed so that its momentary pressure is raised above that of other points in the surrounding medium. Because air is elastic, this disturbance is transmitted progressively in an outward direction as a compression wave. When the tine returns and moves in the inward direction, the air in front of the tine is rarefied so that its momentary pressure is reduced below that at other points in the surrounding medium. This disturbance is also propagated, but in the form of a rarefaction (expansion) wave, and follows the compression wave through the medium.

The compression and expansion waves are also called *longitudinal* waves because the particles of matter of the medium move back and forth longitudinally in the direction of wave travel.

ANSWERS FOR REVIEW QUESTIONS Q45. THROUGH Q47.

A45. Mechanical advantage.

A46. Centripetal force.

A47. Centrifugal force.

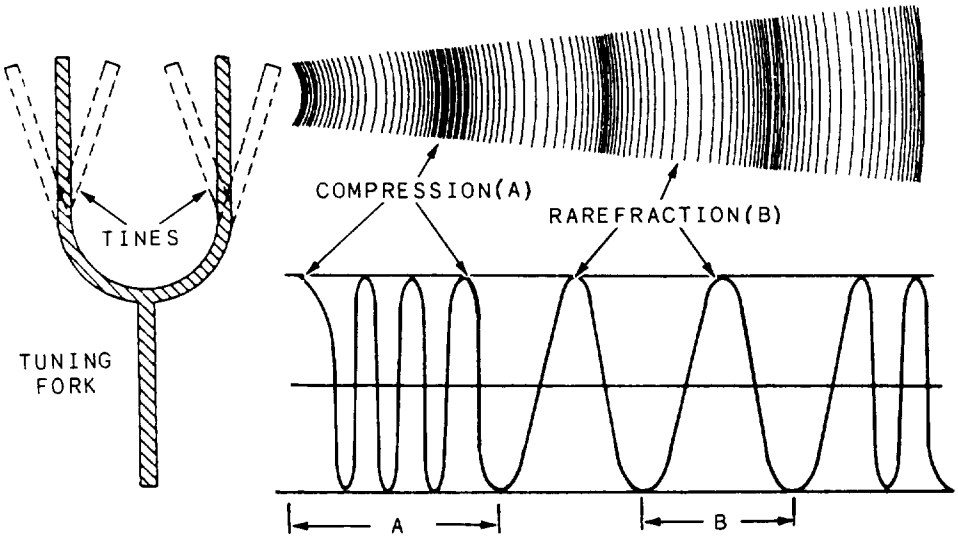


Figure 1-7.-Compression and expansion wave propagation.

Waves in Water

The wave motion of the surface of water is a combination of both transverse and longitudinal waves. The particles of water move in circles or in ellipses. You can see this motion by placing a small cork on the surface of the water and observing it from the side. The cork will be carried upward and in the direction of the wave motion as the crest of the wave approaches. After the crest has passed, the cork falls and is then carried backward.

Standing Waves

Standing waves are produced by two wave trains of the same type and of equal frequency traveling in opposite directions in the same medium, whether the medium be solid, liquid, or gas. Look at figure 1-8. It shows the formation

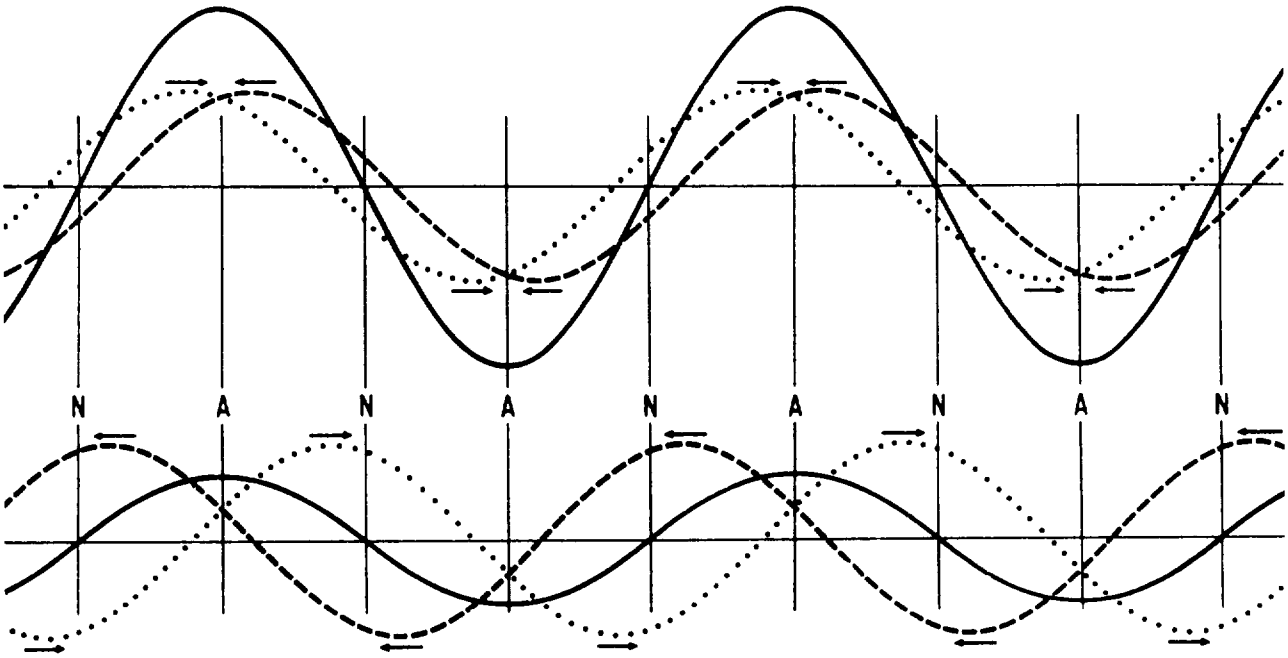


Figure 1-8.-Formation of a standing wave.

of a standing wave represented by the solid curved line. The points A and N along the horizontal axis of the graph are fixed points within the medium and are stationary or standing. Points N are the locations within the medium where the amplitude of the standing wave is **always** medium and are called *nodes*. Successive nodes are a half-wavelength apart. Halfway between the nodes are the antinodes (or loops), represented by points A on the graph. The standing wave reaches its maximum amplitude at point A (a quarter-wavelength from a node). The dotted curved line represents a wave train traveling from left to right, and the dashed curved line represents an equal wave train traveling from right to left, as they would appear if each were the only wave within the medium. As they meet, they combine with each other to form a standing wave (shown by the solid curved line); they cease to exist in their original form.

In the top drawing, the crests of the two identical component waves are approaching each other and coincide at points A. At this time, the standing wave will increase to a maximum amplitude equal to the sum of the two components.

Look at the lower drawing in figure 1-8. After an interval of time, the crests of the component waves pass each other, and the standing wave decreases until it becomes zero at the time the two component waves exactly neutralize each other. After this, the standing wave will increase in amplitude in the opposite direction from that in the drawings. You can see that the points of maximum variation of the standing wave are not moving, and that at points N the standing wave is **always** at zero. At points N, the magnitudes of the two component waves are the same and their deviations are opposite; therefore, at points N, the standing wave is **always** zero.

Q48. What are the characteristics that all types of waves have in common?

Q49. Energy is transferred in a medium by a disturbance that may have an elastic deformation, a pressure variation, an electric or magnetic intensity, an electric potential, or temperature. Continuous variations induced in to a medium is known as a

Q50. Electromagnetic waves are what types of waves?

Q51. Air is elastic; therefore, a disturbance is transmitted progressively out ward as a compression wave. What type of waves behave in this manner?

Q52. How are standing waves produced?

REFLECTION

Lines drawn from the source of waves to indicate the path along which the waves travel are called *rays*. Often, these lines are used in illustrations to show wave propagation. When several rays are drawn from a nearby source, they are shown diverging from the source; rays drawn from a distant source are usually shown as being more nearly parallel.

A **wavefront** is a surface on which the phase of the wave has the same value at all points at a given instant. Wavefronts near the source are sharply curved. As their distance from the source increases, they become more nearly flat.

Within a uniform medium, a ray travels in a straight line. Only at the boundary of two media, or in an area where the velocity of propagation of the wave within the medium changes, do the rays change their direct ion.

When an advancing wavefront meets a medium of different characteristics, some of its energy is reflected back into the initial medium, and some of it is transmitted into the second medium. In the second medium, it continues at a different velocity or is absorbed by the medium. In some cases, all three processes (reflection, absorption, and transmission) may occur to some degree.

As you read this paragraph, look at figure 1-9. **Reflected** waves are waves that are neither

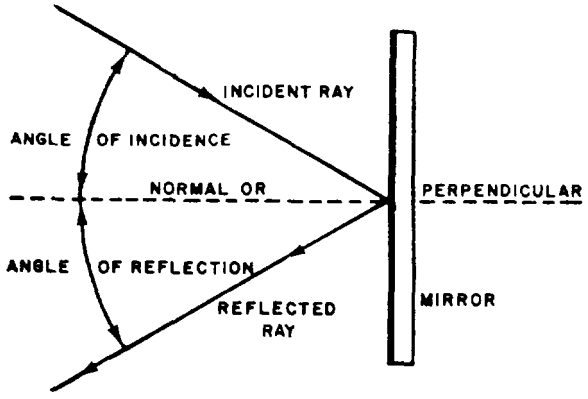


Figure 1-9.-Reflection of a wave.

transmitted nor absorbed; they are thrown back from the surface of the medium they meet. If a ray is directed against a reflecting surface, the ray striking the surface is called the *incident* ray, and the ray that bounces back is the *reflected* ray. An imaginary line perpendicular to the reflecting surface at the point of impact of the incident ray is called the *normal.* The angle between the incident ray and the normal is called the *angle of incidence.* The angle between the reflected ray and the normal is the called the *angle of reflection.*

The law of reflection states that *"The angle of incidence is equal to the angle of reflection."* If the surface of the medium contacted by the incident rays of the wave is smooth and polished (a mirror), each reflected ray is thrown back at the same angle as the incident ray. The path of the ray reflected from the surface forms an angle exactly equal to the one formed by the path of the ray in reaching the medium, therefore, conforming to the law of reflection.

The amount of incident wave energy reflected from a surface depends on the nature of the surface and the angle at which the wave strikes the surface. The amount of wave energy reflected increases as the angle of incidence increases. It is greatest when the ray is nearly parallel to the surface. When the incident ray is perpendicular to the surface, more of the wave energy is transmitted into the substance and less is reflected. At any angle of incidence, a mirror reflects almost all of the wave energy, and a dull black surface reflects very little. Waves that are reflected directly back toward the source cause standing waves.

Q53. A ray is traveling through a medium in a straight line. What would cause the ray to change its direction?

Q54. What happens when a wave is directed against a reflecting surface?

Q55. "The angle of incidence is equal to the angle of reflection." What is meant by this statement?

REFRACTION

When a wave passes from one medium into a medium having a different velocity of propagation for the wave, and if the ray is not perpendicular to the boundary between the two media, the wave changes direction or bends. This is called *refraction.* Look at figure 1-10. You should refer to it as you read the section on

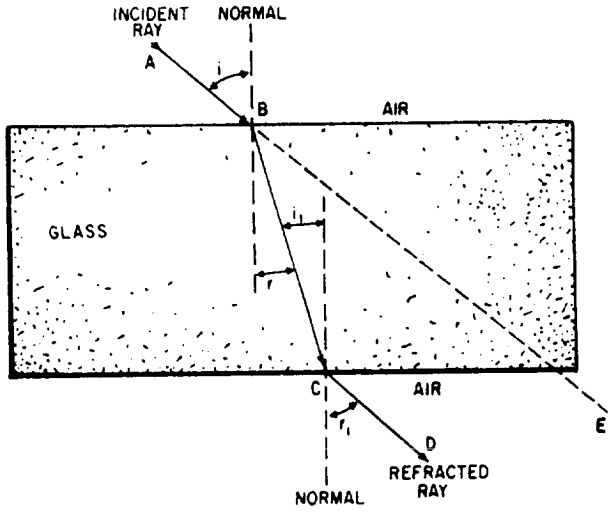


Figure 1-10.-Refraction of a wave.

refraction. The ray striking the boundary is the **incident** ray, and the imaginary line perpendicular to the boundary is the **normal.** The angle between the normal and the path of the ray through the second medium is the **angle of refraction.**

A light ray is shown from points A to B in figure 1-10. This is the **incident ray.** As it nears the boundary between the air and the top of the glass plate, it bends toward the normal and takes the path BC through the glass. You can see that it becomes the **refracted ray** from the top surface and the **incident ray** to the lower surface. The angle formed by the ray and the normal to the lower surface is the second angle of incidence. As the ray passes from the glass to the air, it is again refracted, this time away from the normal, and takes the path CD.

Refraction follows a general rule: *When a ray passes from one medium into another having a lower velocity of propagation for the waves, refraction is toward the normal, so the angle of refraction (r) is smaller than the angle of incidence (i); when a ray passes into a medium having a higher velocity of propagation for the waves, refraction is away from the normal, so the angle of refraction (r_1) is larger than the angle of incidence (i_1). The angle of refraction depends on two factors: (1) the angle of incidence and (2) the index of refraction. The index of refraction is* the ratio of the velocities of the waves within the two media. The greater the angle of incidence, the greater the bending; the greater the difference between the velocities of propagation in the two media, the greater the bending.

When the two surfaces of glass are parallel, a ray leaving the glass is parallel to a ray entering the glass. The distance between these two paths (between lines AE and CD in fig. 1-10) is called *lateral displacement.* Lateral displacement is zero when the incident ray is directed along t he normal, and increases as the angle of incidence increases. Lateral displacement is greater in thicker glass than in thin.

A boundary between two media does not always have a sharp point of transition, such as from the surface of glass to air. Air layers above the earth's surface have different temperatures that cause refraction of sound waves. Thermal layers in the ocean also cause refraction. Variations in the ionosphere cause refraction of radio waves and light rays.

You already know that when a wave encounters a medium having a higher velocity of propagation, refraction is away from the normal, and the angle of refraction is larger than the angle of incidence. When the angle of incidence is increased to the angle at which the refracted wave is 90° to the normal (parallel with the boundary), the angle of incidence is called the *critical angle of refraction.* Any angle of incidence larger than this results in total reflection of the incident wave. The size of the critical angle of refraction depends on the index of refraction of the two media; the larger the index of refraction, the smaller the critical angle of refraction.

ANSWERS FOR REVIEW QUESTIONS Q48. THROUGH Q55.

A48. *a. Transmission*
b. Reflection
c. Refraction
d. Absorption

A49. Wave train. This is a series of waves produced by continuous variations.

A50. They are transverse waves because the disturbance takes place at right angles to the direction of propagation.

A51. Longitudinal waves. They behave this way because the disturbance takes place in the direction of propagation. The waves move back and forth in the direction of wave travel.

A52. They are produced by two wave trains of the same type and equal frequency traveling in opposite directions in the same medium. As two waves traveling in opposite directions meet, they combine with each other, and they cease to exist in their original form.

A53. It would change its direction if it reached the boundary of a media or if it reached an area within the media where the velocity of propagation of the wave changes.

A54. The wave is thrown back from the surface. The ray that strikes the surface is the incident ray and the ray the bounces back is the reflected ray.

A55. The path of a ray reflected from a surface forms an angle that is exactly equal to the one formed by the path of the ray reaching the medium (law of reflection).

DIFFRACTION

Diffraction (fig. 1-11.) is the bending of the path of waves when the wavefront is limited by an obstruction. This is very easy to observe in water waves. Generally, the lower frequency waves diffract more than those at higher frequency. You can hear the diffraction in sound waves by listening to music from an outdoor source. Then, step behind a solid obstruction, such as a brick wall. The high notes, having less diffraction, seem reduced in loudness more than the low notes. Broadcast band radio waves often travel over to the opposite side of a mountain from their source because of diffraction. Higher frequency TV signals from the same city might not be detected on the opposite side of the same mountain.

DOPPLER EFFECT

When there is relative motion between the source of a wave and a detector of that wave, the

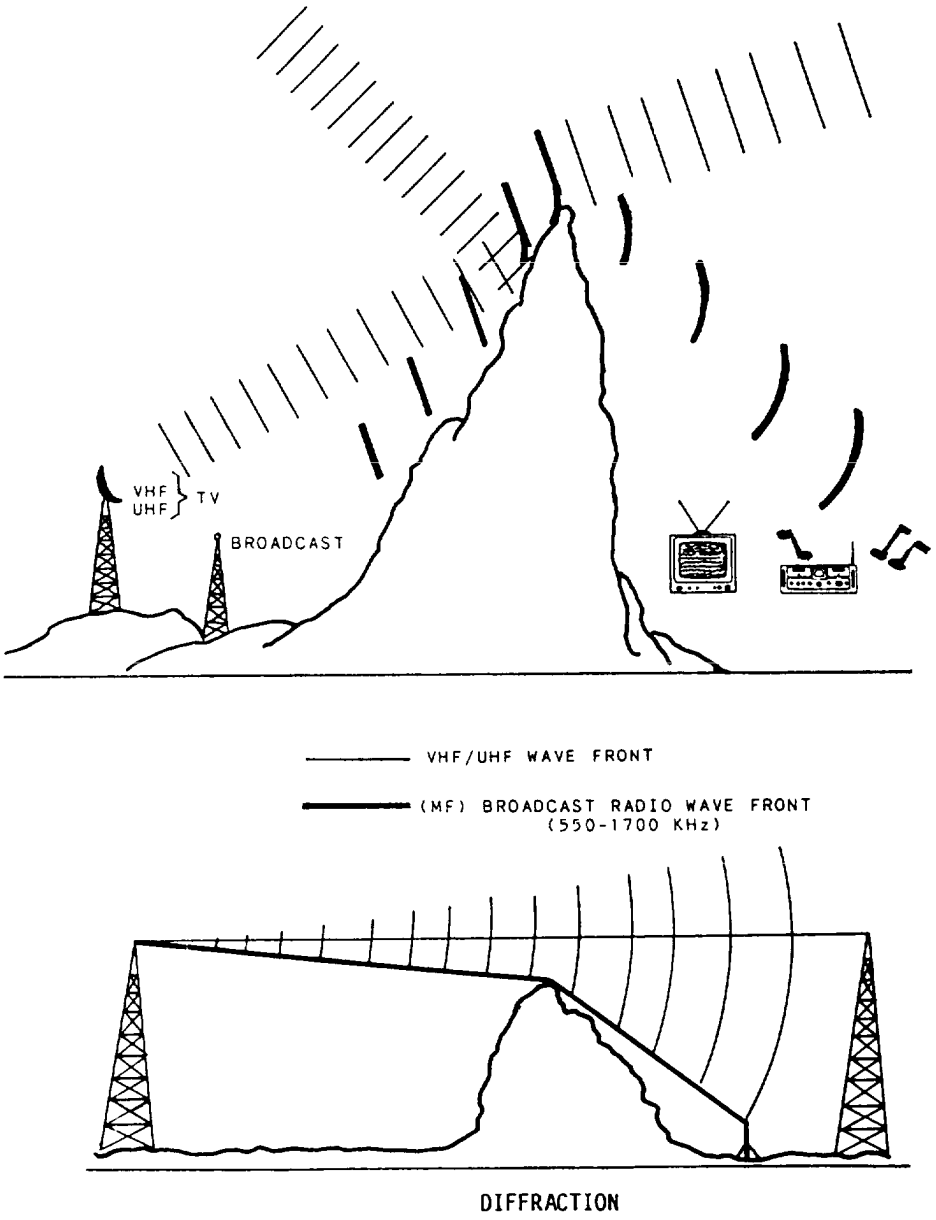


Figure 1-11.-Diffraction.

frequency at the detector position differs from the frequency at the source. If the distance between the source and the detector is decreasing, more wavefronts are encountered per second than when the distance is constant. This results in an apparent increase in the transmitted frequency. Conversely, if the separation is increasing, fewer waves are encountered. There is an apparent decrease in transmitted frequency.

The pitch of the whistle on a fast-moving train sounds higher as the train is coming toward you than when the train is going away. Though the whistle is generating sound waves of constant frequency, and they travel through the air at the same velocity in all directions, the distance between the approaching train and the listener is decreasing. Each wave has less distance to travel to reach the observer than the wave preceding it; the waves arrive with shorter intervals of time between them.

These changes in frequency are called the *Doppler effect.* The Doppler effect affects the operation of equipment used to detect and measure wave energy. The amount of change in the frequency varies **directly** with the relative velocities of the source and detector and **inversely** with the velocity of propagation of the wave within the medium. The Doppler effect is important when dealing with wave propagation applicable to sonar equipment operation, radar search, target detection, fire control, and navigation.

Q56. As a wave passes from one medium into another, what causes refraction?

Q57. What are the two factors that determine the angle of refraction?

Q58. What causes diffraction?

Q59. What is the cause of the Doppler effect?

HEAT

Learning Objective: *Recognize the characteristics of heat and identify the ways in which heat is transferred.*

Heat is a form of energy; it is readily exchangeable with, or convertible into, other forms of energy. For example, when a piece of lead is struck a sharp blow with a hammer, part of the kinetic energy of the hammer is converted into heat. In the core of a transformer, electrical and magnetic energy are exchanged; but due to hysteresis and eddy currents, some of the energy is lost as heat. These are some examples of the unwanted conversions. There are, however, many instances when heat production is desirable, and many devices are used to produce heat.

Some of the characteristics heat possesses make it important to the technician. A knowledge of the nature and behavior of heat will help you understand the operation of some types of electronics equipment. This knowledge will also help you determine the cause of nonoperation or faulty operation of equipment.

NATURE OF HEAT

There are several theories about the nature of heat. The two theories most commonly included in discussions about the nature of heat are the *kinetic theory* and the *radiant energy theory.*

The basis of the **kinetic theory** assumes that the quantity of heat contained in a body is represented by the total kinetic energy possessed by the molecules of the body.

The **radiation theory** treats radio waves, heat, and light as the same general form of energy, differing primarily in frequency. Heat is considered as a form of electromagnetic energy involving a specific band of frequencies falling between the radio-wave and light-wave portions of the electromagnetic spectrum.

A common method of producing heat energy is the burning process. Burning is a chemical process in which fuel unites with oxygen, and usually produces a flame. The amount of heat liberated per unit mass or per unit volume during complete burning is known as the *heat of combustion* of a substance. Each fuel produces a given amount of heat per unit quantity burned.

TRANSFER OF HEAT

There are three methods of heat transfer—conduction, convection, and radiation. In addition to these, a phenomenon called *absorption is* related to the radiation method.

Conduction

The metal handle of a hot pot will burn your hand while a plastic or wooden handle remains relatively cool to touch, even though it is in direct contact with the pot. This phenomenon is due to a property of matter known as *thermal conductivity.*

All materials conduct heat to some degree. When heat is applied to a body, the molecules at the point of application become violently agitated, strike the molecules next to them, and cause increased agitation. The process continues until the heat energy is distributed evenly throughout the material. Aluminum and copper are used for cooking pots because they conduct heat very readily to the food being cooked. Generally, metals are the best conductors of heat.

Among solids, there is an wide range of thermal conductivity. In the original example, the metal handle transmits heat from the pot to the hand, with the possibility of burns. The wooden or plastic handle does not conduct heat very well, so the hand is given some protection. Materials that are extremely poor conductors are called *insulators;* they are used to reduce heat transfer. Some examples of insulators are the wood handle of soldering irons, the finely spun glass or rock wool insulation in houses, and the tape or ribbon wrapping used on steam pipes.

Liquids are generally poor conductors of heat. Look at figure 1-12. The ice in the bottom of the test tube has not yet melted, although the water at the top is boiling. Water is such a poor conductor of heat that the rate of heating water at the top of the tube is not sufficient to cause rapid melting of the ice at the bottom.

Since thermal conduction is a process by which molecular energy is passed on by actual contact, gases are the poorest conductors of heat because their molecules are far apart and molecular contact is not pronounced. A double-pane window with an air space between the panes is a fair insulator.

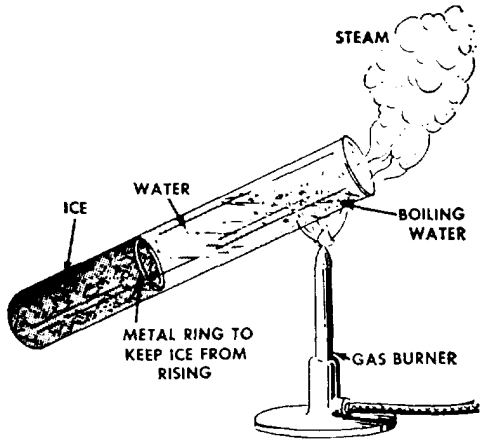


Figure 1-12.-Water is a poor conductor of heat.

Q60. In the radiation theory, heat is generally treated the same way as several forms of energy. List these forms.

Q61. List the three methods of heat transfer.

Q62. Wood handles are used on soldering irons because they are _____.

Q63. In what state is matter the poorest conductor of heat?

Convection

Convection is the process by which heat is transferred by movement of a hot fluid. For example, an electron tube gets hotter and hotter until the air surrounding it begins to move. The motion of the air is upward because heated air expands in volume and is forced upward by the denser cool air surrounding it. The upward motion of the heated air carries the heat **away** from the hot tube by convection. Using a ventilating fan to move the air around a hot object is a fast method of transferring heat by convection. The rate of cooling of a hot vacuum tube is increased by using copper fins to conduct heat away from the hot tube. The fins provide large surfaces against which cool air can be blown.

A convection process may take place in a liquid as well as in a gas; for example, a transformer in an oil bath. The hot oil is less dense (has less weight per unit volume) and rises, while the cool oil falls, is heated, and rises in turn. When the circulation of gas or liquid is not rapid enough to remove sufficient heat, use fans or pumps to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water or oil to help cool large equipment. In airborne installations, electric fans and blowers are used to aid convection.

Radiation

Conduction and convection do not account for all of the phenomena associated with heat transfer. For example, heating through convection can't occur in front of an open fire because the air currents are moving toward the fire. Heating can't occur through conduction because the conductivity of the air is very low, and the cooler currents of air moving toward the fire would

overcome the transfer of heat outward. Therefore, heat must travel across space by some means other than conduction and convection.

Conduction and convection take place only through molecular contact within some medium; therefore, heat from the sun reaches the earth by some other method. (Outer space is an almost perfect vacuum.) The third method of heat transfer is known as *radiation.*

The term *radiation* refers to the continual emission of energy from the surface of all bodies. This energy is known as radiant energy. Radiant energy is in the form of electromagnetic waves and is identical in nature to light waves, radio waves, and X-rays, except for a difference in wavelength. Sunlight is radiant heat energy that travels a great distance through space to reach the earth. These electromagnetic heat waves are absorbed when they come in contact with nontransparent bodies. The motion of the molecules in the body increases, as indicated by an increase in the temperature of the body.

The differences between conduction, convection, and radiation are discussed below,

- Conduction and convection are extremely slow, while radiation takes place with the speed of light. You can see this at the time of an eclipse of the sun when heat from the sun is shut off at the same time as light is shut out.

- Radiant heat may pass through a medium without heating it. For example, the air inside a greenhouse may be much warmer than the glass through which the sun's rays pass.

- Conducted or convected heat may travel in roundabout routes, while radiant heat always travels in a straight line. For example, radiation is cut off when a screen is placed between the source of heat and the body to be protected.

ANSWERS FOR REVIEW QUESTIONS Q56. THROUGH Q63.

A56. As a wave travels through one medium it is traveling at a specific velocity of propagation. When it reaches a new medium, the velocity of propagation changes. If the ray is not perpendicular to the boundary between the two media, the ray will change direction and bend. This is known as refraction.

A57. a. The angle of incidence
b. The index of refraction

A58. Diffraction occurs when the path of waves is bent because of an obstruction.

A59. The relative motion between the source of a wave and a detector of that wave. The frequency of the wave at the detector position differs from the frequency of the wave at the source.

A60. a. Radio waves
b. Heat
c. Light

A61. a. Conduction
b. Convection
c. Radiation

A62. Poor conductors of heat

A63. Gas

Absorption

The sun, a fire, and an electric light bulb all radiate energy, but a body need not glow to give off heat. A kettle of hot water or a hot soldering iron radiates heat. If the surface is polished or light in color, less heat is radiated. Bodies that do not reflect are good radiators and good absorbers. Bodies that do reflect are poor radiators and poor absorbers. This is the reason white clothing is worn in the summer. A practical example of heat control is the Thermos bottle. The flask itself is made of two walls of silvered glass with a vacuum between them. The vacuum prevents the loss of heat by conduction and convection, and the silver coating reduces the loss of heat by radiation.

The silver-colored paint on the radiators in heating systems is used as decoration; it actually decreases the efficiency of heat transfer. The most effective color for heat transfer is dull black; dull black is the ideal absorber and also the best radiator.

Q64. Convection is the process of heat transfer by means of a hot fluid. Name the aid used in airborne installations to aid convection.

Q65. For an object to become a good absorber of heat, it is normally painted _____.

TEMPERATURE

Learning Objectives: *Convert Fahrenheit and Celsius temperatures. Recognize the importance of and identify the principles of thermal expansion. Identify the purpose and use of various types of thermometers.*

If an object is hot when touched, it has a high temperature; if it is cold when touched, it has a low temperature. In other words, temperature is used as a measure of the hotness or coldness of an object. The hotness and coldness of an object are relative. For example, on a cold day, metals seem colder to the touch than nonmetals because they conduct heat away from the body more rapidly. When you leave a warm room to go outside, the outside air seems cooler than it really is. When you come from the outside cold into a warm room, the room seems warmer than it really is. The temperature a person feels depends on the state of his/her body.

Temperature Conversion

There are many systems of temperature measurement, and often you need to convert from one to the other. The four most common scales (fig. 1-13) used today are the Fahrenheit (F), Celsius (C), Kelvin (K), and Rankine (R) scales.

FAHRENHEIT SCALE.— The scale familiar to most Americans is the Fahrenheit scale. Its zero point approximates the temperature produced by mixing equal quantities (by weight) of snow and common salt.

Under standard atmospheric pressure, the boiling point of water is 212° above zero, and the freezing point is 32° above zero. Each degree represents an equal division, and there are 180 such divisions between freezing and boiling.

CELSIUS SCALE.— This scale, formerly called the Centigrade scale, uses the freezing point

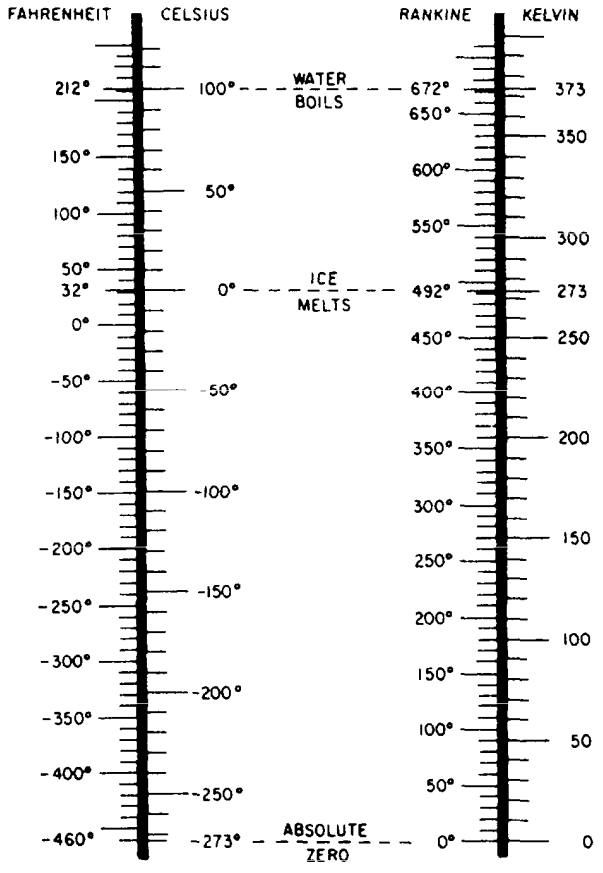


Figure 1-13.-Comparison of the four common temperature scales.

and boiling point of water under standard atmospheric pressure at fixed points of 0 and 100 with 100 equal divisions between. These 100 divisions represent the same difference in temperature as 180 divisions of the Fahrenheit scale, creating a ratio of 100 to 180. The ratio of 100/180 reduces to 5/9, which means a change of 1°F is equal to a change of 5/9°C. A change of 5° on the Celsius scale is equal to a change of 9° on the Fahrenheit scale. Because 0 on the Celsius scale corresponds to 32° on the Fahrenheit scale, a difference in reference points exists between the two scales. (See figure 1-13.)

The Celsius scale is used with most scientific measurements. In your work, you will need to convert Fahrenheit temperatures to their Celsius equivalents. To convert from the Fahrenheit scale to the Celsius scale, you subtract 32° from the temperature and multiply the result by 5/9. For example, to convert 68° Fahrenheit to Celsius, you would perform the following calculations:

$$\frac{5}{9}(68 - 32) = \frac{5}{9} \times 36 = 20\,°C.$$

To convert from the Celsius scale to the Fahrenheit scale, you reverse the process. Multiply the reading on the Celsius thermometer by 9/5 and add 32 to the result.

$$\frac{9}{5}(20) + 32 = 36 + 32 = 68\,°C$$

Another method of temperature conversion is based on the fact that the Fahrenheit and Celsius scales both register the same temperature at –40°; that is, –40°F is equivalent to –40°C. This method of conversion is known as the 40 rule, and you can use the following steps:

Step 1. Add 40 to the temperature that is to be converted. Do this whether the given temperature is Fahrenheit or Celsius.

Step 2. Multiply the result by 9/5 when changing Celsius to Fahrenheit; multiply by 5/9 when changing Fahrenheit to Celsius.

Step 3. Subtract 40 from the result of step 2. This is the answer.

For example, to convert 100°C to the Fahrenheit scale using the 40 rule, perform following calculations:

$$100 + 40 = 140$$

$$140 \times 9/5 = 252$$

$$252 - 40 = 212°F.$$

Remember, always ADD 40 first, then MULTIPLY, then SUBTRACT 40, regardless of the direction of the conversion.

It is important that all technicians be able to read thermometers and to convert from one scale to the other. In some types of electronic equipment, thermometers are provided as a check on operating temperatures. Thermometers are also used to check the temperature of a charging battery.

KELVIN SCALE.— The Kelvin scale was adopted in 1967. It is defined as 1/273.16 of the thermodynamic temperature of the triple point of water. The Kelvin scale is also known as an absolute scale. Its zero point is the temperature at which all molecular motion would cease and no additional heat could be extracted from the substance. It is referred to as absolute zero temperature, which is –273.16°C [commonly used as –273°C (fig. 1-13) for most calculations]. The spacing between degrees is the same as for the Celsius scale; conversion from the Celsius scale to the Kelvin scale is made by adding 273 to the Celsius temperature.

ANSWERS FOR REVIEW QUESTIONS Q64. THROUGH Q65.

A64. Fans and blowers

A65. Dull black

RANKINE SCALE.— The Rankine scale has the same spacing between degrees as the Fahrenheit scale. Its zero point corresponds to 0 Kelvin (absolute zero). This point is calculated as the equivalent of –459.69°F; usually, –460°F is used for calculations. To convert Fahrenheit to Rankine, add 460 to the Fahrenheit temperature.

Since Rankine and Kelvin both have the same zero point, conversion between the two scales requires no addition or subtraction. Rankine temperature is equal to 9/5 times the Kelvin temperature, and Kelvin temperature is equal to 5/9 of the Rankine temperature.

Thermal Expansion

Nearly all substances expand, or increase in size, when their temperature increases. Railroad tracks are laid with small gaps between the sections to prevent buckling when the temperature increases in summer. Concrete pavement has strips of soft material inserted at intervals to prevent buckling when the sun heats the roadway. A steel building or bridge is put together with red-hot rivets so that when the rivets cool they will shrink, and the separate pieces will be pulled together very tightly.

As a substance is expanded by heat, the weight per unit volume decreases. This decrease occurs because the weight of the substance remains the same while the volume is increased by the application of heat. Therefore, you can see that density decreases with an increase in temperature.

Experiments show that for a given change in temperature, the change in length or volume is different for each substance. For example, a given change in temperature causes a piece of copper to expand nearly twice as much as a piece of glass of the same size and shape. For this reason, the connecting wires into an electronic tube are not made of copper; they are made of a metal that expands at the same rate as glass. If the metal does not expand at the same rate as the glass, the vacuum in the tube is broken by air leaking past the wires in the glass stem.

The amount that a unit length of any substance expands for a 1-degree rise in temperature is known as the *coefficient of linear expansion* for that substance. The temperature scale used must be specified.

To estimate the expansion of any object, such as a steel rail, you must know three things about it—its length, the rise in temperature to which it is subjected, and its rate or coefficient of expansion. Expansion is expressed as follows:

expansion = coefficient x length x rise in temperature, or

$$e = kl(t_2 - t_1).$$

In this equation, k represents the coefficient of expansion for the particular substance (in some instances, the Greek letter alpha (α) is used to indicate the coefficient of linear expansion), l represents the length, and t_2 minus t_1 is the difference of the two temperatures.

Use the formula shown above to solve the following problem:

If a steel rod measures exactly 9 feet at 21°C, what is its length at 55°C? The coefficient of linear expansion for steel is 11×10^{-6}.

$$e = (11 \times 10^{-6}) \times 9 \times (55 - 21)$$

$$e = 0.000011 \times 9 \times 34$$

$$e = 0.003366$$

This amount, when added to the original length of the rod, makes the rod 9.003366 feet long. (Since the temperature has increased, the rod is longer by the amount of e. If the temperature had been lowered, the rod would have become shorter by a corresponding amount.)

The increase in the length of the rod is relatively small; but if the rod were placed where it could not expand freely, there would be a tremendous force exerted due to thermal expansion. Thermal expansion is considered when designing ships, buildings, and all forms of machinery.

Table 1-5.-Linear Expansion Coefficients

SUBSTANCE	COEFFICIENT OF LINEAR EXPANSION
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Glass	4 to 9×10^{-6}
Kovar	4 to 9×10^{-6}
Lead	28×10^{-6}
Iron, Steel	11×10^{-6}
Quartz	0.4×10^{-6}
Zinc	26×10^{-6}

Refer to table 1-5 for a list of the coefficients of linear expansion (approximate values) of some substances per °C.

A practical application for the difference in the coefficients of linear expansion is the thermostat. This instrument is made of two strips of different metals fastened together. When the temperature changes, the strip bends because of the unequal expansion of the metals (fig. 1-14). Thermostats (fig. 1-15) are used in overload relays for motors, in temperature-sensitive switches, and in electric ovens.

The **coefficient of surface** or **area expansion** is approximately twice the coefficient of linear expansion. The **coefficient of volume expansion** is approximately three times the coefficient of linear expansion. It is an interesting fact that in a plate containing a hole, the area of the hole

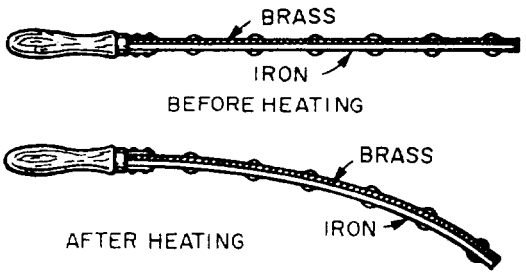


Figure 1-14.-Compound bar.

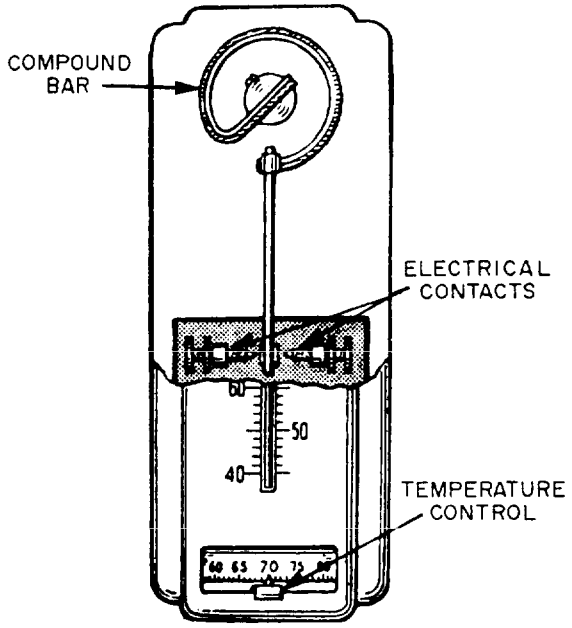


Figure 1-15.-Thermostat.

expands at the same rate as the surrounding material. In the case of a volume of air enclosed by a thin solid wall, the volume of air expands at the same rate as that of a solid body made of the same material as the walls.

Thermometers

The measurement of temperature is known as *thermometry*. Many modern thermometers use liquids in sealed containers. The best liquids to use in the construction of thermometers are alcohol and mercury because they have low freezing points.

LIQUID THERMOMETERS.— The common laboratory thermometer is constructed so it indicates a change of 10 in temperature. A bulb is blown at one end of a piece of glass tubing having a small bore. Then, the tube and bulb are filled with a liquid. During this process, the temperature of both the liquid and the tube are kept at a point higher than the thermometer will reach in normal usage. The glass tube is sealed, and the thermometer is allowed to cool. During the cooling process, the liquid falls away from the top of the tube and creates a vacuum in the thermometer. The thermometer is marked by placing it in melting ice, The height of the cooled liquid column is marked as the 0°C point.

Next, the thermometer is placed in steam at a pressure of 76 centimeters of mercury, and a mark is made at the point to which the liquid inside rises. The space between these two marks is then divided into 100 equal parts (degrees on the Celsius thermometer). This type of thermometer is used in laboratory work and in testing electrical equipment.

SOLID THERMOMETERS.— Because the range of all liquid thermometers is limited, other methods of thermometry are necessary. Most liquids freeze at temperatures between 0°C and –200°C. At the upper end of the temperature range, high heat levels are encountered. Here, the use of liquid thermometers is limited by the high vapor pressures of the liquids. The resistance thermometer and the thermocouple are among the most widely used solid thermometers.

The resistance thermometer makes use of the fact that the electrical resistance of metals changes as the temperature changes. This type of thermometer is usually constructed of platinum wire wound on a mica form and enclosed in a thin-walled silver tube. It is extremely accurate from the lowest temperature to the melting point of the unit.

The thermocouple (fig. 1-16) is an electric circuit. Its operation is based on the principle that when two unlike metals are joined and the junction is at a different temperature from the remainder of the circuit, an electromotive force is produced. The electromotive force is measured with great accuracy by a galvanometers. Thermocouples can be located wherever measurement of the temperature is important and wires run to a galvanometers located at any convenient point. By means of a rotary selector switch, you can use one galvanometers to read the temperatures of thermocouples at any of a number of widely separated points.

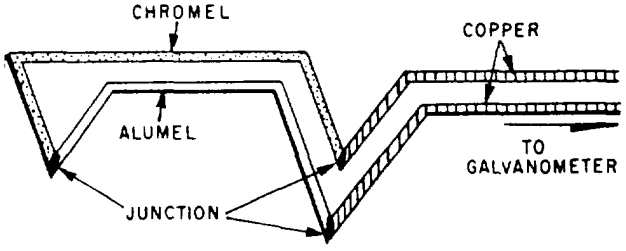


Figure 1-16.-Thermocouple.

The principle of the compound bar (fig. 1-14) is also used in thermometers. The bar may be in the shape of a spiral or a helix so, within a given enclosure, a greater length of the compound bar may be used. This increases the movement of the free end per degree of temperature change. Also, the indicating pointer may be joined to the moving end of the compound bar by means of distance multiplying linkage to make the thermometer easier to read. Often this linkage is arranged to give circular movement to the pointer.

MEASUREMENT OF HEAT

Learning Objective: *Recognize the means of heat measurement in terms of its mechanical equivalent and specific heat.*

A unit of heat may be defined *as the heat necessary to produce some agreed-on standard of change.* There are three such units in common use—the British thermal unit (Btu), the gram-calorie, and the kilogram-calorie.

1. One Btu is the quantity of heat necessary to raise the temperature of 1 pound of water 1°F.
2. One gram-calorie (small calorie) is the quantity of heat necessary to raise 1 gram of water 1°c.
3. One kilogram-calorie (large calorie) is the quantity of heat necessary to raise 1 kilogram of water 1°C. One kilogram-calorie equals 1,000 gram-calories.

NOTE: The large calorie is used in relation to food energy and for measuring comparatively large amounts of heat. In this TRAMAN, the term *calorie* means gram-calorie.

The terms *quantity of heat* and *temperature* are commonly misused. The distinction between them should be understood clearly. For example, two identical pans, containing different amounts of water of the same temperature, are placed over identical gas burner flames for the same length of time. At the end of that time, the smaller amount of water reaches a higher temperature. Equal amounts of heat have been supplied; but, the increases in temperatures are **not** equal. In another example, the water in both pans is the same temperature (80°F), and both pans are heated to the boiling point. More heat must be supplied to the larger amount of water. The temperature rises are the same for both pans, but

the quantities of heat necessary to make the temperature rise are different.

Mechanical Equivalent

Mechanical energy is usually expressed in ergs, joules, or foot-pounds. Energy in the form of heat is expressed in calories or in Btu; 4.186 joules equals 1 gram-calorie; and 778 foot-pounds equals 1 Btu. The following equation is used to convert from the English system to the metric system:

1 Btu = 252 calories.

Specific Heat

Substances differ from one another in the different quantities of heat they require to produce the same temperature change in a given mass of substance. The thermal capacity of a substance is the calories of heat needed, per gram mass, to increase the temperature 1°C. The specific heat of a substance is the ratio of its thermal capacity to the thermal capacity of water at 15°C. Specific heat is expressed as a number that has no units of measurement and applies to both the English and the metric systems.

Water has a high heat capacity. Large bodies of water on the earth stabilize the air and the surface temperature of the earth. A great quantity of heat is required to change the temperature of a large lake or river. Therefore, when the temperature of the air falls below the temperature of bodies of water, they give off large quantities of heat to the air. This process keeps the atmospheric temperature at the surface of the earth from changing very rapidly.

Table 1-6 gives the specific heats of several common substances. To find the heat required to raise the temperature of a substance, multiply its mass by the rise in temperature times its specific heat.

For example, it takes 1,000 Btu to raise the temperature of 100 pounds of water 10°F, but only 31 Btu to raise 100 pounds of lead 10°F.

Table 1-6.-Specific Heats of Some Common Substances

Hydrogen (at constant pressure)	3.409
Water at 4°C	1.0049
Water at 15°C	1.0000
Water at 30°C	0.9971
Ice at 0°C	0.502
Steam at 100°C	0.421
Air (at constant pressure)	0.237
Aluminum	0.217
Glass	0.160
Iron	0.114
Copper	0.093
Brass, zinc	0.092
Silver	0.057
Tin	0.056
Mercury	0.033
Gold, lead	0.031

CHANGE OF STATE

Learning Objective: *Identify the way heat changes the state of matter, to include fusion and vaporization.*

A thermometer placed in melting snow behaves strangely. The temperature of the snow rises slowly until it reaches 0°C. Then, provided the mixture is stirred constantly, it remains at that point until all the snow has changed to water. When all the snow has melted, the temperature again begins to rise. A definite amount of heat is required to change the snow to water at the same temperature. This heat is required to change the water from crystal form to liquid form.

Heat of Fusion

Eighty gram-calories of heat are required to change 1 gram of ice at 0°C to water at 0°C. In English units, the heat required to change 1 pound of ice at 32°F to water at 32°F is 144 Btu. These values (80 gram-calories and 144 Btu) are called the *heat of fusion of water.* The heat used to melt the ice represents the work done to produce the change of state. Since 80 calories are required to change a gram of ice to water at 0°C, when a gram of water is frozen, it gives up 80 calories.

Many substances behave very much like water. At a given pressure, they have a definite heat of fusion and an exact melting point. However, there

are many materials that don't change from a liquid to a solid state at one temperature. For example, molasses gets thicker and thicker as the temperature decreases, but there is no exact temperature where the change of state occurs. Wax, celluloid, and glass are other substances that do not change from a liquid to a solid state at any particular temperature. In fact, measurements of glass thickness at the bottom of windows in ancient cathedrals tend to indicate that the glass is still flowing at an extremely slow rate. Most types of solder used in electronics maintenance also tend to become mushy before melting.

Heat of Vaporization

Damp clothing dries more rapidly under a hot flat iron than under a cold one. A pool of water evaporates more rapidly in the sun than in the shade. Therefore, heat has something to do with evaporation. The process of changing a liquid to a vapor is similar to what occurs when a solid melts.

If a given quantity of water is heated until it evaporates [changes to a gas (vapor)], more heat is used than is necessary to raise the same amount of water to the boiling point. For example, 540 calories are required to change 1 gram of water to vapor at a temperature of 100°C. It takes 972 Btu to change 1 pound of water at 212°F to water vapor (steam) at 212°F. The amount of heat necessary for this change is called the *heat of vaporization of water.* Over five times as much heat is required to change a given amount of water to vapor than to raise the same amount of water from the freezing point to the boiling point.

When water is heated, some vapor forms before the boiling point is reached. As the water molecules take up more and more energy from the heating source, their kinetic energy increases. The motion that results from the high kinetic energy of the water molecules causes a pressure, which is called the *vapor pressure.* As the velocity of the molecules increases, the vapor pressure increases. The boiling point of a liquid is the temperature at which the vapor pressure equals the external or atmospheric pressure. At normal atmospheric pressure at sea level, the boiling point of water is 100°C or 212°F.

> **NOTE:** At sea level, atmospheric pressure is normally 29.92 inches of mercury.

While the water is below the boiling point, a number of molecules acquire enough kinetic energy to break away from the liquid state into a vapor. For this reason, some evaporation slowly takes place below the boiling point. At or above the boiling point, large numbers of molecules have enough energy to change from liquid to vapor, and the evaporation takes place much more rapidly.

If the molecules of water are changing to water vapor in an open space, the air currents carry them away quickly. In a closed container, they become crowded and some of them bounce back into the liquid as a result of collisions. When as many molecules are returning to the liquid state as are leaving it, the vapor is *saturated.* Experiments show that saturated vapor in a closed container exerts a pressure and has a given density at every temperature.

Q66. Convert 96°F to the Celsius scale.

Q67. List the four types of scales.

Q68. What principle is involved in temperature-sensitive switches?

Q69. What type of thermometer is usually used in the laboratory? In aircraft?

Q70. What other principle is used to construct a thermometer?

Q71. What effect does the heat of fusion have on solder?

LIGHT

Learning Objective: *Recognize the characteristics of light and identify colors in the frequency spectrum.*

The exact nature of light is not fully understood, although men have been studying the subject for centuries. There are scientific phenomena that are explained only by the wave theory, and other phenomena that are explained by the particle or corpuscular theory. Gradually, physicists have accepted a theory about light that combines these two views; light is a form of electromagnetic radiation. As such, light and similar forms of radiation are made up of moving electric and magnetic forces.

CHARACTERISTICS

Light waves travel in straight lines. When they meet another substance, they are transmitted, reflected, or absorbed. Substances that permit clear vision through them and transmit almost all the light falling upon them are *transparent.* Substances that allow part of the light to pass but appear clouded and impair vision substantially are called *translucent.* Substances that transmit no light are called *opaque.*

Objects that are not light sources are visible because they reflect part of the light reaching them from some luminous source. If light is neither transmitted nor reflected, it is absorbed or taken up by the medium. When light strikes a substance, some absorption and reflection **always** takes place. No substance **completely** transmits, reflects, or absorbs all the light that reaches its surface.

Luminous Intensity and Intensity of Illumination

Luminous intensify refers to the total light produced by a source. *Intensity of illumination* describes the amount of light received per unit area at a distance from the source. The following terms are generally used when describing luminous intensity and intensity of illumination.

Candlepower. This is the luminous intensity expressed in candelas. A candela is the luminous intensity in the perpendicular direction of a surface of 1/600,000 square meter of a black body at the temperature of freezing platinum under a pressure of 101,325 newtons per square meter.

Footcandle. The intensity of illumination of a surface (illuminance) is directly proportional to the luminous intensity of the light source. It is inversely proportional to the square of the distance between the light source and the surface, Look at figure 1-17. It shows how an experiment can prove the inverse square law of light.

Place a card 1 foot from a light source. The light striking the card is of a certain intensity. Next, move the card 2 feet away. You can see that the intensity of light decreases with the square of the distance (2 x 2, or 4 times) and is one-fourth as bright. Now, move the card 3 feet away from the light; the light is now one-ninth as intense as it was when the light was 1 foot from the card. If you move the card 4 feet away from the light source, the light is one-sixteenth as intense.

The footcandle is one unit of measuring the intensity of incident light using the formula:

$$\text{Illumination in footcandles} = \frac{\text{candlepower of source}}{(\text{distance in feet})^2}.$$

A surface 1 foot from a 1-candlepower source has an illumination of 1 footcandle; but, if the surface is moved to a distance of 4 feet, a 16-candlepower source is required for the same illumination.

ANSWERS FOR REVIEW QUESTIONS Q66. THROUGH Q71.

A66. $\frac{5}{9}(96 - 32) = \frac{5}{9} \times 64 = 35.5\,^{\circ}C$

A67. *a. Celsius*
b. Fahrenheit
c. Kelvin
d. Rankine

A68. Coefficient of linear expansion.

A69. The liquid thermometer is usually used in the laboratory white the solid thermometer is used in aircraft.

A70. The principle of the compound bar.

A71. It causes it to become mushy before it melts; that is, it flows at a very slow rate.

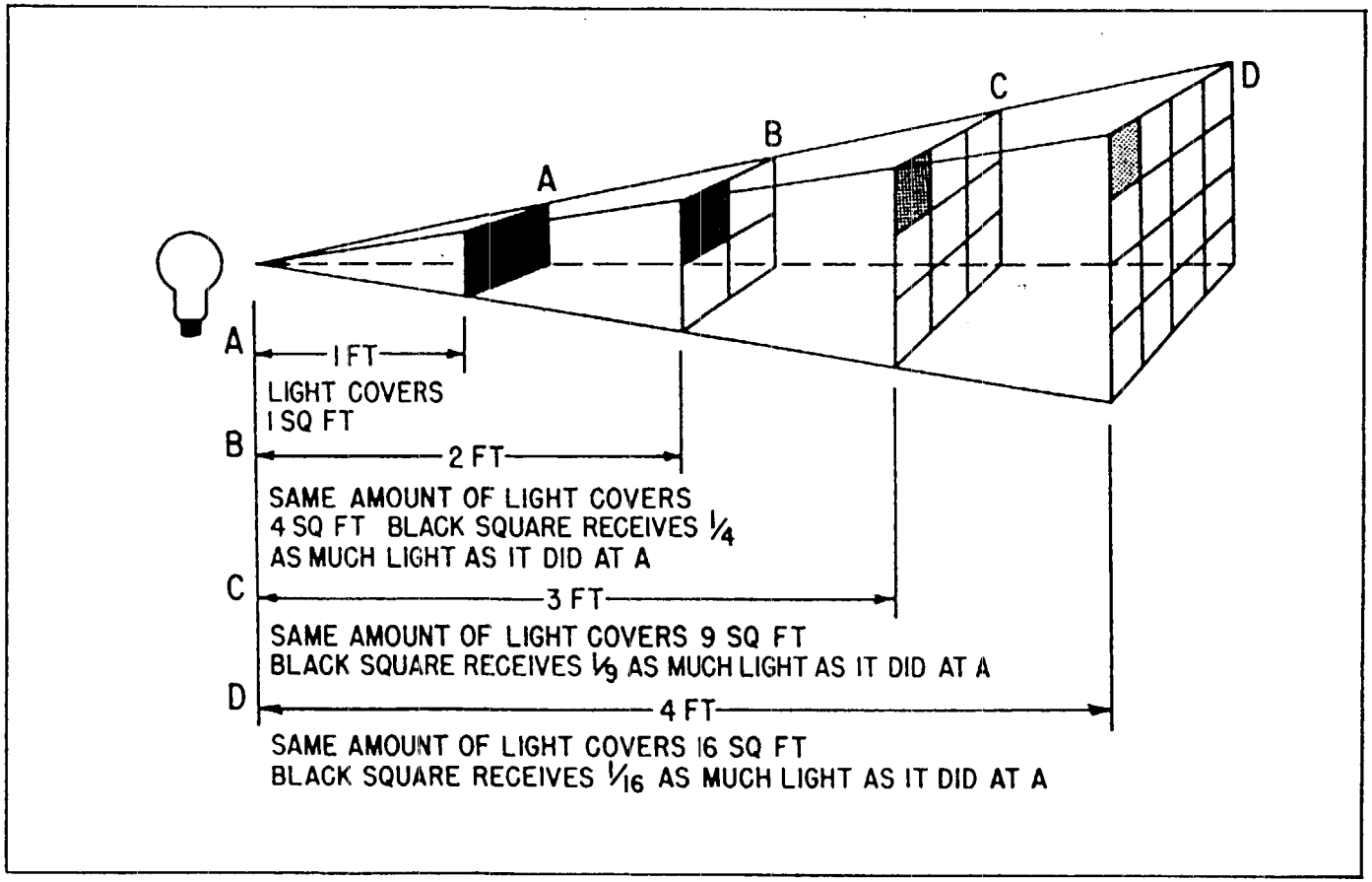


Figure 1-17.—Inverse square law of light.

The inverse square law of light holds true for undirected light only. For light that is directed, the rate its intensity diminishes depends on the rate of divergence of the beam.

Lumen. This unit is the amount of light flowing through a solid angle of 1 radian from a standard candle. The following example helps explain the term *lumen.* If a light source of 1 candlepower is placed in the center of a sphere with a radius of 1 foot, it illuminates every point on the surface of the sphere at an intensity of 1 footcandle. Every square foot of the surface receives 1 lumen of light. The total surface of the sphere is found by the formula $4\pi r^2$. If the radius of a sphere is 1 foot, the area is 4 x 3.1416 x 1^2 = 12.5664 square feet. Therefore, a source of 1 candlepower emits 12.5664 lumens.

The output of light bulbs is given either in candlepower or in lumens. Since the light bulb may not distribute the light equally in all directions, the lumen is most frequently used. Light bulb manufacturers measure the light output in all directions and specify its total output in lumens. When the total output in lumens is known, the average candlepower is computed by dividing the total output in lumens by 4π (12.5664).

Lux. The lux is the illumination given to a surface 1 meter away from a 1-candlepower source and is sometimes called a *meter-candle.*

Phot. The phot is the illumination given to a surface 1 centimeter away from a 1-candlepower source and is sometimes called a *centimeter-candle.*

Luminance. Luminance (or brightness) refers to the light a surface gives off in the direction of the observer. The **lambert** is the unit of luminance equal to the uniform luminance of a perfectly diffusing surface that emits or reflects light at the rate of 1 lumen per square centimeter. For a perfectly reflecting and perfectly diffusing surface, the number of lamberts is equal to the number of phots (incident light).

Q72. List the effects on light waves when they meet a substance.

Q73. What is meant by the term luminous intensity?

Q74. What is meant by the term intensity of illumination?

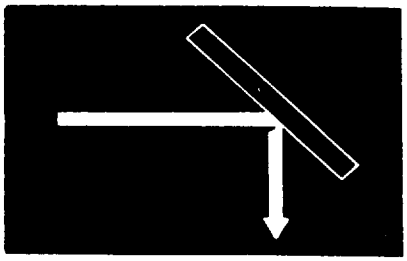
Q75. What is measured by the footcandle?

Q76. What term is usually used to describe the output of a light bulb?

Reflection

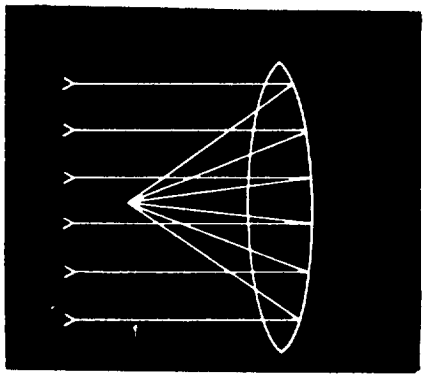
Light waves obey the law of reflection the same way as other types of waves. Optical devices that reflect light are generally classed as mirrors. They are a polished opaque surface, or they are a specially coated glass. Glass mirrors refract as well as reflect; however, if the glass is of good quality and not excessively thick, the refraction causes no trouble. The following discussion is based on the mirror.

Basically, the reflector is used to change the direction of a light beam. The angle of the reflected light is changed to a greater or lesser degree by changing the angle at which the incident light impinges upon the mirror.



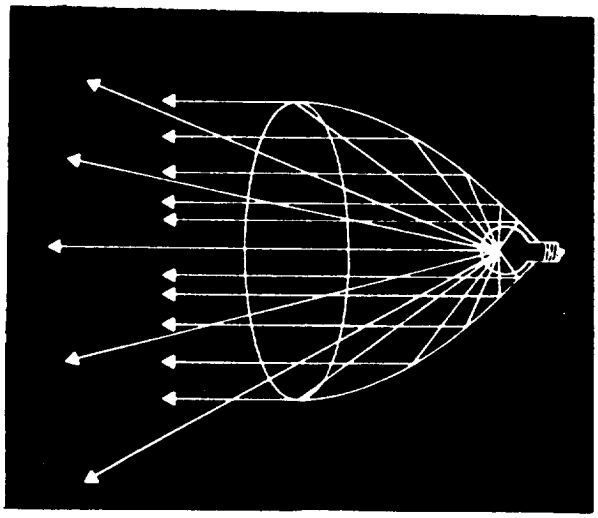
Changing direction.

The reflector is also used to focus a beam of light. The focusing action of a concave mirror is indicated. The point of focus may be made any convenient distance from the reflector by proper selection of the arc of curvature of the mirror; the sharper the curvature, the shorter the focal length.



Focusing a beam.

The reflector can be used to intensify the illumination of an area. The flashlight is an example of this application. You can see that the light source (bulb) is located approximately at the principal focus point, and that all rays reflected from the surface are parallel. You can also see that the reflector does not concentrate all the rays, and some are transmitted without being reflected and are not included in the principal beam.



Illuminating an area.

Refraction

As light passes through a transparent substance, it travels in a straight line. When it passes into or out of that substance, it is refracted like other waves. Refraction of light occurs because light travels at different velocities in different transparent media. To make it easier to predict the outcome of specific applications, many transparent substances have been tested for refractive effectiveness. The ratio of the speed of light in air to its speed in each transparent substance is called the *index of refraction* for that substance. For example, light travels about one and one-half times as fast in air as it does in glass, so the index of refraction of glass is about 1.5. When the law of refraction is used in connection with light, a **denser** medium refers to a medium with a higher index of refraction.

Refraction through a piece of plate glass is shown in figure 1-18. The ray of light strikes the glass plate at an oblique angle along path AB. If it were to continue in a straight line, it would emerge from the plate at point N. But according to the law of refraction, it is bent toward the normal RS and emerges from the glass at point C. As it enters the air, the ray does not continue on its path, but is bent away from the normal XY, and leaves along the path CD in the air.

If the two surfaces of the glass are parallel, the ray leaving the glass is parallel to the ray entering the glass. The displacement depends upon the thickness of the glass plate, the angle of entry into it, and the index of refraction for the glass.

All rays striking the glass at any angle other than perpendicular are refracted in the same manner. In the case of a perpendicular ray, no refraction takes place, and the ray continues through the glass and into the air in a straight line.

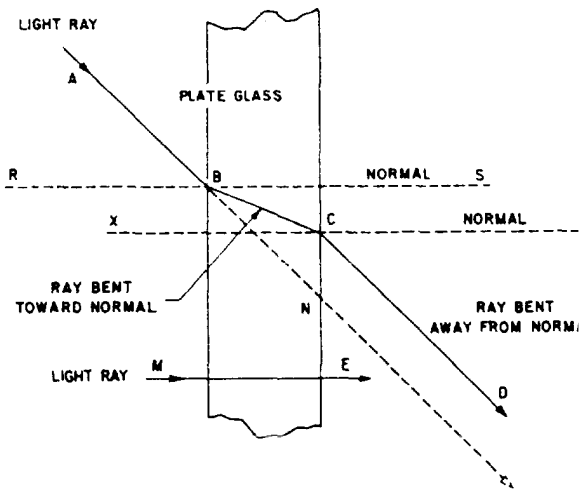


Figure 1-18.-The law of refraction.

ANSWERS FOR REVIEW QUESTIONS Q72. THROUGH Q76.

A72. a. Transmitted through the substance
b. Reflected by the substance
c. Absorbed by the substance

A73. It is the total light produced by a source.

A74. It is the amount of light received per unit area at a distance from the source.

A75. Intensity of incident light.

A76. Lumen.

PRISMS.— When a ray of light passes through a flat sheet of glass, it emerges parallel to the incident ray. **This is true only when the two surfaces of the glass are parallel.** When the two surfaces are not parallel, as in a prism (fig. 1-19), the ray is refracted differently at each surface of the glass and does not emerge parallel to the incident ray.

View A shows that both refractions are in the same direction. The ray coming out of the prism is not parallel to the ray going into it, following the law of refraction. When the ray entered the prism, it was bent toward the normal; and when it emerged, it was bent away from the normal. You can see that the deviation is the result of the two normals not being parallel.

If two triangular prisms are placed base to base (view B), parallel incident rays passing through them are refracted and intersect. The rays passing through different parts of the prisms do not intersect at the same point. With two prisms, there are only four refracting surfaces. The light rays from different points on the same plane are not refracted to a point on the same plane behind the prism. They emerge from the prisms and intersect at different points along an extended common baseline, as you can see by looking at points A, B, and C in view B.

Parallel incident light rays falling upon two prisms apex to apex (view C) are spread apart. The upper prism refracts light rays toward its base, and the lower prism refracts light rays toward its base. The two sets of rays diverge.

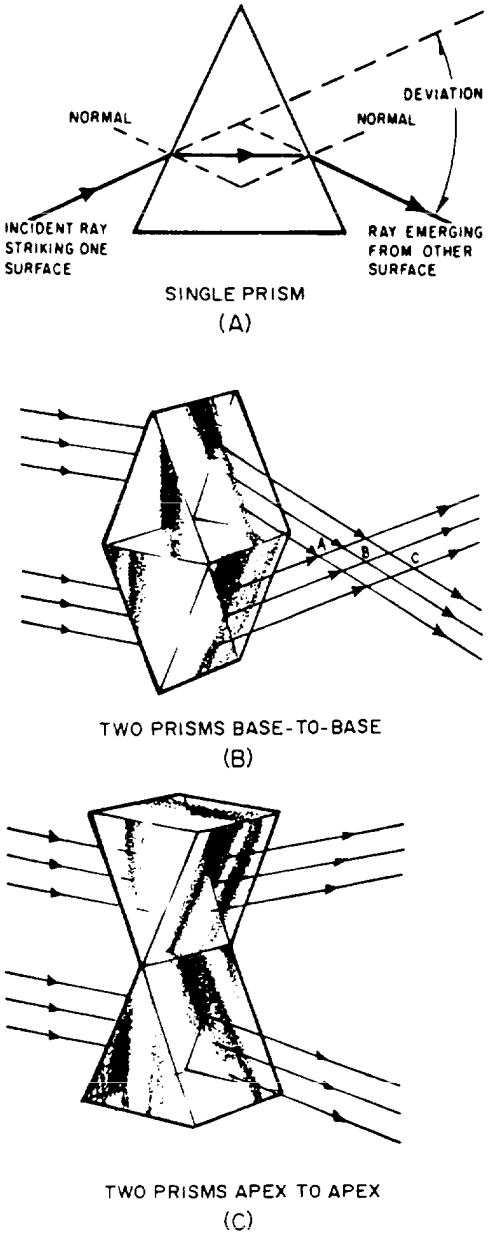


Figure 1-19.-Passage of light through a prism.

POSITIVE LENSES.— A positive (convergent) (fig. 1-20) lens acts like two prisms base to base, with their surfaces rounded off into a curve. Rays that strike the upper half of the lens bend downward, and rays that strike the lower half bend upward.

A good lens causes all wavelengths within each ray to cross at the same point behind the lens. When the incident ray of light enters the denser medium (the lens), it bends toward the normal. When it passes through the lens into the less dense medium (the air), it bends away from the normal.

View B shows the refraction of only one ray of light; but all rays passing through a positive lens behave in the same way. All incident light rays, either parallel or slightly diverging, converge to a point after passing through a positive lens.

The only ray of light that can pass through a lens without bending is the ray that strikes the first surface of the lens at a right angle, perpendicular or normal to the surface. It passes through that surface without bending and strikes the second surface at the same angle. It leaves the lens without bending. This ray is shown in view B.

The terms *positive lens* and *convergent lens* are synonymous; either of them may be used to describe the action of a lens that focuses (brings to a point of convergence) all light rays passing through it. All simple positive lenses are easy to identify since they are thicker in the center than at the edges. The three most common types of simple positive lenses are shown in view C.

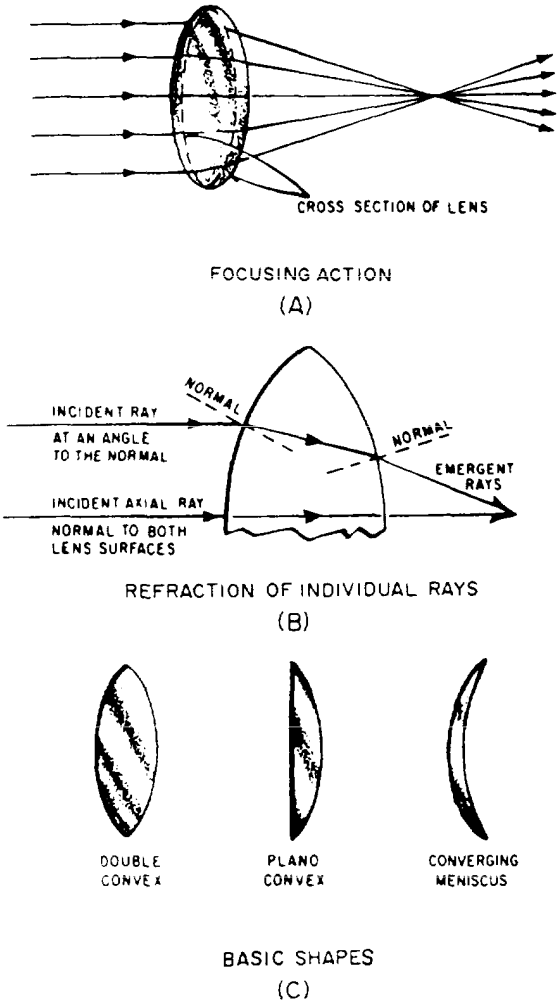


Figure 1-20.-Positive lenses.

NEGATIVE LENSES.— Look back at figure 1-19, view C. Here you can see the refraction of light rays by two prisms apex to apex. If the prism surfaces are rounded, the result is a negative (divergent) lens, A negative lens is called a *divergent lens,* since it does not focus the rays of light passing through it. Light rays passing through a negative lens diverge or spread apart (fig. 1-21, view A).

Look at View B. Here, the law of refraction to one ray of light passing through a negative lens is shown. However, just as in a positive lens, a ray of light passing through the center of a negative lens is not affected by refraction and passes through without bending.

Three simple negative lenses are shown in view C. They are often referred to as *concave lenses* and are identified by their concave surfaces. The simple negative lenses are thicker at the edges than at the center. They are generally used, in conjunction with simple positive lenses, to assist in the formation of a sharper image by

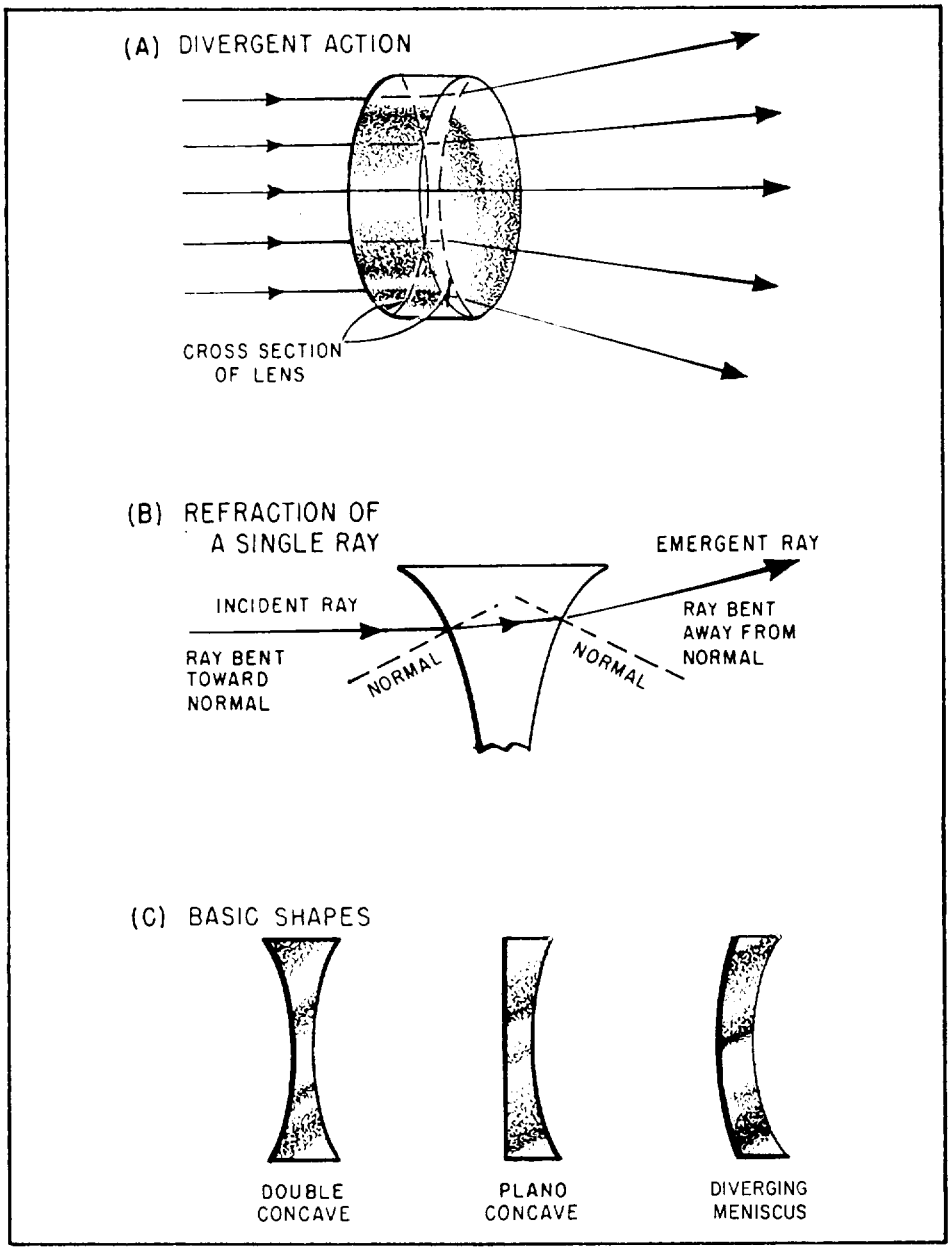


Figure 1-21.-Negative lenses.

eliminating or subduing various defects present in an uncorrected simple positive lens.

Q77. What are the principle uses of reflectors?

Q78. What happens when light passes through a transparent substance?

Q79. List the objects that act as refractors.

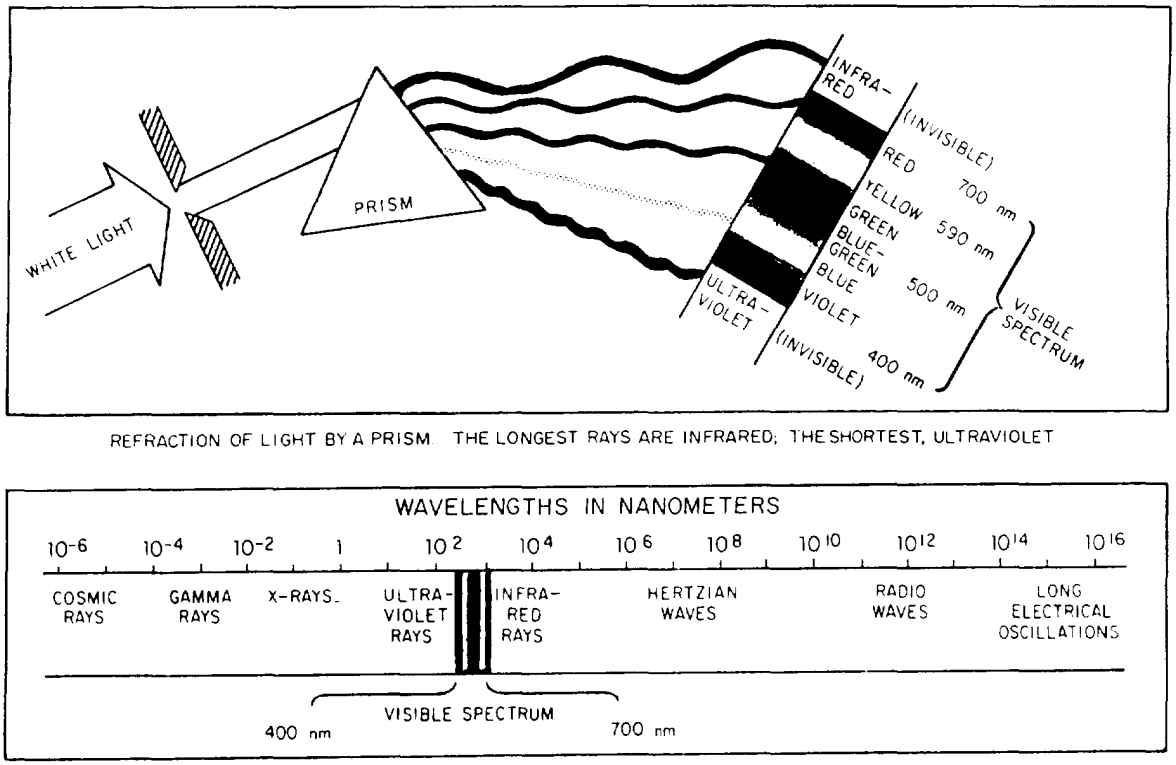
FREQUENCIES AND COLOR

The electromagnetic waves that produce the sensation of light are all very high frequency (VHF) waves, which means that they have very short wavelengths. These wavelengths are measured in nanometers (billionths of meters, or 10^{-9} meters). By looking at figure 1-22, you can see that light with a wavelength of 700 nanometers is red and that a light with a wavelength of 500 nanometers is blue-green. The information in this figure is not exactly correct as the color of light depends on its frequency, not its wavelength.

Wavelength varies, depending on the medium the wave is in. When a wave producing the color red is in air, its wavelength is 700 nanometers. When the same wave is in another medium, its wavelength is other than 700 nanometers. When red light that has been traveling in air enters glass, it loses speed and its wavelength becomes shorter or compressed, but it continues to be red. The color of light depends on frequency and not on wavelength. (Note: The color scale in figure 1-22 is based on the wavelengths in air.)

All color-component wavelengths of the visible spectrum are present in equal amounts in white light. Variations in composition of the component wavelengths result in other characteristic colors. For example, when a beam of white light is passed through a prism (fig. 1-22), it is refracted and dispersed into its component wavelengths. The eye reacts differently to each of these wavelengths, seeing the various colors making up the visible spectrum. The visible spectrum is recorded as a mixture of red, orange, yellow, green, blue, indigo, and violet. You can see that white light results when the **primaries** (red, green, and blue) are mixed together in overlapping beams of light.

NOTE: These are not the primaries used in mixing pigments.



REFRACTION OF LIGHT BY A PRISM. THE LONGEST RAYS ARE INFRARED; THE SHORTEST, ULTRAVIOLET

Figure 1-22.-Electromagnetic wavelengths and the refraction of light.

The **complementary** or secondary colors (magenta, yellow, and cyan) are shown by mixing any two of the primary colors in overlapping beams of light. For example, red and green light mixed in equal intensities make yellow light; green and blue mixed together produce blue-green (cyan) light; and blue and red light correctly mixed produces magenta (purplish red).

Q80. Name the primary colors of light frequencies.

Q81. If you mix the primary colors together, what is the result?

SOUND

Learning Objectives: *Recognize the characteristics of sound and travel. Identify the sound conduction media and recognize its effects on the velocity of sound transmission.*

Normally, the term *sound* refers to hearing. When used in physics, sound refers to a particular type of wave motion. It deals with the generation, propagation, transmission, characteristics, and effects of sound waves.

BASIC CONSIDERATIONS

One example of the generation and propagation of sound waves is the tuning fork (discussed earlier in this chapter). Any object that moves rapidly to and fro or vibrates rapidly, disturbing the surrounding medium, may become a sound source, Sound requires three components—a source, a medium for transmission, and a detector. As widely different as sound sources may be, the waves they produce have certain basic characteristics.

WAVE MOTION

Sound waves are longitudinal-type waves that rely on a physical medium for propagation and transmission. Since the waves are transmitted by the compression and rarefaction of particles of matter in the medium, they cannot be transmitted through a vacuum. Sound waves are similar to other types of waves because they can be reflected, absorbed, or refracted. Sound waves are also subject to the Doppler effect.

The major differences between sound waves, heat, and light waves are the frequencies, the nature of the waves, and the velocities of wave travel.

CONDUCTION MEDIA AND VELOCITY OF TRANSMISSION

In a uniform medium under given physical conditions, sound travels at a definite speed. In some substances, the velocity of sound is higher than in others. Even in the same medium, when temperature conditions differ, the velocity of sound varies. **Density** and **elasticity** of a medium are basic physical properties that govern the velocity of sound.

You can calculate the velocity of compressional waves in centimeters per second when the elasticity and density of the medium are given in cgs units by using the formula

$$\text{velocity} = \sqrt{\frac{\text{elasticity}}{\text{density}}}.$$

The elasticity of most liquids and solids is much greater than gases, and the velocity of sound is faster in them in spite of their larger densities. The coefficient of elasticity for water is 15,230 times that of air, while water has only 773 times the density of air. Because of this, sound travels over four times faster in water than it does in air.

Some velocities of sound are given in table 1-7; these velocities correspond closely to those

Table 1-7.-Comparison of Velocity of Sound in Various Media

Medium	Temperature (°F)	Velocity (FT/SEC)
Air	32	1,087
Air	68	1,127
Aluminum	68	16,700
Carbon dioxide	32	856
Fresh water	32	4,629
Fresh water	68	4,805
Hydrogen	32	4,219
Lead	68	4,030
Salt water	32	4,800
Salt water	68	4,953
Steel	32	16,410
Steel	68	16,850

calculated by using the formula. Compare the velocity of sound in lead and water. Lead has a density that is eleven times greater than water, yet the velocity of sound is only slightly less in lead than in water. The density of steel is over twice that of aluminum, but steel is more elastic. If you compare the velocity of sound in steel and aluminum, you will find that the velocity is almost the same in the two metals.

The elasticities of most gases at equal pressures are the same, so the velocity of sound-through gases is inversely proportional to the square root of their densities. For example, the density of air is almost 16 times that of hydrogen; therefore, the velocity of sound in air is slightly more than one/fourth the velocity of sound in hydrogen. In the other direction, air has a density of slightly less than two-thirds the density of carbon dioxide; therefore, the velocity of sound in air is approximately 1.25 times the velocity of sound in carbon dioxide. (See table 1-7 for actual values.)

The velocity of sound in a gas, such as air, is independent of pressure. When pressure is increased, the density and elasticity both increase at the same ratio. Consequently, the velocity is constant so long as the temperature is not changed. But if the temperature is raised (pressure being constant), densiy diminishes, and the velocity of sound increases. If absolute values for temperature (Kelvin or Rankine) are used, the velocities of sound in air are related to air temperatures by the relation

$$\frac{V_1}{V_2} = \sqrt{\frac{T_1}{T_2}}.$$

This amounts to about a 2-foot-per-second increase for each °C rise in temperature, and about a 1.1-foot-per-second increase for each °F rise in temperature. Since air temperature is usually lower at high altitudes, the velocity of sound is also lower at these altitudes.

For a fixed temperature, the velocity of sound is constant for any medium, and is independent of both the frequency and the amplitude of the sound waves.

Q82. List the three components that are required by sound.

Q83. List the two properties of a medium that govern the velocity of sound as it passes through the medium.

Q84. Sound travels faster in liquids and solids than in gases even though liquids and gases are more dense. Why will sound travel faster in water than it does in air?

Q85. The velocity of sound is lower at high altitudes. Explain why this is so.

CHARACTERISTICS

Learning Objective: *Identify the pitch, quality, and intensity of sound.*

Many words describe sounds, such as whistle, scream, rumble, and hum. Most of these words describe noises, not musical tones. Musical tones

ANSWERS FOR REVIEW QUESTIONS Q77. THROUGH Q81.

A77. a. To focus a beam of light
b. To change the direction of a light beam
c. To intensify the illumination of an area

A78. It is refracted

A79. a. Prisms
b. Positive lenses
c. Negative lenses

A80. a. Red
b. Green
c. Blue

A81. White light

are based on the regularity of the vibrations, the degree of damping, and the ability of the ear to recognize components having a musical sequence.

The ear can distinguish tones that are different in pitch, intensity, or quality. Each of these characteristics is associated with one of the properties of the vibrating source or of the waves that the source produces.

- Pitch is determined by the number of vibrations per second.
- Intensity is determined by the amplitude of the wave motion.
- Quality is determined by the number of overtones (harmonics) that the wave contains.

A sound wave is best described by its frequency rather than by its velocity or wavelength because both velocity and wavelength change when the temperature of the air changes.

Pitch

The term *pitch* describes the frequency of a sound. The recognizable difference between the tones produced by two different keys on a piano is a difference in pitch. The pitch of a sound is proportional to the number of compressions and rarefaction received per second, which, in turn, is determined by the vibration frequency of the sounding source. Sound waves vary in length; a long wavelength sounds as if its pitch is low, while a short wavelength sounds is if its pitch is high.

Pitch is usually measured by comparison with a standard. The standard tone may be produced by a tuning fork of known frequency or by a siren whose frequency is computed for a particular speed of rotation. When the speed is regulated, the pitch of the siren is made equal to that of the tone being measured. The ear can determine this equality directly if the two sources are sounded alternately, or by the elimination of beats by regulating the speed of the siren if the two sources are sounded together.

NOTE: If a sound is below 15 hertz or above 20,000 hertz, it is not normally heard by the human ear. The frequency range over which sound is heard is known as the *audible range,* and the sounds heard are known as *sonics.* Sounds below 15 hertz are subsonics; those above 20,000 hertz are ultrasonics.

On the musical scale, pitch refers to the standard frequency of a given note on the scale. In a few cases, 256 Hz is used for the keynote, sometimes called middle C. For scientific purposes, the A string of the violin is tuned to 440 Hz. The note one octave higher than the first has a frequency twice that of the first, and one an octave lower is one-half the frequency of the first. For example, if middle C on a piano is tuned to 256 Hz, the C an octave higher is 512 Hz, and one octave lower is 128 Hz. A pitch change from 55 Hz to 110 Hz is of just as much consequence as the change from 440 Hz to 880 Hz.

Quality

Most sounds and musical notes are not pure tones. They are mixtures of tones of different frequencies. The tones produced by most sources are composite waves in which the sound of lowest pitch (the fundamental tone) is accompanied by several harmonics or overtones. These harmonics have frequencies that are two, three, four, or more times that of the fundamental frequency. The quality of a tone depends on the number of overtones present and on their frequencies and intensities relative to the fundamental tone. It is this characteristic of difference in quality that distinguishes tones of like pitch and intensity when sounded on different types of musical instruments (piano, organ, violin, and so forth).

Intensity

When a bell rings, the sound waves spread out in all directions, and the sound is heard in all directions. When a bell is struck lightly, the vibrations are of small amplitude, and the sound is weak. A stronger blow produces vibrations of greater amplitude, and the sound is louder. Therefore, the amplitude of the air vibrations is greater when the amplitude of the vibrations of the source is increased, and the loudness of the sound depends on the amplitude of the vibrations of the sound waves. As the distance from the source increases, the energy in each wave spreads out, and the sound becomes weaker.

The intensity of sound in the energy per unit area per second. In a sound wave of simple harmonic motion, the energy is half kinetic and half potential; half is due to the speed of the particles, and half is due to the compression and rarefaction of the medium. These two energies are 90 degrees out of phase at any instant; that is, when the speed of particle motion is at a

maximum, the pressure is normal. When the pressure is at a maximum or a minimum, the speed of the particles is zero.

Loudness is a subjective measurement that depends primarily on the sound pressure, frequency, and waveform of the stimulus. Intensity of sound is an objective measurement of the sound power being delivered, and it is usually measured as the power flowing through a unit area perpendicular to the direction of the waves. One such method specifies microwatt flowing through an area of 1 square centimeter, One microwatt is equivalent to 10 ergs per second or 10^{-6} joules per second.

At any distance from a point source of sound, the intensity of the wave varies inversely as the square of the distance from the source. As a sound wave advances, variations in pressure occur at all points in the transmitting medium. The greater the pressure variations, the more intense the sound wave. Intensity is proportional to the square of the pressure variation, regardless of frequency; therefore, when pressure changes are measured, intensities of sounds having different frequencies can be compared directly.

MEASUREMENT OF SOUND

Learning Objective: *Identify means of sound measurement to include sound units, intensity level, acoustical pressure, and power ratio.*

The range of sound that the human ear can detect varies with the individual. The normal range extends from about 20 to 20,000 vibrations per second. In the faintest audibles speech sounds, the intensity at the ear is about 10^{-} watts/cm^2. At the threshold of feeling, the maximum intensity that the ear perceives as sound is about 10^{-4} watts/cm^2.

The human ear is a nonlinear unit that functions on a logarithmic basis. Its threshold of audibility is reached when intensity is reduced to such a low level that auditory sensation ceases. On the other hand, the threshold of feeling is reached when intensity is increased to such a high level that sound produces the sensation of feeling and becomes painful. By applying this procedure over a wide frequency range, data is used to plot two curves—one for the lower limit of audibility and the other for the maximum auditory response (fig. 1-23). Below the lower curve, the human ear cannot hear the sound. Above the upper curve, the sensation is one of feeling rather than of hearing; that is, the sensation of sound is masked by pain. The area between the two curves shows the pressure ranges for auditory response at various frequencies.

Sound Units

The loudness of sound is not measured by the same type of scale used to measure length. Units of sound measurement vary logarithmically with the amplitude of the sound variations. These units

ANSWERS FOR REVIEW QUESTIONS Q82. THROUGH Q85.

A82. a. A source
b. A medium for transmission
c. A detector

A83. a. Density
b. Elasticity

A84. Because of the elasticity of water, sound travels over four times faster in water than in air. The coefficient of elasticity for water is 15,230 times that of air.

A85. Velocity is constant in a medium when temperature is constant. If temperature rises, density diminishes, and the velocity of sound increases. Therefore, if temperature drops, density increases, and the velocity of sound decreases. Because air temperature is normally lower at high altitudes, the velocity of sound is lower.

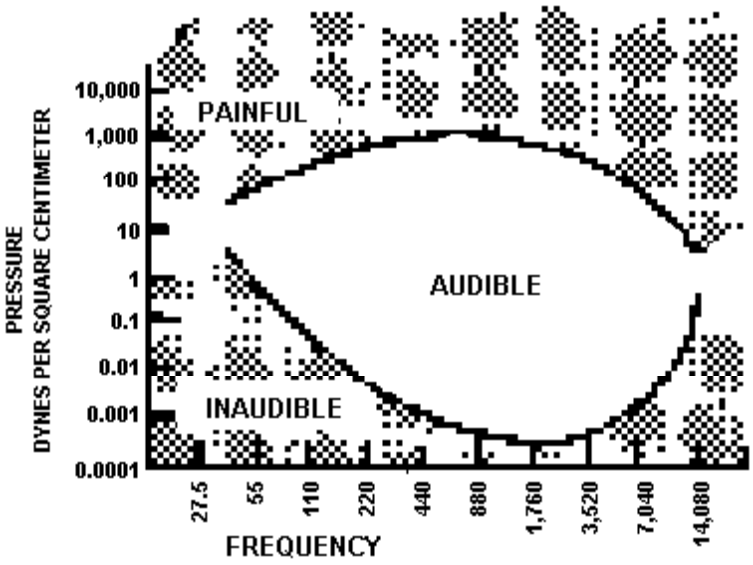


Figure 1-23.-Field of audibility.

are the *bel* and *decibel,* which refer to the difference between sounds of unequal intensity or sound levels. The decibel (one-tenth of a bel) is the minimum change of sound level perceptible to the human ear. A sound for which the power is 10 times as great as that of another sound level differs in power level by 1 bel, or 10 decibels. For example, 5 decibels may represent almost any volume of sound, depending on the intensity of the reference level on which the ratio is based. In sound-system engineering, decibels (dB) are used to express the ratio between electrical powers or between acoustical powers, If the amounts of power to be compared are P1 and P2, the ratio in decibels is

$$dB = 10 \times \log \frac{(P2)}{(P1)}.$$

NOTE: When the logarithmic base is not indicated, it is assumed to be 10.

If P2 is greater than P1, the decibel value is positive and represents a gain in power. If P2 is less than P1, the decibel value is negative and represents a loss in power.

Intensity Level

An arbitrary zero reference level is used to accurately describe the loudness of various sounds. This zero reference level is the sound produced by 10-16 watts per square centimeter of surface area facing the source. This level approximates the **least** sound perceptible to the ear and is usually called the *threshold of audibility*. The sensation experienced by the ear when subjected to a noise of 40 decibels above the reference level would be 10,000 times as great as when subjected to a sound that is barely perceptible.

Acoustical Pressure

Typical values of sound levels in decibels and the corresponding intensity levels are summarized in table 1-8. The values in this table are based on an arbitrarily chosen zero reference level. Note that for each tenfold increase in power, the intensity of the sound increases 10 decibels. The power intensity doubles for each 3-decibel rise in sound intensity.

Q86. List the three characteristics of sound.

Q87. What two terms describe the range of sound the human ear can distinguish?

Q88. How do sound units vary with amplitude of variations?

Q89. The units of sound measurement are the bel and the decibel. They vary logarithmically with the amplitude of the sound variations. To what do the bel and the decibel refer?

Q90. In sound-system engineering, what ratio does dB express?

Q91. What is the arbitrary zero reference level used to describe the loudness of sounds?

SOUND LEVEL (DECIBELS)	INTENSITY LEVEL (WATTS/CM^2)
0	10^{-16}
60	10^{-10}
80	10^{-8}
100	10^{-6}
110	10^{-5}
120	10^{-4}
130	10^{-3}

Table 1-8.-Values of Sound Levels

Power Ratio

The decibel is used to express an electrical power ratio, such as the gain of an amplifier, the output of a microphone, or the power in a circuit compared to an arbitrarily chosen reference power level. The value of decibels is often computed from the voltage ratio or the current ratio **squared.** These values are proportional to the power ratio for equal values of resistance. If the resistances are not equal, a correction must be made. To find the number of decibels from the voltage ratio, assuming that the resistances are equal, substitute E^2 for P in the basic equation:

$$dB = 10 \times \log \frac{E2^2}{E1^2} = 10 \times \log \left(\frac{E2}{E1}\right)^2, \text{ or}$$

$$dB = 20 \times \log \frac{E2}{E1}.$$

To find the number of decibels from the current ratio, assuming that the resistances are equal, substitute I^2 for P in the basic equation:

$$dB = 10 \times \log \left(\frac{I2}{I1}\right)^2, \text{ or}$$

$$dB = 20 \times \log \frac{I2}{I1}.$$

The power level of an electrical signal is often expressed in decibels above or below a power level of 0.001 watt (1 milliwatt) as

$$dBm = 10 \times \log \left(\frac{P}{0.001}\right)$$

where, dBm is the power level above 1 milliwatt in decibels, and P is the power in watts.

The volume level of an electrical signal comprising speech, music, or other complex tones is measured by a specially calibrated voltmeter called a *volume indicator.* The volume levels read with this indicator are read in v units (vu), the number being numerically equal to the number of decibels above or below the reference volume level. Zero vu represents a power of 1 milliwatt dissipated in an arbitrarily chosen load resistance of 600 ohms, which corresponds to a voltage of 0.7746 volt. Therefore, when the vu meter is connected to a 600-ohm load, vu readings in decibels are used as a direct measure of power above or below 1 milliwatt. For any other value of resistance, the following correction must be added to the vu reading to obtain the correct vu value:

$$vu = vu\ reading + 10 \times \log \frac{600}{R}$$

where vu is the actual volume level, and R is the actual load, or resistance, across which the vu measurement is made.

ANSWERS FOR REVIEW QUESTIONS Q86. THROUGH Q91.

A86. *a. Pitch*
b. Intensity
c. Quality

A87. The threshold of audibility and the threshold of feeling.

A88. Units of sound vary logarithmically with the amplitude of the sound variations.

A89. The bel and the decibel refer to the difference between sounds of unequal intensity or sound levels. The decibel describes the ratio of two sound levels.

A90. The ratio between electrical powers or between acoustical powers.

A91. The zero reference level is the sound produced by 10^{-16} watts per square centimeter of surface area that faces the source. It is the least sound perceptible to the ear and is also known as the threshold of audibility.

NOTE: If the volume levels are indicated in units other than vu, the meter calibration, or reference level, must be stated with the decibel value.

ACOUSTICS

Learning Objective: *Identify factors that affect acoustics to include echo, reverberation, interference, and resonance.*

Acoustics is the science of sound, including its propagation, transmission, and effect. The performance of an announcing system or sound system, when used in a room or enclosed space, depends on the acoustical characteristics of the enclosure. Sound originating in an enclosed space is partly reflected and partly absorbed by enclosing surfaces such as walls, ceilings, and floors. This action introduces echoes and reverberations, which may seriously impair the quality or character of the sound.

Light is often thought of first whenever reflection is discussed; however, reflection is equally common in other waves. As an example, echoes are caused by reflection of sound waves.

Echo

An *echo* is the repetition of a sound caused by the reflections of sound waves. For example, when a surface of a room reflects sound, the reflected sound appears as a distinct echo and is heard an appreciable interval later than the direct sound. If the surface is concave, it may have a focusing effect and concentrate the reflected sound energy at one locality. Such a reflection may be several levels higher in intensity than the direct sound, and its arrival at a later time may be particularly disturbing. This condition is corrected by

covering the offending surface with absorbing material to reduce the intensity of the reflected sound;

changing the contour of the offending surface and thus send the reflected sound in another direction;

changing the position of the loudspeaker; or

varying the amplitude or the pitch of the signal.

Q92. Name some of the uses of the decibel as it is used to express an electrical power ratio.

Q93. What type of acoustical disturbance causes an echo?

Q94. A loudspeaker is being used in a fairly large room and is producing considerable echo that limits the usefulness of the speaker. List four ways that the effects of echo can be corrected or modified.

Reverberation

Reverberation is the persistence of sound due to the multiple reflection of sound waves between several surfaces of an enclosure. It is one of the most common acoustical defects of a large enclosure. Its duration varies directly with the time interval between reflections (the size of the enclosure) and inversely with the absorbing efficiency of the reflecting surfaces. The result is an overlapping of the original sound and its images. If excessive, reverberation causes confusion, making speech unintelligible.

The hangar deck of an aircraft carrier is an example of an extremely reverberant area. The volume is large, and the hard steel interior surfaces offer very little absorption. If a single loudspeaker is mounted in a hangar deck, you can understand speech when you are standing directly in front of the loudspeaker. As you move away from the loudspeaker or if you move in a direction that increases the angle between you and the loudspeaker's sound axis, intelligibility decreases rapidly. Sound from a loudspeaker in a reverberant space (such as a hangar deck) is composed of direct sound that reaches the listener without any reflection and indirect sound that is received with at least one reflection.

Intelligibility, under these conditions, is related to the ratio of direct sound to indirect sound. As the listener moves away from the loudspeaker, the ratio of direct sound to indirect sound **at the listener's position** decreases, and intelligibility decreases correspondingly. Therefore, in a highly reverberant space, intelligibility decreases with distance from the loudspeaker.

To prevent sound from becoming unintelligible, install several speakers in an area. This action prevents the sound from becoming unintelligible in a highly reverberant space. The power requirements remain the same; one 25-watt speaker is replaced by five speakers, each

consuming 5 watts. This would greatly increase the direct-to-indirect sound ratio.

Interference

Two sound waves moving through the same medium at the same time advance independently, each producing the same disturbance as if it were alone. The resultant of the two waves is obtained by adding the ordinates (instantaneous magnitudes) of the component waves algebraically,

Two sound waves of the same frequency, in phase with each other, and moving in the same direction are additive. The resultant wave is in phase with, and has an amplitude equal to, the sum of the component waves.

Two sound waves of the same frequency, in phase opposition, and moving in the same direction are subtractive. If the component waves have equal amplitudes, the resultant wave is zero. This addition or subtraction of waves is often called interference.

Two sound waves of slightly different frequency that move in the same direction produce a beat note. For example, two waves originate from two vibrating sources at the same point, and the frequency of one wave is 1 vibration per second greater than the other one at a particular instant. The sources produce additive disturbances at some points and subtractive disturbances at other points on the relative positions of the waves. These changes continue as long as the sources are kept vibrating. The resultant wave has a periodic variation in intensity at a frequency equal to the difference between the original frequencies of the component waves. The difference frequency, referred to as the *beat frequency,* produces a type of pulsating interference particularly noticeable in sound waves. The effect of beat frequency (beats) produces alternately loud and soft pulses or throbs. The effect is most pronounced when the component waves have equal amplitudes.

Resonance

Resonance, or sympathetic vibration, is a common problem encountered in acoustics. It is more serious than some other problems because the possibility exists for damage to equipment. Reverberation and resonance are frequently confused, but they are distinctly different in nature. Reverberation is a result of the reflection of sound waves and of the interaction between the direct and reflected sound. Only a single source is involved. In resonance, however, the offending object becomes a sound source under certain conditions. This may be explained by the following example.

Assume that the natural frequency of vibration of a steel shaft, weighted on one end and held firmly on the other, is 25 vibrations per second. Suppose, that with the system at rest, a sound wave produces a force that acts on the shaft with a to-and-fro motion 125 times per second. This force sets the system to vibrating at 125 vibrations per second. These vibrations are of small amplitude because the rod and weight are trying to vibrate at their natural rate of only 25 vibrations per second. During part of the time, the system is resisting the driving force. The

ANSWERS FOR REVIEW QUESTIONS Q92. THROUGH Q94.

A92. a. Gain of an amplifier
b. The output of a microphone
c. The power in a circuit compared to an arbitrarily chosen reference level

A93. A reflection of sound waves

A94. a. Cover the surface with a material that absorbs sound and reduces the intensity of the reflected sound
b. Change the contour of the surface and aim the reflected sound in another direction
c. Change the position of the loudspeaker
d. Vary the amplitude or pitch of the signal

motion of the system in this case is called a *forced vibration.*

If the force is slowed from 125 vibrations per second to the shaft's natural frequency of 25 vibrations per second, the amplitude of vibration becomes very large. The amplitude builds up to a point where the driving force is enough to overcome the inertia of the system. When these conditions exist, the system is said to be in resonance with the driving force, and sound waves are produced by this vibration.

A common example of resonance is found in a crystal oscillator circuit. When an alternating voltage is applied to a crystal that has the same mechanical (resonant) frequency as the applied voltage, it vibrates, and only a small applied voltage is needed to sustain vibration. In turn, the crystal generates a relatively large voltage at its resonant frequency.

Q95. What is the effect of excessive reverberation in a large area when a loudspeaker is being used?

Q96. Describe action that can be taken to lessen or eliminate reverberation in a large area, such as a hangar deck.

Q97. Describe the effect of beat frequency.

Q98. Why is resonance potentially a serious problem?

ANSWERS FOR REVIEW QUESTIONS Q95. THROUGH Q98.

A95. Sound becomes confusing and speech is unintelligible.

A96. Mount several speakers in the area. This action allows speech to be heard in a reverberant space. Also, the power requirements should remain the same; for example, use five speakers consuming 5 watts instead of one speaker consuming 25 watts.

A97. Two waves traveling in the same direction and having different frequencies produce additive disturbances at some points and subtractive disturbances at other points on relative positions of the waves. The resultant wave has a periodic variation in intensity at a frequency equal to the difference between the original frequencies of the components waves. This difference frequency (beat frequency) produces a pulsating interference of alternately loud and soft pulses or throbs.

A98. Because it can damage equipment.

CHAPTER 2

INFRARED, LASERS, AND FIBER OPTICS

In this chapter, you will learn about infrared, lasers, cryogenics, and fiber optics. The basic operations of these systems are also discussed. For information about the safety precautions you **must** follow, look at chapter 9 of this TRAMAN.

INFRARED

Learning Objective: *Identify infrared advantages and remote sensing types.*

Infrared radiation (IR) is important in missile guidance, target detection, fire control, communications, and mapping. Like radar, IR equipment was developed and used by the military during World War II. In some military applications, IR has advantages over radar. When used for communications, IR is usually less susceptible to detection and interference than visible light. Also, infrared equipment is usually less complex than radar equipment used for similar tasks.

Another advantage of infrared equipment is *remote sensing,* which is the process of detecting or sensing infrared radiation from a target without being in physical contact with that target. While IR detection systems are passive, both active and passive systems are used for remote sensing.

Active systems send a signal to the target and receive a return signal. Radar sets are examples of active systems. Passive systems detect a signal or disturbance starting at the target. The signal may be either target emission or another source. Photography, using natural light, is an example of a passive system. Now, with an idea of some advantages of using infrared, lets get into some of the basics. To help you understand infrared, lasers, and fiber optics, the electromagnetic spectrum and infrared radiation are covered in the next section of the TRAMAN.

ELECTROMAGNETIC SPECTRUM

Learning Objective: *Recognize the characteristics of the electromagnetic spectrum to include the characteristics of the infrared frequency range.*

The term *infrared* is a Latin word meaning *beyond the red.* Humans only see a small part of the entire electromagnetic spectrum. However, other parts of the spectrum contain useful information. The infrared spectrum is a small portion of the entire electromagnetic spectrum. IR radiation is a form of electromagnetic energy. IR waves have certain characteristics similar to those of light and RF waves. These characteristics include reflection, refraction, absorption, and speed of transmission. IR waves differ from light, RF, and other electromagnetic waves only in wavelength and frequency of oscillation.

The IR frequency range is from about 300 gigahertz (10^9 Hz) to 400 tetrahertz (10^{12} Hz). Its place in the electromagnetic spectrum (fig. 2-1) is between visible light and the microwave region used for high-definition radars. The IR region of the electromagnetic spectrum lies between wavelengths of 0.72 and 1,000 micrometers (approximately). Discussion of the IR region is usually in terms of wavelength rather than frequency.

NOTE: Formerly, the micron (10-6 meter) symbol µ expressed measurements of wavelength in the electromagnetic spectrum. In 1967, the 13th General Conference of Weights and Measures abolished the micron and its symbol. This unit is now called the micrometer, symbol µm.

The IR portion of the electromagnetic spectrum is frequently divided into three bands.

1. Near infrared (NIR), which extends from the visible region out to around 1.5 µm

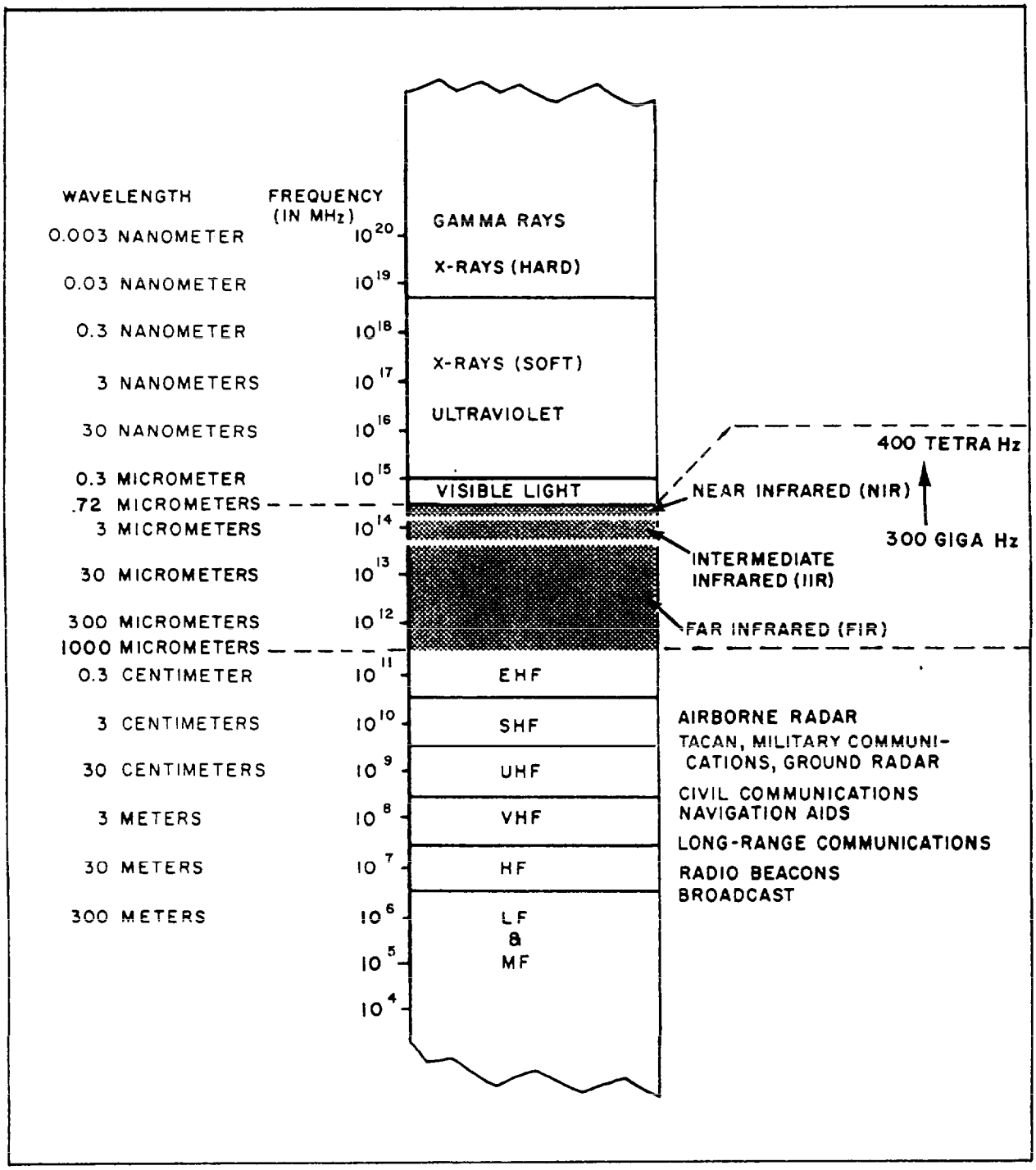


Figure 2-1.-Electromagnetic spectrum.

2. Intermediate infrared (IIR), which extends from 1.5 to 5.6 µm

3. Far infrared (FIR), which extends from 5.6 µm to the microwave frequencies

Some confusion exists because the infrared range of wavelengths is so close to the visible range in the electromagnetic spectrum. Thus, it is not uncommon to hear references to *infrared light.*

Infrared radiation is also known as thermal or heat radiation. All materials emit radiation in the IR region of the electromagnetic spectrum. In addition to emitting this radiation, a solid object subjected to IR radiation undergoes an increase in temperature, absorbs heat, and then reradiates it. For example, when an aircraft is parked in the sun on a runway, it gets hotter and hotter. It also radiates more and more IR radiation. The aircraft retains heat after the sun sets and continues to radiate that heat. Infrared systems detect the presence of an aircraft on a runway even after the aircraft is moved. This happens because the area of the runway that was directly below the aircraft is cooler than the surrounding runway. You can see how the military might use IR radiation. Heat differs from IR waves in much the same way that electricity differs from radio waves.

Q1. List some of the advantages of IR over radar.

Q2. Define remote sensing.

Q3. List the similar characteristics of infrared and light.

Q4. What frequencies of the electromagnetic spectrum are considered to be in the IR frequency range?

Q5. Name the three IR bands of the electromagnetic spectrum.

INFRARED RADIATION

Learning Objectives: *Identify the advantages of IR detection systems. Identify the characteristics of emissivity and the effects of atmospheric attenuation. Identify the types of optical devices used in IR systems.*

All objects above absolute zero (0 K or –273 °C or –460 °F) emit infrared radiation. Radiation emits from any given object over a wide range of wavelengths, but it reaches a peak at one particular wavelength. This wavelength has military applications. Detection of IR energy depends on the contrast between the IR radiation from the source under consideration and IR radiation emitted by the background. A cold object with a warm background has as good a target definition as does a warm object with a cold background.

There are several advantages in using IR for target detection. Some of these are as follows:

- IR systems are passive.
- Complete jamming is difficult. (Although IR systems are sometimes confused.)
- Military targets are usually good sources of IR.
- IR systems are smaller, lighter, less complex, and less expensive than other comparable systems.
- IR systems have a high target resolution.

EMISSIVITY

One useful concept about IR is the **blackbody** concept. A blackbody is an object that absorbs all radiation incident on it. Conversely, the radiation emitted by a blackbody is the maximum for any given temperature. Therefore, a blackbody is a perfect absorber and radiator of IR at all temperatures and wavelengths.

All matter whose temperature is above –273°C (absolute zero) emits IR radiation, The amount of the IR radiation emitted is a function of heat. Theoretically, a perfect emitter is a blackbody with an emissivity of 1. Realistically, the best emissivity is somewhere around .98. The emissivity of various objects is measured on a scale of 0 to 1.

The total energy emitted by an object at all wavelengths directly depends on its temperature, If the temperature of a body increases 10 times, the IR radiation emitted by the body increases 10,000 times. If you plot the energy and its wavelengths emitted by a blackbody on a graph,

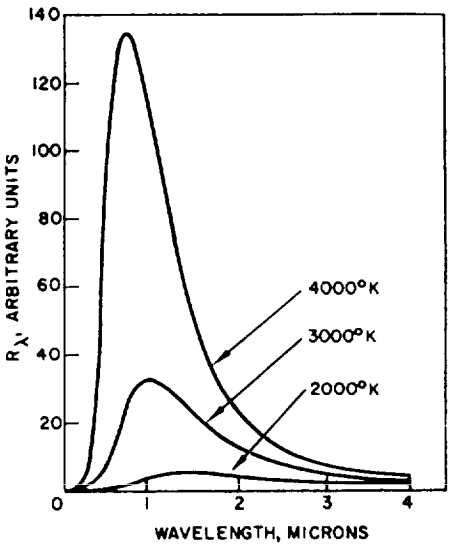


Figure 2-2.-Blackbody radiation.

shill-shaped curve results (fig. 2-2). By looking at this graph, you can see that the energy emitted by short wavelengths is low. As the wavelengths get longer, the amount of energy increases up to a peak amount. After reaching the peak, the energy emitted by the body drops off sharply with a further increase in wavelength.

Emissivity is the ratio of the total radiation emitted by any object at any temperature (T) to the total radiation emitted by an ideal blackbody at the same temperature. Emissivity is used to compare the radiation emitted by an actual radiator (source) with that of a perfect radiator. The emissivity of any object depends on the amount of energy its surface can absorb. If the surface absorbs most of the IR striking it, it emits a relatively high amount of radiation, and the emissivity of the object is comparatively large. If the surface reflects most of the incident radiation, the object has a relatively small emissivity. By definition, *a blackbody has an emissivity of unity.* Therefore, any other body (surface) has an emissivity of less than 1. Table 2-1 shows the emissivity of various surfaces.

Table 2-1.-Emissivities of Various Surfaces

Surface	Emissivity
Blackbody	1.00
Lampblack	0.95
Painted	0.90
Steel, cold-rolled	0.60
Aluminum paint	0.25
Steel, stainless	0.09
Aluminum aircraft skin	0.08
Aluminum foil	0.04
Silvered mirror	0.02

ANSWERS FOR REVIEW QUESTIONS Q1. THROUGH Q5.

A1. IR is usually less susceptible to detection and interference. IR equipment is usually less complex.

A2. Remote sensing is the process of detecting or sensing infrared radiation from a target without being in physical contact with that target.

A3. IR waves have characteristics similar to light, which include reflection, refraction, absorption, and speed of transmission.

A4. The IR frequency range is from about 300 gigahertz to about 400 tetrahertz.

A5. 1. Near infrared (NIR)
2. Intermediate infrared (IIR)
3. Far infrared (FIR)

The basic laws that describe the characteristics of IR were first developed for blackbody radiation (the ideal case). Then they were modified to describe radiation from any source.

Temperature is the most important parameter in determining the IR characteristics of any body. As the temperature of an object changes, two specific changes in the IR characteristics take place:

1. the wavelength where peak radiation occurs shifts, and
2. the total energy radiated varies with the fourth power of the temperature.

There are two laws that describe the relationship between these IR characteristics.

1. **Wein's displacement law.** This law states that "'the wavelength at which maximum radiation occurs (Am) is inversely proportional to the absolute temperature of the body." This law can be expressed by the formula

$$\lambda m = \frac{K}{T}$$

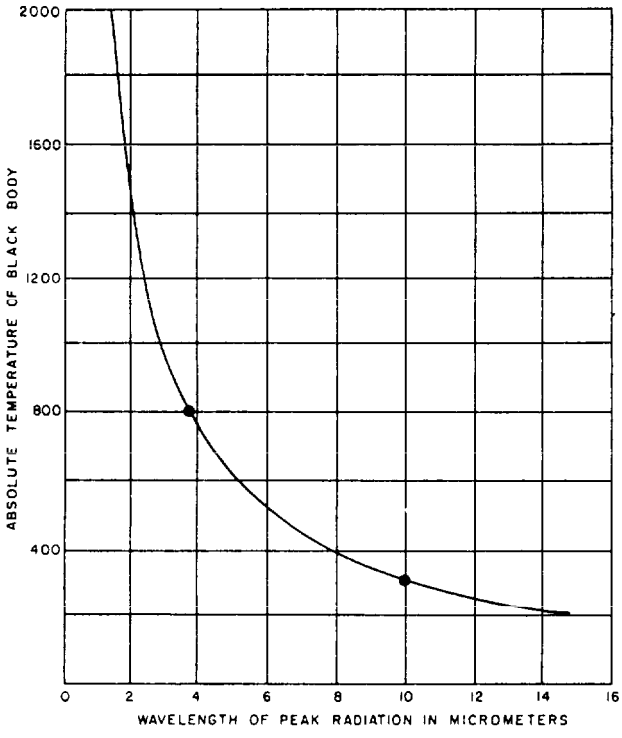


Figure 2-3.-The wavelength of the peak radiation from a blackbody in relation to its temperature.

where wavelength is in micrometers, and the constant (K) has a value (for a blackbody) of about 2,900. For example, a block of ice emits peak energy at about 10 µm and a jet aircraft engine emits peak energy at about 3.5 µm (fig. 2-3).

2. **Stefan-Boltzmann law.** This law states that "radiation intensity (E) is directly proportional to the fourth power of the absolute temperature. " The law can be expressed by the formula

$$E = \sigma T^4$$

where E has dimensions of power per unit areas, and σ (sigma) is the proportionality constant.

Thus, if the temperature of an object is doubled, radiation from the object will be 16 times as much.

The Stefan-Boltzmann law can be modified to include the emissivity factor, and total radiation can be computed from the formula

$$E = \varepsilon \sigma T^4$$

where ε (epsilon) is the emissivity factor of the radiating surface.

Figure 2-4 shows the distribution of energy radiated from a blackbody at various temperatures. A blackbody at a temperature of 300K (81°F) (not shown) radiates 46 milliwatts of power per square centimeter of its surface. A painted surface, such as the skin of a commercial airliner, at the same absolute temperature radiates 41 milliwatts per square centimeter. If the aluminum aircraft skin weren't painted, the emissivity factor would be considerably smaller, and the radiation would be less than 4 milliwatts of power per square centimeter.

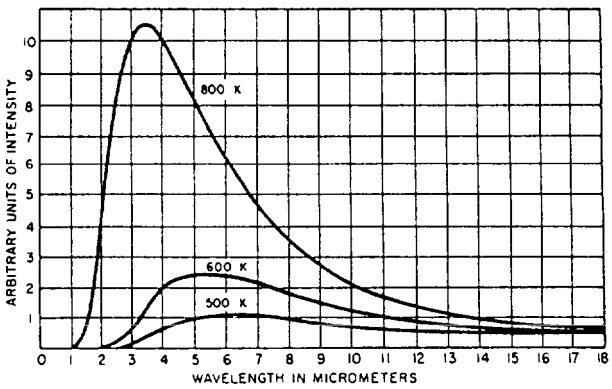


Figure 2-4.-IR distribution curves for a blackbody at various temperatures.

IR from a source covers a good part of the spectrum, but the maximum radiation occurs at some specific wavelength. For example, IR from jet and rocket engine exhaust plumes is primarily due to molecular excitation of water vapor and carbon dioxide, which are characteristic by-products of combustion. This molecular radiation peaks at 2.77pm (due to carbon dioxide alone). However, in a practical situation it is easier to get more radiation from the hot tail pipe and other heated surfaces.

ATMOSPHERIC ATTENUATION

In military applications, the IR transmitting medium is often the atmosphere. The effect of atmospheric attenuation on transmission is a very important factor in considering the overall effectiveness of the systems. There are two primary causes of atmospheric attenuation:

1. scattering by suspended particles (solids), and
2. absorption by free molecules in the atmosphere.

These two attenuations are additive, but absorption is the more important.

The amount of scattering caused by particles depends on the relationship between the wavelength of the radiated energy and the size of the particles. When the wavelength is considerably shorter than the dimensions of the particles, scattering is essentially independent of wavelength. Usually this relationship is the case in the IR spectrum. Therefore, attenuation caused by scattering can be measured at one wavelength and applied over a relatively wide band of wavelengths. However, this technique does not work with attenuation caused by molecular absorption.

The amount of molecular absorption is closely associated with wavelength. The two substances in the atmosphere that absorb the most radiation are water vapor and carbon dioxide. In both substances, there are several wavelength bands in which absorption is relatively high. Molecular resonance causes this condition. (Each molecule has a natural frequency of vibration, or resonant frequency.) The resonant frequencies of these molecules are in the infrared region. Their structure is such that this natural vibration creates an oscillation of the electric charge in the molecules, increasing the absorption. At low altitudes, this absorption is so great in some wavelength bands that the percentage of radiation transmitted drops rapidly to zero. This is due to denser atmosphere at low altitudes. Between these absorption bands are transmission bands in which the atmospheric attenuation is not as great. These transmission bands, known as *windows,* contain wavelengths as shown in table 2-2.

Table 2-2.-Wavelength Limits of IR Transmission Windows in the Atmosphere

0.95	-	1.05	μm
1.2	-	1.3	μm
1.5	-	1.8	μm
2.1	-	2.4	μm
3.0	-	5.0	μm
8.0	-	12.0	μm

The atmosphere is not a very good transmitter of infrared radiation because of the absorption properties of $C0_2$, H_2O, and O_3. Figure 2-5 shows the transmission spectrum characteristics of the atmosphere. You can see that the best transmission is between 3 μm and 5 μm and between 8 μm and 14 μm. The range between these frequencies is a *window,* Infrared imaging devices operate in one of the two windows, usually the 8 μm and 14 μm. The absorption bands are much narrower at high altitudes because of the thinner atmosphere. Therefore, the absorption bands are of lesser consideration in the design of high-altitude IR systems.

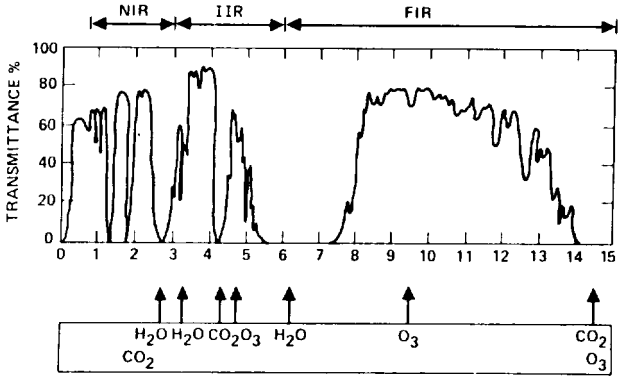


Figure 2-5.-Transmission spectrum of the atmosphere.

OPTICAL DEVICES

Optical devices are used in front-end optics to gather and focus the infrared radiation upon the detector. They can be used because of the similarity between infrared and visible light. Figure 2-6 shows a simple optical system for gathering and focusing IR radiation. The entire system lies within a protective housing to protect the detector and the optical system from the weather. The dome is a continuation of the protective housing and must be able to pass IR radiation easily.

Many of the materials commonly used in visible light optics can't be used in IR imaging systems because these materials are opaque at IR frequencies. The optical materials used in IR imaging systems should have most of the following qualities:

- Be transparent at the wavelengths on which the system is operating.
- Be opaque to other wavelengths.
- Have a zero coefficient of thermal expansion to prevent deformation and stress problems in optical components (parts).
- Have high surface hardness to prevent scratching the optical surfaces.
- Have high mechanical strength to allow the use of thin lenses (high-ratio diameter to thickness).
- Have low volubility with water to prevent damage to optical components by atmospheric moisture.
- Be compatible with antireflection coatings to prevent separation of the coating from the optical component.

Although none of the materials now used for IR optics have all of these qualities, silicon, germanium, zinc selenide, zinc sulfide, and IRTRAN have many of them. The actual material used for IR optics depends on the material's best characteristics and their application.

Typical materials for making domes include glass, quartz, synthetic sapphires, germanium, and silicon. The transmission coefficient of the optical material is an important factor in the design of IR equipment. Glass and quartz are satisfactory material for NIR, and generally for IIR, Figure 2-7 shows that glass, quartz, and synthetic sapphires have excellent transmission characteristics in the visible and near infrared regions. They cut off sharply in the intermediate infrared region. Optical glass is completely opaque to wavelengths longer than 3 μm, quartz cuts off at 4 μm, and synthetic sapphire loses its

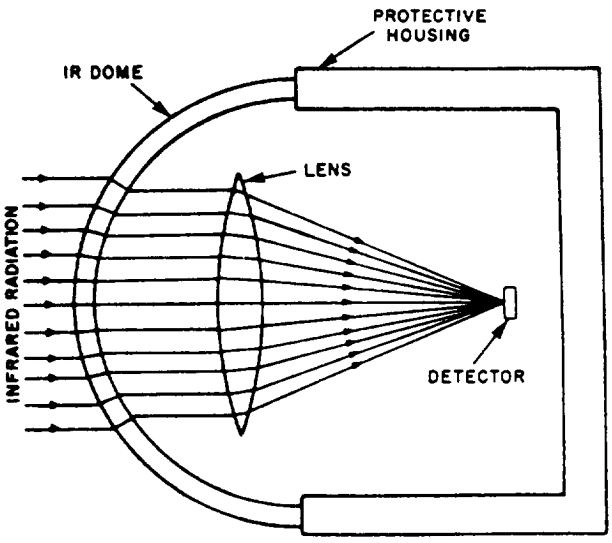


Figure 2-6.-Simple IR optical arrangement.

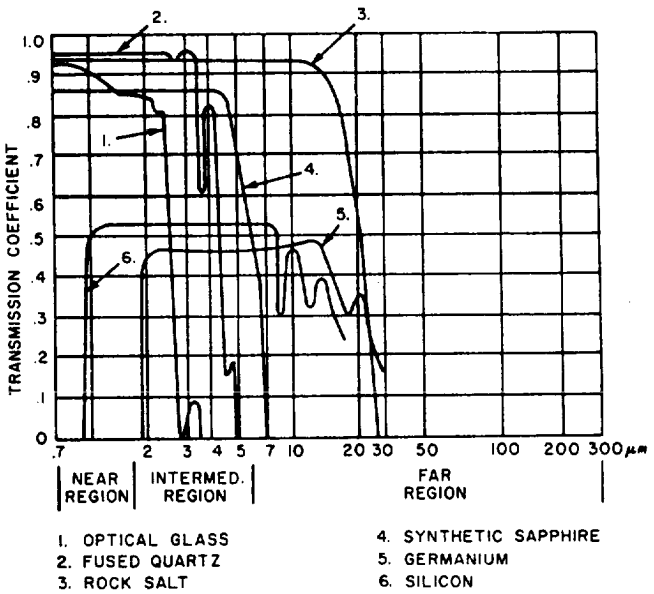


Figure 2-7.-Wavelength versus transmission coefficient.

transparency at wavelengths greater than 6 pm. Germanium and silicon are semiconductor materials that are opaque to visible light and transparent to IR throughout most of the near and intermediate infrared regions.

FIR requires a completely different type of optics. Single crystals of silver chloride, rolled flat, are satisfactory windows for the transmission of FIR. Single crystals of sodium chloride (rock salt), cut and ground into a lens or window, is excellent for FIR. However, rock salt is highly soluble in water; therefore, it must be protected from atmospheric moisture. This characteristic makes rock salt impractical for use as an IR dome material.

There are some problems involved in designing IR optical systems. The material used must match the wavelength to which the detector will respond. Optical materials are physically weak, and many damage easily by high temperature and thermal shock. Pressure and chemical reactions will change the properties of some optical materials.

Heat is another problem. When any part of the IR optical system becomes heated by the energy it absorbs, the energy reradiates at wavelengths other than those of the original radiation. If the detector is sensitive to these new wavelengths, this closer source will obscure the target or cause ghost images.

Surface reflections and attenuation by the material cause attenuation in optical materials. Surface reflections may be overcome by anti-reflection coatings. Attenuation by the material is the more serious problem.

IR systems often have a chopping reticle (chopper) in the principal focal plane. The chopper generally is a rotating disc with some clear and some opaque areas. Although a chopper is not absolutely necessary in a search system, it has several useful properties. The chopping rate furnishes a conveniently high carrier frequency for the electronic amplifiers, and the reticle pattern can operate as a discriminator or filter. Manufacturers can design this filter for the types of background expected to provide better differentiation between target and background.

Optical filters in IR instruments isolate certain wavelength regions of interest, such as atmospheric windows, and screen out undesired wavelengths. There are three general types of filters:

1. Those that pass short waves.
2. Those that pass a particular band of waves.
3. Those that pass long waves.

Q6. List the advantages in using IR for target detection.

Q7. What is the blackbody concept?

Q8. Of all the parameters in determining IR characteristics, which one is the most important, and why?

Q9. What is the primary factor that affects the IR transmitting medium and its primary cause?

Q10. Absorption is the major cause of attenuation in IR system design. What happens at higher altitudes?

Q11. List the problems involved when designing IR optical systems.

Q12. Optical filters isolate certain wavelengths and screen out undesired wavelengths. What are the three general types of filters?

DETECTORS

Learning Objective: *Identify the characteristics of detectors to include thermal* detectors.

The most critical component of any IR system is the detector (or sensor), which detects and converts IR into an electrical signal. The characteristics of the atmosphere and of the source (if it is a military target) cannot change. Optical materials are somewhat standard, as are display devices and control circuits. Research and development have resulted in some very good all-around detectors, but selecting the proper detector for a particular application must be done carefully. Many variables confront the selection process. These variables and the characteristics of the radiation involved determine the selection of the detector.

DETECTOR CHARACTERISTICS

The detector is the most important component of the IR imaging system. There are many types of detectors, each having a distinct set of operating characteristics. Bolometers, Golay cells, mercury-doped germanium, lead sulfide, and phototubes are the most commonly used types of detectors. Two ways to characterize detectors is

by their optical configuration or by the energy-matter interaction process. Two classes of detectors include the photoelectric and thermal. There are two types of optical configurations—elemental and imaging.

1. Elemental detectors. Elemental detectors average the portion of the image of the outside scene falling on the detector into a single signal. To detect the existence of a signal in the field of view, the detector builds up the picture by sequentially scanning the scene. The elemental detector requires time to develop the image because the entire scene requires scanning.

2. **Imaging detectors.** Imaging detectors yield the image directly. An imaging detector is like a myriad of point detectors. Each of the detectors respond to a discrete point on the image. Therefore, the imaging detector produces the entire image instantaneously. A good example of an imaging detector is photographic film.

To compare the relative merits of different detectors in different situations, you must know several parameters of detector operation. These parameters make it possible to discuss the characteristics of a particular detector in terms applicable to any detector.

Responsivity

When IR strikes either the photoelectric or thermal detector, a change takes place in the detector material, causing an electrical output signal. The responsivity (R) of the detector is the amount of output signal that each unit of input radiation intensity produces. Responsivity is expressed by the following ratio:

$$R = \frac{\text{detector output}}{\text{IR Input}}$$

where R is generally given in volts per watt.

Many factors influence responsivity such as detector and source temperatures, detector area, detector time constant, and spectral distribution of the radiation.

Spectral Response

One important influence on the responsivity of a detector is the change in detector sensitivity with the change in the wavelength of received radiation. The spectral limit of responsivity is the wavelength, where the value of responsivity is half that of its maximum value. Spectral response is a nonlinear characteristic. Therefore, you must know its value for each wavelength considered. Any discussion of values must include details of the conditions involved.

Time Constant

In any IR scanning system, the time constant of the detector must be such that the detector can fully respond before the radiation intensity changes. The time constant is the time required for the detector to develop 63 percent of its maximum output signal. The maximum scanning rate depends on this time constant.

Noise Equivalent Power (NEP)

Noise exists in any circuit that carries current. Most outside noises can be reduced or eliminated by shielding and proper design. However, thermal noise is an ever-present problem.

Power supplies used with IR detectors require extremely good filtering. Since the IR radiation received by the detector is very small, noise of any appreciable amount could be enough to generate weak IR signals or cause false targets. IR systems generate many different types of noise. The most important of these are—

- current noise, caused by bias currents within the detector, and
- Johnson (thermal) noise, caused by thermal fluctuations in the detector material.

At low bias voltages, current noise is negligible, and the output noise consists almost entirely of Johnson noise. The current noise increases linearly with bias voltage and may eventually become the primary source of noise.

NOTE: In modern IR systems, cryogenic cooling of the detector reduces much of the Johnson noise.

Another useful and important detector parameter is the noise equivalent power (NEP) of a detector. NEP is the radiation power (in watts) that must strike a detector to produce a signal response equal to the noise output over a reference bandwidth. Thus, a signal-to-noise ratio is equal to 1.

When comparing two different IR detectors, the one with the lower NEP has the higher useful sensitivity. Since this use of NEP may be confusing, another parameter, defectivity may be easier to use. *Detectivity* is simply the reciprocal of the given NEP of a detector. Thus, the higher defectivity a cell has, the higher its useful output. For example, a detector with an NEP of 4.0×10^{-9} has a defectivity of

$$\frac{1}{4.0 \times 10^{-9}}$$

or 2.5×10^{8}.

The best IR detector would have the greatest possible spectral response within the frequency band of interest, and the lowest possible NEP (or highest possible defectivity). A properly chosen detector might have a maximum range of 90 miles, with a signal-to-noise ratio of 5, from a 1-square-meter target at 300K. This range is equivalent to an ability to detect IR emitted by a cubic inch of ice at 3 miles.

Energy-Matter Interaction

There are two basic types of energy-matter interaction. They are the photon effect (photoelectric effect) and the thermal effect.

ANSWERS FOR REVIEW QUESTIONS Q6. THROUGH Q12.

A6. 1. IR systems are passive
2. Complete jamming is difficult
3. Military targets are usually good sources of IR.
4. IR systems are smaller, lighter, less complex, and less expensive
5. IR systems have a high target resolution

A7. A blackbody is an object that absorbs all radiation incident on it and emits the maximum radiation for any given temperature.

A8. Temperature is the most important parameter in determining the IR characteristics of any body. As temperature of an object changes, the wavelength where peak radiation occurs shifts, and the total energy radiated varies.

A9. The effect of atmospheric attenuation on transmission is a very important factor in considering the overall effectiveness of the system. The two primary causes are scattering by suspended particles (solids) and absorption by free molecules in the atmosphere.

A10. The absorption bands are much narrower at high altitudes because the atmosphere is thinner; therefore, there are less considerations in designing high-altitude IR systems.

A11. 1. The material used must match the wavelength the detector responds to.
2. Optical materials are physically weak and damage easily by high temperature and thermal shock.
3. Pressure and chemical reactions can change the properties of some optical materials.

A12. 1. Those that pass short waves
2. Those that pass a particular band of waves
3. Those that pass long waves

PHOTON EFFECT.— In the photon effect energy-matter interaction, the photons of the radiant energy interact directly with the electrons in the detector material. Usually, detectors using the photon effect use semiconductor material. There are three specific types of photon effect detection.

The three major types of photodetectors are the photoconductive, photovoltaic, and photoemissive types. The signal-to-noise ratio of each of these detectors is the limiting factor in determining its effectiveness.

1. Photoconductive. Photoconductivity is the most widely used photon effect. It is also known as the *internal photoelectric effect. (See* fig. 2-8.) Radiant energy changes the electrical conductivity of the detector material. An electrical circuit measures the change in the conductivity.

The photoconductor contains a semiconductor crystal that absorbs the photon energy from the radiation, which strikes the surface of the crystal. This changes the crystal's resistance or conductivity. Several different materials are used for this type of detector, including lead sulfide, lead telluride, lead selenide, and cadmium sulfide. Gold-doped germanium is a good detector material. However, there are some difficulties such as long time constants.

2. Photovoltaic effect. In the photovoltaic effect (fig. 2-9), the radiant signal causes a potential difference across a PN junction. The photocurrent (current generated by light) adds to the dark current (current that flows with no radiant input). The total current is proportional to the amount of light that falls on the detector.

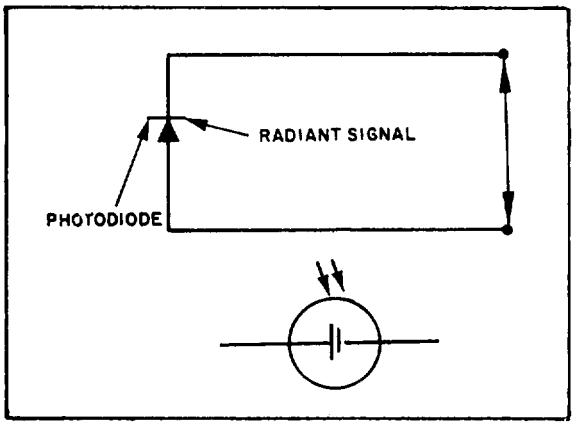


Figure 2-9.-Photovoltaic effect and graphic symbol.

The photovoltaic effect uses a photovoltaic cell similar to a solar cell. This is a semiconductor with a high-resistance, photosensitive barrier between two layers. When exposed to IR, a potential difference builds up across the two layers of the cell.

3. Photoemissive. The photoemissive effect (fig. 2-10) is also the external photoelectric effect. The action of the radiation causes the emission of an electron from the surface of the photocathode in the surrounding space.

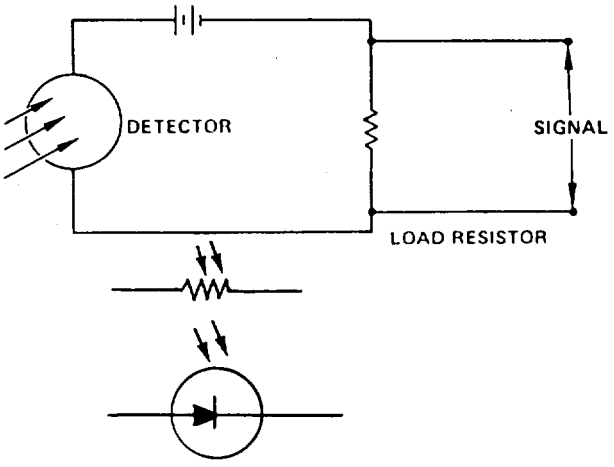


Figure 2-8.-Photoconductive detector circuit and graphic symbols.

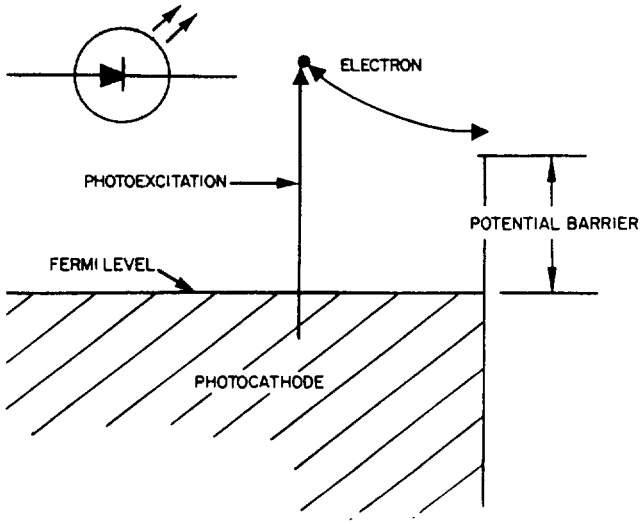


Figure 2-10.-Photoemissive effect and graphic symbol.

The photoemissive cell's cathode is exposed to IR and causes electronic emission. The number of emitted electrons depends on the intensity of the IR striking the cathode.

THERMAL EFFECT. —The thermal effect type of energy-matter interaction involves the absorption of radiant energy in the detector. This results in a temperature increase in the detector element. You detect the radiation by monitoring the temperature increase in the detector. Both the elemental and imaging forms of detectors use the thermal effect.

THERMAL DETECTORS

Thermal detection is the sensing of the change in temperature of the detector material as a result of IR striking its surface. There are three different types of sensing elements employed in modern thermal detectors.

1. The thermopile, a series combination of several thermocouples
2. The bolometer, which senses changes in resistance of the detector material
3. The pneumatic cell, which uses the expansion of a gas as an indicator

Thermocouple

One of the basic heat detectors is the thermocouple. When applying heat to the junction of two dissimilar metals such as iron and copper, a measurable voltage is generated between them. Figure 2-11 shows a basic thermocouple.

The voltage difference across the thermocouple is small. However, you can increase the sensitivity to a point where the thermocouple becomes useful as an IR detector. You can obtain an increase in sensitivity by connecting or stacking several thermocouples in series, forming a thermopile. The complete thermopile action is like connecting several flashlight cells in series; the output of each thermocouple adds to the output of the others. For example, 10 thermocouples, with individual outputs of 0.001 volt, have a total output of 0.01 volt when connected in series.

The effective sensitivity increases further by mounting a thermopile at the focal point of a parabolic reflector. When using this method, the reflector focuses the IR from the target onto the thermopile.

Bolometer

A bolometer is a very sensitive device whose resistance will vary, depending on the IR exposure. There are two main classes of bolometers—the barretter and the thermistor.

A barretter is a variable resistor made of a short length of very fine wire (usually platinum) that has a positive temperature coefficient of resistance. (A substance has a positive temperature coefficient if its resistance increases with an

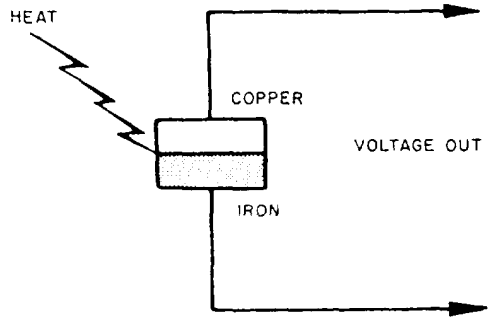


Figure 2-11.-Thermocouple.

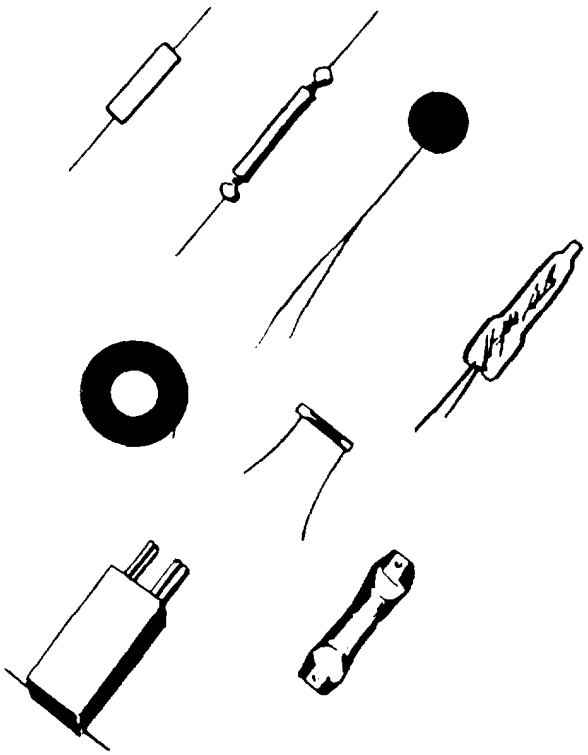


Figure 2-12.-Various thermistors.

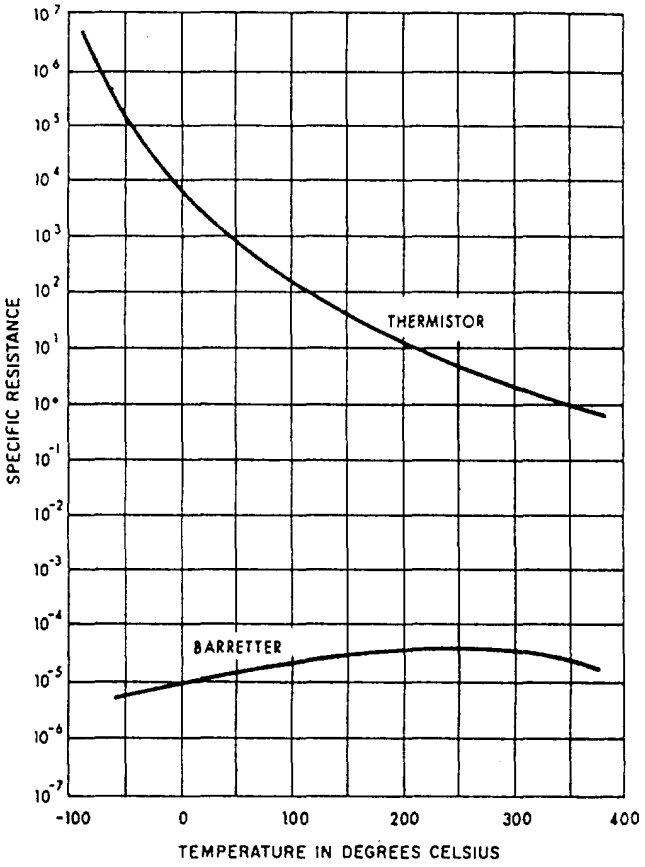


Figure 2-13.-Comparison of thermistor and barretter sensitivity.

increase in temperature. It has a negative coefficient if its resistance decreases with an increase in temperature.)

A thermistor is a variable resistor made of semiconductor material, such as an oxide of manganese, nickel, cobalt, selenium, or copper. The thermistor has a negative temperature coefficient of resistance. A thermistor is usually in the form of a bead, disc, rod, or flake, as shown in figure 2-12. The mixing of various proportions of the heat-sensitive materials provide specific characteristics of resistance versus temperature necessary for target detection.

Figure 2-13 shows changes in resistance that a typical thermistor can produce compared to those in a barretter. Note the thermistor has the steeper temperature coefficient of resistance curve. Therefore, it is the more sensitive of the two sensors.

One simple type of infrared detector consists of two thin strips of platinum that form two arms of a Wheatstone bridge. To increase the thermal

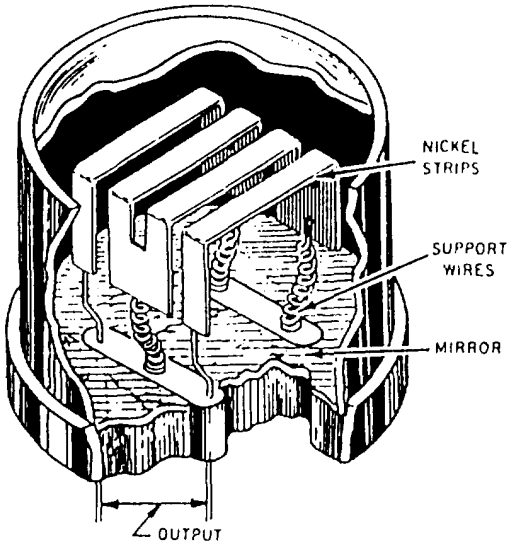


Figure 2-14.-Infrared detecting device.

sensitivity of the strips, one strip is black on one side. The blackened surface absorbs the IR. As the strip absorbs heat, its resistance changes and unbalances the bridge. The imbalance causes a change in current produced by an external voltage applied to the input terminals of the bridge.

The infrared detecting device (fig. 2-14) is like the one discussed in the previous paragraph. It consists of four nickel strips supported by mounting bars that have electrical leads attached to them. A silvered parabolic reflector (mirror) focuses the IR on the nickel strips. The change of resistance in the strips causes an unbalanced condition in the bridge circuit, producing an output signal.

Pneumatic Cell

Another unique infrared detector is the Golay detector (pneumatic cell), shown in figure 2-15.

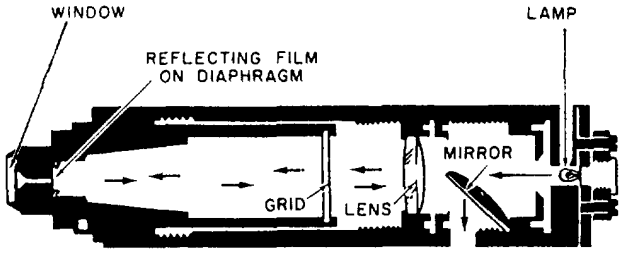


Figure 2-15.-Golay detector.

This detector is actually a miniature heat engine. IR energy entering the window causes expansion of a volume of gas located between the reflecting diaphragm and the window. The lamp at the after end of the detector emits a light beam. The lens focuses the beam that passes through the grid and onto the reflecting diaphragm.

Changes in the amount of infrared energy entering the window cause changes in the shape of the diaphragm. This causes its light-reflective properties to vary accordingly, modulating its light output. The light reflected from the diaphragm passes back through the grid, which intensifies the variations of the reflected light. After passing through the grid, some of the light (reflected by the diaphragm) strikes the mirror. This light reflects to a photocell of high sensitivity (not shown in the figure). The modulated output of the photocell is a voltage proportional to the intensity of the IR entering the window.

The Golay detector has the most rapid response of any infrared detector, but it can operate only when intermittently receiving radiant heat. An optical chopper can interrupt the flow of IR to the cell periodically. Another advantage of the Golay detector is its extremely wide bandwidth, making it a good choice for use in IR spectrum analysis.

Q13. What is the most critical component of any IR system?

Q14. List the most common types of detectors.

Q15. Define responsivity as it relates to the detector.

Q16. What are two of the most important types of noise generated by an IR system?

Q17. Name the two basic types of energy-matter interaction.

Q18. What are the three major types of photodetectors?

Q19. Three different types of sensing elements are used in modern thermal detectors. What are they?

Q20. The Golay detector has the most rapid response of any infrared detector, but it requires an optical chopper. Why does it need the optical chopper?

APPLICATIONS

Learning Objective: *Identfy military applications to include homing techniques, imaging system component operation, and configurations.*

The number of military and industrial applications of IR has grown in recent years. A complete discussion of all applications is beyond the scope of this manual, but some IR systems and concepts applicable to military situations are discussed in the following paragraphs.

During World War II, infrared found its first military use in a snooperscope device. This device worked in total darkness, and outlined enemy troops by the heat radiated from their bodies. A rifle with a sniperscope made it possible to see a target in total darkness and to fire with normal accuracy at a target.

Since IR is invisible but behaves much like visible light (that is, it can be reflected and controlled in a beam pattern), it served as a means of communication for specific wartime purposes. Development of equipment to receive the invisible light was the base for design and successful use of some important weapons. Infrared used for short-range communication between sea-level stations, such as ships, affords excellent security. Line-of-sight limitations of IR rays and their rapid attenuation at sea level provides security for short-range communications. Military use of infrared for communications requires a powerful source and a sensitive receiver for detecting the modulated source. Such sources and receivers are available for near infrared energy.

Photography uses infrared because it is effective against camouflaged targets. Night photography, using infrared, can produce a better visual presentation of terrain than the best mapping radar.

Navigation also uses infrared. Ground speed indicators are available that can compete with Doppler radar. Anticollision circuits using IR are undergoing experiments.

Image-forming devices, thermal or ship detection devices, and infrared radar are also using IR. The portable infrared detector (PID) is a passive far infrared (FIR) equipment for detecting personnel, vehicles, tanks, small boats, and ships. It detects the difference in temperature between a body and its immediate background and provides an audible signal output. A larger FIR system for ship detection is the stabilized ship detector (SSD). This system provides a permanent

record of the true bearing of all targets detected within the angle scanned. Infrared radar uses a pulsed IR source and receives reflected IR energy as in microwave radar.

Infrared has excellent application to guided missiles. Military targets, such as ships, factories, and aircraft, are normally warmer than their surroundings. Detection of these targets is from the heat they radiate. Heat radiated at lower temperatures is particularly important in passive detection of surface targets. There is no economical way for the enemy to camouflage self-radiated heat.

The Felix bomb was the first guided missile to use IR. Its automatic guidance system was an infrared homing device in the nose of the bomb. The Felix bomb was reliable and adequate for operational use. World War II ended before it could be used under combat conditions. However, this bomb opened the way to a new and different method of guidance, infrared homing.

A homing guidance system controls the flight path of a missile by a device in the missile that reacts to some distinguishing feature of the target. Homing guidance systems are the most accurate of all guidance systems. There are three types of homing systems; they are subdivided by the source of target radiation.

1. Active homing—Both the source that illuminates the target and the receiver that detects the echoes are within the missile.
2. Semiactive homing—The target illumination is from some source outside the missile, and the missile receiver uses the target reflections.
3. Passive homing—The missile receiver detects the natural radiation of the target.

Active and semiactive types of homing systems typically use radar or lasers. Passive types use heat, light, or in some cases, a radio or radar signal for homing.

The Sidewinder is probably the most simple and economical guided missile. It contains an infrared homing system and can destroy high-performance aircraft flying at any altitude from sea level to about 50,000 feet.

While it is unlikely that IR will ever entirely replace radar, IR has certain advantages over radar. You can expect that radar and IR will be used together in fire control, guidance, and search applications.

INFRARED IMAGING SYSTEMS

An infrared imaging system consists of detectors, a scene disection system, front-end optics, a refrigeration system (if required), and an image processing system.

Detectors

You have learned about imaging detectors. Now, you will learn how imaging detectors are used in IR imaging systems. Detectors convert the IR radiation signal into an electrical signal for processing into information used by an operator. Detectors have many different configurations for their use in IR imaging systems.

DETECTOR ARRAY.— The detector (element) needs only a small portion of the image scene to achieve maximum resolution. You can form an array by grouping several detector elements (fig. 2-16, view A). This array has closely packed elements in a regular pattern. Thus, the image of the scene spreads across the array like a picture or a mosaic with no scanning. Each detector element views a small portion of the total scene. The disadvantage of this type of system is that each detector element requires a supporting

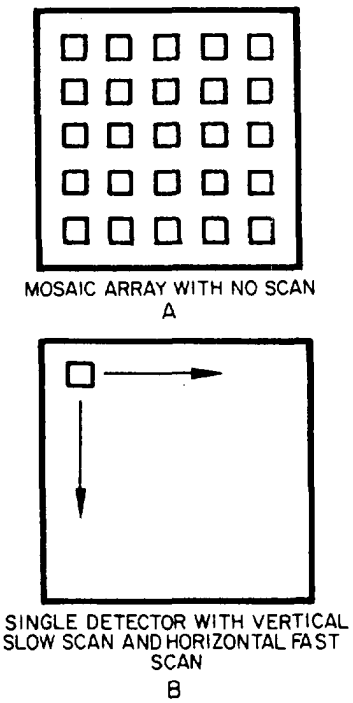


Figure 2-16.-Detector arrays.

electronic circuit to process the information that it provides. Also, each detector element requires a preamplifier to boost the signal to a useful level.

SINGLE DETECTOR.— Another method that provides the operator with information is the single scanning detector (fig. 2-16, view B). Here, there is one detector requiring one set of supporting circuitry. In this type of system, the scanning of the image is across the detector so that the detector can see the whole image. An optical system supplies the scanning. This type of system is adequate if real-time information is not important, or if the object of interest is stationary or not moving quickly.

Scene Disection System

The scene disection system scans the scene image. There are many types of scanning—one associated with each type of detector array. A single detector with one fast scan axis and one slow scan can scan the scene rapidly in the horizontal direction and slowly in the vertical direction.

A vertical linear array is scanned rapidly in the horizontal direction. One detector element scans one line of the image. In the linear array, there is a space one element wide between each element. The scan is one axis with an interlace. After each horizontal scan, the mechanism shifts the image upward or downward one detector element width. This allows the next scan to cover any of the missed lines.

Each system has an optimum configuration of detector array and image disection. If the number of elements in the detector array are increased, the system becomes more complicated. The cost of the system increases, and the reliability of the system decreases. If you decrease the number of detectors, you reduce the amount of information that you can process. A compromise between increasing the number of elements (increased cost) and decreasing the number of elements (reduced information) is to use a linear array scanned in one direction only. Each detector

ANSWERS FOR REVIEW QUESTIONS Q13. THROUGH Q20.

A13. Detector.

A14. Bolometers, Golay cells, mercury-doped germanium, lead sulfide, and phototubes.

A15. The responsivity (R) of the detector is the amount of output signal that each unit of input radiation intensity produces.

A16. (a) Current noise caused by bias currents within the detector.
(b) Johnson (thermal) noise caused by thermal fluctuations in the detector material.

A17. Photon and thermal effect.

A18. Photoconductive, photovoltaic, and photoemissive

A19. (a) The thermopile, which is a series combination of several thermocouples.
(b) The bolometer, which senses changes in resistance of the detector material.
(c) The pneumatic cell, which uses the expansion of a gas as an indicator.

A20. The Golay detector has the most rapid response of any infrared detector, but it can operate only when intermittently receiving radiant heat.

scans one line of the scene image. This reduces the complexity of the electronics and increases the amount of information you can process. Thus, the viewing size of the scene and the detail of the scene increase.

There are many types of mechanisms you can use to scan the scene. When scanning using two axes, you must synchronize the two scanning motions. The electronic signal that controls the sampling of the detectors must also synchronize with the scanning motions.

Front End Optics

The front end optics collect the incoming radiant energy and focus the image at the detectors. The optics may be reflective or refractive, or a combination of both. Many systems offer a zoom capability, allowing a continuous change in amplification of the image without changing the focus. Spectral filters restrict the wavelength of light entering the system. This prevents unwanted wavelengths of light from reaching the detector and interfering with the imaging process.

Refrigeration System

Many types of infrared detectors require low temperatures to operate properly. A refrigeration system in imaging systems provide the necessary operating temperatures. The two types of detector cooling are the open cycle and closed cycle types.

The open cycle type of cooling provides a reservoir of liquified cryogenic gas. The liquid travels to the detector, where it reverts to a gas. As it changes from a liquid to a gas, it absorbs a lot of heat from the surrounding area and the detector.

The closed cycle type of cooling compresses the gas, and the heat generated by the compression is radiated away by the use of a heat exchanger. The gas then returns to the compressor, and the cycle repeats itself.

Image Processing Systems

The image processing system converts the data collected by the detectors into a video display. Multiplexing of the data from the detectors allows handling by one set of electronics. Then further processing ensures the information coming from the detectors is in the correct order of serial transference to the video display. At this point, the addition of any other display information takes place.

Other image processing systems amplify the signals from the detectors and send them to an LED display. Others optically amplify by photomuhiplier tubes and project on a phosphorescent screen.

INFRARED IMAGING SYSTEM CONFIGURATIONS

Presently, the Navy uses several IR imaging system configurations. They are the direct view parallel scan linear system, the serial scan parallel video two-dimensional array system, and the serial scan standard video system.

Direct View Parallel Scan Linear System

The direct view parallel scan linear system (fig. 2-17) is the simplest type of infrared imaging

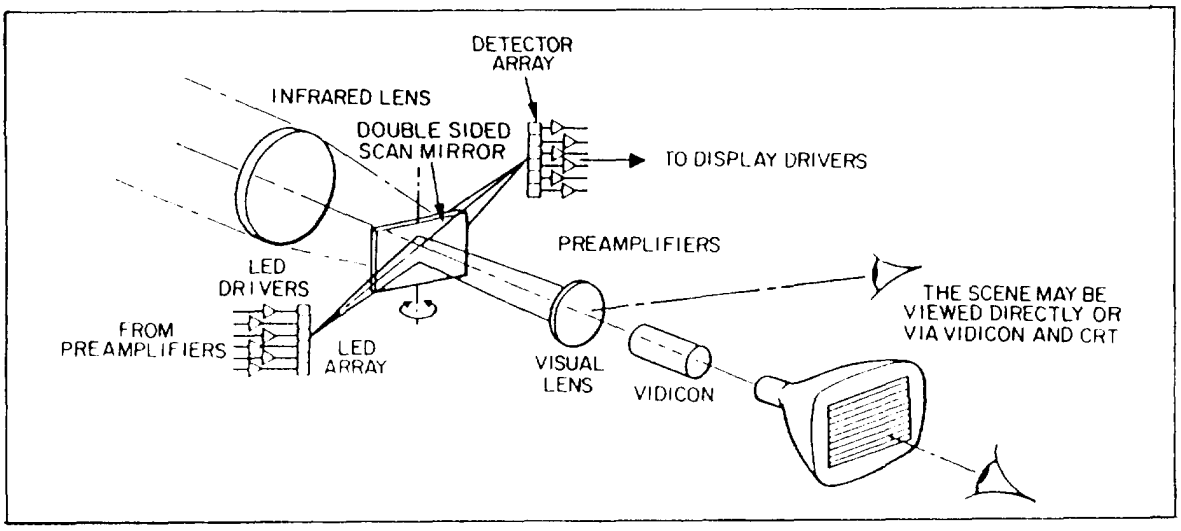


Figure 2-17.-Direct view parallel scan linear system.

system. The scene image enters the system through the infrared lens. Then, it strikes a double-sided scan mirror. The image scans across a linear detector array. Preamplifiers amplify the signals from the detectors. Then, the signals are sent to the LED drivers, which lie in a linear array. Light from the LED array scans across the field of view of an ordinary eyepiece directly from the second side of the scan mirror, or it is viewed on a cathode-ray tube (CRT).

Serial Scan Parallel Video Two-Dimensional Array System

Figure 2-18, view A, shows a serial scan parallel video two-dimensional array system. A two-dimensional array of detectors is coupled one for one to a similar array of LED. The scan mirror operates in two dimensions. This system offers the same options of direct viewing or CRT viewing as found in the one-dimensional array.

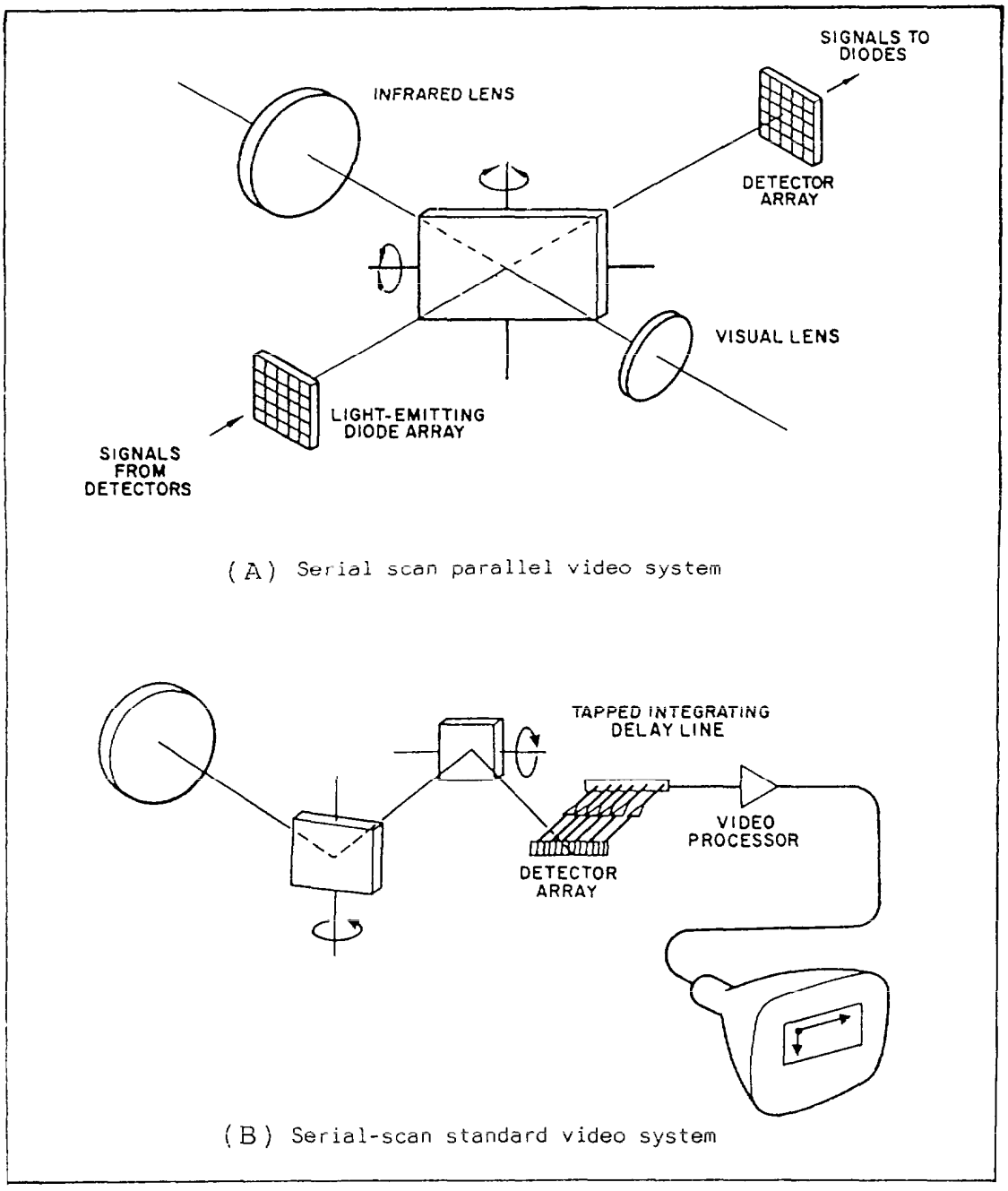


Figure 2-18.-Serial scan video systems.

Serial Scan Standard Video System

Figure 2-18, view B, shows a serial scan standard video system. Scanning of the incoming image is done in two dimensions by a scan mirror and an interlace mirror. The interlace mirror shifts the image one detector element width. This is using a linear detector array. Preamplifiers amplify the information from each detector. Then, it is sent to the delay circuitry for changing into serial form. This circuitry samples each detector at the appropriate time for correct length of time, resulting in a serial output to the video processor.

ELEMENTS OF A SCANNING INFRARED IMAGING SYSTEM

Refer to figure 2-19 while you read about the elements of a scanning infrared imaging system.

The observer views the system output and interprets the information while operating the controls. The system control interfaces between the operator and system, allowing the operator to control the system.

The stabilization and pointing gimbals provide a stabilized platform from which the imaging system operates. It isolates the system from vibration and sudden motions of the aircraft. Also, it provides a pointing capability for the imaging system.

The collecting optics and filters collect the light (thermal radiation) originating from the target. Special filters or optical components that transmit only the desired wavelengths filter any unwanted wavelengths of radiation. The optical components focus the scene image on the detector array.

The optomechanical scanner scans the scene image across the detector array in a process called *scene disection.* The optomechanical scanner includes a mirror(s) or prism(s) with the mechanical drive controlled by a scan synchronizer.

The scan encoders convert mechanical information about the motion of the scanner to electronic signals. These encoders synchronize the scanner motion with the image generation of the video monitor. This information then goes to the scan synchronizer.

The scan synchronizer controls the motion of the scanner. It interacts with the video process to synchronize the scanner with the display image generation.

The detector assembly contains the detector array that converts the optical signal from the target to an electrical signal. The detector cooler provides cooling for the detector assembly, if required. The detector bias and preamplifier circuits supply voltage or current for operating the detectors. They scan the detectors at the appropriate times, and they amplify the signal

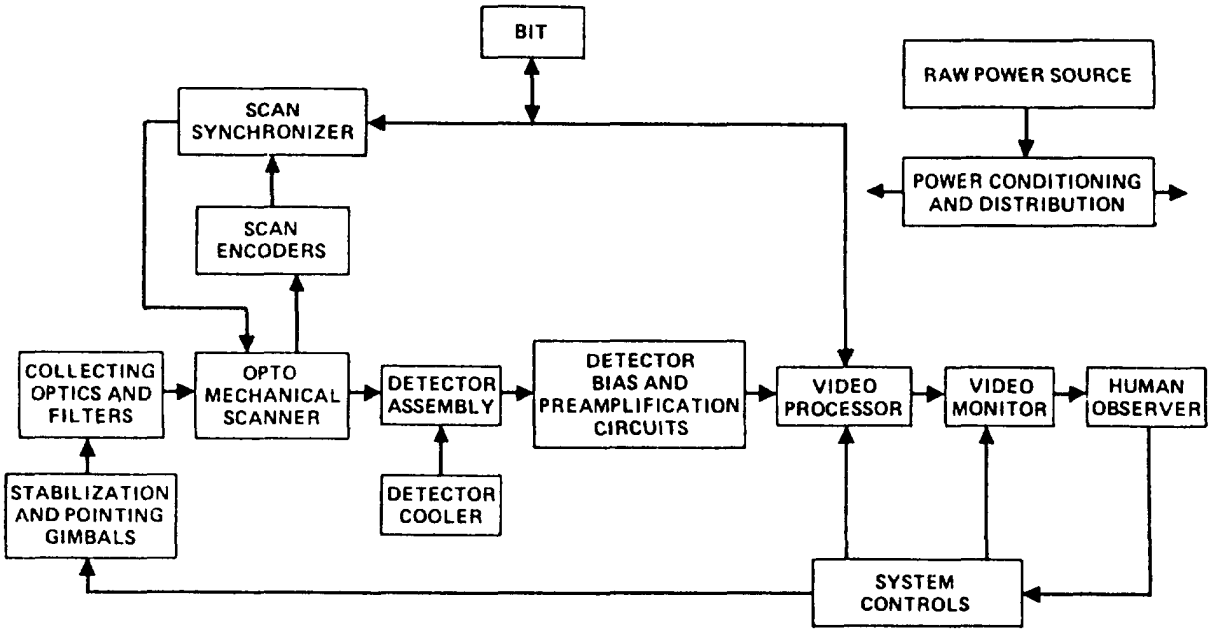


Figure 2-19.-Forward looking infrared (FLIR) set block diagram.

from the detectors before further processing. They also convert the output of the detectors into a serial form.

The video processor converts the detector information into the format necessary for the video monitor. It adds any additional information for the observer, if needed. The video monitor, usually a CRT, provides information to the operator.

The built-in test (BIT) locates and reports the nature of failures in the system.

Q21. There are many uses for infrared, including short-range communication, navigation, and anticollision circuit experimentation. Why is infrared used in photography?

Q22. Name the three types of homing systems classified by their source of radiation.

Q23. List some of the components of a typical infrared imaging system.

Q24. What is the purpose of front end optics?

Q25. Why do some infrared imaging systems need refrigeration systems?

Q26. Name some of the elements and components of a scanning infrared imaging system.

INTRODUCTION TO CRYOGENICS

Learning Objective: *Identify cryogenic characteristics.*

Cryogenics is the science that involves the study of very low temperatures. The word *cryogenic* comes from the Greek root *cryo* or *kyros,* which means icy cold or relating to the cold .

Cryogenic temperatures extend from – 150°C downward to –273°C (absolute zero). Under such extreme temperatures, many metals become brittle and shatter, atmospheric gases turn into liquids, electrical resistance disappears in some materials, and current flows indefinitely without loss (super conductivity).

Heat is a form of energy, and cold is the absence of heat. When a system cools, heat flows out of the system. Therefore, you might say cold is physical manifestation of a lack of energy. The temperatures of a system are an internal feature of the system; therefore, cold can relate to a low internal energy of a system.

Many modern systems require cryogenic temperatures to operate properly, imaging systems being one of these. The detectors of the imaging system require cooling for maximum efficiency. Therefore, you need some sort of refrigeration system to provide these low temperatures. If you are to understand the operating principles of a refrigeration system, you must understand thermodynamics. Before you begin the following section, refer to figure 2-20. This figure illustrates a numerical scale that you can use to measure degrees of hot and cold.

When bodies at different temperatures meet in thermal contact, heat flows from the body at the higher temperature to the body at the lower temperature. The flow of heat stops when the two bodies are at the same temperature (thermal equilibrium).

IDEAL GAS LAW

Nearly all thermodynamic systems have a working fluid of some type. To explain the ideal gas law, we use a theoretical fluid (gas, depending upon temperature), and this fluid is the **ideal gas.** The assumptions about the nature of this ideal gas are as follows:

- The molecules that make up ideal gas are very hard, small spheres whose volume you may disregard when compared to the volume of the gas as a whole.

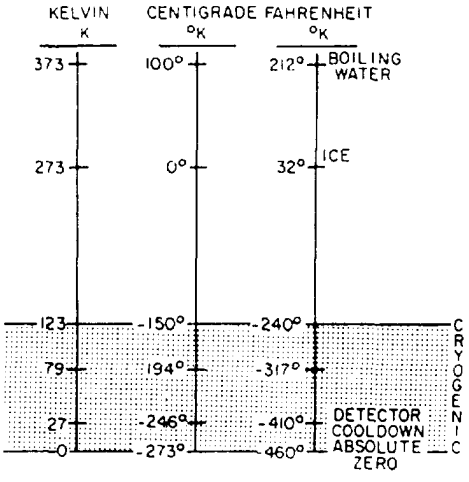


Figure 2-20.-Absolute temperature scale.

- The molecules do not interact with each other, only with the walls of the container; they do so by elastic collision (a molecule leaves the wall at the same speed it was traveling before the collision).

Real gas behaves like ideal gas, especially at low pressures. However, real gas differs from ideal gas in the following ways. The molecules of a real gas are large enough that their volume does matter when calculating gas volumes, and the molecules do collide with each other.

ENERGY

Energy is the driving force of the universe. You can make the following assumptions about energy:

- Energy is the **fuel** required to make things happen.
- No system can operate without a transfer of energy.
- Heat is a form of energy.
- A system has an internal energy (which includes all potential and kinetic energies of the system or molecules of a gas).
- A closed system conserves energy, although it may change energy states (potential to kinetic).

ENERGY AND THE IDEAL GAS

In the ideal gas, energy is in the form of kinetic energy of the molecules. When the internal energy of the gas increases, the molecules move faster; therefore, they have a higher kinetic energy. If the mass of the molecules is low, the molecules move faster. Therefore, the higher the temperature of the ideal gas, the higher its internal energy and the faster the molecules move.

Molecular motion (movement of molecules within a mass) also produces the phenomenon of pressure. As the molecules move about a container, they collide with the walls, exerting a force on the walls. The hotter the gas, the faster the molecules collide with the walls; thus, the higher the pressure.

PHASE CHANGES

Matter exists in three states: gas, liquid, and solid. For matter to change from a solid to a liquid or from a liquid to a gas, it must absorb a large amount of energy. The reverse is also true. *Fusion* is the process by which a solid changes to a liquid. *Vaporization* is the process by which a liquid changes to a gas. This process is a good vehicle for heat transfer. It is the basic theory behind refrigeration.

LAWS OF THERMODYNAMICS

The four laws contained in this section deal with thermodynamics, They are basic to the theory of refrigeration and cryogenic systems.

1. The Zeorth law of thermodynamics states that "when *two systems of the same temperature are in thermal contact, no heat will flow."*

Heat will flow between two systems when one system is at a higher temperature than the other. In this case, heat will flow away from the higher temperature.

There are three types of heat flow: convection, conduction, and radiation (fig. 2-21). Convection is the transfer of heat through macroscopic movement of material. (Macroscopic meaning large or visible as opposed to microscopic [small or invisible].) Conduction is the transfer of heat through materials when there is no macroscopic motion, as in the heat flow in metals. The rate

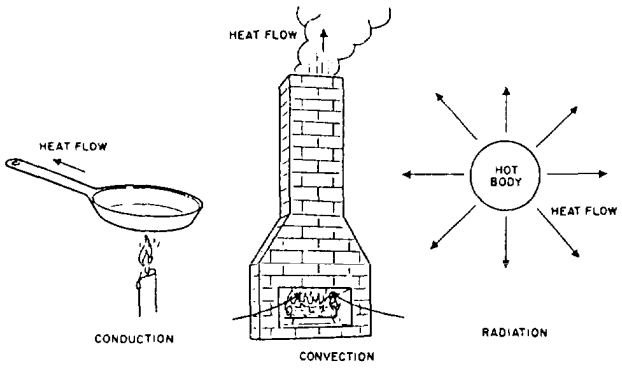


Figure 2-21.-Heat flow, conduction, convection, and radiation.

of heat flow depends upon the following physical situations:

a. The higher the temperature gradient, the greater the rate of heat flow (the temperature gradient is equal to the difference in temperatures divided by the distance over which the heat must flow).

b. The larger the area across which the heat is flowing, the higher the rate of heat flow.

c. The shorter the distance the heat must flow, the higher the rate of heat flow.

Radiation is the transfer of energy by electromagnetic radiation. All bodies that have a temperature greater than 0 K give off electromagnetic radiation. The higher the temperature, the greater the amount of radiation emitted.

2. The first law of thermodynamics states that "the *change in the internal energy of a system is equal to the heat introduced into the system minus the energy expended by the system when it does work on the environ merit."*

3. The second law of thermodynamics states that "a *cyclic process must transfer heat from a hot reservoir if it is to convert heat into energy."* Also, work must be done to transfer heat from a cold reservoir to a hot reservoir.

4. The third law of thermodynamics states that "it *is not possible by any procedure, no matter how idealized, to reduce the temperature of any system to absolute zero in a finite number of steps."*

Absolute zero is a limit that you can only approach and never achieve. The lowest temperature that has ever been attained is .00002 K. The closer that a system gets to 0 K, the harder it is to get heat from the system.

PRINCIPLES OF REFRIGERATION

Refer to figure 2-22 during the following discussion. The working fluid used in the system is CCl_2F_2 (Freon). The compressor (A) delivers gas at high temperature and pressure to the coils (B). Water or air cooling removes the heat from the gas in (B), resulting in condensation of the gas into a liquid. The liquid flows by force through a small orifice (C) and expands as it leaves the orifice. It leaves the valve as a mixture of liquid and vapor at a lower temperature. The mixture of liquid and vapor now enters the coil (D), and heat from the surrounding area supplied to the working fluid converts the remaining liquid to a gas. The gas enters the compressor, and the cycle-repeats.

ANSWERS FOR REVIEW QUESTIONS Q21. THROUGH Q26.

A21. Photography uses infrared because it is effective against camouflaged targets, and night photography can produce a better visual presentation of terrain than the best mapping radar.

A22. Active, semiactive, and passive.

A23. The infrared imaging system consists of detectors, a scene disection system, front-end optics, a refrigeration system, and an image processing system.

A24. The front-end optics collect the incoming radiant energy and focuses the image at the detectors.

A25. Refrigeration systems provide the necessary operating temperatures for imaging systems.

A26. Stabilization and pointing gimbals, collecting optics and filters, optomechanical scanner, scan encoders, scan synchronizer, detector assembly, and video processor.

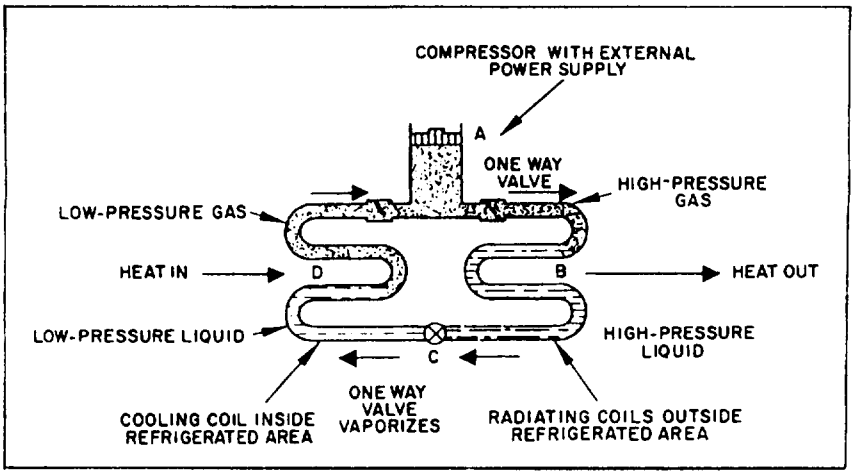


Figure 2-22.-Common refrigeration cycle.

Q27. Define cyrogenics and identify its temperature range.

Q28. What happens when bodies of different temperatures meet in thermal contact?

Q29. Energy is the driving force of the universe. What assumptions can you make about energy?

Q30. Name the three types of heat flow.

Q31. How does heat flow through radiation?

LASERS

Learning Objectives: *Identify the principles of optics and lasers to include terms, theory, and the partical theory of light. Recognize the purpose of Q-switching and identify solid-state laser types.*

A laser is a device that produces or amplifies ultraviolet, visible, or infrared radiation. This is done by a process of controlled stimulated emission. The word *laser* is an acronym for light amplification by stimulated emission of radiation. The first lasers were used for surveying because they accurately measured distance. Later, lasers were used by the military. The initial military application of the laser was for fire control. To direct gunfire, the range to and the direction of the target must be determined. This is done by the laser system. Then, the data gathered by the laser system is used to direct the weapon system. Currently, the technology exists for laser designation of the target for laser-guided munitions. Military laser systems have both a range-finding capability for conventional munitions and a designation for laser-guided munitions.

TERMS

There are several terms that you may find useful when dealing with lasers. These are *watts, irradiance, joules,* and *radiant exposure.*

Watts. A watt is a unit of power associated with light energy.

Irradiance. Irradiance is the amount of power per unit area, watt/cm^2. Energy cannot be created or destroyed. In a vacuum, the amount of energy that is available at the output of the laser is the same amount of energy contained within the beam at some point downrange. However, since lasers are not normally used in a vacuum, some energy is lost downrange. Figure 2-23 shows a typical laser beam. The amount of energy available within

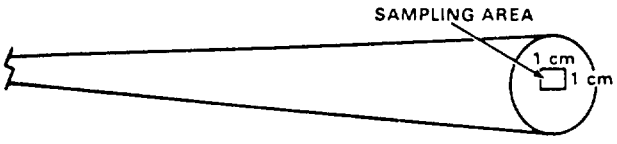


Figure 2-23.-Irradiance.

the sampling area is considerably less than the amount of energy available in the beam. For example, a 0.1-watt laser output might have 0.04 watt measured within a 1-square-centimeter (cm^2) sampling area. In this example, the irradiance is 0.04 watt/cm^2.

Joule. A joule is a unit of energy. It is the number of watts being delivered during a short period of time (1 watt per second).

NOTE: The output of a continuous-wave (CW) laser is normally given in watts while the output of a pulsed laser is normally given in joules.

Radiant exposure. Radiant exposure is the amount of energy per unit area, J/cm^2.

PRINCIPALS OF OPTICS AND LASERS

NOTE: Before reading this section, you should review the information on light found in chapter 1.

The theory of lasers was published around 1956. Along with the theory, a study was reviewed. In the study, methods of extending the range of lasers were looked at using various solids and gases as the method of range extension. It was from this study that laser theory evolved. The first laser was built in 1960 by Hughes Research Laboratories.

A simplified solid-state laser currently used by the military is shown in figure 2-24. The elements of the laser are the material, pump source, optical

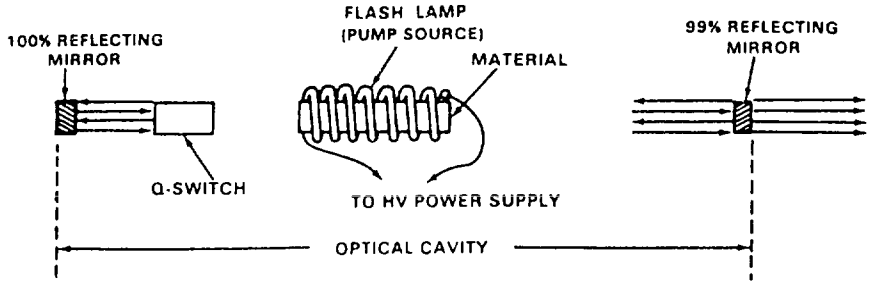


Figure 2-24.-Typical solid-state laser.

ANSWERS FOR REVIEW QUESTIONS Q27. THROUGH Q31.

A27. Cyrogenics is the science that involves the study of very low temperatures. The word comes from the Greek root cyro or kyros, which means icy cold or relating to the cold. Cyrogenic temperatures extend from −150°C downward to −273°C (absolute zero).

A28. When bodies at different temperatures meet in thermal contact, heat flows from the body at the higher temperature to the body at the lower temperature. The flow of heat stops when the two bodies are at the same temperature (thermal equilibrium).

A29. (a) Energy is the fuel required to make things happen.
(b) No system can operate without a transfer of energy.
(c) Heat is a form of energy.

A30. Convection, conduction, and radiation.

A31. Radiation is the transfer of energy (heat) by electromagnetic radiation. All bodies above absolute zero (0 K or −273°C) radiate.

cavity (amplifying and modifying the emission), and the output radiation.

The electrons in the atoms of the laser material normally reside in a steady-state lower energy level. When energy is added to the atom, the electrons are raised to a higher energy level. The flash lamp (fig. 2-24) is the device used in the solid-state laser to add energy to the atoms. When energy is added to the electrons, they are in an unstable condition. They stay in this condition for a short time and then spontaneously return to their steady-state lower energy level. The transition of the electrons from the higher energy level to the lower energy level releases energy in the form of photons of light. The emitted light rays travel back and forth in the optical cavity through the lasing material between the 100-percent reflecting mirror and the 99-percent reflecting mirror. The photons collide with other excited electrons in the laser material, thereby stimulating the emission of other photons of light. The light energy is amplified in this manner until sufficient energy is built up to be transmitted through the 99-percent reflecting mirror. This action is termed *lasing*. The equipment that accomplishes lasing is the laser.

Find the Q-switch shown in figure 2-24. It is used to provide pulses of extremely short duration. One type of Q-switching is provided by a rotating prism. Only at the point of rotation where there is a clear optical path is light energy allowed to pass. Another type of Q-switching device is a normally opaque electro-optical device such as a Pockels cell. At the time of voltage application, the Pockels cell becomes transparent to light. A complete optical path is formed that allows the transmission of light.

The construction of the gas laser is slightly different from that of the solid-state laser. A glass tube filled with gas is placed in the optical path. This tube replaces the lasing material and flash lamp in the solid-state laser. A voltage (the external energy source) is applied to the tube. The light emitted from this type of laser is normally continuous wave rather than pulsed.

Light from a conventional light source is extremely broadband. It emits several wavelengths across the electromagnetic spectrum. But, if you place a filter that allows only a very narrow band of wavelengths (such as a red filter) in front of a broadband light source, only red light exits the filter. An analogy can be made between the light from the filter and the light from the laser, with one exception—there is only a single wavelength emitted from the laser.

The wavelength (or color) of light emitted from the laser depends on the type of material used in the laser. For example, if a **Nd:YAG** crystal is used as the material in the laser, the laser emits light with a wavelength of 1.064 micrometers. Look at figure 2-25. It shows you some of the types of material that are used for lasing and the wavelengths that are emitted by lasers using these materials. Note that some materials and gases emit more than one wavelength. In these cases, the wavelength of the light emitted depends on the optical configuration of the laser.

Light from a conventional light source diverges or spreads quite rapidly. If you hold a sheet of paper near a 100-watt light bulb, the entire sheet is illuminated. Figure 2-26 shows the divergence (amount of beam spread) from a conventional light source. On the other hand, laser light has a very narrow beam divergence. If a sheet of paper is held the same distance from the laser as it was from the conventional light source, the laser light has a very narrow beam divergence; it shows a very small point of light (fig. 2-27). The laser light beam has a very narrow beam divergence. For example, if the paper were placed double the distance from the original point, the spot would be twice the size of the one first described. If a paper were held three times the distance, a spot three times the original size would be seen.

Materials reflect, absorb, or transmit light rays. Reflection of light can be shown by using a mirror. If light rays strike a mirror, almost all of the energy incident on the mirror is reflected. Refer to figure 2-28. This figure shows how a plastic or glass surface acts on an incident light ray, The amount of energy transmitted, absorbed, and reflected equals the amount of energy incident on the surface of the material.

A surface is termed *specular* when the sizes of surface imperfections and variations are much smaller than the wavelength of the incident optical radiation. A surface is termed *diffuse* when surface irregularities are randomly oriented and much larger than the incident optical radiation. In the intermediate region of the laser section of the electromagnetic spectrum, it is sometimes necessary to regard the diffuse and specular components separately.

If light is incident upon an interface that separates two transmitting media (such as an air-glass interface), some light is transmitted while some is reflected, and no energy is absorbed at the interface. Since no energy is absorbed at the

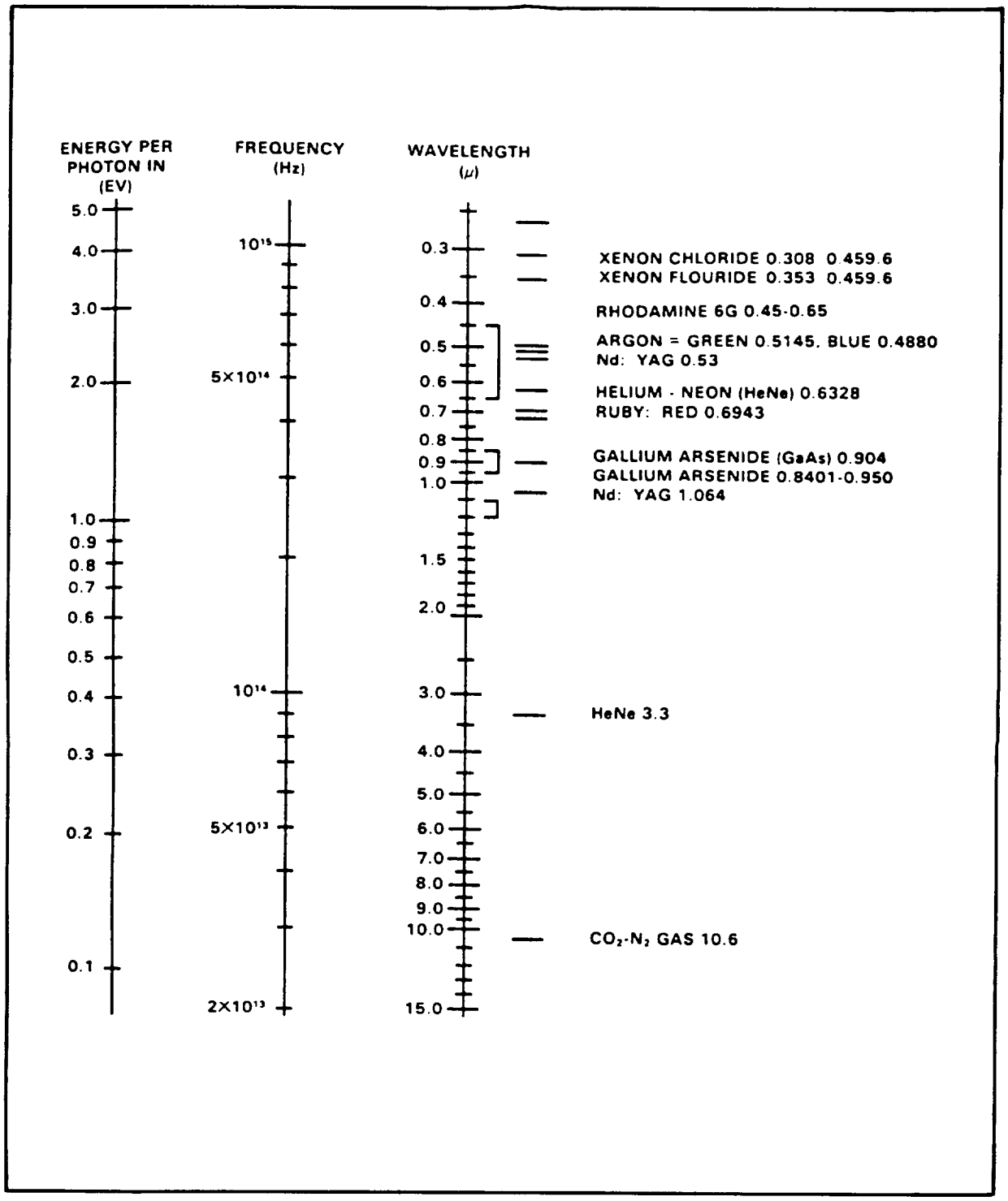


Figure 2-25.-Laser electromagnetic spectrum.

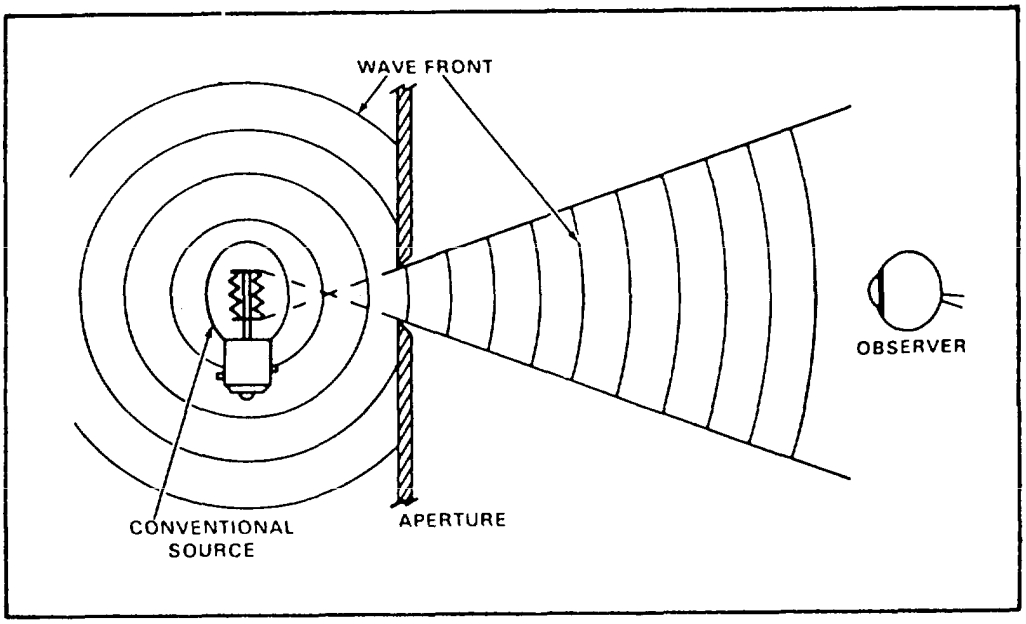


Figure 2-26.-Divergence of a conventional light source.

interface, T + R = 1.00; where T and R are the fractions of the incident beam intensity that are transmitted and reflected.

T and R are the transmission and reflection coefficients, respectively. These coefficients depend not only upon the wavelength of the radiation, but they also depend upon the angle of incidence of the beam. The amount of the incident light beam that is reflected and the amount that passes through the material (transmitted) also depends upon the polarization (aligning the light to certain directions) of the light beam.

The angle θ that an incident ray of radiation formed with the normal to the surface determines the angle of refraction and the angle of reflection (the angle of reflection equals the angle of incidence). The relationship between the angle of incidence (θ) and the angle of refraction (θ') is n sine (θ) = n´ sine (θ'), where n and n´ are the incidence of refraction of the media that the incident and transmitted rays move through, respectively.

A flat specular surface does not change the divergence of the incident light beam significantly. However, a curved surface may change the divergence, The amount of change in the divergence depends upon the curvature of the surface and the beam size incident to the surface.

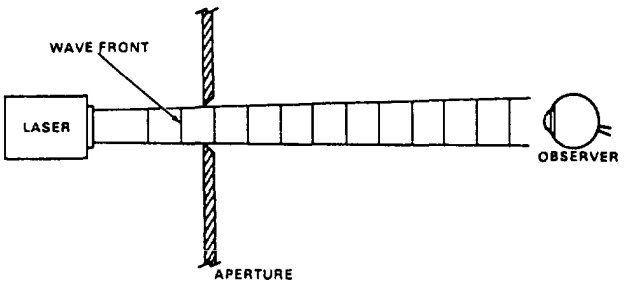


Figure 2-27.-Divergence of a laser source.

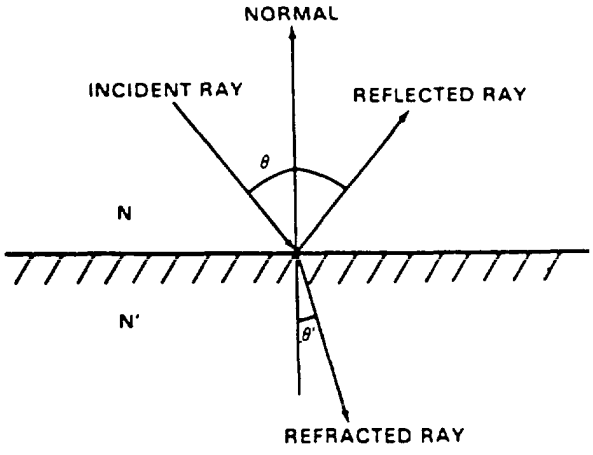


Figure 2-28.-Light ray incident on a glass surface.

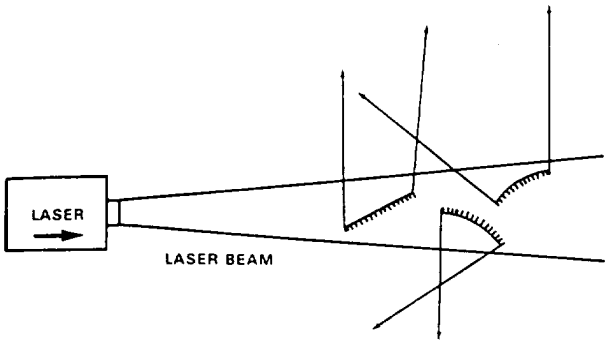


Figure 2-29.-Specular reflectors.

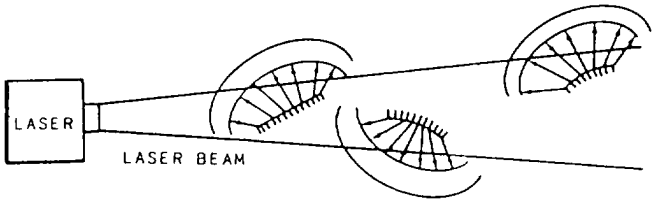


Figure 2-30.-Diffused reflectors.

In figure 2-29, the reflection of an incident laser beam is shown on the two surfaces. (The divergence and curvature of the reflector have been exaggerated.) You should note that the value of irradiance measured at a specific range from the reflector is less after reflection from the curved surface than when a beam is reflected from a flat surface.

A diffuse surface is a surface that reflects the incident laser beam in all directions. The beampath is not maintained when the laser beam strikes it. Whether a surface is a diffuse reflector or a specular reflector depends upon the wavelength of the incident laser beam. A surface would be a diffuse reflector for a visible laser beam, while it might be a specular reflector for an infrared laser beam, such as CO_2. Look at figure 2-30. It shows the effect of different curvatures of diffuse reflectors on incident laser beams.

Q32. Describe the basic principle of a laser.

Q33. What determines the wavelength (or color) of light emitted by a laser?

Q34. Some terms are useful in dealing with lasers. These include watts, joules, and irradiance. What is meant by irradiance?

Q35. What is meant by a diffuse surface?

LASER THEORY

To understand laser and infrared operation, you must understand wave propagation, the component parts of waves, and wave interaction.

Wave Propagation

Wave propagation is the travel of a wave through a medium. Refer to figure 2-31. Here a

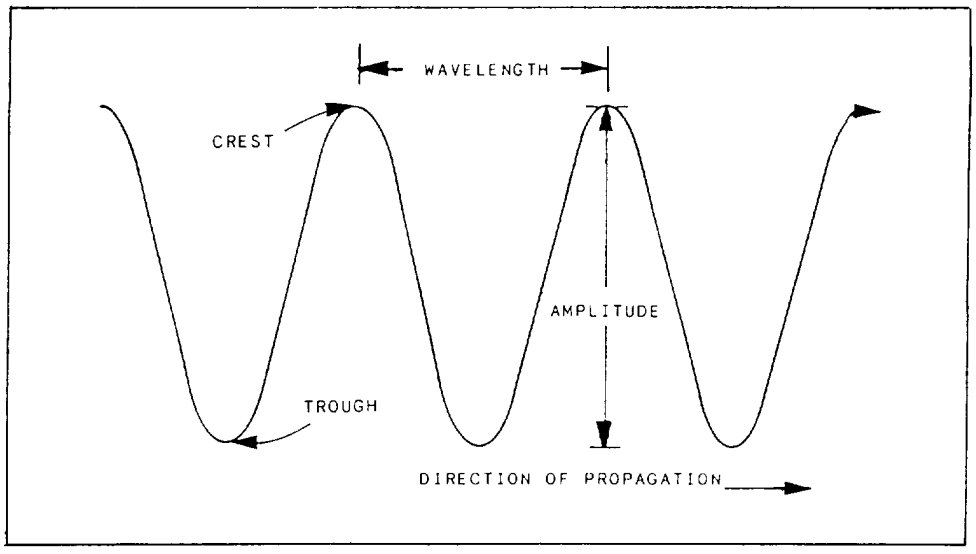


Figure 2-31.-Parts of waves.

plain wave is shown, and you can see that the propagation (direction of travel) is perpendicular to the lines of the crest. Another type of wave is a spherical wave that propagates outward like that which a pebble causes when it is thrown into a pond.

Wave Optics

When light strikes an object or a medium, it is either reflected or absorbed. Wave optics involve the reflection or absorption of waves.

REFLECTION.— Refer to figure 2-32. This figure illustrates light reflection and refraction. As an incident wave strikes a reflective surface, it is reflected from the surface. If the reflective surface is smooth, the angle of reflection equals the angle of incidence.

REFRACTION.— Again, refer to figure *2-32.* When light passes through a transparent medium, it is bent or refracted. The term *index of refraction* refers to the amount that the light is bent or the angle of refraction. The higher the index of refraction, the more the light is bent. The index of refraction is a function of wavelength of the incident light. Since different colors have different wavelengths, they have a different index of refraction.

DIFFUSION.— Earlier, you saw how light is reflected when it strikes a smooth surface. When the same type of beam strikes a rough surface, the light is scattered. The term used to describe this scattering is *diffusion.* Diffusion allows you to see nonluminous objects.

Lens Optics

Lenses are used extensively in laser and infrared system operation. Therefore, you need to understand lens optics before you can understand the system. A *lens is* defined as a piece of transparent material with two opposite refracting surfaces. Converging and diverging lenses are the two categories of lenses. Within these categories, there are three basic types of lenses—convex, concave, and meniscus (fig. 2-33), The converging lenses are thin at the edge and thick in the middle, while the diverging lenses are thick at the edges and thin in the middle.

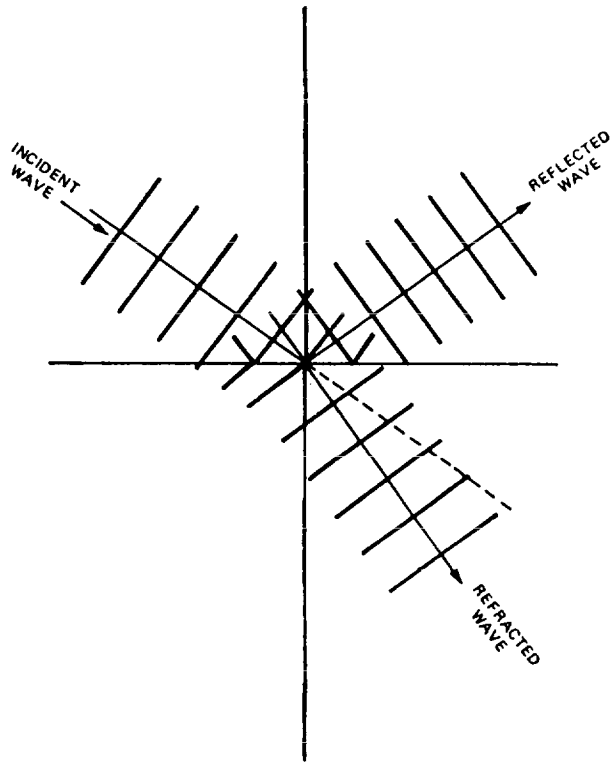


Figure 2-32.-Reflection and refraction.

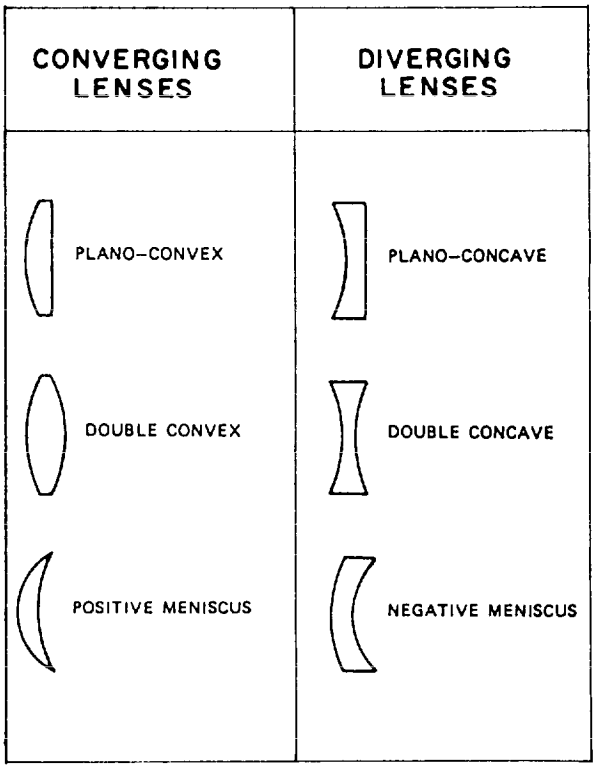


Figure 2-33.-Types of lenses.

THIN CONVERGING LENS.— A thin converging lens is shown in figure 2-34. Light rays traveling parallel to the axis of a thin convex lens are refracted so that they converge at a point called the *focal point* of the lens. The distance from the center of the lens to the focal point is the *focal length* of the lens.

THIN DIVERGING LENS.— A thin diverging lens is shown in figure 2-35. In the case of a thin diverging lens, light rays that travel parallel to the axis of the concave lens are refracted so that they diverge at a point known as the *focus.* The distance from the center of the lens to the focus is known as the *focal length.* Since the focus is on the viewing side of the lens, it is considered negative.

Particle Theory of Light

Light, and all other forms of electromagnetic radiation, is energy. Light is composed of particles called photons, which are bundles of massless energy.

PHOTOELECTRIC EFFECT.— In 1887, Heinrich Hertz discovered that metals eject electrons when illuminated. This discovery gave rise to the particle theory of light. The photoelectric effect is shown in figure 2-36. The following conclusions can be drawn about the nature of light:

- The number of photoelectrons ejected is proportional to the intensity of light; that is, the more intense the light, the greater the number of photoelectrons ejected.

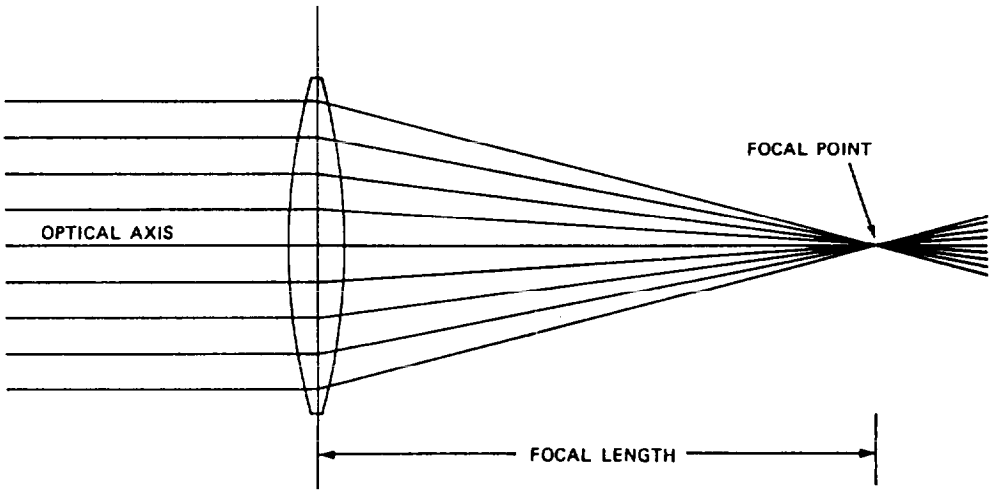


Figure 2-34.-Thin converging lenses.

ANSWERS FOR REVIEW QUESTIONS Q32. THROUGH Q35.

A32. A laser is a device that produces or amplifies ultraviolet, visible, or infrared radiation by controlled stimulated emission.

A33. Type of material used in the laser.

A34. Irradiance is the amount of power per unit area.

A35. A diffuse surface is a surface that reflects the incident laser beam in all directions.

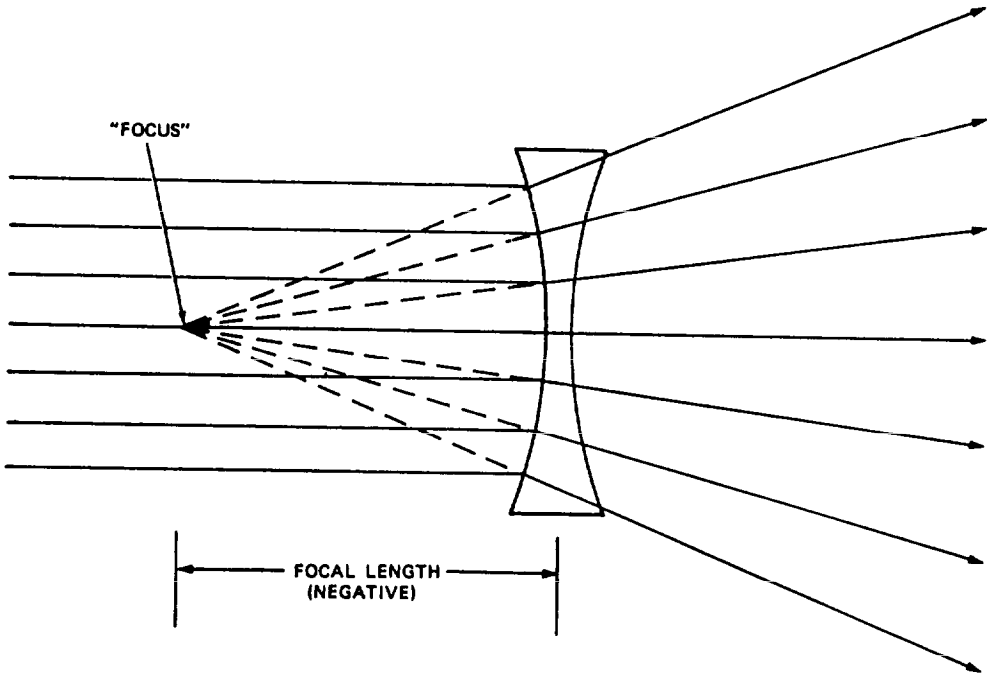


Figure 2-35.-Thin diverging lenses.

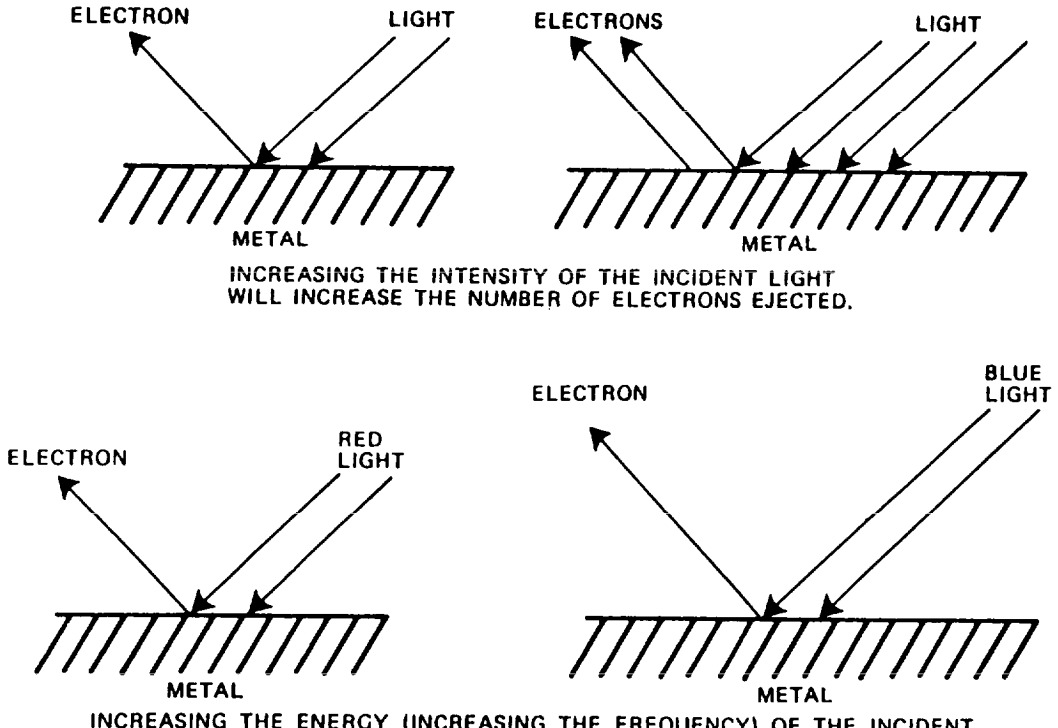


Figure 2-36.-Photoelectric effect.

- Maximum kinetic energy (Kmax) is a function of the frequency of incident light.

- Photoelectrons are ejected instantaneously, regardless of the intensity of the incident light.

- The surface of the specific metal has a threshold frequency; that is, the threshold is the minimum frequency of light that causes photoelectrons to be ejected.

PHOTON THEORY OF LIGHT.— The photon theory of light was announced by Einstein in 1905. This theory explains the photoelectric effect and adds to the understanding of the photoelectric effect in the following ways:

- A beam of light is a stream of photons. The intensity of the beam is proportional to the number of photons in the beam. If one photon knocks out one electron, the photoelectrons will be proportional to the intensity of the beam.

- The energy created in the collision of the photons is transferred instantaneously.

Stimulated Emissions

Lasers operate by stimulated emission. Refer to figure 2-37 while you read this section. An excited atom is struck by a photon. The energy of the incident photon is equal to the transition energy of the excited atom, and the excited atom triggers or *stimulates* an emission from atom number two. The output produced by the stimulation is emitted instantaneously upon impact, and it is considered an amplified output.

Refer to figure 2-38. The laser rod and the flash lamp are placed at the foci of the elliptical mirror (fig. 2-38, view A). The elliptical mirror can be focused on the laser rod and also the flash lamp. The flash lamp is fixed (fig. 2-38, view B). The photons from the lamp enter the laser tube, causing the tube to go to a high state (excited). The input light signal hits the excited atoms of the laser rod, causing stimulated emissions (fig. 2-38, view C). Finally, the amplified signal leaves the laser tube (fig. 2-38, view D).

Q-Switching

As you can see by looking at figure 2-39, uncontrolled laser output consists of a series of

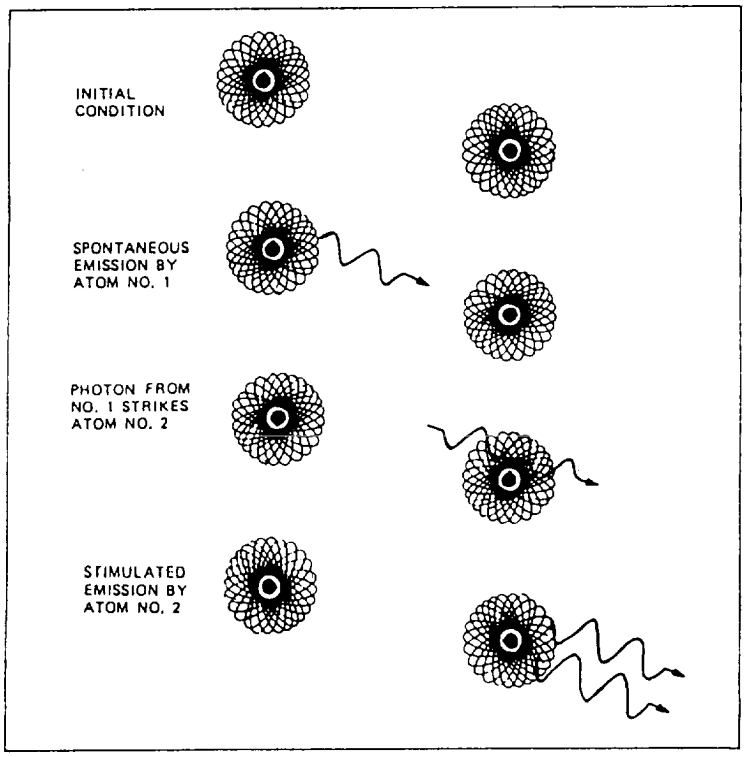


Figure 2-37.-Stimulated emission.

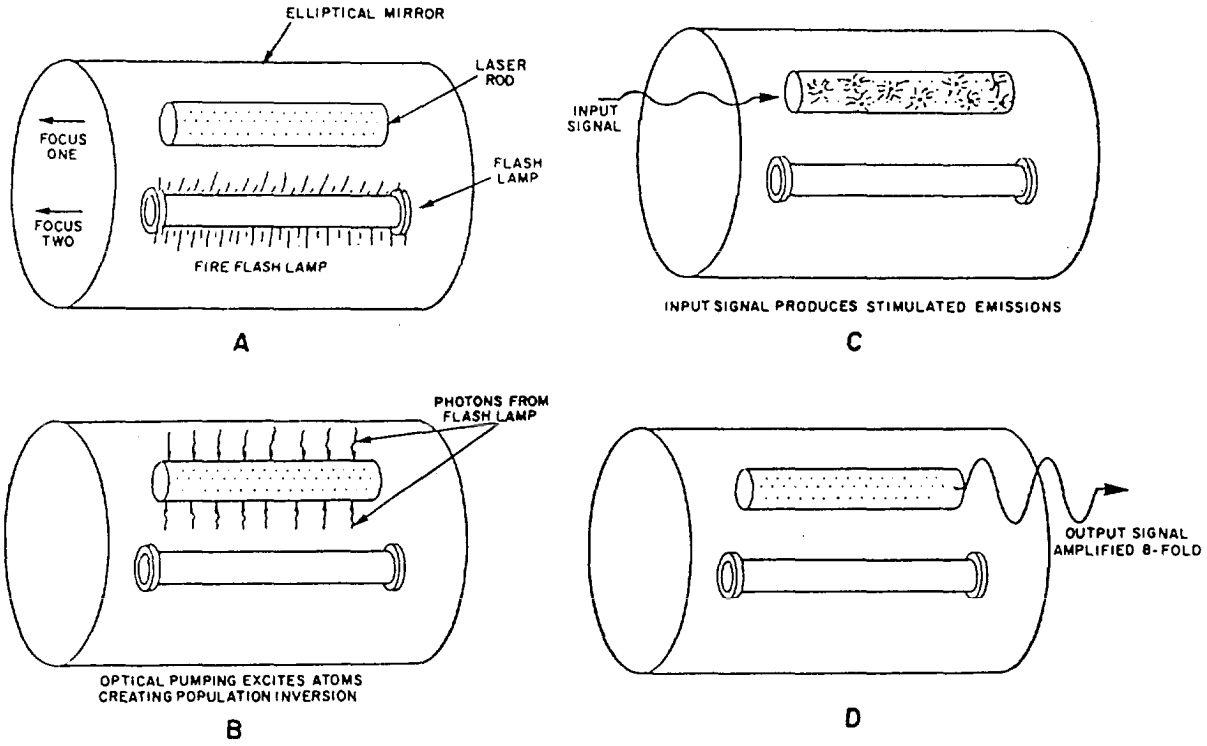


Figure 2-38.-Light amplification.

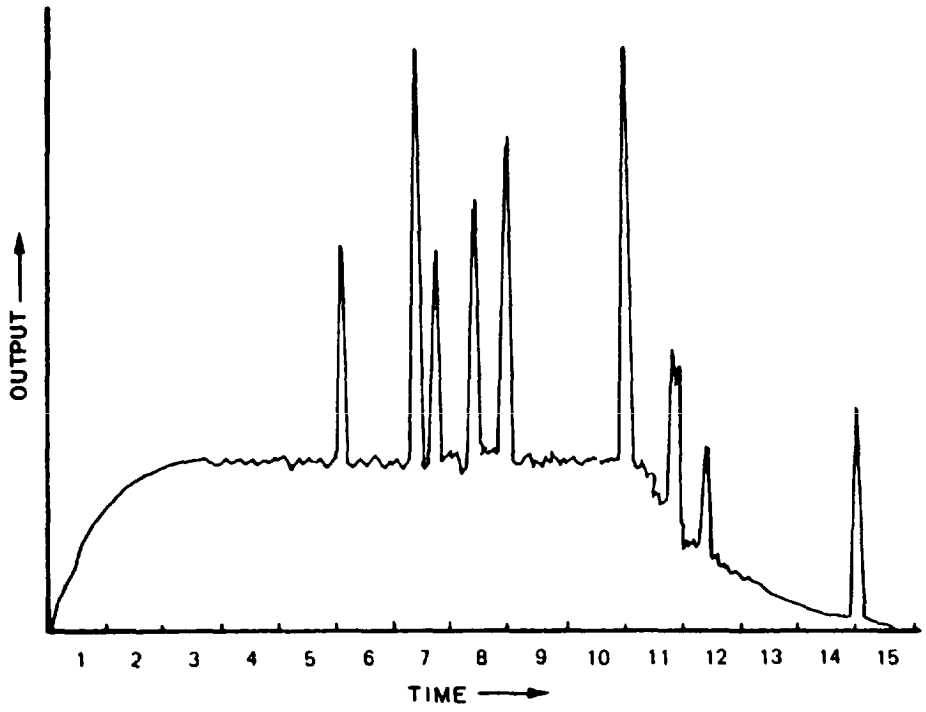


Figure 2-39.-Typical laser output.

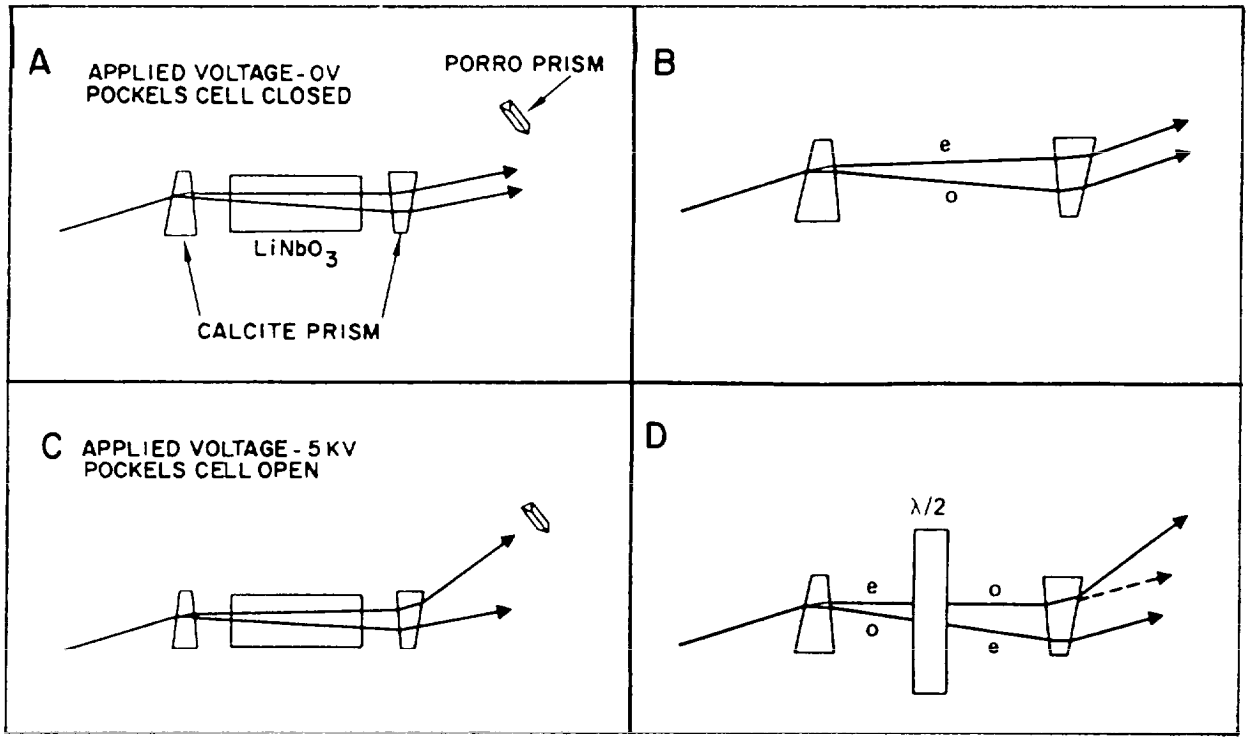


Figure 2-40.—Pockels cell.

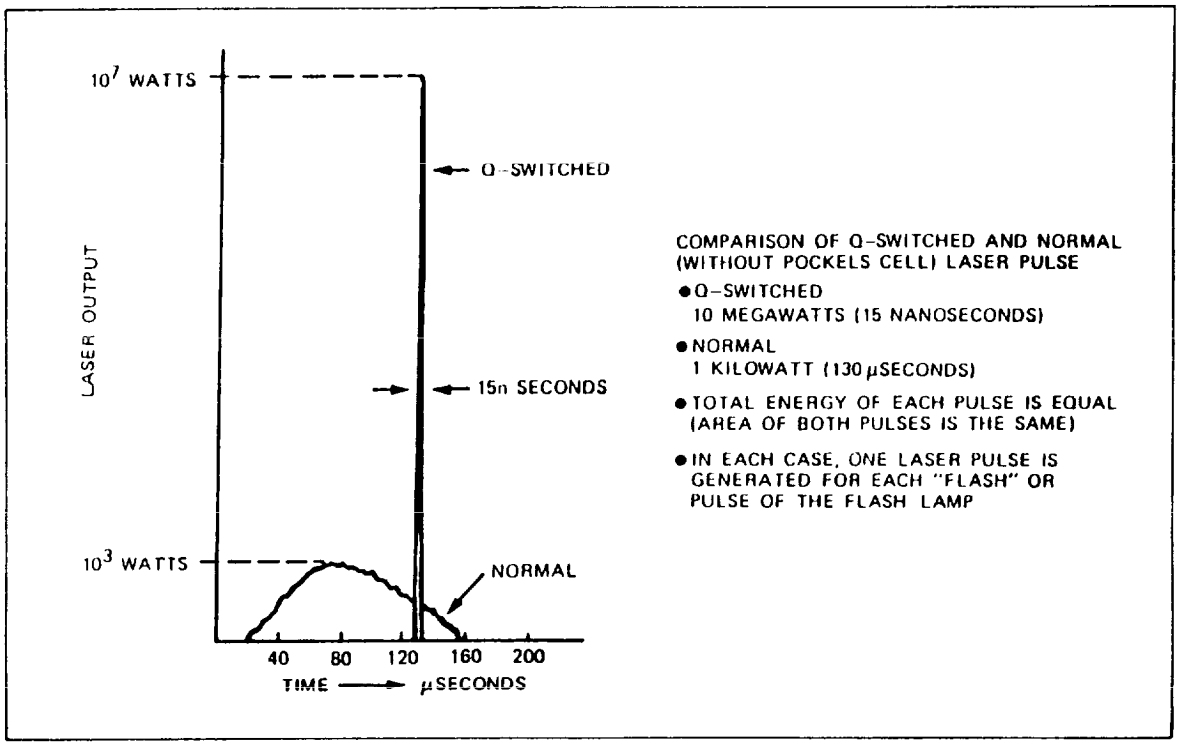


Figure 2-41.-Laser pulse comparison.

sharp spikes with random heights and random intervals. Normally, this type of output is unusable. Some method of control is needed to regulate or change this output into a single pulse of demand, and quality switching (Q-switching) meets this need.

There are many ways to provide Q-switching, from simple mechanical methods to more elaborate electronic methods. The type of Q-switching discussed in this chapter is the Pockels cell.

POCKELS CELL.— The Pockels cell is a type of electro-optic Q-switch (fig. 2-40). The Pockels cell is placed between the laser rod and the mirror (fig. 2-40). This cell is composed of lithium niobium ($LiNbO_3$).

POCKELS CELL WITH ZERO VOLTAGE APPLIED.— When light from the laser strikes the first calcite prism, the calcite prism splits the light into ordinary **o** and extraordinary **e** beams, which are diverged slightly. These beams strike the second prism where they are bent or diverged again. They leave this prism in parallel and strike a mirror, which reflects them 100 percent. The light stays inside the Pockels cell; thus, there is zero output.

POCKELS CELL WITH 5 KV APPLIED.— Look at figure 2-40, views A and B. Once again, the light from the laser strikes the first calcite prism. Again, it splits and becomes the o beam and e beam. These two beams strike the lithium niobium with the voltage applied, and it becomes birefringent. (Birefringent means to refract the light in different directions.) The outputs from the lithium are the **e** beam and the **o** beam, rotated by 90°. This causes the beams to interchange or become each other. The new **o** beam strikes the second prism where it is refracted sharply to hit the Porro prism, which reflects it sharply back into the optical path to provide the feedback that causes sustained optical oscillations (power buildup). The Pockels cell is the device that allows these oscillations to build until a threshold is reached. Then the laser fires (fig. 2-41).

Solid-State Lasers

The demand for lasers with diverse applications caused the development of many types of lasers. Most lasers are grouped into five categories—solid state, gas, ion, chemical, and dye. Solid-state lasers were developed first and were most widely used for military applications. For this reason, solid-state lasers are the type discussed in this chapter.

CRYSTALLINE LASERS.— Crystalline lasers are widely used. Two materials are used in these lasers: the matrix substance *(host)* and an impurity *(dopant).* The host is an inert, optically transparent crystalline substance. The main purpose of the host is to lattice sites (honeycomb arrangement) occupied by the dopant. The substances commonly used as the host include sapphires, yttrium aluminum garnet (YAG), fluorite, glass, calcium tungstate, and calcium molybdate. Dopants are ions of rare earth metals, with the exception of chromium. The most commonly used dopants are chromium, neodymium, holmium, erbium, uranium, and samarium.

RUBY LASERS.— The host material for ruby lasers is sapphire crystalline alumina. The dopant is triply ionized chromium, which gives a characteristic red color. Although natural rubies could be used in lasers, their use is rare because large natural rubies with uniform color are rare. Synthetic crystals can be grown to a desired size with no flaws and uniform color.

NEODYMIUM YAG LASER.— Normally, the YAG laser is used as a continuous-wave (CW) laser. The YAG is the host for the trivalent neodymium ion (ND^{+3}) dopant. The neodymium gives the YAG a pale, reddish-purple color. The laser rod is produced synthetically, as is the ruby laser. The major difference between the ruby and YAG laser is the output wavelength.

SEMICONDUCTOR DIODE LASERS.— A semiconductor functions somewhere in between a metal (conductor) and a nonmetal (insulator). At high temperatures, the semiconductor has low resistance; while at very low temperatures (near absolute zero), it has extremely high resistance. An example of a semiconductor diode laser is shown in figure 2-42. The semiconductor diode

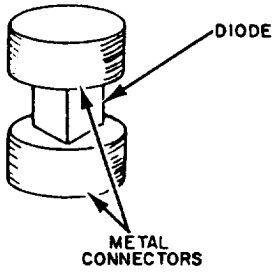


Figure 2-42.-Diode laser.

is made by sandwiching a diode between two metal conductors that are polished to provide feedback. The semiconductor diode laser has several advantages when compared to other types of lasers.

- They are more efficient.
- They have a wider bandwidth.
- They are faster and do not require Q-switching.

Military Applications

Target designation and range-finding are two of the military applications of lasers.

TARGET DESIGNATION.— Target designation is provided by a laser fixed on a target. A beam is reflected from the target and produces a small, bright spot. Then, a laser-guided bomb, shell, or missile can home in on the spot. To prevent the enemy from jamming the signal, a coded pulse repetition rate is added.

RANGE-FINDING.— When used for range-finding, a laser fires a pulse of light that is pointed at a target. When the pulse is fired, a clock starts. The pulse strikes that target and is reflected. When the returning pulse is detected, the clock stops. Because the speed of light is known, this system is accurate to within 1 foot at a range of 2 miles.

Q36. Explain wave optics.

Q37. Name two categories of lenses.

Q38. What is the particle theory of light?

Q39. What is meant by stimulated emission (fig. 2-37)?

Q40. List the five categories in which most lasers are grouped.

DETECTING-RANGING SET (DRS) AN/AAS-33A

Learning Objectives: *Identify major components and functions of the AN/AAS-33A. Identify the system shop replaceable assemblies (SRAs) and recognize their functions.*

The Detecting-Ranging Set (DRS) AN/AAS-33A is part of the A-6E integrated weapons system. The DRS provides three electro-optical sensors and associated controls and indicators to enhance the all-weather capability of the weapons system to detect, recognize, and identify targets accurately.

> **NOTE:** While reading this section, you should refer to table 2-3 for a listing of the components and associated assemblies of the AN/AAS-33A. The physical location of the AN/AAS-33A within the aircraft can be seen by referring to figures 2-43 through 2-48.

The three sensors are housed in a 20-inch, fully gimballed turret and are collectively known as the *receiver group (RG).* This group is installed in the aircraft underneath the radome, forward of the nosewheel. The three sensors are the laser range finder/designator (LRD), forward air controller (FAC) receiver, and forward looking infrared (FLIR) receiver. The LRD is also known as the *laser receiver-transmitter.* The LRD functions as a range finder and target designator. It provides range-to-target data to the ballistic computer set and designated targets for laser-guided bombs (LGBs). The FAC receiver is used as an aid for the bombardier/navigator (B/N) in locating a target designated by an external laser source from a ground observer or another aircraft. A laser source can serve as the offset aimpoint in the solution of a computer-controlled bombing attack. The FLIR receiver is a passive sensor that is used to detect targets of interest by their emitted infrared radiation. The infrared radiation signals are processed and a real-time, television-like image is displayed on the FLIR indicator.

The SRAs consist of turret-stabilized platform, FLIR receiver, laser range finder designator, forward air controller receiver, reciprocating compressor, electronic control amplifier, generator processor, signal processor, infrared indicator, detecting ranging set control, power supply, and cable assembly.

TURRET STABILIZED PLATFORM (TSP)

The turret stabilized platform (TSP) consists of a two-axis turret and a vernier two-axis gimbal that provides azimuth coverage of –195° and elevation coverage of +20° to +180°. A turret stow position of 0° azimuth and –210° elevation

Table 2-3.-AN/AAS-33A Components

REF DES	NOMENCLATURE	PLACARD OR COMMON NAME
	Components	
89A1	Receiver Group 0R-203/AAS-33A or OR-203A/AAS-33A	Receiver group (RG)
	Major SRAs:	
	1. Forward Looking Infrared Receiver	FLIR receiver
	2. Laser rangefinder/Designator or Laser Receiver-Transmitter (LRT)	Laser rangefinder designator (LRD) or laser receiver-transmitter (LRT)
	3. Forward Air Controller Receiver	FAC receiver
	4. Turret Stabilized Platform	Turret stabilized platform (TSP)
89A2	Reciprocating Compressor HD-1032/ AAS-33A	Compressor
89A3	Power Supply PP-7417/AAS-33A	Low voltage power supply (LVPS)
89A4	Generator Processor 0-1761/AAS-33A	Laser transceiver electronics (LTE)
89A5	Signal Processor CV-3460/AAS-33A	Laser receiver electronics (LRE)
89A6	Electronic Control Amplifier AM-6959A/ AAS-33A	Electronic control amplifier (ECA)
89A7	Infrared Indicator IP-1301/AAS-33A	Forward looking infrared indicator (FLIR)
89A8	Detecting-ranging Set Control C-10301/ AAS-33A	DRS control panel
89A9	Temperature Control C-10358/AAS-33A	—
	Cable Assembly W1 of AN/AAS-33A	Pulse forming network cable (PFN cable)
89A10	3-Way, 2-Position, DRS Solenoid Selector Valve	Solenoid selector valve
	Associated Assemblies	
02A2	Nosewheel Well Circuit Breaker Box (Forward)	Nosewheel well circuit breaker panel (FWD)
02A3	Bombardier/Navigator Circuit Breaker Panel	—
02A11	Nosewheel Well Circuit Breaker Panel (Aft)	CB panel (NWW) (Aft)
03A2	Top Deck Relay Box	—
14A10	Temperature Control Box	—
23A1	Caution Dim and Test Light Assembly	Caution lights panel

Table 2-3.—AN/AAS-33A Components—Continued

REF DES	NOMENCLATURE	PLACARD OR COMMON NAME
Associated Assemblies—Continued		
50A1	Ballistics Computer CP-985/ASQ-133 or CP-1391/ASQ-155A	Ballistics computer
50A3	Computer Control C-9535/ASQ-155	Pedestal control unit (PCU)
50A10	Analog-to-Digital/Digital-to-Analog Converter CV-3163/ASQ-155	A/D converter
61A1	Mission Recorder Electronics Unit MX-9276/USH-17(V)	Electronics unit
61A3	Mission Recorder Control Panel C-9071/ USH-17(V)	MISSION RECORDER control panel
75A4	Power Supply PP-6574/APQ-148	Low-voltage power supply (LVPS)
75A12	Analog Display Indicator IP-722D/ AVA-1 or IP-722F/AVA-1	ADI
75A15	Fault Locating Indicator ID-1933/APQ-156	BIT panel
75A16	Pilot's Control Box	PCB
S67	Nose Gear Down and Locked Switch	—
S6030	Right Main Gear Weight-on-Wheels Switch	—

ANSWERS FOR REVIEW QUESTIONS Q36. THROUGH Q40.

A36. Wave optics involve the reflection or absorption of waves. Light strikes an object or medium and is either reflected or absorbed.

A37. Converging and diverging.

A38. The particle theory of light states that "light is composed of particles called photons, which are bundles of massless energy."

A39. The energy of the incident photon in figure 2-37 is equal to the transition energy of the excited atom; the excited atom triggers or stimulates an emission from atom two.

A40. Solid state, gas, ion, chemical, and dye.

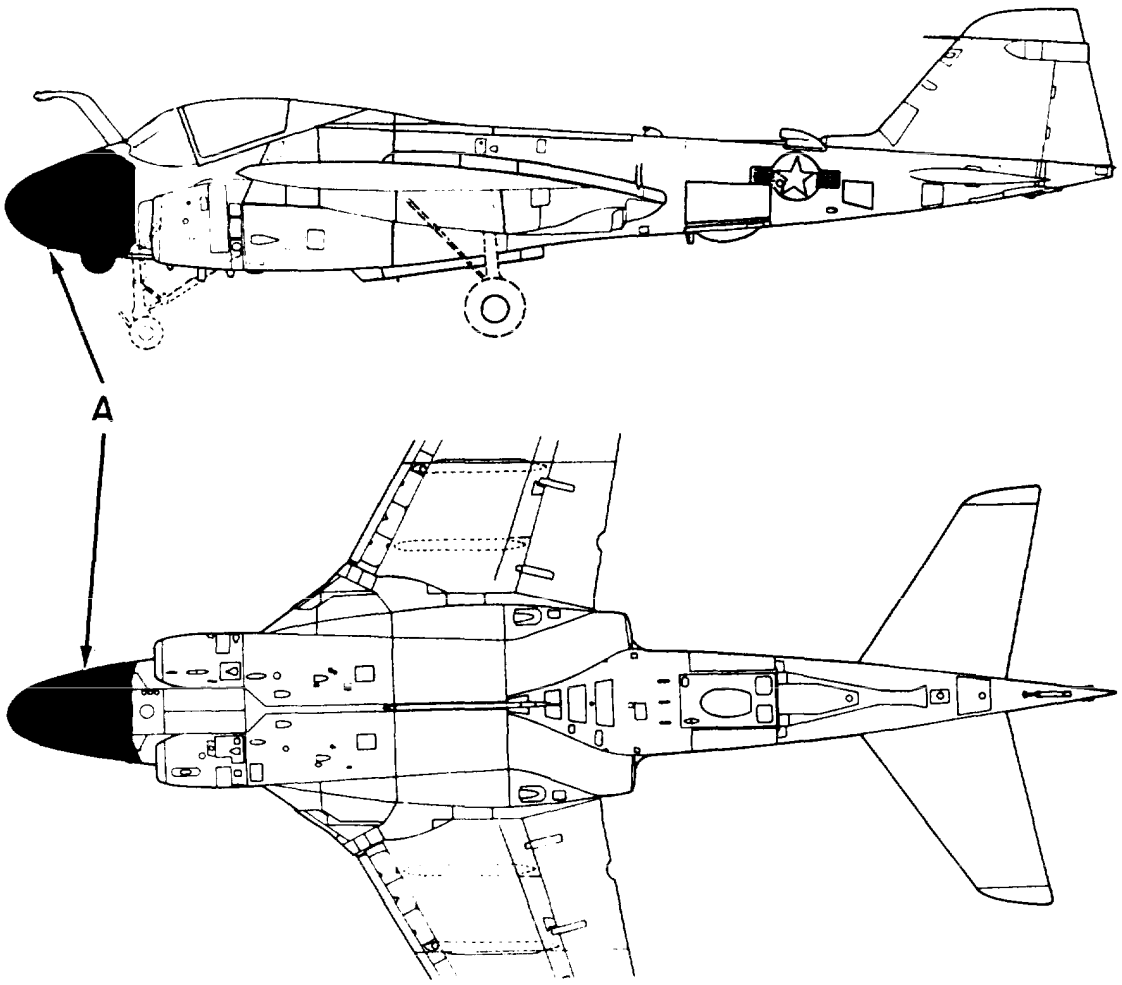


Figure 2-43.-Outside view A-6E.

protects the three optical windows of the lower ball when the receiver group is not in the on-target mode of operation. A hydraulic motor connected to the aircraft hydraulic system provides power for turret outer azimuth drive. The elevation axis and inner gimbal drives are powered electrically.

FLIR RECEIVER

The FLIR receiver provides infrared target detection and recognition capability. It has a continuous optical zoom ratio capability of 5 to 1 (5x). A counterbalance weight moves in an opposing motion to the zoom to maintain a balance when the FLIR is installed in the TSP.

LASER RANGE FINDER DESIGNATOR (LRD)

The LRD provides target ranging and designating capability. It contains separate telescopes for its transmitter and receiver, which view through a common window on the TSP. Computer control of range-finding and target designation modes is provided.

FORWARD AIR CONTROLLER (FAC) RECEIVER

The FAC receiver provides position information of acquired targets that are illuminated by remotely operated ground or airborne laser designators. It receives the laser energy through a separate window on the TSP. A four-quadrant

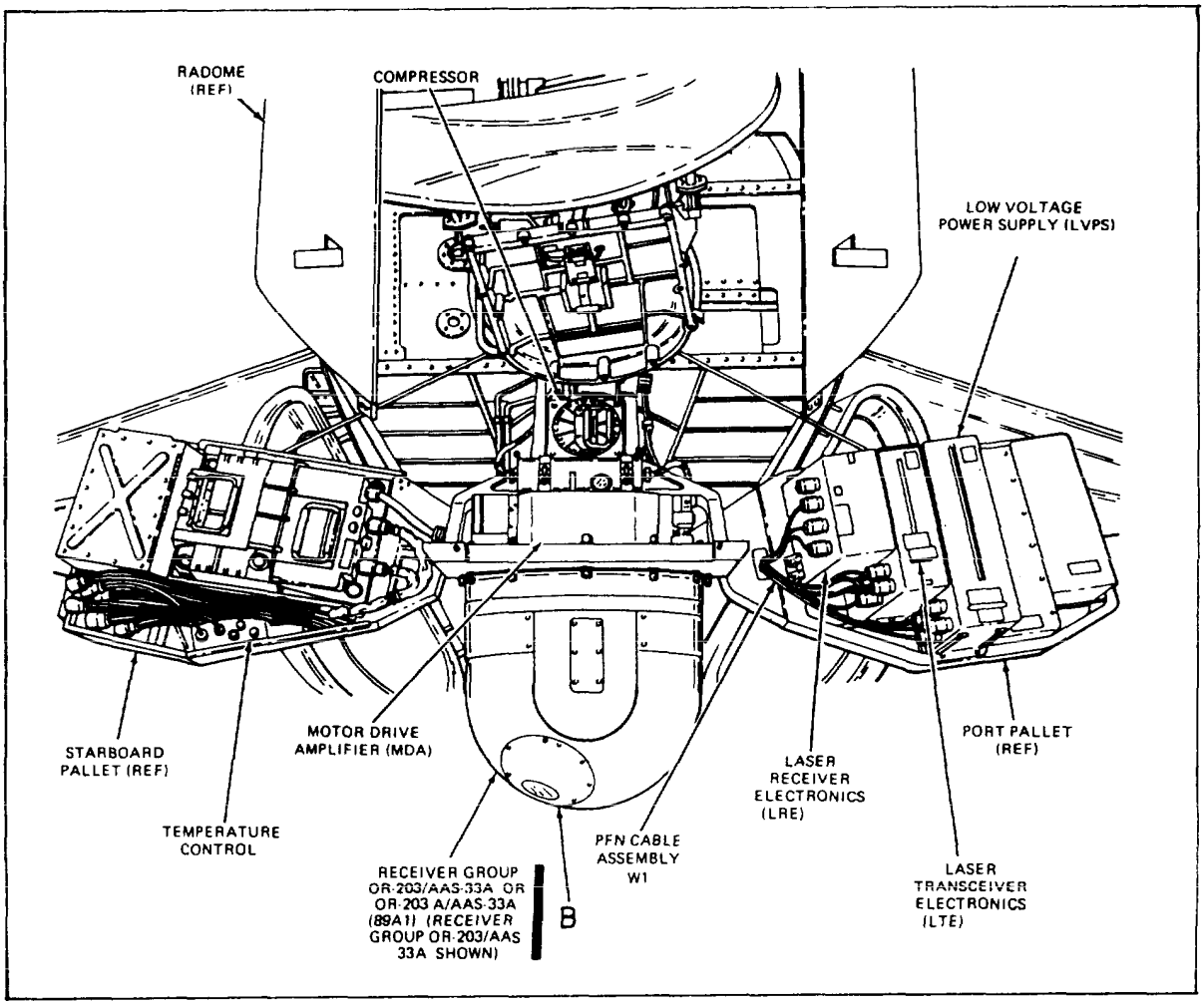


Figure 2-44.-Aft view with pallets extended and radome raised.

detector generates the position signals, which are processed to locate the position of a target symbol displayed on the FLIR indicator.

RECIPROCATING COMPRESSOR HD-1032/AAS-33A

The HD-1032/AAS-33A compressor is a piston device that is driven by a 115-volt ac, 400-Hz, three-phase induction motor that is an integral part of the compressor assembly. The compressor provides helium pressure pulses for the required cooling for the detectors.

ELECTRONIC CONTROL AMPLIFIER (ECA) AM-6959/AAS-33A

The ECA contains the electronics circuits that provide the capability to accurately position or show the receiver group up to 1 radian/sec in response to input signals from the ballistic computer.

GENERATOR PROCESSOR 1761/AAS-33A

The generator processor is also known as the *laser transceiver electronics (LTE).* It provides precise timing signals and a high-voltage firing pulse to the LRD. All mode commands and power for the laser subsystem interface with the rest of the DRS through LTE.

SIGNAL PROCESSOR CU-3460/AAS-33A

The signal processor is also known as the *laser receiver electronics (LRE).* It processes four video

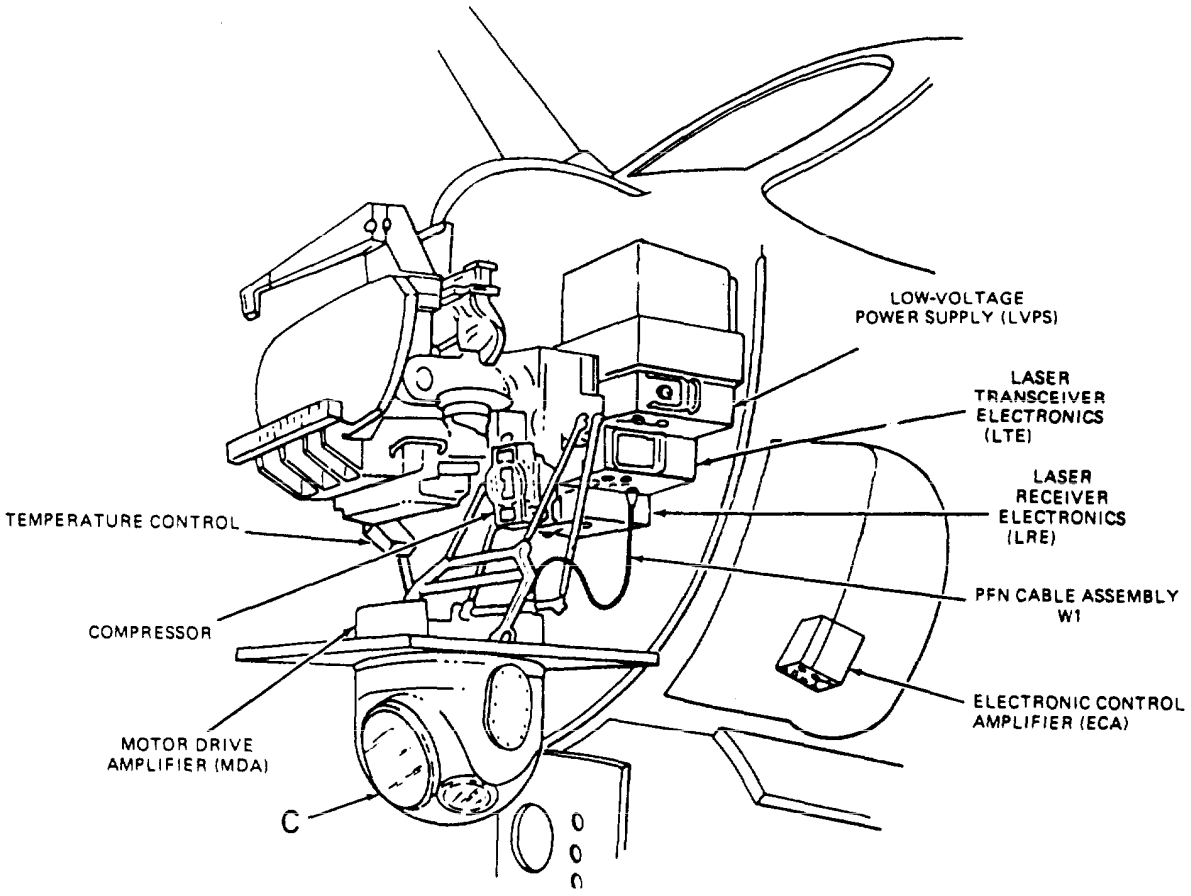


Figure 2-45.-View looking inboard and aft with pallets stowed.

signals from the FAC receiver, which are proportional to the position of a designated target in the FAC receiver field of view.

INFRARED INDICATOR IP-130/AAS-33A

The infrared indicator (fig. 2-48, view A) presents a high-resolution video display of the infrared scene in real-time on an 8-inch diagonal CRT. In-flight video tape recordings can be made and played back on the infrared indicator. Six status lights on the front panel provide the B/N with the operating status of the DRS subsystem.

DETECTING-RANGING SET (DRS) CONTROL C-10301/AAS-33A

The DRS control panel (fig. 2-48, view B) provides on/off power and mode command control logic for FLIR, stabilization, laser, and FAC subsystem operation. It also has controls for the FLIR indicator and FLIR subsystem. The DRS control panel also houses the BIT interface circuits between the aircraft BIT panel and the DRS WRAs.

POWER SUPPLY PP-7417/AAS-33A

The low-voltage power supply (LVPS) generates the low voltage necessary to operate the entire DRS system.

CABLE ASSEMBLY WI (PFN CABLE)

The PFN cable conducts the pulse-forming network voltage from the LTE to the receiver group.

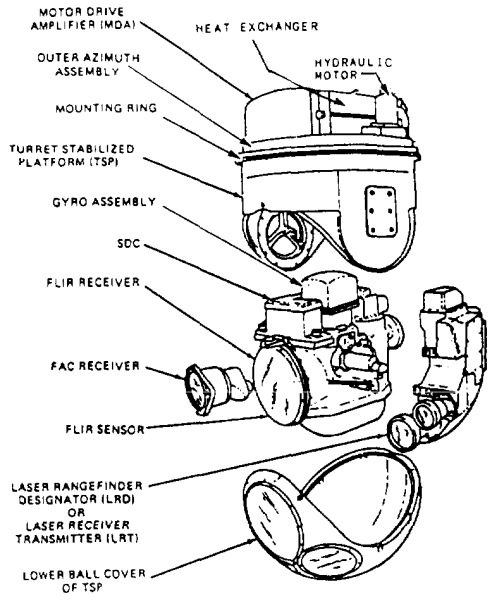


Figure 2-46.-Receiver group.

FIBER OPTICS

Learning Objectives: *Describe fiber optics to include a basic system, advantages, and fiber construction. Describe light transmission, fiber types, cables, and coupling.*

Fiber optics has revolutionized the telephone industry and will become the preferred norm of aviation and electronics technology. You won't see the cumbersome myriad of wires, connections, and cabling we have today. Weight will be reduced, and capabilities will be increased. As an Aviation Electronics Technician, you should see fiber optic technology in the near future.

Fiber optics is not new. In the mid 1800s, William Wheeler patented a device for piping light from room to room, Alexander Graham Bells' photophone could reproduce voices through detection of the amount of light received from a modulated light source. In the last decade, a practical means of sending light has evolved—in the form of glass fibers.

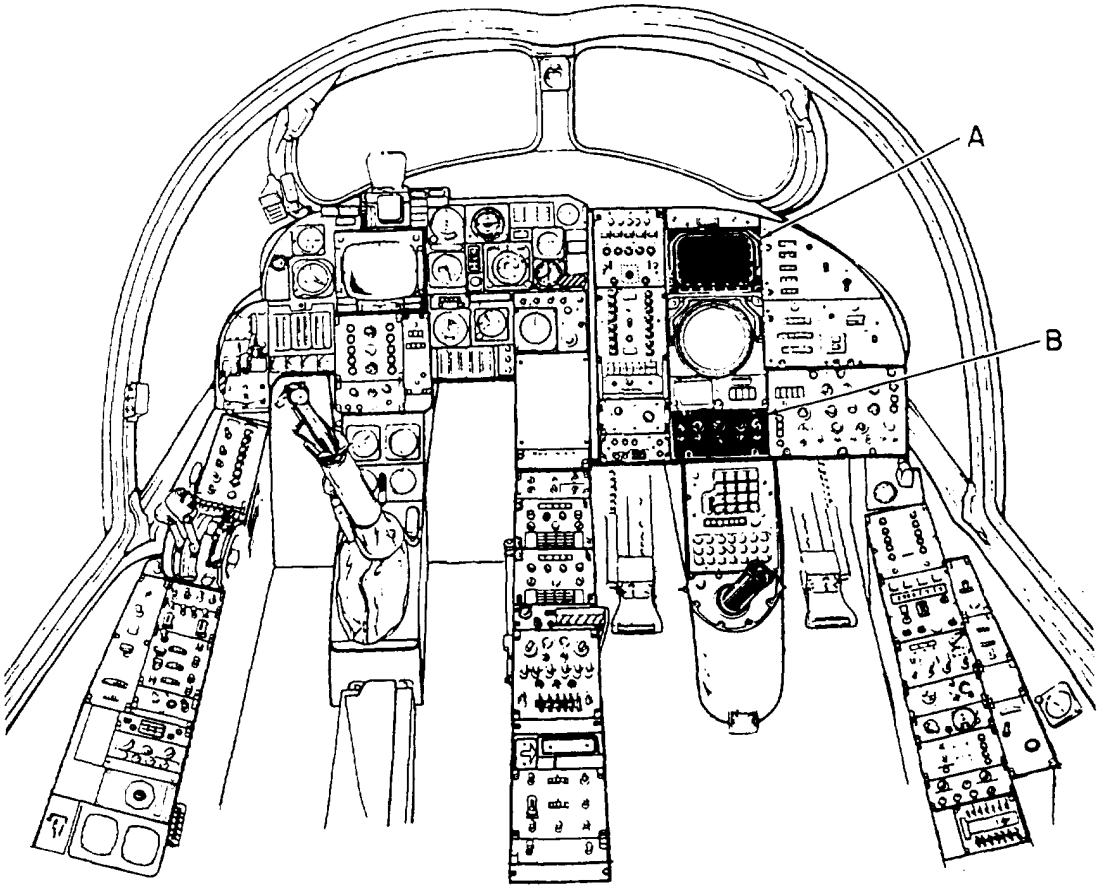


Figure 2-47.-Cockpit.

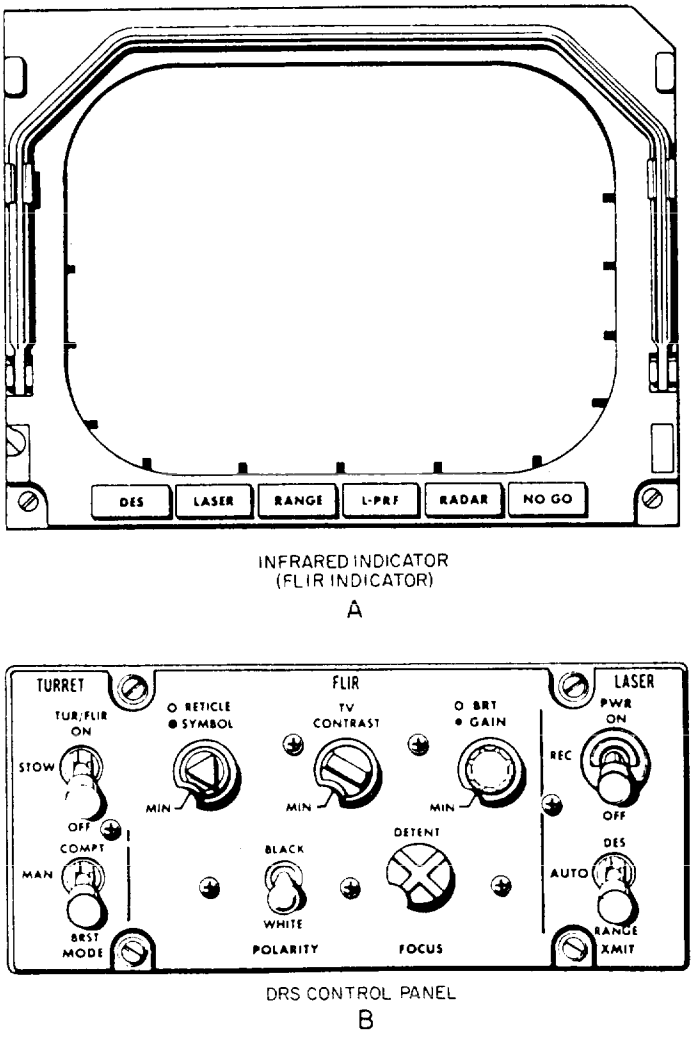


Figure 2-48.-FLIR indicator and control panel.

BASIC SYSTEM

The principles of fiber optics follow the basic properties of light, as discussed in chapter 1, and include refraction and reflection. Light traveling within a fiber obeys the laws of propagation. Fiber optics is the technique of sending data in the form of light through long, thin, flexible fibers of glass, plastic, or other transparent materials. A basic fiber optic system (fig. 2-49) consists of a transmitter, a fiber medium, and a receiver. The transmitter converts electrical signals into current to drive a light source for injection into a fiber. The fiber or fibers guide(s) the light to a light detector that converts the light back into an electrical signal. The receiver is a low-noise and large-voltage gain receiver that provides further processing.

ADVANTAGES OF FIBER OPTIC SYSTEMS

There are many advantages of using fiber optics over systems in use today. Some of these advantages are shown below:

- Fiber optics can be used in flammable areas because light, not an electrical pulse, is the energy sent.



Figure 2-49.-Basic fiber optic system block.

- Fiber optic systems are immune to radio frequency interference (RFI), electromotive interference (EMI), and noise caused by lightning and cross talk.
- Fiber optic systems are immune to electromagnetic pulse effects induced by nuclear explosions.
- Fiber optics aren't affected by moisture or temperature changes.
- Fiber optic systems are easy to repair.
- Fiber optic systems have very high data transmission rates.
- Fiber optic devices are small and lightweight.

OPTICAL FIBER CONSTRUCTION

A typical fiber is a transparent, dielectric cylinder (core) enclosed within a second transparent dielectric cylinder (cladding). The core and cladding are enclosed by insulation (fig 2-50). The dielectric cylinders consist of various optical glasses and plastics. The *cladding,* which has a relatively low index of refraction, encloses the core, which has a very high index of refraction. The cladding contains most of the transmitted light within the core. This low index prevents light leakage and increases efficiency. The *insulation* protects a single fiber or several fibers from stress and the environment.

LIGHT TRANSMISSION

The light injected into a fiber travels in a series of reflections from wall to wall between the core and cladding. The reflections depend on the cone of acceptance and resulting angles of refraction and reflection propagation (fig 2-50). The *cone of acceptance* is the area in front of the fiber that determines the angle of light waves it will accept. The *acceptance angle* is the half-angle of the cone of acceptance. The light enters the core and refracts to the interface of the core and cladding. The light reflects at the same angle of impact. The light, reflecting from wall to wall, continues at the same angle to the end of the fiber at the detector. Like the physics of light, the maximum *critical angle* is that angle that, when surpassed, won't reflect; in this case, it is lost in the cladding of the fiber. As long as the light wave is at a lesser angle than the maximum critical angle of the fiber (as determined by the function of the fibers' core and cladding indexes of refraction), light will travel to the receiver.

TYPES OF OPTICAL FIBERS

There are two types of optical fibers. The step-index type has large differences in the core

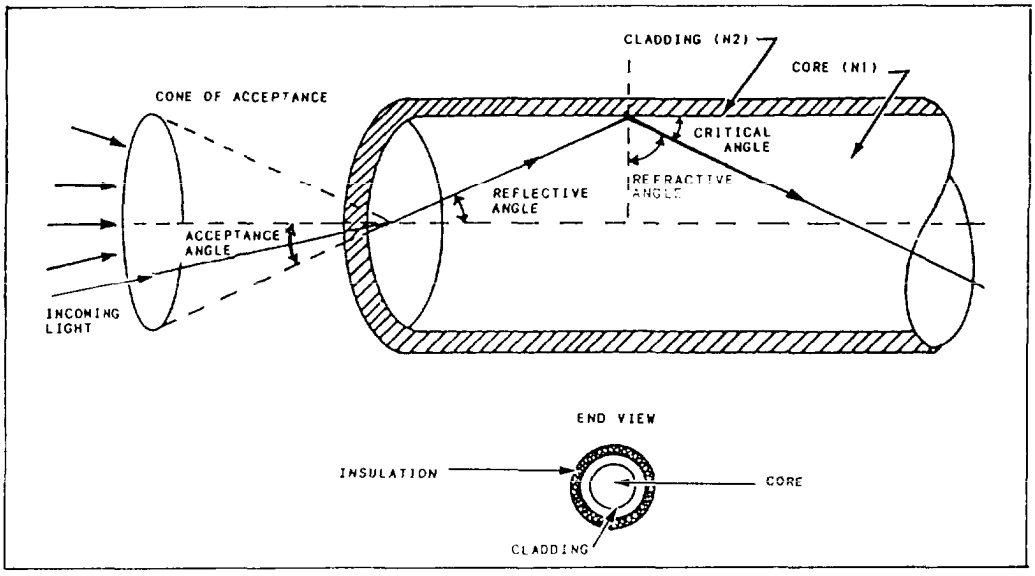


Figure 2-50.-Transmission of light in a fiber.

and cladding indexes of refraction. When held constant, these differences cause light to reflect from the interface back through the core to its opposite wall.

The graded-index type has a decreasing core refractive index as the radial distance from the core increases. This causes the light rays to continuously refocus as they travel down the fiber. These types operate in either single-mode or multi-mode operation. Single-mode operation accepts a specific wavelength, otherwise large attenuation will result. The multi-mode type operates over a range of wavelengths with minimum signal loss. (See fig. 2-51.)

PROPERTIES OF OPTICAL CABLES

Optical cables are affected by many physical properties, Some of these are discussed in the following section.

Numerical Index

The numerical index of optical cables deals with the sine of the angle of acceptance. The numerical aperature (NA) or numerical index can be found using the formula shown below:

$$NA = \sin i = \sqrt{n1^2 - n2^2}$$

where i = acceptance angle, n1 = Core Index of Refraction, and n2 = Cladding Index of Refraction.

The acceptance angle is a measure of the numerical aperature (NA) or numerical index of a fiber. This lets the manufacturer select the proper fiber for the desired specific light waves and for optimum power coupling. NA is a measure of the light capture angle (half-acceptance angle). It describes the max core angle of light rays that will be reflected down the fiber by total reflection.

The refractive index (Index of Refraction) of a material is the ratio of the speed of light in a vacuum to the speed of light in the material. Review chapter 1 for more information on refraction if you don't understand this section. The higher the refractive index of a material, the lower the velocity of light through the material. Also, there will be more refraction or bending of the light when it enters the material.

If NA increases, angle i must have increased, and the fiber sees more light. NA can never be greater than 1.0; normal values are low (0.2 and 0.6).

Dispersion

Dispersion is the spreading or widening of light waves due to the refractive index of the material and the wavelength of the light traveling in the fiber. There are two types of dispersion—intermodal and intramodal.

Intermodal (multi-mode) dispersion. Intermodal dispersion is the propagation (travel) of rays of the same wavelength along different paths through the fiber. These wavelength rays arrive at the receiving end at different times.

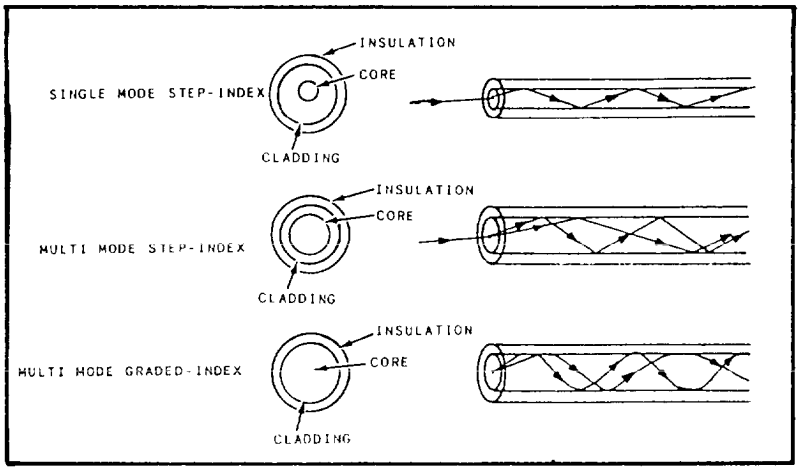


Figure 2-51.-Types of optical fibers.

Intramodal dispersion. Intramodal dispersion is due to variations of the index of refraction of the core and cladding.

Attenuation

Attenuation is the loss or reduction in amplitude of the energy transmitted. These losses are due to differences of refractive indexes and imperfections in fiber materials. Also, man-made scratches or dirt and light scattering within the fiber cause unwanted losses. Efforts to reduce these losses include the forming of the following standard parameters:

- Bandwidth parameters. Bandwidth parameters include attenuation curves, which provide all designers the ability to chose the best fiber. These parameters are plotted in decibels per kilometer (dB/km). They measure the efficiency of the fiber as a comparison of light transmission to light loss through a fiber.

- Rise time parameters. These parameters set speed requirements for operation.

- Fiber strength parameters. These parameters set tensile strength standards to help reduce flaws and microcracks in the fiber.

FIBER COUPLING

One important aspect of a fiber system is the connection between the fiber and the other parts. The coupling efficiency is the ratio of power accepted by the fiber to the power emitted by the source

$$\left(\frac{P_f}{P_s}\right).$$

Coupling efficiency increases with the square of the NA (numerical aperature) and decreases with source and fiber mismatches. Optical power coupled into the fiber is a function of the radiance of the source and the NA.

Q41. A basic fiber optic system consists of a transmitter, a fiber medium, and a receiver. Describe the basic technique of fiber optics.

Q42. List the advantages of fiber optic systems.

Q43. By what means does light travel through a fiber optic?

Q44. What is the difference between single-mode and multi-mode operation?

Q45. Attenuation is the loss or reduction of energy transmitted. Efforts to reduce these losses include the forming of standard parameters. What are these parameters?

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ANSWERS FOR REVIEW QUESTIONS Q41. THROUGH Q45.

A41. Fiber optics is the technique of sending data, in the form of light, through long, thin, flexible fibers of glass, plastic, or other transparent materials.

A42. (a) Usable in flammable areas
(b) Immune to noises generated by RFI, EMI, lightning, and cross talk
(c) Immune to electromagnetic pulse effects
(d) Not affected by moisture or temperature changes
(e) Easy to repair
(f) Very high transmission rates
(g) Small size and lightweight

A43. The light injected into a fiber travels in a series of reflections from wall to wall between core and cladding. The reflections depend on the cone of acceptance and resulting angles of refraction and reflection propagation.

A44. Single-mode types accept a specific wavelength, otherwise, large attenuation results. Multi-mode types operate over a range of wavelengths, with minimum signal loss.

A45. (a) Bandwidth parameters provide designers the ability to choose the best fiber.
(b) Rise time parameters set the speed requirements for fiber operation.
(c) Fiber strength parameters set tensile strength requirements to help reduce flaws and microcracks in the fiber.

CHAPTER 3

ANALOG FUNDAMENTALS

A computer is a device that performs mathematical calculations on input data to yield new and generally more useful results. The first computer, an abacus, was used by the ancient Greeks and Remans. The abacus is a simple kind of manually operated device using sliding beads. If operated according to definite rules, you can perform addition and subtraction very rapidly.

The development of the computer probably contributed more to the advancement of today's weapons systems than any other single factor. Without the use of such complex machines, the solution of today's weapon control problem would be impossible.

NOTE: You should remember that the methods presented in this chapter are basic. Many variations of these methods are found in equipment.

Analog computers are used for situations where continually varying solutions are needed for problems whose factors are continuously varying. Generally, these factors are physical quantities, such as velocity, direction, or range. Such physical quantities are conveniently represented by degrees of shaft rotation, magnitude or phase of a voltage, or the speed and direction of movement of some mechanical part. The varying instantaneous summation, or simultaneous solution, of outputs from all the computing parts is the computer's output.

The accuracy of an analog computer is determined by the percentage of errors of the devices used, multiplied by the maximum quantity of the input variables.

The computer's output is applied as needed, depending on the purpose of the computer. For example, in a fire control computer, the computer output positions a weapon-sighting reticle in relation to the direction of flight. As the pilot maneuvers to keep an enemy target within the reticle, the weapons are properly aimed. In a bombing computer, the computer output releases bombs at the proper time and drives indicators that give the aircraft's position at all times in latitude and longitude.

To understand analog computers, you need a review of synchros and various types of servo systems. The particular type of servo system or synchro (such as electromechanical, electro-hydraulic, hydraulic amplidyne, or pneumatic) depends on the type of load for which it was designed.

Synchros are used primarily for rapid and accurate transmission of information between equipment and stations. Speed and accuracy are the key fundamentals of synchros in their role in the operation of a weapons, communications, underwater detection, and navigation systems used in the Navy. Synchros are fast but weak; they need the help of a servo. Servos are powerful. They move heavy loads accurately and may be remotely controlled with great precision by synchro devices. This combination is unbeatable, and it is the foundation for analog computation and performance in many systems.

You will not read about any specific servo system in this chapter. Instead, you are introduced to the basic systems, their essential components, and how each functions. If you want specific details on the theory and operation of a particular system, refer to the technical manuals for that system. In addition, you should review the basic theory of synchros and servomechanisms as discussed in module 15 of the Navy Electricity and Electronics Training Series (NEETS), NAVEDTRA 14187. After this review, you will be ready for this discussion of basic servomechanisms and their purpose in analog computation.

Q1. Analog computers are used for situations where continually varying solutions are needed for problems whose factors, such as velocity, direction, or range, are constantly changing. Is this statement true or false?

Q2. Describe the primary use of synchros.

BASIC SERVOMECHANISMS

Learning Objective: *Identify various types of servo systems and components including alignment and characteristics.*

The essential components of a servomechanism are a data transmission system, servo control amplifier, and servomotor. These components are shown in the block diagram in figure 3-1, and are discussed in the following paragraphs.

The four functions of the data transmission system are to—

1. measure the servo output,
2. transmit or feedback the signal, which is proportional to the output, to the error detector (a differential device for comparing two signals),
3. compare the input signal with the feedback signal, and
4. transmit to the servo amplifier a signal that is proportional to the difference between the input and output signals.

The signal obtained by comparing the servo input and output is called the *servo error,* represented by the symbol E. In figure 3-1, you can see that the servo error (E) is the difference between the input (θ_i) and the output (θ_o). This is stated mathematically as

$$E = \theta_i - \theta_o.$$

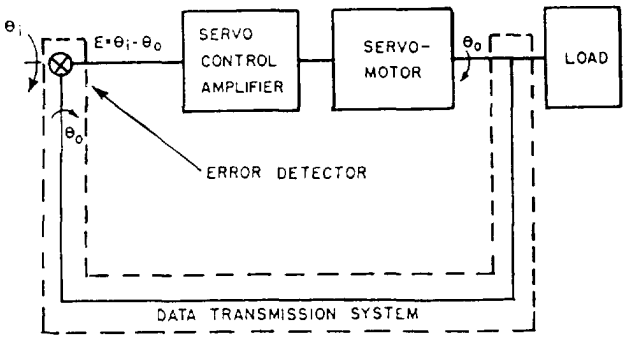


Figure 3-1.-Simplified block diagram of a servomechanism.

In many servo systems, the servo input and output devices are remotely located from each other and from the servo amplifier. Because of this, some means is required to transmit the output information back to the device receiving the input command and transmitting the servo error to the servo amplifier. This system of transmission, as well as the comparing device (error detector), is part of the data transmission system. The servo amplifier receives the error signal from the error detector. Next, it sufficiently amplifies the signal to cause the output device to position the servo load to the commanded position. Finally, the servo amplifier transmits the amplified signal to the servomotor.

The servomotor positions the servo load. It must be capable of positioning the load within a response time based on the requirements of the system.

ERROR DETECTORS

The error detector compares the input with the servomechanism output in the data transmission system. The error detector is a mechanical or an electrical device. In aircraft weapons systems, most error detectors are electrical devices because they are adapted to widely separated or remotely installed components. Most electrical devices are either potentiometer (resistive) or magnetic devices.

Electrical error detectors are either ac or dc devices, depending on the requirements of the servo system. An ac device compares the two input signals. Then it produces an error signal with the phase and amplitude to indicate both the direction and the amount of control necessary to accomplish correspondence. In a dc device, the polarity of the output error signal determines the direction of the correction necessary.

ANSWERS FOR REVIEW QUESTIONS Q1. AND Q2.

A1. True.

A2. Synchros are used for rapid and accurate transmission of information between equipment and stations.

Error detectors are used in gyrostabilized platforms and rate gyros. In stabilized platforms, synchros are attached to gimbals. Any movement of the platform around the gyro axes is detected by the synchro, and the error voltage is sent to the appropriate servo system.

In rate gyros, an E-transformer is used to detect gyro precession. The E-transformer is sensitive to slight changes, but its movement is limited to a small amount. It is used with constrained gyros.

POTENTIOMETER

Potentiometer error detector systems are used where the input and output of the servomechanism have limited motion. These systems have the following advantages:

- High accuracy.
- Small size.
- Either a dc or an ac voltage may be obtained as the output.

Disadvantages of potentiometer error detector systems include the following:

- Limited motion.
- A life problem that results from wear of the brush on the potentiometer wire.
- The potentiometer voltage output changes in discrete steps as the brush moves from wire to wire.
- Some potentiometers require a high drive torque to rotate the wiper contact.

A balanced potentiometer error detector is shown in figure 3-2. The purpose of this circuit is to give an output error voltage proportional to the difference between the input and output signals. In the following paragraphs, you will learn how the potentiometer error detector works. Refer to figure 3-2 as you read the following paragraphs.

The command input shaft is mechanically linked to R1, and the load is mechanically linked to R2. An electrical source of 115 volts ac is applied across both potentiometers.

When the input and output shafts are in the same angular position, they are in correspondence, and there is no output error voltage. If the input shaft is rotated, the wiper contact of R1 is moved. This action causes an error voltage to be developed and applied to the control amplifier. The error voltage is the difference of the voltages at the wiper contacts of R1 and R2. The amplifier output causes the motor to rotate both the load and the wiper contact of R2 until both voltages are equal. When this occurs, there is no output error voltage.

In figure 3-2, both R1 and R2 are shown grouped together. In actual practice, the potentiometers may be remotely located from each other. R2, the output potentiometer, may be located at the output shaft or load. The remote location of one of the components does **not** remove it as part of the error detector.

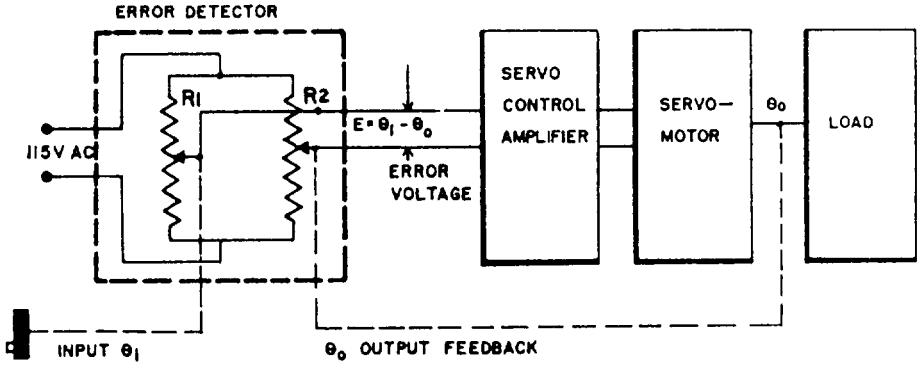


Figure 3-2.-Balanced potentiometer error detector system.

E-Transformer

The E-transformer (fig. 3-3) is a type of magnetic device that is used as an error detector. It is used in systems that do not require the error detector to move through large angles.

The primary excitation voltage is applied to coil A on the center leg of the laminated core. The coupling between coil A and the secondary windings (coils B and C) is controlled by the armature, which is displaced linearly by the input signal. When the armature is positioned so the coupling between the windings is balanced (null), the output voltage is minimum. The output voltage is minimum because of the series opposing connections of the secondary windings. The phase of the output voltage on either side of the voltage null differs by 180 degrees. The amplitude can be made proportional to the displacement of the armature from its null voltage position. This error detector is small and accurate, but it permits only limited input motion.

Control Transformers

Synchros have relatively high accuracy, low noise level, reasonably small driving torques, and long life. These qualities also apply to synchro control transformers. The synchro control transformer has an unlimited rotation angle. Both the input and output to the synchro control transformer may rotate through unlimited angles. However, synchro control transformers are large, consume large amounts of power, and the output supplied to the servo control amplifier is always ac modulated with the servo error.

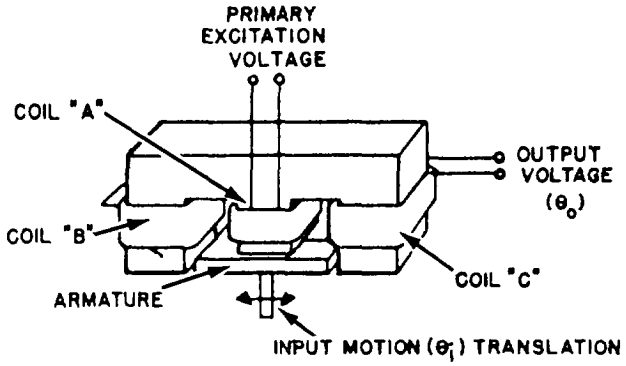


Figure 3-3.-E-transformer error detector.

Alternating current may be used to represent the value of a function if the following conditions are met:

1. The frequency of the ac is greater than the maximum frequency response of the measuring devices used.

2. If negative values of the variables are allowed, the devices must be phase sensitive.

Look at figure 3-4. It shows a dc signal and the same function represented by an ac voltage. The instantaneous value of the ac signal does not indicate the value of the function. However, the average value of the ac signal is used to represent the value of a function. For example, if the ac signal is the input to a servomotor, the motor must not attempt to follow every variation of the ac signal; it must follow the average value. Following the average value is essential because a negative ac signal does not exist. But, negative values **can** be indicated by a change in the phase of the signal. Look at figure 3-4. During the period when the dc signal is positive, the positive peaks of the ac signal correspond to the positive peaks of the ac reference. During the period when the dc signal is negative, the positive peaks of the ac signal correspond to the negative peaks of the reference signal; that is, the signal is 180 degrees out of phase with the reference. There are ac servomotors that rotate in one direction when the input signal is in phase

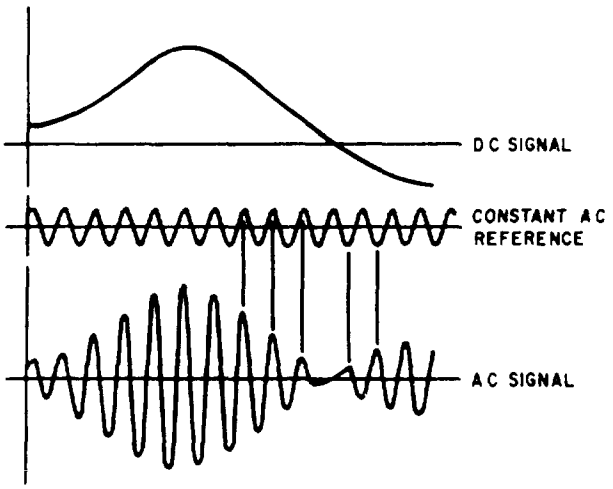


Figure 3-4.-AC modulated with servo error.

with a reference voltage and in the other direction when the signal is out of phase with the reference voltage.

A synchro data transmission system is made up of a synchro transmitter, a synchro control transformer, and, at times, a differential transmitter. The synchro transmitter transforms the motion of its shaft into electrical signals for transmission to the synchro control transformer, which makes up the error detector (fig. 3-5).

The stator of the transmitter consists of three coils spaced 120 electrical degrees apart. The voltage induced into the stator windings is a function of the transmitter rotor position. These voltages are applied to the three similar stator windings of the synchro control transformer. The voltage induced in the rotor of the synchro control transformer depends on the relative position of this rotor with respect to the direction of the stator flux.

Look at figure 3-6. The variation of the synchro control transformer output voltage is a function of the rotor position relative to an assumed stator flux direction. There are two positions of the rotor, 180 degrees apart. Only the one whose output voltage is zero will correspond to the stable operating position of the servo.

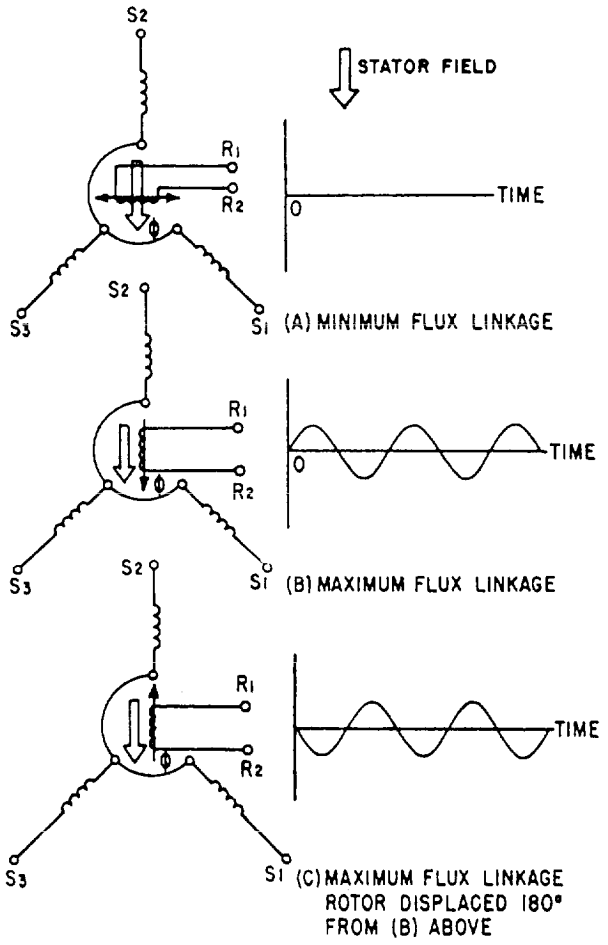


Figure 3-6.-Induced voltage in synchro control transformer rotor.

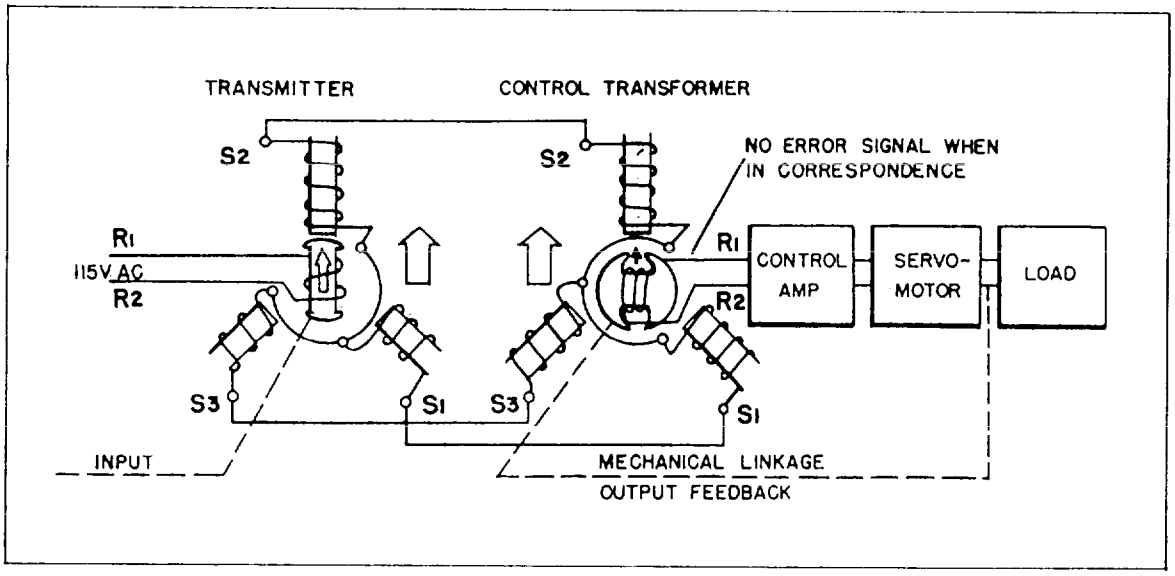


Figure 3-5.-The control transformer as an error detector.

When a synchro differential transmitter (fig. 3-7) is used for additional inputs to the servo system, it is connected between the synchro transmitter and the synchro control transformer. When the synchro differential rotor is in line with its stator windings, the differential transmitter acts as a one-to-one ratio transformer. The voltages applied to the synchro control transformer are the same as the voltages from the synchro transmitter. If the synchro differential transmitter rotor is displaced by a second input, the voltages for the synchro transmitter to the control transformer are modified. The synchro differential transmitter modifies the voltages by the amount and direction of its rotor displacement. Thus, the two inputs are algebraically added and fed to the synchro control transformer as a single input.

Flux Gate

A flux gate element is used to drive or excite a control transformer. It is usually used in compass systems. The flux gate operates on the principle of using the earth's magnetic field to produce a second harmonic current flow in the element. This, in turn, produces a voltage in the stator windings of the control transformer that is in direct proportion to the earth's magnetic north. It is desirable to use the horizontal component of the earth's field only. Therefore, a gyro is used to hold the element level with the earth's surface, or the element is suspended by a spring and uses the properties of a pendulum to maintain a horizontal position. The assembly is rigidly mounted to the aircraft and turns in an azimuth as the aircraft turns.

Q3. Within a servomechanism, what is the function of the data transmission system?

Q4. What determines whether an ac or dc electrical error detector is used in a particular servo system?

Q5. List the advantages of potentiometer error detector systems.

Q6. Describe the E-transformer and explain where it can be used.

Q7. What means are used to indicate negative values from ac signals from a synchro control transformer?

MULTIPLE-SPEED DATA TRANSMISSION SYSTEMS

The static accuracy (accuracy of load control) of a servomechanism is limited by the accuracy of the data transmission system. The accuracy of this system is increased by using a multiple-speed data transmission system along with a one-speed system. The error-detector elements of the multiple-speed transmission system rotate at some multiple of the shaft being controlled. The elements of the one-speed transmission operate one-to-one with respect to the controlled shaft.

Figure 3-8 shows a diagram of a multiple- and a one-speed system. This is called a *dual-speed*

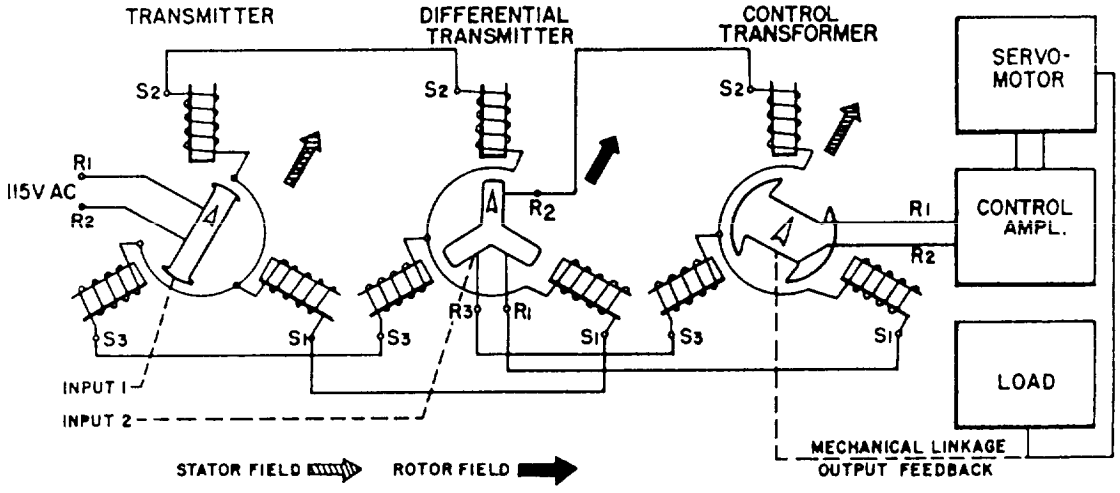


Figure 3-7.-Synchro differential transmitter used for additional input.

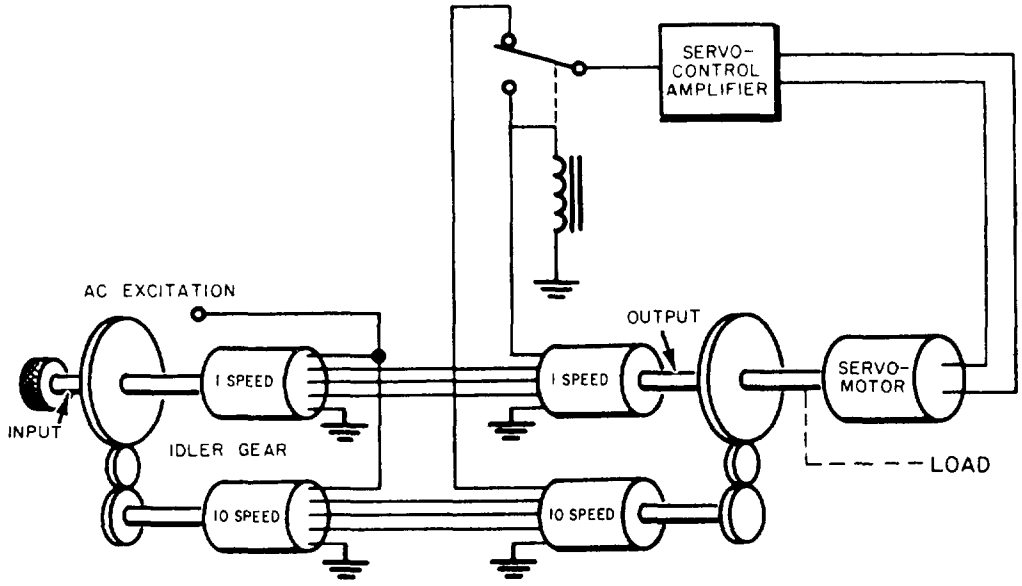


Figure 3-8.-Dual-speed data transmission system.

system because it can transmit data at two different speeds. If the input shaft of this system turns through 1 degree, the one-speed transmitter is rotated 1 degree, and the multiple-speed unit is rotated 10 degrees. The synchro control transformer associated with each of these transmitters is geared in similar ratios with respect to the servo output shaft. A 1-degree error between the position of the input and output shafts produces a relative rotor displacement of 1 degree in the one-speed synchros and 10 degrees in the multiple-speed synchros. If the relationship between the rotor displacement and output voltage is linear, the error signal in the multiple-speed system is 10 times that of the one-speed system. This amplification of the error signal in the data transmission link reduces the signal amplification required in the servo controller. If the synchro has an inherent error of 0.1 degree with respect to its own shaft, the consequent servo error introduced by a one-speed data transmission system is of corresponding value. However, the consequent servo error introduced by a 10-speed data transmission system is only one-tenth as great, or 0.01 degree.

The multiple-speed error detector does have a disadvantage. It might fall out of step and synchronize in a position different than the correct one by an integral number of revolutions of the multiple-speed synchro. Look at figure 3-8. If the output shaft were held fixed and the input shaft rotated 36 degrees, the 10-speed synchro transmitter would turn one complete revolution. The error signal from the multiple-speed error detector would be zero. If the output shaft were released, the system would operate in a stable fashion with a 36-degree error between the input and output shafts. **A one-speed error detector, along with the multiple-speed detector, is used to prevent this ambiguous synchronization.** An error signal selector circuit may switch control of the servo to the one-speed data transmission system. However, this only occurs whenever the servo error becomes large enough to permit the multiple-speed system to synchronize falsely.

The simplest device to control an error-selector circuit is shown in figure 3-8. It is a single-pole, double-throw relay actuated by the output of the one-speed error detector. The relay is shown in the de-energized position. When the output of the one-speed synchro is high, the relay is energized, and the one-speed circuit controls the servomotor. When the output is low, the relay opens and the 10-speed synchro controls the circuit. Remember, the synchro output is high when there is a large error.

The relationship of the coarse (one-speed) synchro output and the fine (10-speed) synchro

output is shown in figure 3-9, view A. The shaded areas represent the area where control is switched from the one-speed circuit to the 10-speed circuit. With the selector circuit shown, it is possible to have a single ambiguous synchronizing point. This point is at the 180-degree position of the one-speed (coarse) synchro. At this point, the one-speed (coarse) synchro and 10-speed (fine) shafts are nulled (but 180 degrees out of phase), and control switches to the one-speed circuit.

The false synchronization position is eliminated by driving the multiple-speed synchro at any odd multiple of the one-speed synchro. The phase relationship of a one-speed and seven-speed system is shown in figure 3-9, view B. Although there is still a null of both synchros at the 180-degree position of the one-speed synchro, their outputs are in phase. This position is unstable, and the servo will **not** remain at this point.

The system shown in figure 3-8 is not used in operating equipment because of the load the relay places on the one-speed synchro. In actual practice, an electronic circuit (operated by synchro

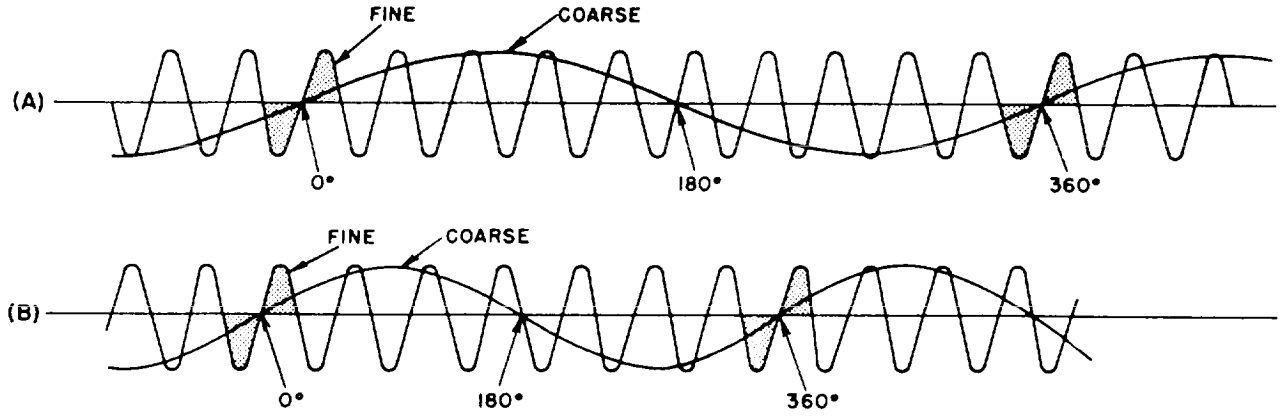


Figure 3-9.-Phase relationships of fine and coarse synchro voltages; (A) 1-speed and 10-speed: (B) 1-speed and 7-speed.

ANSWERS FOR REVIEW QUESTIONS Q3. THROUGH Q7.

A3. The data transmission system measures the servo output, transmits or feedbacks the signal, compares input signal with feedback, and transmits the differerrce signal to the servo amplifier.

A4. Electrical error detectors are either ac or dc devices, depending on the requirements of the servo system.

A5. Potentiometer error detector systems are used where the input and output of a servomechanism has limited motion. These systems have the following advantages:

a. High accuracy.
b. Small size.
c. Either a dc or ac voltage may be obtained as the output.

A6. The E-transformer is a type of magnetic device that is used as an error detector in systems that do not require the error detector to move through large angles.

A7. A negative ac signal does not exist; but, negative values can be indicated by a change in phase of the ac signal.

voltages) could use and control the relays. However, the outputs of the synchros are fed to an electronic circuit biased so that the fine synchro voltage is not used when the coarse synchro voltage is high. This method does not require a relay.

The disadvantage of the multiple-speed error detector is the need for an additional synchro system and switching circuit to avoid false synchronization. The increased servo accuracy that results from amplifying the error signal and the effective reduction of the inherent synchro errors accounts for use of multiple-speed data transmission systems.

SERVO CONTROL AMPLIFIERS

Earlier, you learned that the output of an error detector (error voltage) is fed to a servo control amplifier. This signal is small in amplitude and requires amplification to actuate a prime mover. In addition to amplification, the servo control amplifier might transfer the error signal into suitable form for controlling the servomotor or output member. It may also have the special characteristics needed to obtain a stable, fast, and accurate operation.

Electronic and magnetic servo amplifiers are used in aircraft weapons systems. The operation of electronic amplifiers and their circuits is covered in NEETS, module 8, NAVEDTRA 14180.

Servo amplifiers have the basic characteristics of amplifiers. They also have the following needed criteria:

- A flat gain versus frequency response for a frequency well beyond the frequency range used
- A minimum of phase shift with a change in level of input signal (zero phase shift is desired, but a small amount can be tolerated, if constant)
- A low output impedance
- A low noise level

Servo amplifiers use either ac or dc amplifiers, or a combination of both. The application of dc amplifiers is limited by problems such as drift and provisions for special bias voltages needed in cascaded states. Drift, a variation in output voltage with no change in input voltage, is caused by a change in supply voltage or a change in value of a component. Therefore, many servo amplifiers use ac amplifiers for voltage amplification.

MODULATORS

Ac amplifiers amplify error signals better than dc amplifiers. They do not need well-regulated power supplies and costly precision components. But, some aircraft weapons systems do use a dc voltage for an error signal. The dc error voltage is changed to an ac signal by a modulator (sometimes called a *chopper).* Modulator circuits used in servo control amplifiers are phase sensitive. They produce an ac output signal whose amplitude is proportional to the dc input signal, and their phase indicates polarity.

Vibrator Modulators

A modulator is either an electromechanical vibrator (fig. 3-10) or an electronic circuit. An ac

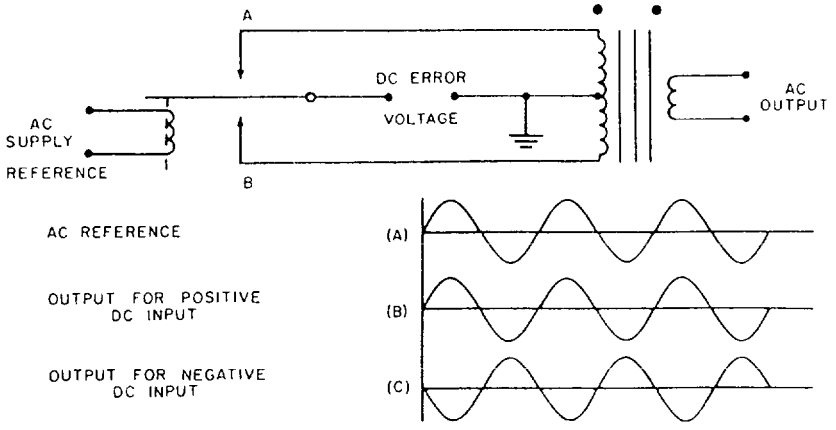


Figure 3-10.-A vibrator modulator.

supply voltage is used to vibrate the contacts of the vibrator in synchronism with the supply voltage. The dc error voltage is applied to the center contact. The reference voltage causes the center arm to contact point A during the first half cycle and point B during the second half cycle. Then, the output is shown by waveform B if the error voltage is positive, and by waveform C when the error voltage is negative.

Electronic Modulator

The electronic modulator circuit (fig. 3-11) is a diode-ring modulator. It works by causing a changing current to flow through one-half of the primary transformer (T2) and then through the other half at a rate of 400 hertz. Each half cycle of changing current produces a half cycle of sinusoidal output voltage. The phase of the output voltage compared to the 400-hertz carrier depends on the direction of current through each primary half.

When the dc control voltage is positive, diodes CR1 and CR4 are forward biased. When the dc control voltage is negative, diodes CR2 and CR3 are forward biased. Therefore, when two of the diodes are forward biased by the dc control voltage, the other two are reverse biased and cut off. As long as the instantaneous amplitude of the carrier voltage is less than the dc control voltage, the cutoff diodes remain reverse biased. The current flows through one of the conducting diodes and through one of the half windings.

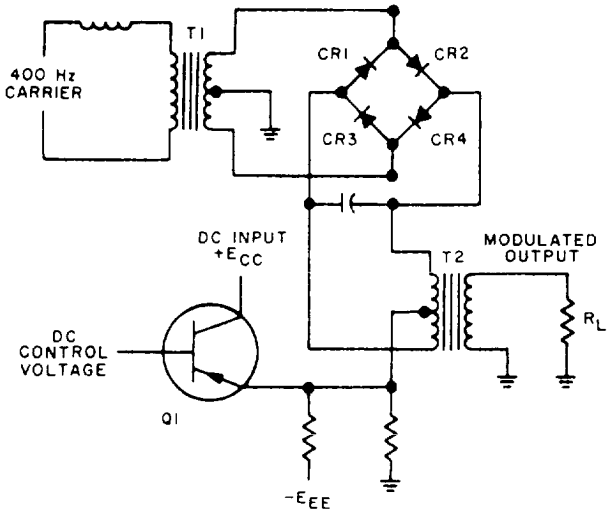


Figure 3-11.-An electronic mudulator.

If the amplitude of carrier voltage exceeds the dc control voltage, one of the reverse-biased diodes becomes forward biased, and the diode conducts. This interrupts the current flowing through the half winding, and the output voltage amplitude is clipped at the value it had when the current was interrupted.

The capacitor connected across the primary of T2 filters any high-frequency components associated with the clipped half-cycle of the sine wave so that a nearly sinusoidal output half cycle occurs. The output's amplitude is nearly equal to the output voltage at the time of clipping.

The capacitor operates by coupling the high-frequency components of the clipped voltage through the nonconducting half windings. The high-frequency components are canceled because they produce currents that flow in opposite directions in both halves of the center-tapped primary windings; they produce magnetic fields that cancel each other.

The amplitude of each half cycle of the 400-hertz carrier voltage is modulated by the dc control voltage. The polarity of the control voltage determines the phase of the modulated carrier voltage output relative to the unmodulated carrier voltage input. This is the result of the direction of current flow through the half winding. The direction depends on which diode is forward biased as a result of the polarity of the dc control voltage.

Q8. The static accuracy of a servomechanism is limited by _____.

Q9. List the basic components of a dual-speed data transmission system.

Q10. Servo amplifiers have the basic characteristics of amplifiers. They also meet what additional criteria?

Q11. What are the two types of modulators used in servo control amplifiers? Describe their function.

PHASE DETECTORS

You have learned that an ac amplifier has advantages over a dc amplifier, a dc error voltage can be changed into an ac signal, and the ac signal can be amplified and applied to an ac servomotor. Some systems, however, use dc servomotors, which require the ac signal be converted to dc. To do this, a phase detector (sometimes known as a *demodulator) is* used.

Bridge Phase Detectors

Look at figure 3-12 as you read this section. It shows a phase detector using a bridge circuit. With no error input signal and only the reference voltage applied, CR1 and CR2 conduct in series when point C is on its positive half cycle. When point C is on its negative half cycle, CR3 and CR4 conduct in series. If the drops across the diodes and resistances are equal, points A and B are at ground potential on both half cycles, and the output voltage is zero.

An error signal is applied to the bridge in phase with the referenced voltage, and points A and C are both on their positive half cycles. Electron flow is from point G on the reference transformer T2 to point D, through CR2 to point A, from point A to the center tap on T1, and to E through R_L to G. On the next half cycle, both points A and C change polarity, and the electron flow is from point G to point C, through CR3 to point B, through T1 to the center tap, to the right to point E, and through R_L to ground, developing a negative dc output voltage.

If the error signal is applied out of phase with the reference voltage and positive at points A and D, electron flow is from point G up through R_L. The flow continues left to the center tap of T1, down to point B, through CR4, down to point D, and left to point G. On the next half cycle, both points A and D change polarity. Therefore, electron flow is from G up through R_L, to the center tap of T1, up to point A, through CR1 to point C, and right to the center tap to point G. On both half cycles of the error and reference voltages, electron flow is up through R_L, developing a positive voltage output at point E. In both cases, the magnitude of the dc produced at point E depends on the amplitude of the ac error signal. The polarity of the dc signal depends on the phase of the ac error signal. C_L filters the pulses and provides smooth dc.

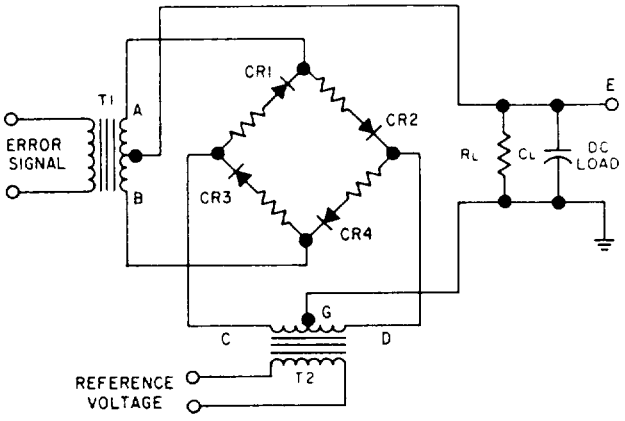


Figure 3-12.-Bridge phase detector.

Triode Phase Detectors

A triode phase detector (fig. 3-13) uses NPN transistors and provides amplification of the error signal in addition to phase detection. In this circuit, the collectors of the transistors are supplied with the ac reference voltage so that the collector voltages are in phase. In this explanation, no error signal is present at T2. When the collectors of Q1 and Q2 are positive, the two transistors conduct equally. The collector current that flows sets up magnetic fields in the dc motor

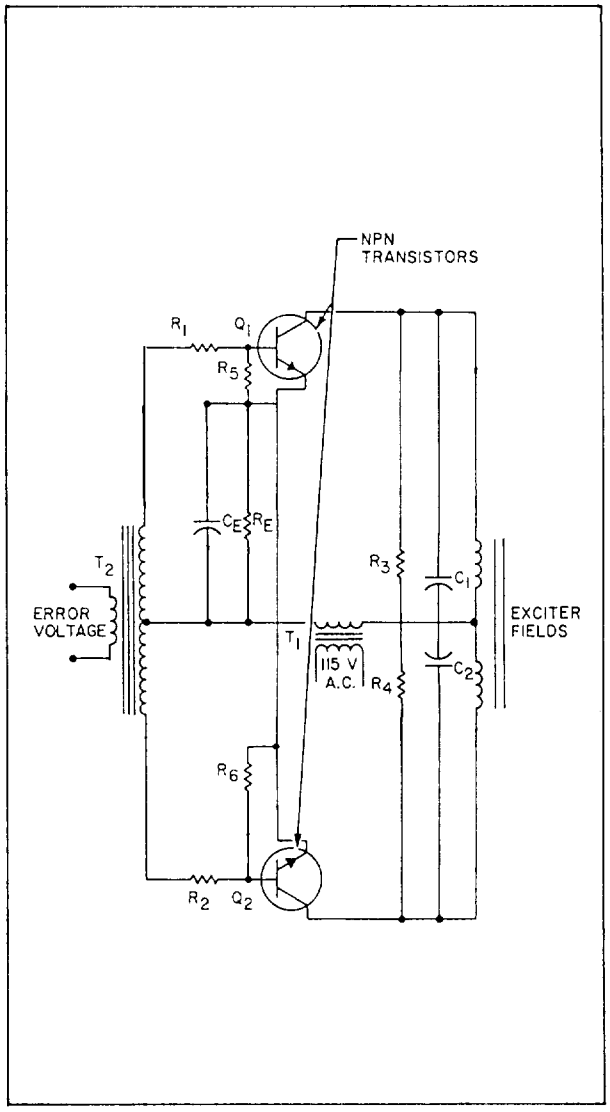


Figure 3-13.-Triode phase detector.

exciter windings that are equal and opposite; therefore, the fields cancel and produce no output. When the collector voltages are on a negative half cycle, C1 and C2 discharge through their respective exciter windings to maintain a constant dc through the windings.

An error signal is introduced into the primary of T2 with a phase relationship that causes the base of Q1 to be positive at the same instant that the collector of Q2 is positive. When this occurs, the following conditions exist:

- On this half cycle, the conduction of Q1 is increased above its no-error-signal condition.

- The heavier collector current causes a stronger field to be created in the upper exciter winding.

- At this same instant, the base of Q2 is on a negative half cycle, and its average conduction is reduced to a level below that of its no-error-signal condition.

- The lower level of collector current causes a weaker field to be produced in the lower exciter winding.

- Since the magnetic fields produced in the exciter windings are no longer of equal amplitude, they no longer cancel each other.

- The exciter produces an output voltage of a polarity controlled by the polarity of the resultant field and of an amplitude controlled by the relative strength of this resultant field.

- The exciter output causes the proper mechanical actions necessary to reduce the amplitude of the error to zero.

- As the error signal is reduced to zero, the current conduction through Q1 and Q2 is again balanced. Also, the exciter fields are equal and opposite, canceling each other, reducing the exciter output to zero, and stopping the mechanical action. Resistors R1 and R2 prevent excessive base current when the error angle is large.

SPECIAL AMPLIFIER CIRCUITS

You have already learned how a servo control amplifier can change a dc error signal to an ac signal. You have also learned that an ac error

ANSWERS FOR REVIEW QUESTIONS Q8. THROUGH Q11.

A8. The static accuracy (accuracy of load control) of a servomechanism is limited by the accuracy of the data transmission system.

A9. Look at figure 3-8, which shows a diagram of a multiple- and one-speed system. This is called a dual-speed system because it can transmit data at two different speeds.

A10. Servo amplifiers have the following criteria:

a. A flat gain versus frequency response for a frequency well beyond the frequency range used.
b. A minimum of phase shift with a change in level of input signal (zero phase shift is desired, but a small amount can be tolerated, if constant).
c. A low output impedance.
d. A low noise level.

A11. A modulator is either an electromechanical vibrator or an electronic circuit used to convert a dc error voltage to an ac signal, whose amplitude is proportional to the dc input signal, and whose phase indicates polarity.

signal may be detected to supply a dc voltage to a servomotor or controller. In the following paragraphs, you will learn about other special amplifier circuits.

Two-Stage DC Servo Control Amplifier

If more power is required by the servomotor than the servo amplifier (fig. 3-14) can supply, a push-pull dc amplifier is inserted between the phase-sensitive transistors and the servomotor. Refer to the schematic diagram shown in figure 3-14. The output of the phase detector transistors is now taken across the parallel RC networks in the collector circuit.

The bias source (E_{cc}) for the dc amplifier is connected with its positive terminal on the base side. This positive voltage subtracts from the highly negative voltage across the capacitor. A negative voltage results that allows the transistor to operate on the linear portion of its characteristic curve.

When there is no signal input from the error detector, the collector currents of the phase-sensitive rectifiers are equal. The outputs of Q1 and Q2 are applied to the base of Q3 and Q4, respectively. Equal output from Q1 and Q2 causes equal currents to flow in Q3 and Q4. With R5 and R6 equal in resistance and current, the voltage across the motor is zero. Consequently, the motor does not turn.

Now, you are going to analyze a signal output from the error detector. Assume that the error signal makes the base of Q1 positive and the base of Q2 negative. The collector current of Q1 increases, and the collector current of Q2 decreases. An increasing collector current in Q1 increases the charge on capacitor C1. Conversely, a decreasing collector current in Q2 decreases the charge on capacitor C2. As a result of the change in error signal, the voltage on the base of Q3 is now more negative that the voltage on the base of Q4. This increased negative voltage on the base of Q3 decreases its collector current, and the voltage e3 decreases. The decreased negative voltage on the base of Q4 increases its collector current, and the voltage e4 increases. As a result, a voltage difference appears across the motor armature, and the motor rotates. When the output signal from the error detector reverses in phase, the sequence of events causes the motor to reverse its direction of rotation.

Magnetic Amplifiers as Servo Control Amplifiers

The servomotor used with the magnetic amplifier (fig. 3-15) is of an ac type. The

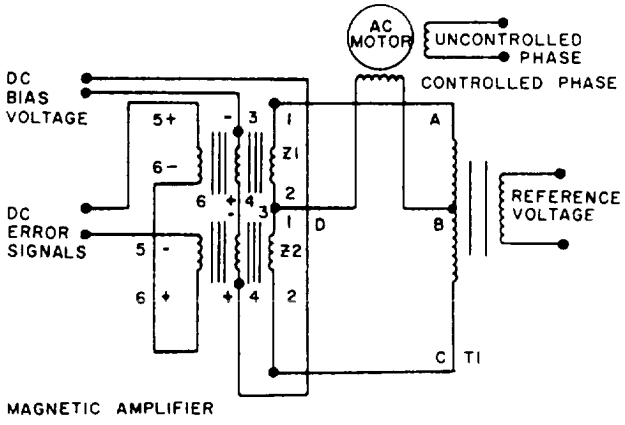


Figure 3-15.-Magnetic amplifier servo control amplifier.

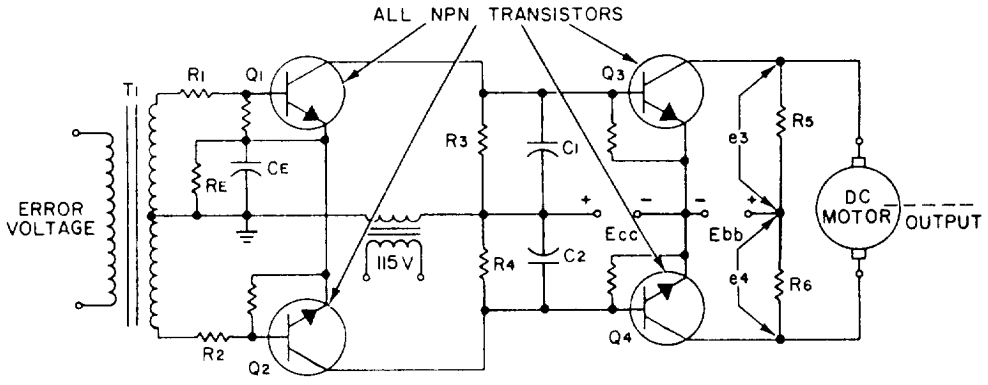


Figure 3-14.-Two-stage dc servo control amplifier.

uncontrolled phase is connected in parallel with transformer T1 by using a phase-shifting capacitor, or it is connected to a different phase of a multiphase system. The controlled phase is energized by the magnetic amplifier, and its phase relationship is determined by the polarity of the dc error voltage.

The magnetic amplifier consists of a transformer (T1) and two saturable reactors, each having three windings. Note that the dc bias current flows through a winding of each reactor, and the windings are connected in series aiding. This bias current is supplied by a dc bias power source. A dc error current also flows through a winding in each reactor; however, these windings are connected in series opposing.

The reactors Z1 and Z2 are equally and partially saturated by the dc bias current when no dc error signal is applied. The reactance of Z1 and Z2 are now equal, resulting in points B and D being at equal potential. There is no current flow through the controlled phase winding.

If an error signal is applied causing the current to further saturate Z2, the reactance of its ac winding is decreased. This current through Z1 tends to cancel the effect of the dc bias current and increase the reactance of its ac winding. Within the operating limits of the circuit, the change in reactance is proportional to the amplitude of the error signal. Hence, point D is now effectively connected to point C, causing motor rotation. Reversing the polarity of the error signal causes the direction of rotation to reverse since point D is effectively connected to point A.

The basic magnetic servo amplifier discussed above has a response of approximately 6 to 20 hertz. In some applications, this delay is excessive, creating too much error. This error is reduced to about 1 hertz by use of special push-pull circuits.

Amplifier Integrator

A servo system in a steady-state condition will have a constant positional displacement between input and output, which is called the *error.* The only way to reduce this error is to increase the drive torque. Therefore, a new signal is introduced that is related to the error. The error is not changing; it isn't a derivative signal or proportional to the error. If it were, it would decrease as the error decreases, and a new condition would be met without removing the error. The only way to reduce the error is to produce a signal proportional to the integral of the error. Then, if a torque proportional to the time integral of the error is added to the normal torque that is proportional to the error, the error is eventually reduced to zero. An amplifier integrator circuit is used for this purpose.

A simple and commonly used integrator (fig, 3-16) consists of two circuit elements—a resistor and a capacitor. The voltage across the capacitor is proportional to the integral of the charging current. The formula to find the voltage across a capacitor is

$$E = \frac{Q}{C}.$$

For any given capacitor (C), the voltage depends directly on the charge (Q), which is the imbalance of electrons on the two capacitor plates. The amount of the charge depends on the current flow and the time that the flow exists.

Because the voltage is proportional to the integral of the charging current, the RC circuit can be used as an integrator. The capacitor voltage is the integrator output. A charging current must be supplied that is proportional to the input information. The resistor is used to produce the proportional current from an input signal voltage (e_i). At the instant this voltage is applied, the current becomes

$$i = \frac{e_i}{R}.$$

This condition, unfortunately, does not continue. As the capacitor becomes charged, the capacitor voltage opposes the charging current. This makes the charging current less proportional to the input signal, which results in an error in the output. The ideal output, for a constant input signal, is a steadily increasing output. This steady increase is attained **only** when the signal voltage is first applied, and the capacitor is not appreciably charged.

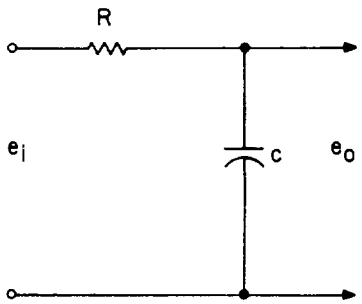


Figure 3-16.-Simple integrator.

One way to fix this error in the RC integrator is to use a circuit with a long-time constant. This type of circuit delays the charging of the capacitor, which results in a more accurate integration of an input signal. The ideal output is a perfect triangular wave. Although a long-time constant produces more accurate results, it also provides a much lower output for the same input signal. Better integration is possible by using a high-gain, feedback amplifier.

An amplifier integrator is shown in figure 3-17. This circuit arrangement has a high-gain amplifier known as the *Miller integrator*. The amplifier produces an output that is not limited by the input signal. Also, the amplifier supplies any energy that is required in the output. The function of the input signal is to control the charging current.

The operation can be explained if you make the following assumptions:

- There is a constant input, as shown in figure 3-17, view A.
- At the start, the initial condition is zero—$e_i = e_g = e_o = 0$.
- The capacitor is discharged.

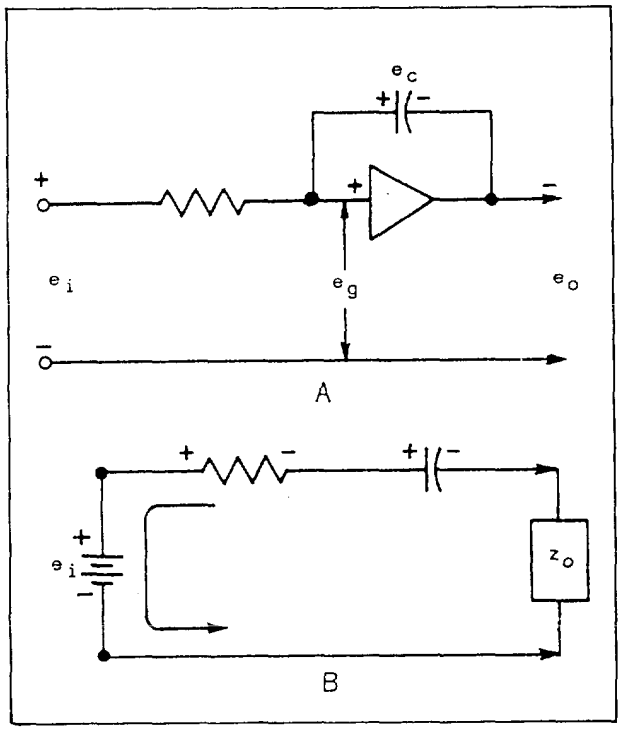


Figure 3-17.-Amplifier integrator.

The positive voltage to be integrated (e_i) is applied. The capacitor charges with a polarity as shown, since electrons are attracted from the left plate. The charging path is shown in figure 3-17, view B.

A voltage measured at the amplifier input (e_g) tends to rise in the positive direction since this point is directly coupled to e_i. However, this rise tends to be opposed by the degenerative feedback voltage from the output. The output will be $-Ae_g(e_o)$, where A stands for the amplifier gain. The minus sign indicates that the output polarity or phase is opposite to the input. The output changes A times faster or steeper than e_g. The output voltage is negative and helps charge the capacitor.

For a certain input voltage, the charging current is limited to a particular value that tends to keep e_g practically zero. If the current exceeds this value, e_g decreases a small amount because of the increased voltage drop across R. The e_o decreases, and the charging current decreases to the original value. If the initial charging current decreases, the opposite action occurs. Therefore, the value of the charging current is stabilized to a specific value proportional to the input voltage. This eliminates the error caused by e_i, and the charging current does not remain proportional in the fundamental RC integrator.

The constant charging current must be produced by e_o, despite the fact that the steadily increasing capacitor voltage opposes the charging current. To do this, e_o must steadily increase. This **steady increase** in e_o is exactly the integrator output voltage desired for a constant signal input. Similar action is produced for a condition where the input signal suddenly becomes negative. Polarities are the reverse of those described in the above paragraph.

Remember, simple examples are used for explanation. The desired result is produced for a more complicated signal input. If e_i were removed, little or no effect would be produced on the output that existed at that instant, since the amplifier output would oppose the tendency for the capacitor to discharge.

The limits for e_o are determined by the amplifier and **not** by e_i or the range of e_g. The output range is designed to produce an increasing output for any probable input amplitude and period of application. The exception to this is an integrator designed to function as a limiter.

Q12. What is the purpose of phase detectors?

Q13. A simple and commonly used integrator consists of what two circuit elements?

OUTPUT DEVICES

The output of the servo control amplifier is fed to an output device. This device supplies torque, power, and dynamic characteristics needed to position the servo load. Ideally, the power device requires small power from the control amplifier, accelerates rapidly, is small and light, lasts, has small time lags, and has an adequate speed range. In aircraft weapons systems, the electric motor is often used as an output device. However electromagnetic clutches, hydraulic devices, and pneumatic devices are also used.

Electric Motors

Electric motors are used to drive the servo load in aircraft weapons systems. The type of electric motor used in a particular piece of equipment is determined by the following power factors—type of power available, output power, speed range, inertia, and electrical noise.

ALTERNATING-CURRENT MOTORS.— Alternating-current motors are used in low-power servo applications. They are simple and reliable. The commutator's don't spark, and they respond rapidly. Their disadvantage is their narrow speed range. For the theory of operation of ac motors, you should refer to NEETS, module 5, NAVEDTRA 14177.

The two-phase induction motor is a widely used ac servomotor. The stator of the motor consists of two similar windings positioned at right angles to each other. The rotor is wound with short-circuited turns of wire, or it is a squirrel-cage rotor. The squirrel-cage rotor is the type more frequently used. It is made up of heavy conducting bars that are set into armature slots, and the bars are shorted by conducting rings at the ends.

The ac voltages applied to the two stator windings must be 90 degrees out of phase to cause the rotor to turn. The direction of rotation is determined by the phase relationship of the stator windings, which is determined by the servo error detector. One phase is connected directly to one of the stator windings. The other phase is used to energize an error detector. The resulting error voltage is either in phase or 180 degrees out of phase with the signal applied to the error detector. This causes the controlled phase to either lead or lag the uncontrolled phase by 90 degrees.

Most induction motors have low starting torque and high torque at high speed. For servo applications, high starting torque is needed for the system to have a low time lag. This may be done by increasing the armature resistance with the use of material such as zinc for the conducting bars. The increased torque at low speed results in decreased torque at high speed. However, increased stability of the servo system is a desirable result of the change.

Split-phase ac motors are similar to the two-phase induction motor. The difference is the phase-shifting network used to shift the phase of the voltage supplied to one of the windings by 90 degrees. This is usually done by connecting a capacitor in series with the uncontrolled winding of the stator. Direction of rotation and reversal is accomplished in the same way as in the two-phase motor.

Other types of ac motors may be used with an ac power supply, including the shaded pole, universal, and repulsion motors. Many methods of getting rotation reversal are used in these motors. However, they are not normally found in aircraft weapons systems.

DIRECT-CURRENT MOTORS.— Direct-current motors have the following advantages over ac motors—higher starting torque, reversing torque, and less weight for equal power.

Series motors are characterized by their high starting torque and poor speed regulation with a change in torque. Higher torque is obtained on reversal of direction with a series motor. However, it is a unidirectional motor and requires special switching circuits to get bidirectional characteristics. This is normally done by switching either the armature or field connections, but not both.

The split-series motor is a variation of the series motor that has bidirectional characteristics. The motor has two field windings on its frame, but only one is used for each direction of rotation. This reduces the number of relay contacts needed for reversing by one-half. This double winding reduces the torque capabilities of the motor as compared to a straight-series motor wound on the same frame.

The most frequently used dc servomotor is the shunt motor. Its direction of motion is controlled by varying the direction of flow of either the

armature or field current. The uncontrolled current is usually maintained constant to preserve a linear relationship between the motor output torque and the voltage or current input. Usually, the field windings are two diffentially wound coils that make it easier for the servo control amplifier to control the direction of the field current. The field current is usually controlled with receiving-type vacuum tubes. The larger armature currents require thyratrons or generators as current regulators, but they are not normally found in aircraft weapons systems.

Magnetic Clutches

Any device that uses an electrical signal to control the coupling of torque from an input shaft to an output shaft is a magnetic clutch. This coupling is accomplished by the contact between friction surfaces or by the action of one or more magnetic fields. A magnetic clutch is used only to couple the input torque to the output shaft. This makes it capable of controlling large amounts of power and torque when compared to its size and weight. The magnetic clutch is used with a large flywheel driven at high speed by a small motor. This allows the flywheel to give very large acceleration to the load when the magnetic clutch is energized.

There are two distinct types of magnetic clutches. Some transmit torque by physical contract of frictional surfaces. Others use the action of magnetic flux produced by two sets of coils, or one set of coils and induced eddy currents that result from rotating the one set of coils near a conducting surface. The eddy current type of clutch offers smoother operation and has no wear problem due to friction. Both types have suitable control characteristics and are found in servomechanisms.

Hydraulic Devices

Hydraulic components used in servo-mechanisms are frequently found in aircraft weapons systems. Hydraulic power devices, such as motors and associated control valves, have an advantage of a response that is much faster than the best electric motors and equal to that of a magnetic clutch system. They also require a minimum of maintenance, are accurate, and are well adapted to heavy loads.

The following are the essential components of a hydraulic system:

- A source of high-pressure oil and a sump to receive discharge oil
- A control valve and means of using an actuating signal
- An actuator (motor or cylinder)

NOTE: The theory of operation of hydraulic systems is discussed in *Fluid Power,* NAVEDTRA 14105 (series).

The source of high-pressure oil serves as a source of power to operate the actuator. However, this source is controlled by the control valve. The valve is actuated by the output from the servo control amplifier. This control is normally accomplished by feeding the error signal to a solenoid-controlled valve. The actuator is usually an axial motor that is reversible and of the variable speed type. Some applications may use a cylinder, where linear motion is required for positioning.

Q14. The output of the servo control amplifier is fed to an output device to provide the torque, power, and dynamic characteristics needed to position the servo load. List these devices and describe their function.

Q15. Why are alternating-current motors frequently used in low-power servo applications?

Q16. Describe a magnetic clutch.

SERVOMECHANISM OSCILLATION

Learning Objectives: *Describe servo-mechanism oscillation. Identify procedures for correction and control to include damping, integral control, gain, phase, and balance.*

Servomechanisms are used in aircraft weapons systems. They perform various functions and meet certain performance requirements. These requirements involve speed of response and accuracy and the way the system responds in carrying out its command functions. All systems contain certain errors, the problem is to keep them within allowable limits.

You already know that the servomotor must develop sufficient torque and power to position the load in a minimum of time. The servomotor and its connected load have sufficient inertia to drive the load past the point of command position. This overshooting results in an opposite error voltage, reversing the direction of rotation of the servomotor and the load. Again, the servomotor tries to correct the error, and again, it overshoots the point of correspondence. Each reversal requires less correction until the system is in correspondence. The time required for the oscillations to die out determines the transient response of the system, and is reduced by using damping.

DAMPING

Damping reduces the amplitude and duration of oscillations that exist in a system. The simplest form of damping is viscous damping, which is the application of friction to the output load or shaft proportional to the output velocity. The **amount** of friction applied to the system is critical and materially affects the results of the system. When just enough friction is applied to prevent overshoot, the system is *critically damped.* When the friction is greater than needed for critical damping, the system is overdamped; when damping is slightly less than critical, the system is slightly underdamped. A slightly underdamped system is usually the desired condition. The application of friction absorbs power from the motor, which is dissipated in the form of heat.

A pure, viscous damper would absorb an excessive amount of power from the system. A system that has some of the characteristics of a viscous damper with somewhat less power loss is actually used. Two types of systems are discussed in this section—a dry friction clutch to couple a weighted flywheel to the output drive shaft and an eddy current damper.

Remember, the damper using a dry friction clutch coupled to a weighted flywheel to the output drive shaft has somewhat less power loss than a pure, viscous damper. A flywheel has the property of inertia. But, since the flywheel is coupled to the output shaft with a friction clutch, any rapid change in velocity of the output member causes the clutch to slip. This effectively disconnects the flywheel instantaneously, yet allows sufficient power to be coupled to the flywheel to overcome its inertia. As the inertia is gradually overcome, the flywheel gains speed and approaches the velocity of the output member. As the point of correspondence is neared and the error signal is reduced, the inertia of the flywheel gives up power to the system. This causes the load to increase its overshoot. When the system tries to correct for the overshoot, the inertia of the flywheel adds to the output load, reducing the effect of the correcting signal. The effect dampens

ANSWERS FOR REVIEW QUESTIONS Q12. THROUGH Q16.

A12. Some systems use dc servomotors, which require the ac signal be converted to dc. To do this, a phase detector (sometimes known as a demodulator) is used.

A13. A simple integrator circuit consists of a resistor and a capacitor, as shown in figure 3-16.

A14. Electric motors drive the servo load in aircraft weapons systems; magnetic clutches couple input torque to the output shaft; and hydraulic components are much faster than the best electric motors and equal to that of a magnetic clutch system.

A15. They are simple, reliable, have no commutator sparking, and provide rapid response.

A16. Any device that uses an electrical signal to control the coupling of torque from an input shaft to an output shaft.

the oscillations in the system, reducing its transit time.

The eddy current damper uses the interaction of induced eddy currents and a permanent magnet field to couple the output shaft to a weighted flywheel. Look at figure 3-18. The solid line shows the action of the load without damping. Note the time required to reach a steady-state condition without damping. With damping, this time is reduced, although the initial overshoot is increased. You can also see that a viscous damper effectively reduces transient oscillations, but it produces an undesired steady-state error.

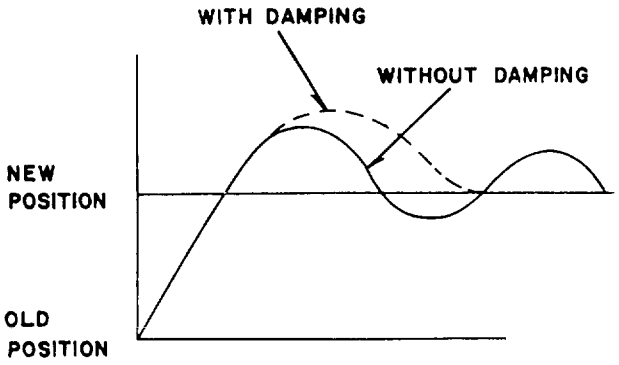


Figure 3-18.-Effect of friction damper.

How well the load is controlled is a measure of the steady-state performance of a servo system. If the load is moved to an exact given position, then the servo system has a **perfect steady-state performance.** If the load is not moved to the exact position, then the system is not perfect, and the difference in error is known as the *steady-state* error. Steady-state error is either one or both of the following—a velocity lag or a position error. Velocity error is the steady-state error due to viscous drag during velocity operation. Position error is the difference in position between the load and the position order given to the servo system. Since the friction damper absorbs power from the system, its use is normally limited to small servomechanisms.

Error-rate damping overcomes the disadvantages of viscous dampers. Error-rate damping works by introducing a voltage that is proportional to the rate of change of the error signal. The voltage is fed to the servo control amplifier and combined with the error signal.

Look at figure 3-19. You can see the effect of error-rate damping on the torque output of the servomotor. Curve A shows the torque that results from the error voltage; curve B shows the torque that results from the error-rate damper; and curve C shows the resultant of curves A and B.

You should note that the torque that results from the damper increases the total torque as long as the error component is increasing. Once the error component starts to decrease, the error-rate damper produces a torque in an opposite direction. This reduces the transit time of the system.

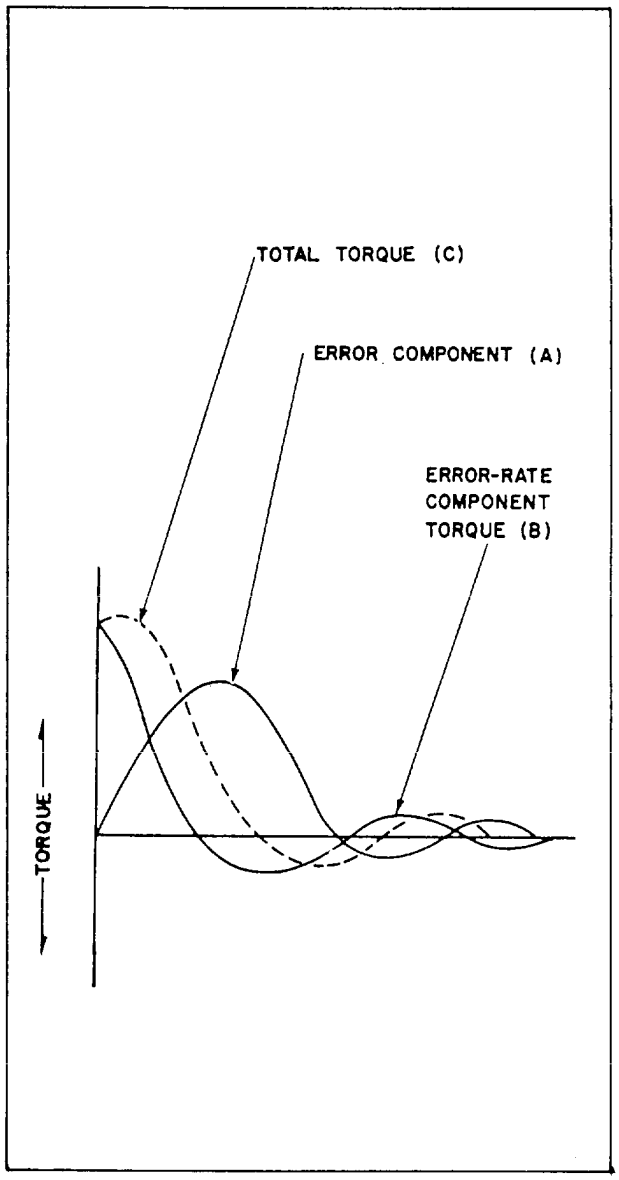


Figure 3-19.-Torque variations using error-rate damping.

Normally, two methods are used to generate an error-rate voltage in aircraft weapons systems—the tachometer and electrical networks.

The tachometer error-rate damper is essentially a generator, which has an output voltage proportional to its shaft speed. The tachometer is connected to the shaft of the output member, giving a voltage proportional to its speed. Look at figure 3-20. Here, you can see that the output voltage is fed to a network that modifies this voltage so it is proportional to a change in input voltage. The voltage is fed back to the servo control amplifier and added with the error signal.

Electrical networks used for error-rate damping are a combination of resistors and capacitors used to form an RC differentiating network. These networks, sometimes referred to as *phase advance* or *lead* networks, vary in design, depending on the type of error signal.

NOTE: For a detailed explanation of RC circuits, refer to Navy Electricity and Electronics Training Series (NEETS), module 2, NAVEDTRA 14174.

In practice, networks are limited to the dc type (fig. 3-20) because a small change in frequency of the power source causes unstable results. A dc network may be used in an ac system through the use of a demodulator (detector) before the network. However, the output of the network must be modulated for use in the remainder of the ac system. Like the tachometer, the output of the network is fed to the servo control amplifier.

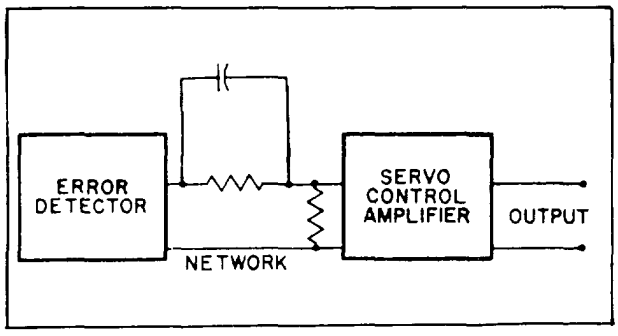


Figure 3-20.-Error-rate stabilization network.

INTEGRAL CONTROL

Servomechanisms used in aircraft weapons systems are sometimes required to follow an input function whose magnitude changes at a constant rate with time. The antenna system tracking a target is such a system. If the input is the angle of a shaft, the velocity of the shaft is constant for a substantial percentage of time. The servomechanism is required to respond to this type of input with substantially zero error. The error that characterizes the servo response to a constant velocity input is known as the *velocity error.*

An integral control is used to correct a velocity error or an inaccuracy due to a steady-state error. The integral control modifies the error voltage so the signal fed to the servo control amplifier is a function of both the amplitude and time duration of the error signal. A variable voltage divider is used to do this because its output increases with time for a constant input. As in all voltage dividers, the output is the only portion of the input that effectively reduces the amplitude of the error signal. To compensate for the loss of amplitude, additional amplification is used, either in the form of a preamplifier or a higher gain servo control amplifier. When the overall gain of the system is increased to give a normal output for transient error signals, small velocity or steady-state error signals of long duration result in an increased output to the servomotor because of the action of the integral control.

The integral control (fig. 3-21) consists of a combination of resistors and capacitors connected to make an integrator circuit for a dc error signal. The value of the components is such that the capacitor does not have sufficient time to change with fluctuations in error voltage. Only that portion of the transient error signal developed across R1 is impressed on the amplifier. But, if there is a velocity error or steady-state error of longer duration, the capacitor (C1) charges. This increases the amplitude of the amplifier input.

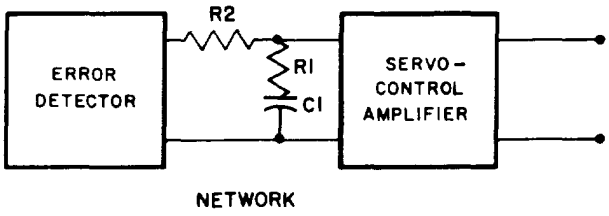


Figure 3-21.-Integral stabilization network.

Networks shown in figure 2-21 are not limited to dc systems. A demodulator may be used before the integrator, and its output modulated for easier amplification.

GAIN, PHASE, AND BALANCE

The overall system gain has an important effect on the servomechanism response characteristics. It is one of the more easily adjustable parameters in electronics servo controllers. Increasing the system gain reduces the system velocity errors and steady-state errors that result from restraining torques on the servo load or misalignment in the system. An increase in system gain increases the speed of response to transient inputs. However, excessive gain **always** decreases the rate at which oscillatory transients disappear. Continued increase in the system gain produces instability.

Servo systems using push-pull amplifiers must be balanced to ensure equal torque in both directions of the servomotor. You should check this adjustment periodically because a change in the value of a component causes an unbalanced output. You balance it by adjusting the system for zero output with no signal applied.

A phase control is included in some servo systems using ac motors. The two windings of the ac servomotor are energized by ac signals that are 90 degrees apart. A phasing adjustment is normally included in the system to compensate for any phase shift in the amplifier circuit. (An uncorrected phase shift causes unstable operation of the system.) This adjustment may be located in the control amplifier or, in the case of a split-phase motor, it may be in the uncontrolled winding.

Q17. Describe servomechanism oscillation.

Q18. Name the level of damping that is the desired condition.

Q19. A servo system has a perfect steady-state performance. What is meant by this statement?

Q20. Normally, what two methods are used to generate an error-rate voltage in aircraft weapon systems?

Q21. Describe the purpose of an integral control.

Q22. What is the effect of increasing system gain on servomechanism response characteristics?

ZEROING SYNCHRO UNITS

Learning Objective: *Recognize zeroing procedures for synchro and servo systems.*

So far, you have learned that it is important for servo systems to be accurate. In any servomechanism using synchro units, it is important that the units are zeroed electrically. As you read the rest of this section, refer to figure 3-22.

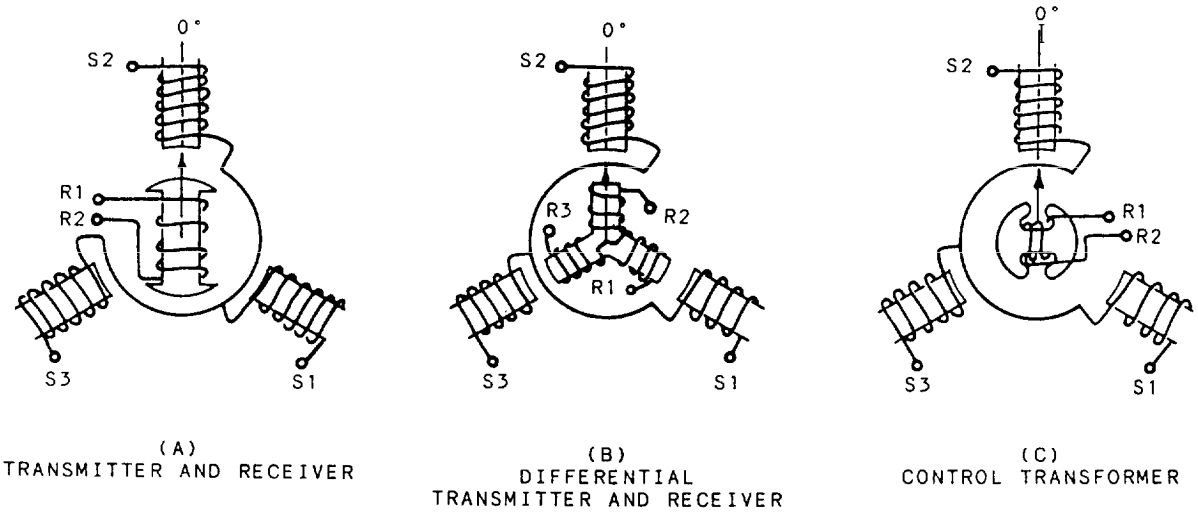


Figure 3-22.-Synchro electrical zero positions.

Look at figure 3-22, view A. For a synchro transmitter or receiver to be in a position of electrical zero, the following conditions must be met:

- The rotor must be aligned with S2.
- The voltage between S1 and S3 must be zero.
- The phase of the voltage at S2 must be the same as the phase of the voltage at R1.

The most common methods of zeroing synchro transmitters and receivers are the electrical lock and ac voltmeter methods. The method used to zero a synchro depends on how the synchro is used.

The electrical lock method is used if the rotor is free to turn. This is done by connecting S1 and S3 to R2 using a jumper wire and connecting S2 to R1 (fig. 3-23). When power is applied, the rotor positions itself in the zero position. After the synchro is zeroed, the pointer is adjusted to indicate zero.

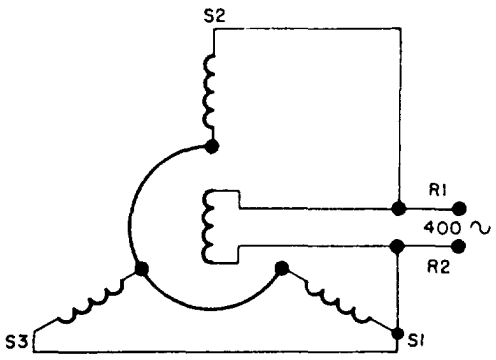


Figure 3-23.-Electrical lock method of zeroing a synchro.

The majority of synchros used in aviation weapons systems have their rotor gears driven or

ANSWERS FOR REVIEW QUESTIONS Q17. THROUGH Q22.

A17. The servomotor and load have sufficient inertia to drive the load past the point of command resulting in overshoot and an opposite error voltage that reverses the direction, again overshooting the point of correspondence. Each reversal requires less correction until the system is in correspondence.

A18. The desired level of damping is slightly underdamped.

A19. How well the load is controlled is a measure of the steady-state performance of a servo system. If the load is moved to an exact position, the servo system has a perfect steady-state performance.

A20. The tachometer and electrical networks. The tachometer error-rate damper is essentially a generator having an output voltage proportional to its shaft speed, and the electrical networks are a combination of resistors and capacitors used to form an RC differentiating net work.

A21. Integral control corrects a velocity error or an inaccuracy caused by a steady-state error.

A22. Increasing system gain reduces the system velocity errors and those steady-state errors that result from restraining torques on the servo load or misalignment in the system. Also, it increases the speed of response to transient inputs and decreases the rate at which oscillatory transients disappear. Continued increase in system gain produces instability.

mechanically coupled to a driving member. In these cases, the ac voltmeter method is used to zero the synchro. The synchro is zeroed by rotating the stator or housing until its electrical zero is reached. Before zeroing the synchro, you must set the mechanical unit that positions the synchro to its indexing or *zeroing* position. To do this, align the unit to this index, and install its indexing pins in the holes that are provided. The points hold the unit to its index and keep it from moving.

The ac voltmeter method is used to zero the synchro by connecting the meter and jumper wires (fig. 3-24, view A). Rotate the energized synchro until a zero reading is obtained on the voltmeter. Since rotor positions of 0 and 180 degrees produce the zero reading, you must determine if the phase of S2 is the same as R1. Make the connections shown in figure 3-24, view B. If the proper polarity relationship exists, the voltmeter indicates less than the excitation voltage being applied to the rotor. If the indication is greater than the rotor excitation voltage, the rotor or stator must be rotated 180 degrees and the previous step performed again.

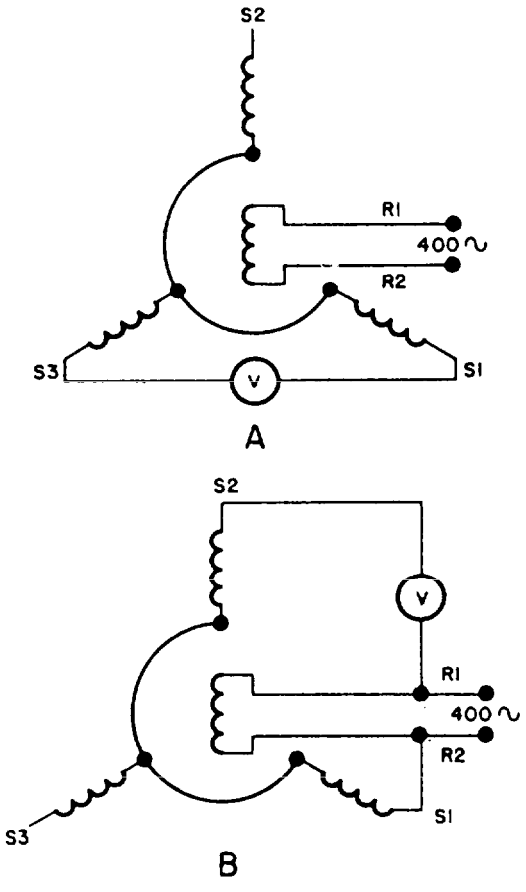


Figure 3-24.-Ac voltmeter method of electrically zeroing synchro receiver or transmitter.

DIFFERENTIAL TRANSMITTER

When the three windings of the rotor are in correspondence with their respective stator windings and their respective voltages are in phase, the synchro differential transmitter or receiver is in the electrical zero position (fig. 3-22, view B). The differential transmitter synchro is normally used to insert a correction into a synchro system; therefore, it is usually driven either directly or through a gear train. Before you zero the differential transmitter synchro, zero the unit whose position the differential synchro transmits first. After doing this, connect the differential synchro, as shown in figure 3-25, view A. Turn the synchro in its mounting until the voltmeter shows a minimum indication. Then, make the connections shown in figure 3-25, view B. Again, turn the synchro slightly in its mounting until a minimum voltage is indicated by the voltmeter.

DIFFERENTIAL RECEIVER

Look at figure 3-22, view B. It shows the electrical zero for a differential receiver. To zero a differential receiver synchro, you make the

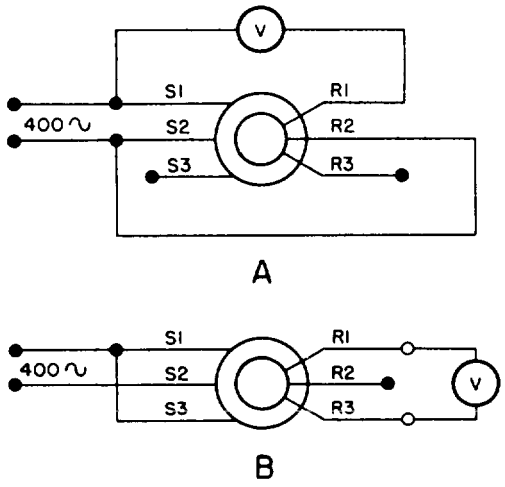


Figure 3-25.-Electrically zeroing a differential transmitter.

connections shown in figure 3-26. As soon as the power is applied to the synchro, the rotor assumes a position of electrical zero. Then, set the dial to zero, and reconnect the unit to the circuit.

CONTROL TRANSFORMER

The synchro control transformer is normally zeroed by using the ac voltmeter method. Remember, the electrical zero position of the control transformer is 90 degrees from that of a receiver. This must occur because the rotor winding must be perpendicular to the stator's resulting magnetic field to have a zero output (fig. 3-22, view C). Make the coarse adjustment by connecting the meter and unit as shown in figure 3-27, view A. Rotate the rotor to give a minimum or null reading on the voltmeter. The final adjustment is made when you connect the unit, as shown in figure 3-27, view B, and displace the rotor a few degrees in both directions to determine the null or electrical zero position. Once the zero position is determined, the unit is locked.

Now that you have a better understanding of servo systems, you are ready to learn about analog computation and analog computer functions.

Q23. What conditions must be met for a synchro transmitter or receiver to be in a position of electrical zero?

Q24. Name the most common methods used to zero synchros.

Q25. Under what condition should you use the electrical lock method?

Q26. What action should you take before you zero the differential transmitter synchro?

Q27. How does the electrical zero position of a control transformer differ from that of a receiver?

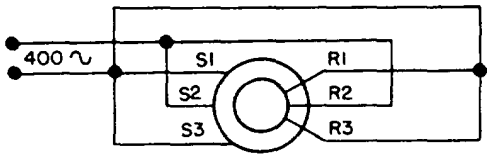


Figure 3-26.-Electrically zeroing a differential synchro receiver.

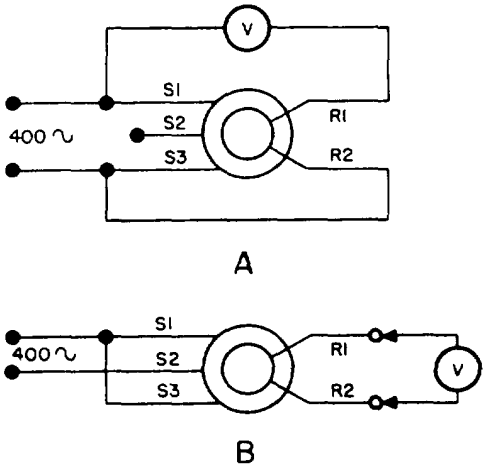


Figure 3-27.-Electrically zeroing a control transformer synchro.

COMPUTER CLASSIFICATION

Learning Objective: *Recognize computer classifications and identify various computations of an analog computer.*

Computers are classified as either digital or analog. They are further classified by their construction—electronic, electromechanical, or mechanical.

Electronic computers use electrical units, such as resistance, electrical impulses, voltage amplitude and phase, and other electrical units, to represent physical quantities. Computers of this type usually contain electronic and magnetic amplifiers, phase detectors, modulators, and demodulators.

Electromechanical computers represent numbers of variables in both electrical and mechanical units. A typical application may use both electrical and mechanical inputs to a servomechanism, and may have a mechanical output.

Mechanical computers use mechanical quantities to represent the input and output values. They normally contain devices that add, subtract, multiply, or divide by means of gear ratios, shaft rotations, etc. Mechanical-computing devices are discussed in *Basic Machines,* NAVEDTRA 14037.

Complex and accurate computers are used in aviation weapons systems. These computers are not normally of any one type, but contain some features of all types. Their classification is based

on the predominant type of computing device found in the equipment.

COMPUTATION PRINCIPLES

Learning Objective: *Identify linear functions of a computer and solve given mathematical problems.*

An airborne analog computer must fulfill a number of requirements, including the following:

1. It must possess sufficient accuracy to solve a problem within the required limits.
2. It must be constructed so that it can withstand the stresses of airborne use and still require a minimum of maintenance.

From the maintenance standpoint, the analog computer should use as many similar components as practical, keeping the number of spare parts to a minimum. This requires the rearrangement of equations from their simplest form to ones that are more complicated. Many computers have been designed around equation rearrangement.

EQUATION REARRANGEMENT

The equation below represents a typical problem to be solved within a computer.

$$J = \frac{Rt_f}{R_f}$$

Where, the dependent variable J is a mathematical quantity determined by the independent variable R (present range of airborne target), t_f is the time of flight of the projectile, and R_f is the future range of the target. The quantity J has no significant meaning other than that it represents the term

$\frac{Rt_f}{R_f}$ in the above equation.

One method of solving this problem requires the use of a servo system.

Remember, the operation of a servomechanism depends on its ability to compare two quantities and feed an error signal to its output device. This, in turn, causes the error signal to be canceled. The servo system gives a continuous solution to the problem if the formula is rearranged to give a zero output. By multiplying both sides of the above equation by

$$\frac{R_f}{Jt_f}$$

and transposing, the equation can be written as follows:

Another example of equation rearrangement involves the use of logarithms. A computer problem may involve the multiplication and division of several quantities. Refer again to the equation

$$J = \frac{Rt_f}{R_f}.$$

It can be arranged as follows:

$$\log_{10}J = \log_{10}R + \log_{10}t_f - \log_{10}R_f.$$

The logarithm of each quantity is found electronically by using specially designed networks. When the equation has been changed into the logarithmic form, the computation is done by simplified addition and subtraction of the quantities. Magnetic amplifiers are suited for solutions of this type.

Frequently, the results of logarithmic computation are used in the logarithmic form. However, the antilogarithm is also found by using a network giving an answer to the problem in the same form in which it was originally stated.

IMPLICIT SOLUTION

The use of computers to solve complex problems does not always afford a direct solution to all parts of the problem. Thus, the solution may be based on indirect or implicit methods.

Implicit problem solving may accomplish subtraction by means of addition, division by means of multiplication, the extraction of a square root by means of squaring, and differentiation by means of integration. The following is a

comparison of explicit and implicit methods of problem solving:

	EXPLICIT	IMPLICIT
Subtraction	c = a – b	c + b = a
Square root	$c = \sqrt{a}$	$c^2 = a$
Division	c = a/b	c b = a

The implicit function technique is used frequently in airborne computers. Many times the implicit method is more accurate or more convenient, based on the information available to the computer. Servomechanisms and amplifiers that use negative and positive feedback are well suited for implicit operations.

QUANTITY REPRESENTATION

Representation of quantity is *that physical quantity used by an analog computer to represent a specific input quantity.* For example, a specific quantity, such as the range from the gun platform to the target aircraft, is identified with a dc voltage fed to the analog computer for the solution of the problem.

IDENTITY OPERATIONS

An identity operation is defined as *any operation that does not change the mathematical quantity represented.* Examples of identity operations arc changes in scale factor, voltage level, and impedance.

Change in Scale Factor

In an analog computer, the scale factor is the ratio of the analog unit to the equation unit, or

$$\text{the scale factor} = \frac{\text{analog units}}{\text{equation units (physical)}}.$$

Any change in analog units without a corresponding change in equation units results in a change in scale factor. For example, a 10-volt positive dc signal is selected to represent a range of 1,000 yards.

$$\text{Scale factor} = \frac{+10 \text{ volts}}{1{,}000 \text{ yards}}$$

$$= 0.01 \text{ volt per yard.}$$

If the 10-volt signal is fed through a dc amplifier having a voltage gain of 10, the analog unit is now equal to 100 volts. The scale factor is as follows:

$$\text{Scale factor} = \frac{+100 \text{ volts}}{1{,}000 \text{ yards}}$$

$$= 0.1 \text{ volt per yard.}$$

Therefore, the scale factor was changed by the action of the amplifier.

ANSWERS FOR REVIEW QUESTIONS Q23. THROUGH Q27.

A23. Refer to figure 2-22. Conditions required for a synchro transmitter or receiver to be at electrical zero include the following:

a. Rotor aligned with S2.
b. Voltage between S1 and S3 is zero.
c. Phase of voltage at S2 must be same as that at R1.

A24. The ac voltmeter and the electrical lock methods are used to zero synchros.

A25. Use the electrical lock method if the rotor is free to turn.

A26. You should zero the unit whose position the differential synchro transmits first.

A27. The electrical zero position of the control transformer is 90 degrees from that of a receiver since the rotor winding must be perpendicular to the stators, resulting in a magnetic field having a zero output.

When the multiplier is less than one, simple net works of resistance, capacitance, or inductance are normally used. When the constant of multiplication is greater than one, amplifiers whose gain has been accurately calibrated are used.

Change of Voltage Level

Computers, such as those that use addition and subtraction, must frequently change or shift the voltage level or reference to a level that is usable by subsequent components or units. An example of a shift in voltage level is found in a direct-coupled amplifier, where the equipment is limited by the output of the dc supply for the amplifier.

Change of Impedance

A change in output impedance may be required to match the various sections of a computer. This may be accomplished by the use of networks and, in some cases, the use of cathode or emitter followers or other amplifiers using feedback.

Q28. List the three construction classes of analog and digital computers.

Q29. The rearrangement of equations from their simplest form to more complex forms is required in computers from a maintenance standpoint. What is the reason for this rearrangement?

Q30. Solving a subtraction problem by using addition involves what technique?

Q31. Define quantity representation.

Q32. Define identity operations.

Q33. Determine the scale factor for a +15-volt signal representing 300 yards.

MATHEMATICAL FUNCTIONS

Learning Objective: *Recognize linear and nonlinear functions of analog computers.*

In this section of the TRAMAN, linear and nonlinear functions are discussed. The discussion includes linear and nonlinear mathematical functions as they are used as analog computation devices.

LINEAR FUNCTIONS

Learning Objective: *Identify summation, multiplication, and division as linear functions of analog computers.*

In mathematics, a linear function is one that can be shown by a straight line on rectangular coordinate graph paper. Linear functions include operations that involve summation (addition and subtraction), multiplication, and division. They do not include operations involving squares, square roots, trigonometric functions, and logarithms (nonlinear functions).

Summation

Summation is accomplished by using electrical, mechanical, or electromechanical devices. Voltages are added, motions are added, or voltages and motions may be combined to give an output proportional to their input.

ELECTRICAL SUMMATION.— To simplify the presentation, both electrical and electronic summing devices are discussed under this heading. The first device is the series circuit in which the output voltage E_o is the series addition of the input voltages E1 and E2.

$$E_o = E1 + E2 \quad (1)$$

Only one of the input voltages can be grounded. Any others must be isolated from ground. This is shown in figure 3-28. Note that the secondary of the transformer is **not** grounded, while the voltage E1 is from a grounded source. Isolating

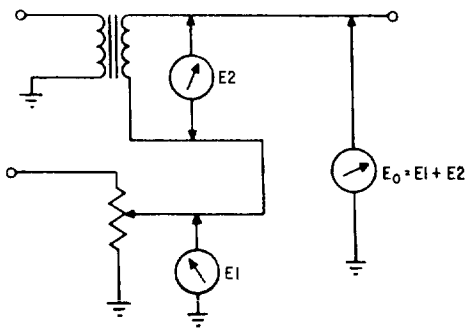


Figure 3-28.-Series addition.

transformers must be carefully designed to minimize capacitive coupling from primary to secondary winding, which would cause phase shift variations.

Series adding is used when voltage sources are inductive units (such as synchros, tachometers, and resolvers) already isolated from ground. Series summation is also used when the attenuation of parallel summation networks cannot be tolerated.

When subtracting two ac voltages by the electrical summation method, they should be 180 degrees out of phase for correct results. Combining voltages that are **not** in phase or 180 degrees out of phase results in a quadrature voltage, causing an error in the output.

If dc voltages are to be added in series, transformers cannot be used. A separate dc power supply is required for each term or input to obtain isolated sources of voltage.

A parallel resistance network can be used to electrically produce the algebraic sum of several input voltages. Voltages E1 and E2 are connected in series with two resistors R1 and R2 and terminated at a common junction, as shown in figure 3-29. The voltage E_o is **not** the actual sum of the input voltages, but is proportional to that sum.

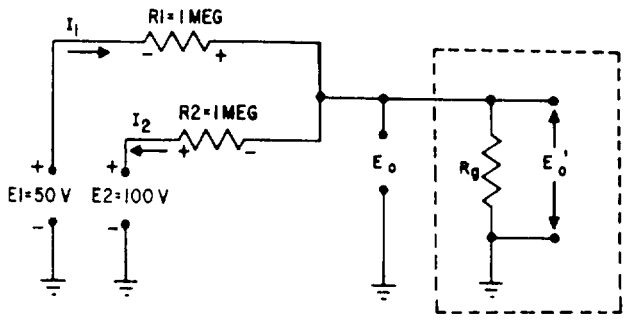


Figure 3-29.-Parallel summation network.

Using the values given in figure 3-29, you can prove that the output voltage E_o is proportional to the inputs. If the voltage E_o feeds into an infinite impedance, there is no load current. The circuit is now considered a series circuit. For more

ANSWERS FOR REVIEW QUESTIONS Q28. THROUGH Q33.

A28. Computers are classified as either digital or analog. They are further classified by their construction, as electronic, electromechanical, or mechanical.

A29. Use of as many similar components as practical, keeping the number of spare parts to a minimum.

A30. Implicit problem solving allows using addition to accomplish subtraction. For example,

Explicit	*Implicit*
$c = a - b$	$c + b = a$

The implicit function technique is used frequently in airborne computers.

A31. Quantity representation is that physical quantity used by an analog computer to represent a specific input quantity, such as a dc voltage whose value represents a range.

A32. Identity operation is any operation that does not change the mathematical quantity represented.

A33. Scale factor $= \frac{+15 \text{ volts}}{300 \text{ yards}} = .05$ *volt per yard.*

information about electrical summation, you should refer to Naval Electricity and Electronics Training Series (NEETS), module 15, *Principles of Synchros, Servos, and Gyros,* NAVEDTRA 14187. Therefore,

$$I1 = 12. \tag{2}$$

Then, since all branches are parallel,

$$E1 + I1R1 = E2 - I2R2 = E_o. \tag{3}$$

Solving for the currents in each part of equation (3) and substituting the results into equation (2),

$$\frac{E_o - E1}{R1} - \frac{E2 - E_o}{R2} = 0. \tag{4}$$

Solving equation (4) for E_o,

$$E_o = \frac{\frac{E1}{R1} + \frac{E2}{R2}}{\frac{1}{R1} + \frac{1}{R2}} \tag{5}$$

or, by further simplication,

$$E_o = \frac{R2E1 + R1E2}{R2 + R1}. \tag{6}$$

Therefore, an expression for voltage E_o was obtained in terms of the sum of the two input voltages and their respective series resistors.

The voltage E_o was obtained by assuming a very high-impedance load. If a grid resistor R_g is included, the voltage E_o is determined by

$$E_o' = E_o \times \frac{R_g}{\frac{R1 \quad R2}{R1 + R2} + R_g}.$$

As you know, the voltage output is not the actual sum of the input voltages, but is proportional to that sum. The following example illustrates this proportionality:

E1 = 50 volts E2 = 100 volts

R1 = 1 megohm R2 = 1 megohm

Then, using equation (5),

$$E_o = \frac{\frac{50}{1 \times 10^6} + \frac{100}{1 \times 10^6}}{\frac{1}{1 \times 10^6} + \frac{1}{1 \times 10^6}}$$

$$E_o = \frac{150}{2} = 75 \text{ volts.}$$

If E_o were the actual sum of the input voltages, the voltage output would be 150 volts. However, this difference in actual sum and proportional voltage is compensated for by a change in scale factor. When a difference between two terms is required (subtracted), a negative voltage is used to represent the quantity being subtracted. Both the negative and positive voltages are fed to the parallel resistance network.

Scale Factor.— Although addition is a summation of voltages, the computer's real job is to add physical units, such as feet per second or degrees per minute. The proper application of scale factors makes the addition of the physical units of an equation possible. The following transformation formula is used for this purpose:

Equation units x scale factor = analog units.

When the physical inputs to the analog computer are represented by voltages, the final solution in the proper units is found by dividing the summed voltages by the output scale factor. If the voltages E1 and E2 in figure 3-30 were chosen to represent 1,000 feet each, the scale factor for the input voltages would be 1 volt per 10 feet, and should be written as 1 volt/10 feet.

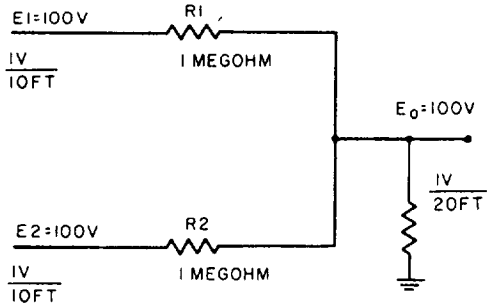


Figure 3-30.-Scale factors assigned to parallel resistor summation networks.

If the output physical units are to equal the sum of the input physical units, the scale factor at the output must be 1 volt/20 feet. Using the transformation formula, you can find the sum of the physical units as follows:

$$2{,}000 \text{ feet} \times \frac{1 \text{ volt}}{20 \text{ feet}} = 100 \text{ volts.}$$

In the examples you have seen, the input scale factors were identical. Consider the operation of the summing circuit (fig. 3-3 1) if the input scale factors are different. In the equation, D_t = D1 + D2, D1 has a scale factor of 1 volt/10 feet, and D2 is represented by the scale factor 1 volt/5 feet. Since the physical units per volt of the scale factors must add directly, the output scale factor is 1 volt/15 feet. This result is obtained in terms of units per volt (reciprocal of scale factor) for the addition operation. Direct addition of the scale factors for D1 and D2 does not result in the desired addition of physical units because the scale factor definition places the physical units in the denominator.

Look at figure 3-31. Here you can see that the correct answer for D_t is 2,000 feet. If the analog unit at the output is known and the output scale factor is known, what values of R1 and R2 supply the answer? The analog unit is obtained by substituting in the following formula:

$$\text{analog unit} = \text{equation unit} \times \text{scale factor}$$

$$= 2{,}000 \text{ feet} \times \frac{1 \text{ volt}}{15 \text{ feet}}$$

$$= 133 \text{ volts.}$$

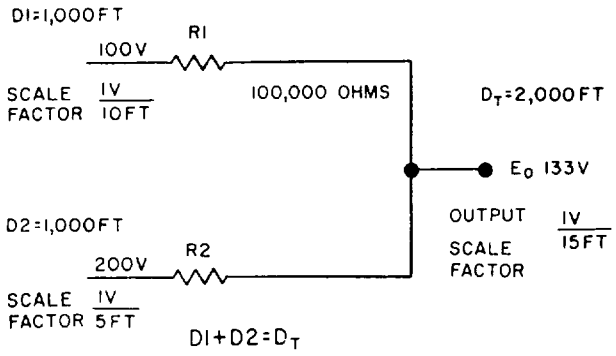


Figure 3-31.-Addition with unequal scale factors.

Refer back to equation (6). You can see that R1 cannot equal R2 as in the previous example. You can select one resistance value arbitrarily; consequently, R1 may be set equal to 100,000 ohms, a typical value. Substituting known values in equation (6) and solving for R2

$$133 = \frac{(R2 \times 100) + (100{,}000 \times 200)}{100{,}000 + R2}$$

R2 = 200,000 ohms.

As an AT, you will not be expected to compute component sizes or scale factors. However, by understanding scale factors, you will understand what is done in each stage of a computer.

Electronic Amplifiers Used for Isolation.— In analog computers, it is not always possible to apply the output of parallel resistor summation networks directly to subsequent circuits without getting nonlinear results because of loading. Loading is avoided by using an isolation amplifier with a high-impedance input and a low-impedance output between the summation network output and the succeeding computer component.

Since the signal magnitude is the computed quantity, the gain of these isolation amplifiers must be maintained quite accurately. The gain of any amplifier, of course, is affected by such things as a weak tube or transistor, a shift in power supply voltage, temperature changes, etc. The use of negative feedback is quite effective in solving this problem. Since a large amount of negative feedback is required if the full advantage of feedback stabilization is to be obtained, high-gain amplifiers are needed in such circuits. The gain of the amplifier itself does not affect the overall circuit gain because of the negative feedback. Figure 3-32 shows the basic circuit using an isolation amplifier.

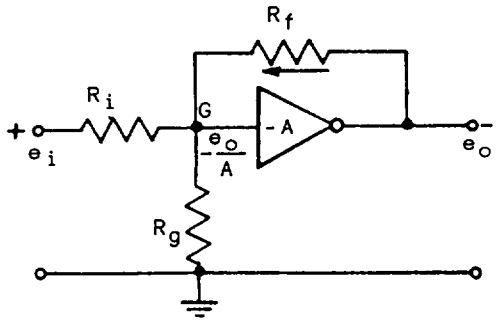


Figure 3-32.-Basic isolation amplifier circuit.

As you read the rest of this section, refer to figure 3-32. The amplifier output is fed back to the summing point G at the input of the amplifier through the feedback resistance R_f. Since the gain of the amplifier is extremely high, the voltage $-e_o/A$ at the summing point G is nearly zero. (Remember that the value of any fraction whose denominator is extremely large approaches zero.) Therefore, the current through R_g is negligible. Assuming the amplifier input does not draw current (normally a good assumption) and the amplifier gain is high (that is, 1/A is much less than 1), the current through R_i equals minus that through R_f; by Kirchhoff's current law at point G,

$$\frac{e_i}{R_i} = \frac{e_o}{-R_f}.$$

This equation can be rearranged to obtain an expression for gain as follows:

$$\frac{e_o}{e_i} = \frac{-R_f}{R_i}.$$

This is the basic equation that describes the operation of any circuit having a high-gain amplifier with negative feedback. It is well worth remembering.

If $R_i = R_f$, the circuit gain is unity, and the circuit is effective as a precision isolation device. The loading that this circuit presents to its driving circuit is essentially R_i since the voltage at point G is essentially zero.

If the amplifier gain deteriorates with age, there is some point at which the approximate expression for circuit gain no longer holds. A more exact expression showing the effect of amplifier gain is

$$\frac{e_o}{e_i} = \frac{-R_f}{R_i}\left(\frac{A}{1+A}\right).$$

You can use this equation to show that even if the amplifier gain is designed to be only 100, a reduction in gain to about 50 percent is required to reduce the circuit gain by 1 percent.

Summing Amplifiers.— High-gain dc amplifiers are used in many applications where isolation characteristics are needed. A typical application is in summing circuits, where loading effects are serious. When used in this way, they are connected as shown in figure 3-33. The entire circuit, including the electrical summing network, the high-gain amplifier, and the feedback loop, is known as a *summing amplifier.*

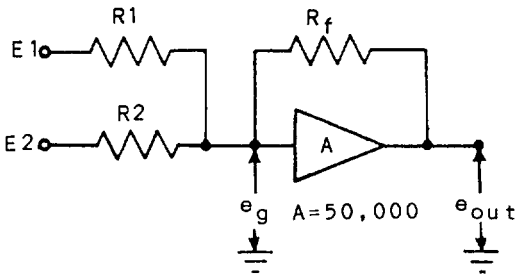


Figure 3-33.-Summing amplifier schematic.

Remember that the overall gain of the feedback amplifier circuit is determined by the ratio of feedback impedance to total input impedance. When this ratio is 1 (both impedances equal), the gain of the amplifier circuit is unity. The circuit algebraically adds all the input voltages.

Realistically, the number of inputs to a summing amplifier is limited by amplifier saturation. A typical summing amplifier input voltage range is from –50 volts to +50 volts and an output voltage range from –100 volts to +100 volts. This means that the total input voltage cannot exceed ±50 volts. The individual voltage inputs and gains must provide a total output that does **not** exceed ±100 volts. When these conditions are exceeded, amplifier saturation occurs and further linear amplification is impossible.

Operational Amplifiers.— Almost any mathematical operation can be performed by suitable mechanical and electronic devices. Some of these operations have already been discussed. Others, including the calculus operations of differentiation and integration, are discussed later in this chapter. The use of high-gain dc amplifiers is commonplace in the performance of these mathematical operations, therefore, the term *operational amplifiers.* This term, used throughout the remainder of this chapter, means any high-gain dc amplifier that uses negative feedback.

Ideally, dc amplifiers used in operational amplifiers can produce an output voltage that is an exact magnified version of the input voltage, but exactly 180 degrees out of phase with the input. For a number of reasons, practical amplifiers fail to perform in this ideal manner.

The usual operational amplifier consists of three cascaded dc-amplifier stages with a

combined open loop gain of 50,000, or 92 dB. The closed loop gain (that is, the gain obtained when a feedback resistor that is equal in value to the input resistance is connected between the output plate and the input grid) is unity.

At the high gains used in these amplifiers, any spurious voltage variations in the dc-amplifier stages may produce a considerable amount of undesired variation or drift in the amplifier output voltage. Drift shows up as a voltage imbalance appearing at the amplifier output terminals in addition to the correct output voltage. When it occurs in computer applications, this imbalance produces errors in the computation.

There are four main causes of drift:

1. Power supply voltage variation
2. Filament voltage variation or transistor bias variation
3. Varying resistance values
4. Varying vacuum tube characteristics or transistor parameters

Other operational amplifier errors are caused by seemingly insignificant currents and voltages, such as leakage currents, voltage drops in ground loops, and grid currents. The resulting currents are in the order of fractions of a microampere. Yet, these currents flow through the input resistors. A current of 0.1 microampere flowing through a 1-megohm resistor will generate an error voltage of 0.1 volt.

Look at figure 3-34. If an assumed 0.2-volt, grid-voltage change is produced by a filament-voltage change, an output-voltage change of 200 volts is obtained, even though the input signal voltage is zero. By means of a similar analysis, you can show that plate or collector supply voltage changes and cathode or emitter emission variations all tend to increase the output voltage imbalance, and that they produce the most serious effects when they occur in the first stage.

The main cause of drift in transistorized dc amplifiers is changes in transistor parameters caused by temperature variations. The most widely used drift reduction circuit is the differential amplifier (fig. 3-35). As the name implies, the output voltage (taken between collectors) is equal to the difference between the two input voltages. Any output variations caused by drift voltages are canceled because both transistors are almost equally affected, and the difference voltage between collectors remains constant.

The circuit (fig. 3-35) can be used either with two inputs or with one input having a fixed bias. In either case, collector current drawn by one transistor affects that drawn by the other because of the common emitter resistor. For more information on differential amplifiers, refer to Navy Electricity and Electronics Training Series (NEETS), module 8, *Introduction to Amplifiers,* NAVEDTRA 14180.

For example, an increase in the collector current of transistor Q1 increases the emitter voltage of transistor Q2. However, the base-to-emitter voltage of transistor Q2 is decreased (if the base voltage is held constant) since the difference between the base voltage and emitter voltage appears there. Consequently, the base current of transistor Q2 decreases, and the collector voltage increases. Since the collector voltage of transistor Q1 decreases, the difference voltage becomes greater.

The differential amplifier provides a gain determined by the current gain of each stage. As one collector voltage is reduced, the other collector voltage is increased. The difference between the two collectors is much greater than the difference between the two input voltages

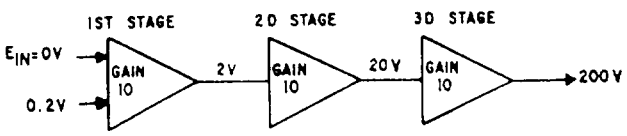


Figure 3-34.-Amplification of three stages of gain.

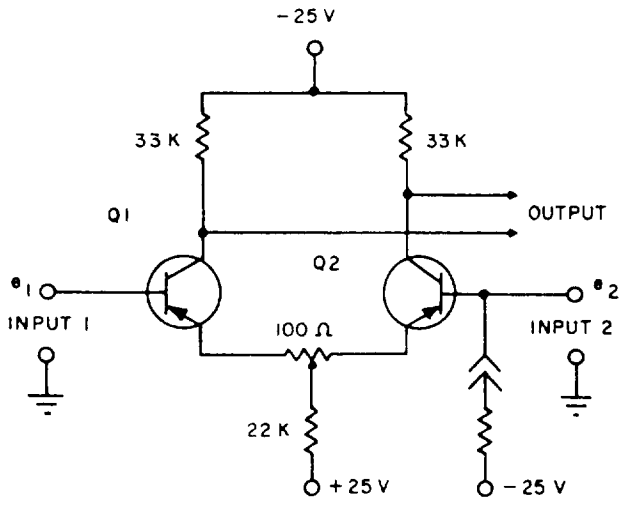


Figure 3-35.-Basic differential amplifier.

because of the current gain of the two transistors. The high value of emitter resistance and voltage also provides a very high input impedance.

The potentiometer in the emitter circuit is used to adjust the circuit output voltage when no input is present. By varying the emitter voltages of the two transistors, it is possible to select the values of quiescent base currents.

As you have already learned, most operational amplifiers consist of a basic three-stage dc amplifier. Multiple stages are used to obtain high gain. An odd number of stages is used to obtain the required reversal of polarity between the input and output voltages. (Remember, negative feedback is used in the operational amplifier.)

Figure 3-36 shows a schematic of a three-stage, dc amplifier that consists of two differential amplifiers and a conventional amplifier. Negative feedback is used within the amplifier to provide stable gains over a wide range of frequencies. Negative feedback occurs when a portion of the output voltage is fed back to transistor Q2. The base current caused by this voltage is amplified and affects the emitter voltage of Q1. The voltage fed back to Q2 is in phase with the input voltage to Q1. Q1 and Q2 form a difference amplifier, and the amplifier's output is an amplified version of the algebraic difference between the base input signals at Q1 and Q2. The feedback voltage to Q2 causes a feedback current that subtracts from, or partly cancels the effect of, the input voltage to the base of Q1. You can see that although Q2's feedback voltage is exactly in phase with Q1's input voltage, it has a negative feedback effect.

In negative feedback circuits, a fixed portion of the output voltage is fed back to the input and used to cancel out a portion of the input voltage

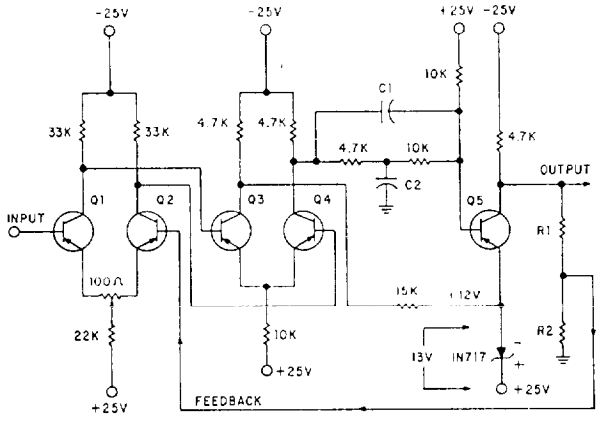


Figure 3-36.-A three-stage, dc amplifier.

or current. In some ways the feedback circuit (fig. 3-36), consisting of R1 and R2, is like the collect or-to-base negative feedback.

The feedback and the output voltage of the overall amplifier must be exactly in phase with the input voltage and current to function properly. Unfortunately, the input capacitances of each stage introduce time delays or phase shifts. These phase shifts depend on the frequency components of the signal passing through the amplifier. Without some form of compensation, distortion is produced as a result of the summation of two current waveforms that are not exactly in phase. The resistor capacitor network applying base current to transistor Q5 provides the extra phase shift required to make the output voltage exactly in phase with the input voltage and current.

ELECTROMECHANICAL SUMMATION.— If the inputs or outputs of a summing operation cannot be physically brought together, a synchro system is used. A chain of three synchro units consisting of a synchro transmitter, a synchro differential transmitter, and a synchro receiver adds or subtracts shaft rotations. If an output voltage rather than a shaft rotation is needed, the synchro receiver is replaced with a synchro control transformer. Gear ratios are added between the input shaft and the differential transmitter rotor to introduce coefficients. The accuracy of a synchro summing system is increased by using a two-speed, synchro transmission system.

Multiplication

Multiplication is a mathematical operation performed by computers using the following devices:

- Electronically by transistor amplifiers, electron-tube amplifiers, or by magnetic amplifiers
- Electromechanically by potentiometers
- Mechanically by multipliers

ELECTRONIC METHODS.— Every linear amplifier is a multiplier. The dc amplifier previously discussed had a voltage gain of 100. In this section, you will hear about a high-gain, operational amplifier with a gain of 25,000. The complete high-gain, operational amplifier is

shown in figure 3-37. The maximum allowable output voltage is ±5 volts. Since the circuit voltage gain is 25,000, the input signal should not exceed ±0.0002 volt (0.2 millivolt).

When the amplifier is used as an operational amplifier, the following restrictions are observed:

- The input signal times the gain with feedback should never produce an output greater than 5 volts.

- The input resistor is small compared to the input resistance of the operational amplifier. This limits the value to about **5K** (one-tenth of the input resistance). The feedback resistor can be any desired value.

- The input resistance of the following stage must be 1,500 ohms or more.

As you read this section, look at figure 3-37. The input stage is composed of transistor Q1 and is a grounded collector amplifier. The voltage divider in the collector circuit provides a small negative voltage for the collector of the transistor. This voltage, approximately –0.8 volt, allows the output of the stage to assume small negative values. The input voltage varies from zero to ±0.0002 volt. As a result, the output voltage of the first stage is in this range.

The second stage consists of transistor Q2, which is a common emitter amplifier. The 33-ohm resistor in the emitter circuit is part of the bias network for the stage; that is, the voltage divider network causes the emitter junction to be positive with respect to the base. This results in the flow of a small bias current. Also, the 33-ohm resistor causes a negative feedback to occur in the second stage. Although this feedback reduces stage gain, it also provides wide frequency response and reduces noise, drift, and other undesirable effects.

Transistors Q3 and Q4 form the third stage and the output stage. Both are high gain, common emitter amplifiers. Emitter resistors are used to provide self-bias. Positive feedback is used in these stages to offset the negative feedback introduced by the emitter resistors. The positive feedback is obtained by feeding a portion of the voltage developed across the collector resistors to the emitter. The emitter of the output stage also receives a bias voltage through the series resistor from the positive voltage supply.

A block diagram of the high-gain operational amplifier is shown in figure 3-38. By looking at this block diagram, you can see the feedback paths. Note that a single capacitor (C1) is used for phase shift correction. In addition, a special positive feedback path is provided for the higher frequency components of the input signal. The output of the third stage is in phase with the input because the input stage does not invert the signal.

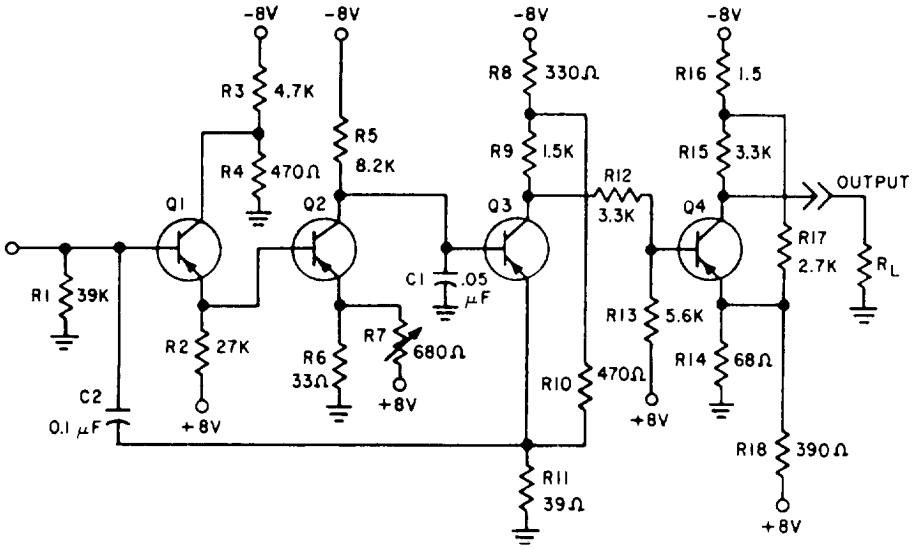


Figure 3-37.-A high-gain operational amplifier.

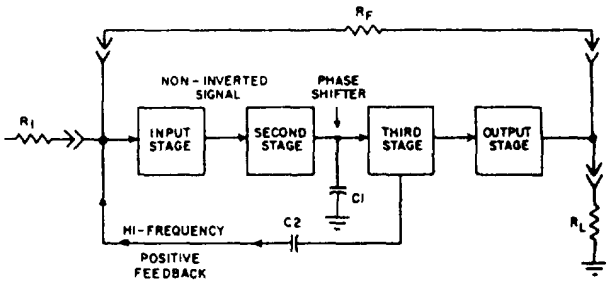


Figure 3-38.-Block diagram of a high-gain operational amplifier.

External feedback resistors are also shown in the block diagram. The gain, with feedback, can be varied from 1 (input resistor of 4.7K and feedback resistance of 4.7K) to 10 (input resistor of 4.7K and feedback resistance of 47K). Higher gains are obtained by using higher values of feedback resistance. In most analog computer applications, a gain of 10 is sufficient. Feedback in amplifiers is discussed in detail in Navy Electricity and Electronics Training Series (NEETS), module 8, *Introduction to Amplifiers,* NAVEDTRA 14180.

Electron tube amplifiers are also capable of solving multiplication problems involving two variables as represented by the equation

$$e_o = kxy.$$

Figure 3-39 shows a typical triode multiplication circuit. One variable input is applied as grid bias (preferably a dc voltage), which establishes the gain of the stage. The other variable input is applied to the grid of the tube.

The output is a proportional quantity equal to the grid signal modified by the gain, which is proportional to the variable bias voltage. This circuit is limited in scope and accuracy due to variations in tube characteristics, contact potential, plate and filament supply changes, etc.

An improved multiplying circuit is shown in figure 3-40, view A. Its operation is like the circuit shown in figure 3-39 except that it uses two separate grids. The voltage gain of the stage is controlled by the voltage on grid 3 (shown by the curve in figure 3-40, view B).

The gain of the amplifier is proportional to the voltage e_3 and may be expressed as follows:

$$A = ke_3.$$

If the output voltage e_o is directly proportional to e_1, the input signal is

$$e_o = Ae_1.$$

Substituting for A, the equation reads

$$e_o = ke_1e_3.$$

The output is a proportional quantity as indicated by the constant k.

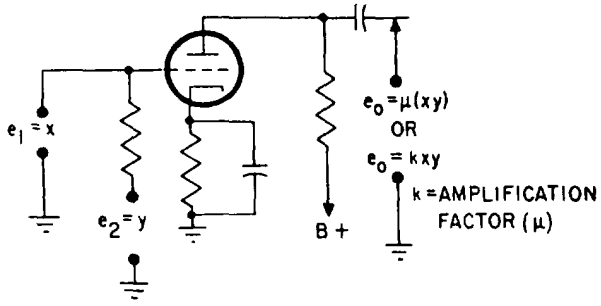


Figure 3-39.-Variable-gains tube as a multiplier circuit.

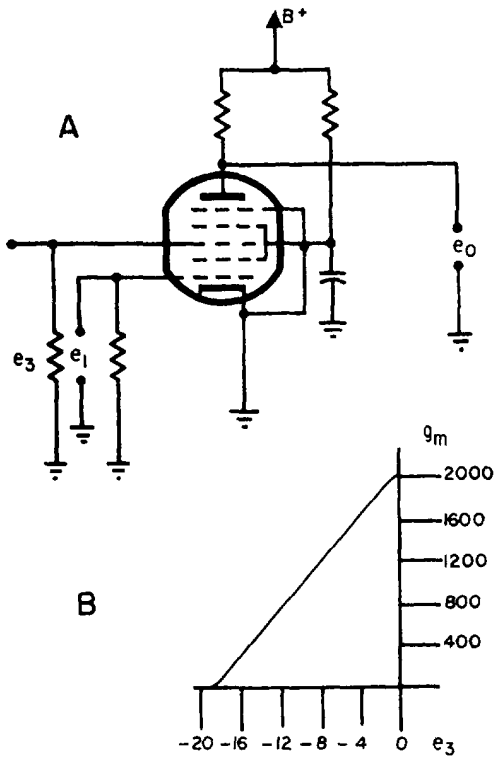


Figure 3-40.-A multielectrode tube used as a multiplier.

NOTE: In discussions of amplification as related to computers, it is common to emphasize that an odd number of amplifiers inverts the signal. This is interpreted mathematically by use of a negative sign; the symbol A (for amplification factor) is often written as –A.

Magnetic amplifiers are also used to multiply one factor by another. The saturable core reactor element in a magnetic amplifier makes the magnetic amplifier easily adaptable for multiplying operations. Its amplification is made proportional to a bias current over a limited range. However, accuracy is limited by variations in magnetic characteristics and winding resistance due to temperature variations.

ELECTROMECHANICAL METHODS.— Other than synchros, some of the electromechanical devices used for multiplication are potentiometers and precision variable autotransformers (usually known by the trade name *Variac).*

Precision potentiometers are frequently used as multipliers in aviation fire control equipment because they are accurate, rugged, simply constructed, and inexpensive. They are equally well suited for ac or dc applications. Figure 3-41 shows a typical potentiometer-type multiplier circuit.

The voltage occurring between the wiper and one end of the potentiometer is in reality the product of multiplying two quantities:

$$E_o = E_{in}\theta.$$

One quantity is the voltage impressed across the resistor element, and the other is the position of the wiper. When E_{in} is 100 volts and θ is 100 percent, E_o is equal to 100 volts. If θ is 50 percent of full-shaft rotation, E_o is equal to 50 volts. Such close correspondence is achieved only if the potentiometer is a precision device with linear resistance.

A grounded center tap on the potentiometer winding permits either positive or negative output, depending on the polarity of the input voltage and the position of the wiper shaft. The potentiometer multiplier actually multiplies a quantity by a factor of less than one. This presents no problem because the scale factor is adjusted to give the desired output.

Autotransformer multiplication is identical with potentiometer multiplication with one exception—the input must be an ac voltage. The input impedance of an autotransformer is high, and its regulation under load variations is very good due to the low dc resistance of the winding. The low output impedance of the variable autotransformer lets you connect it directly to other transformers, potentiometers, or inductive resolvers without intervening isolation amplifiers.

Division

Instrumentation of division problems in an explicit form is generally difficult to perform. However, division is done by taking the reciprocal oft he divisor and multiplying it by the dividend. This allows the use of less complex multiplication devices, a method normally found in avionics equipments.

ELECTROMECHANICAL DIVIDERS.— A rheostat, or a potentiometer connected as a rheostat in a voltage divider circuit, provides a means of dividing a voltage by a shaft position. The voltage divider is an extremely simple method of dividing. The input voltage is applied to one end of the rheostat; the second input is the shaft position of the rheostat. Figure 3-42 shows the operation of a rheostat divider network.

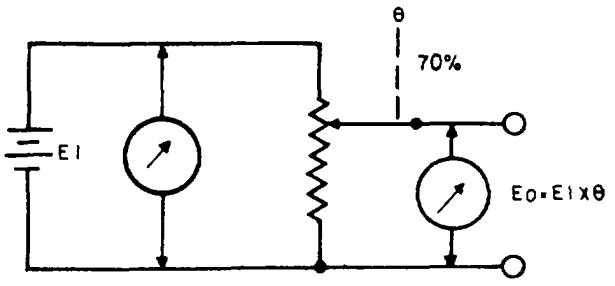


Figure 3-41.-Potentiometer-type multiplier circuit.

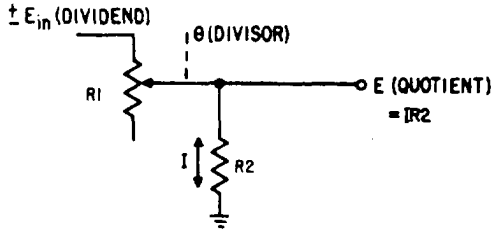


Figure 3-42.-Rheostat divider network.

Since the shaft position of the movable contact controls the series resistance, current is a quotient of voltage divided by the circuit resistance. The quotient can be obtained as a voltage across the fixed resistor R2, in series with the rheostat. As in any analog system of division, the divisor cannot go to zero since the quotient would then become infinity. R2 limits the current, and its value establishes the range of the divisor.

A voltage, E_{in}, is made proportional to one input, and the resistance R1 + R2 is proportional to the second input.

The current

$$I = \frac{E_{in}}{R1 + R2}.$$

The output voltage

$$E = \frac{E_{in}}{R1 + R2} \times R2$$

or

$$\frac{E_o}{R2} = \frac{E_{in}}{R1 + R2}.$$

Substituting K for the constant value of R2, and θ for the variable R1:

$$\frac{E_o}{K} = \frac{E_i}{\theta + K}.$$

The term *K affects* E_o only as a scale factor change. It affects θ only as a shift in value. For example, consider the equation for determining angular velocity.

$$\omega = \frac{S}{D} \text{ radians per second}$$

where S is linear velocity in feet per second, and D is the slant range with limits from 600 to 6,000 feet.

The value of R2 represents the minimum range of 600 feet and R1 + R2 represents 6,000 feet. Therefore,

$$\frac{R2}{R1 + R2} = \frac{600}{6,000} \text{ or } R1 = 9R2.$$

A value for R2 is selected that will produce reasonable current limits over the range of E_{in}. If E_{in} has a range from +100 to –100 volts, and the maximum current drawn is 10 mA, R2 becomes 10,000 ohms. R1 will then vary from 0 to 90,000 ohms as D goes from 600 to 6,000 feet. E_o at maximum speed and minimum range is as follows:

$$\frac{100 \times 10,000}{10,000} = 100 \text{ volts.}$$

When D = 6,000 feet, maximum speed produces an angular velocity output represented by an output voltage E_o of

$$\frac{100 \times 10,000}{90,000 + 10,000} = 10 \text{ volts.}$$

Since range cannot have a negative value, this method is only suitable when the divisor has the same polarity at all times.

Division can also be done using a servomechanism (fig. 3-43). The system has two

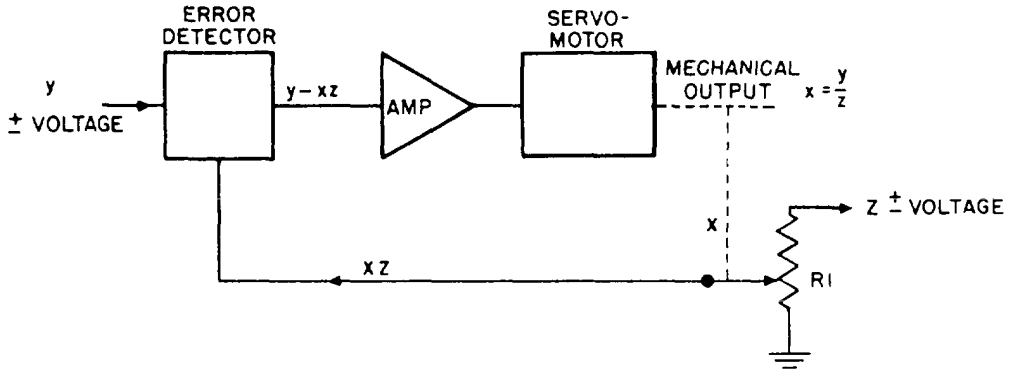


Figure 3-43.-Division with a servomechanism.

electrical inputs, whose amplitude and polarity are determined in other units. The voltage (Y) is fed directly to the error detector. The voltage (Z) is multiplied by the shaft position (X). The product (XZ) is fed to the error detector and compared with the input (Y). As in any servo system, the error voltage drives the servomotor in the direction that will cancel the error voltage, giving a zero output.

Servomechanisms are often used for implicit division in computers. Division is usually represented by the equation

$$X = \frac{Y}{Z}.$$

However, in order to use a servomechanism, the equation is arranged as

$$Y - X Z = 0 .$$

The instrumentation of the equation is shown in figure 3-43.

ELECTRONIC DIVIDERS.— Electronic division can be performed by inserting a vacuum tube in place of the variable resistor in a rheostat divider network. The plate resistance of the tube is varied by the voltage applied to the control grid.

Figure 3-44 shows the circuit of an electronic divider. The cathode resistor, R_K, performs the same function as R2 in figure 3-42. As in other electronic circuits, the circuit must be operated within limits determined by its components.

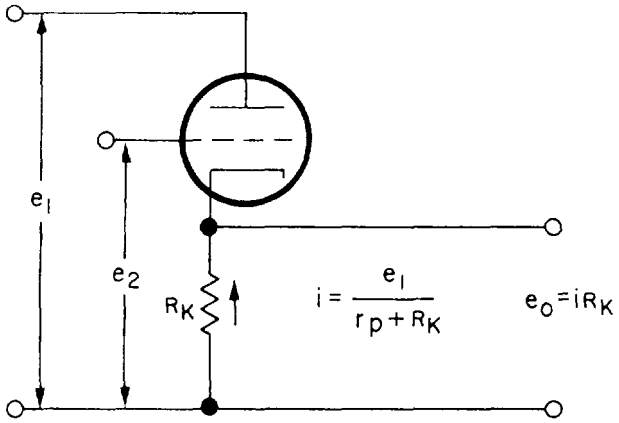


Figure 3-44.-Electronic divider circuit.

Q34. In mathematics, a linear function is graphed as a straight line. What mathematical operations are included in linear operations?

Q35. The proper application of scale factors makes the addition of physical units of an equation possible. What is the transformation formula for this?

Q36. Describe the components that comprise a typical summing amplifier?

Q37. What is/are the purpose(s) of using an odd number of multiple stages in operational amplifiers?

Q38. List some electromechanical methods used for multiplication.

Q39. State the equation a servomechanism would use in performing implicit division in a computer.

NONLINEAR FUNCTIONS

Learning Objective: *Identify power and roots, trigometric functions, and logarithms as nonlinear functions of analog computers.*

Instrumentation of various mathematical operations, such as raising a term to a power or extracting a root of a term, is discussed in this section. It also includes a discussion about the generation of trigonometric functions.

Most nonlinear operations are performed by mechanical, electromechanical, and electronic devices. However, one type of device is more adaptable to a particular operation than another. Nonlinear mathematical operations are also performed by special applications of the linear devices previously discussed. For example, a term may be raised to the second power by simply multiplying it by itself, using some type of linear multiplier.

Power and Roots

A variety of methods is used in aviation fire control equipment for solving problems involving powers and roots. The most common method uses electromechanical principles.

The solution of an armament control problem requires the use of devices capable of raising terms

to a power. In most cases, the term is raised to the second power (squared). There are several electronic circuits that can perform this operation. The simplest circuit is a modified multiplying circuit previously discussed and shown in figure 3-40. By applying the input value to both grids 1 and 3, the output voltage is proportional to the square of the input.

Another electronic circuit capable of squaring is the *squaring amplifier*. It consists of a paraphase amplifier, with its output driving push-pull triode amplifiers. Its output is also proportional to the square of the input, requiring a change in scale factor.

A common electromechanical method of raising a term to a power is by successive multiplication with potentiometer multipliers (fig. 3-41).

When the equation is $y = kx^2$, ganged potentiometers are used, provided that x is a common shaft position of the potentiometers. This circuit is shown in figure 3-45. The variable (x) may be raised successively to higher powers by repeating this circuit with additional potentiometers.

The voltage (ex) at the variable tap of R1 is proportional to x at all times. The voltage at the tap of R1 is fed through an isolating circuit to R2. The voltage to R2 is equal to ex. This voltage is again multiplied by x, and the output voltage at the variable tap of R2 is equal to x times ex, or ex^2.

Using the values shown in figure 3-45, the squaring process is explained mathematically as follows: The fixed voltage e corresponds to the constant k, in the expression y = kx. Placing the two forms of the equation side by side for comparison,

$y = kx^2$	$e_o = ex^2 = [ex](x)$
$y = 100(0.50)^2$	$e_o = [(100)(0.50)](0.50)$
$y = 25$	$e_o = 25$

The mechanization of these equations, in terms of percentage of travel by the potentiometer wipers, is described as follows: If the control of the potentiometers (x) were calibrated in equal units from 0 to 10, then 5 on the dial would represent 50 percent of total travel, and 50 percent of El would appear at the wiper of R1. With this 50 volts applied to R2 and the wiper of R2 at 50 percent of the travel, 25 percent (50 percent x 50 percent) of E1 will appear at the wiper of R2. If, in this case, the output meter is calibrated to read 0 = 100 volts, then it will read 25. In effect, we have squared the number 5.

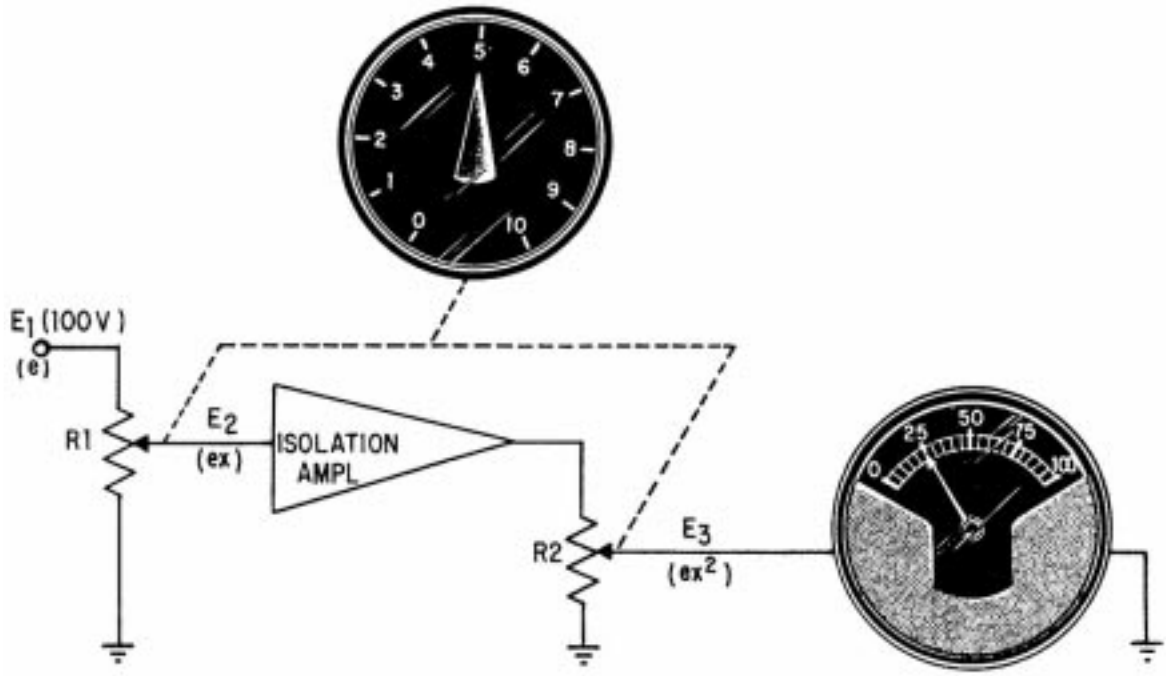


Figure 3-45.-Powers by successive multiplication.

The power to which a quantity can be raised is limited by the practical limits of voltage available to R1.

The root of a term maybe extracted by either electromechanical or electronic devices. In fact, any multiplying or integrating device capable of raising a term to a power and also capable of producing inverse functions is capable of producing roots. However, extracting roots is usually accomplished by electromechanical devices.

An electromechanical device for extracting the root of a term or number is the servomechanism feedback loop that uses ganged potentiometers, as shown in figure 3-46. The equation $y = \sqrt[n]{x}$ may be written as $x - y^n = 0$ by raising both sides to the *nth* power and transposing the y term. Now the equation is in the required form for servomechanism instrumentation. Square root is solved by multiplying the output quantity by itself and using this value as the feedback term. The output of the square root device is in the form of a shaft position.

Q40. A squaring amplifier consists of what other circuits?

Q41. The root of a term may be extracted by what types of devices?

Trigonometric Functions

Trigonometric processes are carried out with inductive resolvers, potentiometers, or

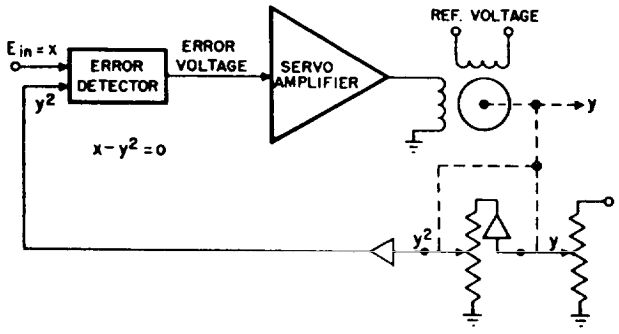


Figure 3-46.-Square root servomechanism.

all-mechanical devices. Electronic networks consisting of R and C are sometimes used to perform some trigonometric functions, such as vector addition.

The trigonometric functions most often used in avionics equipment are sines and cosines of angles. However, the four remaining functions may be computed based on the sine and cosine. If you are not familiar with trigonometry, you should study *Mathematics,* volume 2, NAVEDTRA 10071-B.

INDUCTIVE RESOLVER.— This is one of the most common ac electromechanical devices used to generate trigonometric functions. It is basically a right triangle solver, using windings to represent the sides and magnetic flux to represent the hypotenuse. The shaft rotation

ANSWERS FOR REVIEW QUESTIONS Q34. THROUGH Q39.

A34. Linear functions include operations that involve summation (adding and subtracting), multiplication, and division.

A35. Equation units × scale factor = analog units.

A36. The summing amplifier is the entire circuit including the summing network, the high-gain amplifier, and the feedback loop.

A37. The use of multiple stages increases gain, and an odd number of stages provides reversal of polarity between the input and output voltages for negative feedback.

A38. Synchros, potentiometers, and variacs.

A39. $Y - XZ = 0$.

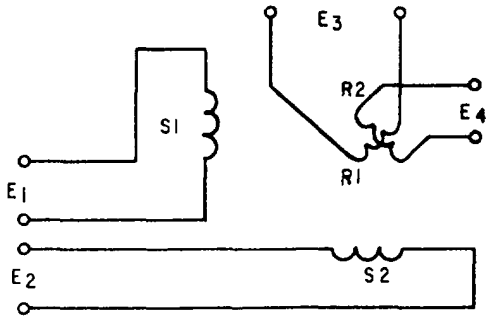


Figure 3-47.-Inductive resolver diagram.

corresponds to one of the angles of the right triangle that is to be solved.

The construction is very similar to that of a synchro except that both the rotor and stator have two windings oriented 90 degrees from each other, as shown in figure 3-47. Their primary use is to resolve a voltage into two components at right angles or to combine two component voltages into their vector sum.

When a rotor winding is parallel to one stator winding, the device acts as a one-to-one transformer. As the rotor winding is rotated, the voltage induced depends on the sine of the angle of rotation times the applied voltage.

$$E_o = (E_{in})(\sin\theta)$$

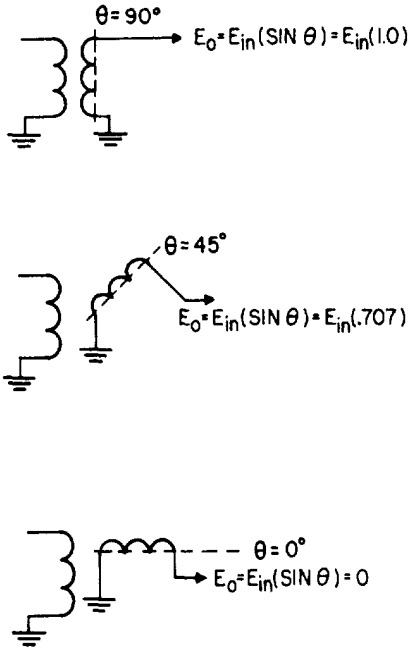


Figure 3-48.-Inductive resolver action.

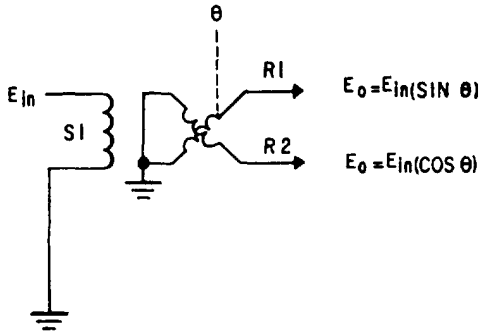


Figure 3-49.-Inductive resolver with two-phase winding.

Figure 3-48 shows the action of the inductive resolver for three positions.

If the second rotor winding (R2) (fig. 3-49) is at right angles to the first winding, its output will correspond to the cosine of the rotation angle, since

$$\cos\theta = \sin(\theta + 90°).$$

Resolvers are low-impedance devices. Isolation or booster amplifiers are generally used as driving circuits if the inductive resolver input signal originates in a high-impedance source, such as a potentiometer. Isolation amplifiers have a low output impedance and can correct for any undesirable phase shift developed in the resolver. Since inductive resolvers operate only with ac voltages, they cannot be used in dc analog computers.

Some operations require that the computer be capable of transforming data from a polar (fig. 3-50) to a rectangular coordinate system. If the position of a point or object is defined by a vector, the polar dimensions of the vector may be converted to rectangular coordinates. The vector quantity, distance r and angle θ, may be resolved into horizontal and vertical distances, x and y respectively, with a two-phase inductive

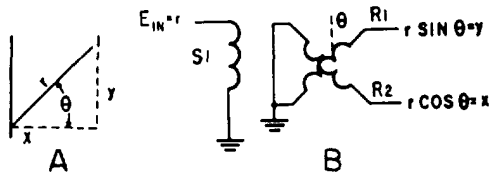


Figure 3-50.-Polar to rectangular transformation.

resolver. By feeding a voltage representing the distance r into the stator winding and rotating the rotor shaft through an angle corresponding to θ, voltages representing x and y are produced at the rotor windings.

POTENTIOMETERS.— Sine and cosine potentiometers are special devices used to select a voltage indicative of either the sine or cosine of an angle. Output voltages proportional to the product of the input voltage and either the sine or cosine of the angle through which the shaft is rotated can be obtained from the specially designed potentiometers.

Logarithms

The application of logarithms to perform multiplication and division was briefly discussed earlier in this chapter. By studying the logarithmic processes in *Mathematics,* volume 2, NAVEDTRA 10071-B, you can see that logarithms are also useful in raising a term to a power or extracting a root of a term. In this section, the primary concern is with computing devices for obtaining the logarithm of a term.

Under some conditions, diodes and contact rectifiers have nearly exponential variation of current with voltage or logarithmic variation of voltage with current. However, the operating limits of a single diode are surpassed by the requirements of most armament control computers. This limitation makes the use of circuits, such as the one shown in figure 3-51, necessary to produce logarithmic functions,

The purpose of this circuit is to produce an output voltage that is proportional to the logarithm of the input current. By looking at figure 3-51, you can see that R2, R4, and R6 form a voltage divider network. The cathode of each rectifier is connected through a resistor to some point on the voltage divider. This effectively acts as bias, causing each rectifier to be cut off until its anode reaches a potential higher than its cathode.

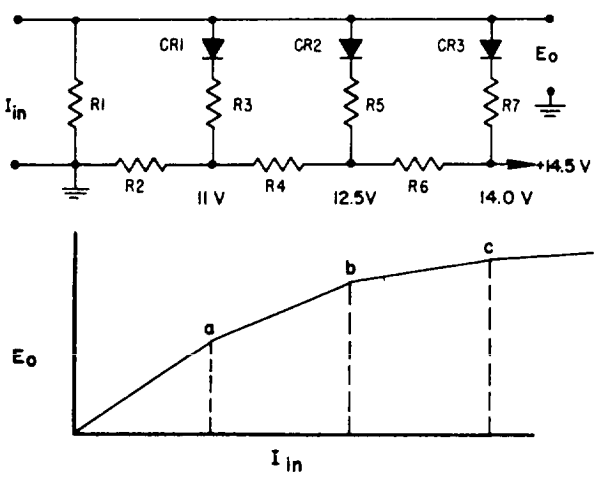


Figure 3-51.-Typical logarithmic shaping net work.

As the input current is applied, current flow is up through R1, producing an output voltage proportional to the current (E = IR). As the current, hence the voltage drop across R1, becomes great enough, the positive voltage at the top of R1 becomes great enough to bring CR1 into conduction. As soon as CR1 conducts, it effectively places R3 in parallel with R1, lowering the total resistance and producing less voltage drop for a given increase in input current. This accounts for the bend in the curve at point **a.** The circuit response curve shows how the slope is successively reduced as additional rectifiers come into conduction. Note that an increased number of rectifiers could result in a more perfect curve. However, the circuit shown provides an output well within the tolerances required for airborne computers,

There are several means available to obtain the antilogarithm of a quantity. This is done either by using an exponential characteristic directly or by using a feedback loop. Implicit methods may also be used, such as taking the derivative of the term in order to eliminate the logarithm in the equation.

ANSWERS FOR REVIEW QUESTIONS Q40. AND Q41.

A40. It consists of a paraphase amplifier with its outputs driving push-pull triode amplifiers.

A41. The root of a term may be extracted by either electromechanical or electronic devices.

Q42. What is the primary use of an inductive resolver?

Q43. Logarithm applications include multiplication and division, but also include what other applications?

CALCULUS

Learning Objective: *Recognize the various components of calculus as used in analog computers.*

Calculus is a branch of mathematics that deals with the rate of change of a function and with the inverse process. The inverse process is the determination of a function from its rate of change. The process of determining the rate of change of one variable with respect to another is known as *differentiation* or *differential calculus.* The process of determining the sum of many minute quantities is known as *integration* or *integral calculus.*

DIFFERENTIATION

Before going into the actual process of differentiation, you need to know the terminology used in the process. Consider the equation x = f(y). You should read it as x equals a function of y. If the derivative of x is taken with respect to y, then it would be written as

$$\frac{dx}{dy} = d\frac{[f(y)]}{dy},$$

which, in notation form, is

$$\frac{dx}{dy} = f'(y),$$

$$dx = f'(y)dy.$$

You should note that the prime indicates the first derivative of the function. When the derivative is a time derivative, it is common practice to shorten the symbol even more, especially for diagrams. For example, dx/dt (where t represents time) is often shortened to x (note the dot over the x).

Although y represents any variable, you are generally interested in the derivative with respect to time. The derivative of a quantity with respect to time can be thought of as the time rate of change of that quantity, For example, for motion along a straight line, the derivative of the distance traversed with respect to time is the velocity or the time rate of change of distance. Similarly, the derivative of a voltage with respect to time is the time rate of change of that voltage. Figure 3-52 is a graphic representation of the derivative of a voltage. If a voltage E_{in} is changing at a constant rate (fig. 3-52, view A), then the derivative E_o of that voltage has a constant value (fig. 3-52, view B).

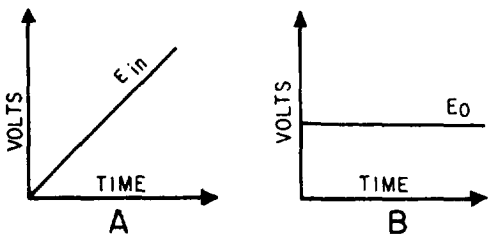


Figure 3-52.-Graphic representation of the derivative of a voltage.

Electronic Methods

The rate at which an input voltage is changing is obtained from a simple series-connected resistor and capacitor circuit (fig. 3-53, view A). Notice that the output voltage of this circuit appears across the resistor. With the proper values of R and C to provide a short RC time constant and with a square-wave input voltage E_{in}, the output voltage E_o is that shown in figure 3-53, view B.

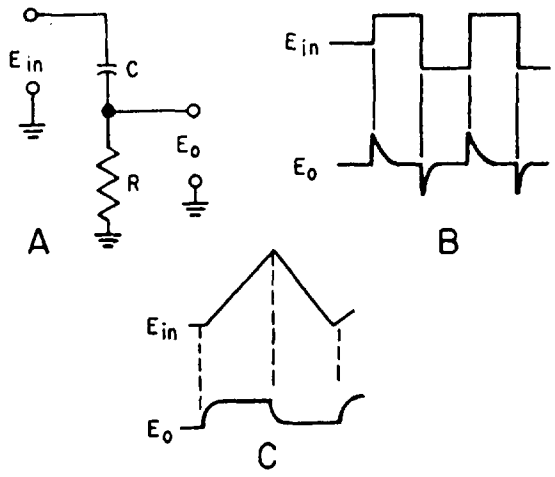


Figure 3-53.-Simple differentiating circuit.

When the rate of change of E_o is greatest and when the rate of change of E_{in} is zero, the output E_o tends toward zero. The derivative of a triangular wave or a sawtooth wave is shown in figure 3-53, view C. These facts show that the output voltage is approximately equal to the time rate of change (derivative) of the input voltage.

The primary disadvantage of the simple differentiating circuit is the time required for the output voltage to become equal to the derivative of the input voltage. Shortening the RC time constant to decrease this time decreases the amplitude of the output voltage. Also, you should be aware that the higher the output amplitude, the less the output resembles the derivative of the input voltage. Thus, for good discrimination, a small output voltage is required.

A feedback amplifier differentiator is shown in figure 3-54. This type of differentiator works better than the simple differentiator circuit. Its output voltage approximates the derivative of the input voltage in a much shorter time and with greater accuracy. However, the use of a differentiator circuit using a feedback amplifier is limited to those situations where introduction of electronic noise is not a serious problem. The differentiator circuit acts as a high-pass filter, and this causes amplification of circuit noise and introduces instability in the amplifier. In a circuit where noise is already a problem, differentiation must be accomplished by setting up an implicit function; this allows indirect differentiation by operating **in reverse** and using integrators.

The following discussion involves the application of a feedback amplifier. You should already understand the theory of negative feedback amplifiers. If, for some reason, you do not understand this theory, study module 8 of the Navy Electricity and Electronics Training Series (NEETS).

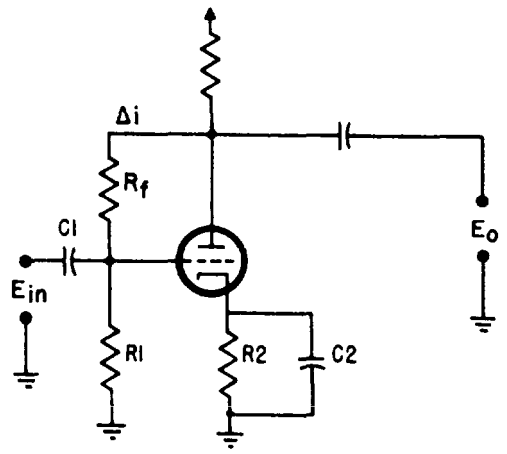


Figure 3-54.-Differentiating circuit using a feedback amplifier.

Before beginning the discussion about the operation of the differentiator amplifier circuit, the following conditions are established:

- The amplifier must be biased to operate near the center of its linear range and not draw any grid current when operating within its specified limits.

- The grid voltage is near ground potential and changes only a very small amount when the input signal varies. This occurs because the feedback voltage tends to prevent any change in grid voltage.

- Since the grid voltage remains almost constant, any change in plate voltage due to an input signal appears almost entirely across the feedback resistor, causing a corresponding change in current through it. Therefore, the output voltage E_o is given by the formula $E_o = -\Delta i R_f$. In this formula, E_o is the change in plate voltage resulting from an input signal applied to the grid,

ANSWERS FOR REVIEW QUESTIONS Q42. THROUGH Q43.

A42. An inductive resolver generates trigonometric functions, and primarily resolves a voltage into two components at right angles, or combines two component voltages into their vector sum.

A43. Logarithms are also useful in raising a term to a power or extracting a root of a term.

Δi is the change in current flowing through the feedback resistor, and R_f is the feedback resistor.

The formula can be restated simply by remembering that a differentiator produces an output **only** when there is a change in the input voltage. The amplitude of the output voltage (at) is equal to the change in feedback current (ac component), multiplied by the resistance of the feedback resistor. The negative sign serves to emphasize the fact that a polarity inversion is introduced by the amplifier.

Refer to figure 3-54. Consider the action of the circuit with a constantly changing voltage applied. For explanation purposes, consider a back-to-back sawtooth that is starting downward from its apex. As the negative-going signal starts downward, electrons from the grid side of C1 start to flow through R_f (electrons are attracted to the higher potential of the plate), causing the grid voltage to drop. This action reduces plate current, causing a rise in plate voltage. A portion of the plate voltage increase is fed back to the grid, causing it to rise in potential. However, since the feedback voltage is only a small portion of the plate signal, the grid cannot come back to its initial voltage. The grid and plate will reach a state of equilibrium almost instantly, and will remain balanced as long as the current through R_f is constant. With an input voltage that is linear, the discharge current of C1 remains constant through R_f until the input reverses its direction.

Since the plate is the source of the output, watch its action closely. Remember that the output is only the ac component of the plate voltage. When the input signal started downward, the plate voltage shot up and leveled off instantaneously, and it remained at this level until the input signal reversed its direction. This produced a square-wave output that is opposite in polarity to the input. The other half-cycle will produce a similar output. Therefore, the output is a voltage waveform indicative of the rate of change of the input voltage. In the fire control computer, this input voltage may represent an input variable such as range, and the output voltage may represent range rate or velocity.

Electromechanical Methods

When the derivative of a voltage is desired, a generator driven by a servomechanism is used. In this case, the servo transforms the voltage to be differentiated into a corresponding shaft position. A generator that is driven by the servo shaft produces an output voltage proportional to the speed of the motor. The rate generator voltage is a derivative of the rotor displacement with respect to time or a measure of the rate of rotor rotation. (See figure 3-55.)

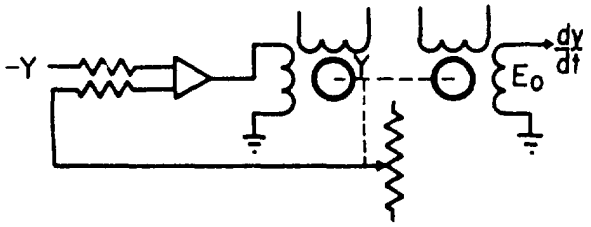


Figure 3-55.-Electromechanical differentiator.

The derivative range is limited by the response of the servomechanism. A system having moving parts with appreciable inertia cannot respond satisfactorily to a voltage step function where the slope is infinite.

INTEGRATION

Integration is the process of summing up an infinite number of minute quantities. In the solution of the armament control problem, integration is usually the summing of certain quantities in respect to time. For example, taking the integral of velocity between certain limits of time will give the distance traveled.

The process of integration is like determining the area under a curve. In the case of a step function input, the curve may be considered as a rectangle having one side variable with time. Look at figure 3-56, view A. The solid curve Y1

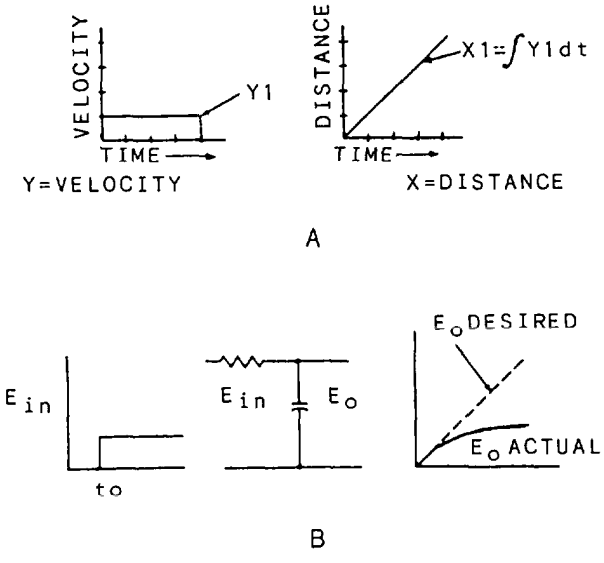


Figure 3-56.-Integration of area.

shows the velocity at any time—in this case, a constant velocity. The distance traveled is equal to the velocity multiplied by the time. With proper scale values, the distance is given by the numerical area under this (rectangular) curve; that is, area = height (or velocity) multiplied by length (or time).

On the distance-time diagram (fig. 3-56, view A), the sloping line X1 shows the total distance traveled at any instant of time, The larger the step input, the steeper the slope of the line in the distance-time diagram.

The distance traveled, X, must continue to increase as long as there is a positive value of velocity, Y. When X is represented by a voltage, there are limitations on its maximum value due to circuitry to be used.

The integral of a dc voltage is a voltage with constant slope, as shown in figure 3-57. Normally, there is no need for integrating dc voltages, but this effect is identical to the voltage wave for step inputs.

A simple integrator is shown in figure 3-58, view A. Here, a square-wave voltage is applied to the input, and the output voltage appears across the capacitor. During the positive portions of the input voltage, the output voltage is the sum of all the positive quantities, which results in an increasing voltage. During the negative portions of the input voltage, the output voltage is the sum of all of the negative quantities in the input, which results in a decreasing voltage. Look at the waveforms in figure 3-58, view B. Compare them wit h the output of the simple differentiator circuit. The integrator output and the differentiator output combined equal the instantaneous input voltage, except for circuit losses.

For further details on simple integrator circuits, review the discussion of this topic in the Navy Electricity and Electronics Training Series (NEETS), module 9.

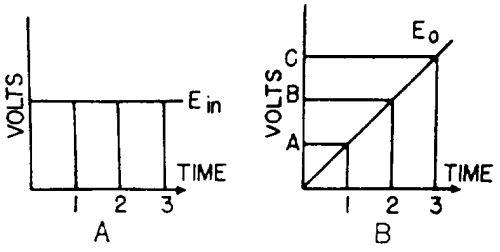


Figure 3-57.-Graphical representation of integration of a voltage.

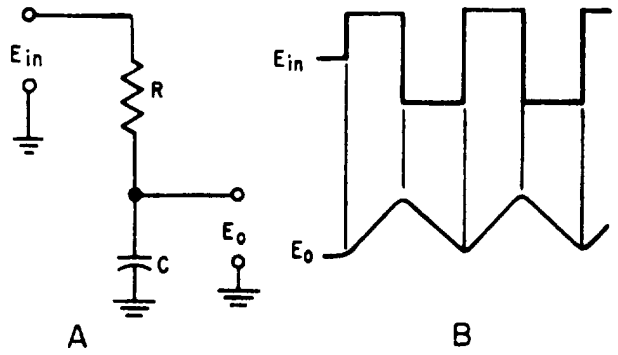


Figure 3-58.-Simple integrating circuit.

An integrating amplifier circuit using a feedback amplifier is shown in figure 3-59. This circuit is very similar to the differentiating amplifier circuit previously discussed. However, you should note that the negative feedback is coupled by a large coupling capacitor. This capacitor, along with the input resistor and load resistor, performs the integration. The amplifier functions only to improve its response and linearity. The input circuit also uses an isolation resistor (R_i) to allow the amplifier input to be maintained at an almost constant potential when an input signal is applied.

The output is based on the rate of charge, or discharge, of the feedback capacitor. The amplifier functions to maintain the charge, or discharge, of the integrating capacitor in the most linear portion of the RC curve. The net effect is that the capacitor voltage does not oppose the input voltage, and the capacitor-charging current is a direct function of the input signal voltage.

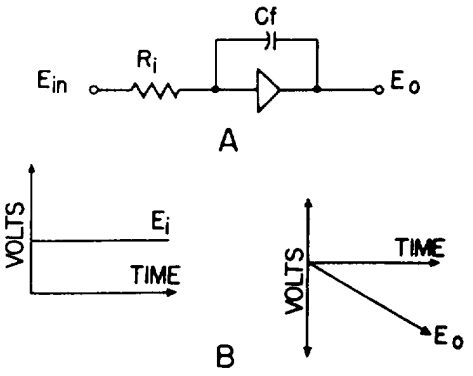


Figure 3-59.-A common integrating circuit.

Q44. Describe the process of differentiation and integration.

Q45. What calculus processing circuit is limited to use where electronic noise is not a serious problem?

Q46. What calculus circuit allows indirect differentiation by operating in reverse?

Q47. What components of an integrating amplifier use a feedback amplifier?

GROUPED OPERATIONS

Learning Objective: *Identify the grouped operations of an analog computer and problems encountered in computation.*

So far, you have learned about computing devices for performing various mathematical operations. Now, you are ready to learn about several instruments or devices grouped together for the solution of a problem. The grouping discussed will **not** make up a workable computer; it will show you that by grouping devices, the solution of more complex equations can occur. You should remember that this grouping may involve only a small portion of a complete computer.

PROBLEMS ENCOUNTERED

When various devices are selected to carry out a grouped operation, certain problems are almost certain to develop. Such problems are present even in grouping the simplest devices. Here again, this information is presented not to help you design a computer but to help you understand more complex computers.

Change of Representation

If two or more computing devices are connected, the use of two or more methods of representation is frequently required. The output of the first device may not have the same representation as required by the input of the second device. An example might be the multiplication of two voltages by a potentiometer-type multiplier. To multiply successfully, one of the voltages would have to be represented by a shaft rotation.

Scale Factor

Another problem that must be considered when grouping two or more devices is that of scale factor. As you have learned, a change of scale factor takes place any time the device produces a proportional output. Such devices include those that perform the operations of adding, multiplying, dividing, etc.

Impedance Matching

When the output of one electronic circuit is fed to another, the input impedance of the second circuit or stage may affect the operation of the first. Therefore, it is important that the input impedance of the second circuit be matched to the output impedance of the driving stage. A mismatch may result in an error in the computer, making the complete computer inaccurate. Two devices often used between two computing circuits are the emitter-follower and impedance-matching transformers. Impedance matching in the use of electrical components, such as resolvers and control transformers, must also be considered.

Speed of Computation

The speed of response of a device is important in a grouped operation. Some devices have a shorter response time than others. For example, a device with a minimum speed of computation time, when required to function longer than the minimum time, may lose a considerable percentage of its accuracy. The overall accuracy of a group of devices could be reduced below the desired tolerance due to one device requiring a longer time to function than the rest of the group. The speed of response is an important factor in regard to the stability of computers that use feedback.

TYPICAL EQUATION SOLUTION

In the solution of a navigation problem, it is necessary to find the hypotenuse of a right triangle when the length of the two sides is given. Navigation computers normally use ground range or horizontal range because ground range rates are more constant than slant range rates. However, to minimize the possibility of error, you convert computed ground range into slant range for comparison with observed radar range. This

requires a constant solution from the following equation:

$$r = \sqrt{H^2 + R^2}$$

where

r = slant range

H = altitude

R = ground range

A block diagram of a squaring-type triangle solver is shown in figure 3-60. The quantities H and R are squared and summed. The summed quantity $(R^2 + H^2)$ is fed to a device that extracts the square root, giving an output equal to r.

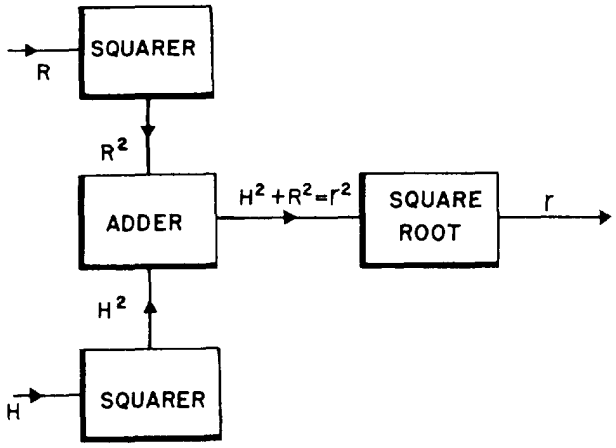


Figure 3-60.-Block diagram of right triangle solver.

A simplified circuit capable of performing the above operation is shown in figure 3-61. The quantities H, R, and r are represented by their respective shaft positions. Ganged potentiometers are used for squaring each quantity. A voltage proportional to $H^2 + R^2$ appears across R4 and is fed to a feedback amplifier. Here the signal is amplified, and the scale factor is corrected before being fed to the difference amplifier.

Potentiometers R15 and R16 are squaring potentiometers, with the output being a voltage proportional to r^2. This signal is also amplified and fed to the difference amplifier. If the voltage r^2 is equal to the voltage $H^2 + R^2$, the output from the difference amplifier is zero, and the position of the r shaft is indicative of

$$\sqrt{H^2 + R^2}.$$

However, if there is a difference in the two inputs, the output signal fed to the servo amplifier will cause the servomotor to rotate in a direction to reduce the difference voltage, thus correcting the output r.

Remember, this example is only one of many possible ways of solving for the values in a right triangle. It is included only to show you that the devices discussed earlier in this chapter may be grouped for the solution of more complex equations.

There are many applications of the analog-type computer in naval aviation. The trend in the development of today's weapons systems is

ANSWERS FOR REVIEW QUESTIONS Q44. THROUGH Q47.

A44. Differentiation is the process of determining the rate of change of one variable with respect to another. Integration is the process of determining the sum of many minute quantities.

A45. The use of a feedback differentiator circuit using a feedback amplifier is limited to those situations where introduction of electronic noise is not a serious problem.

A46. Integrators enable an implicit function.

A47. The feedback coupling capacitor, along with the input resistor and load resistor, performs the integrator.

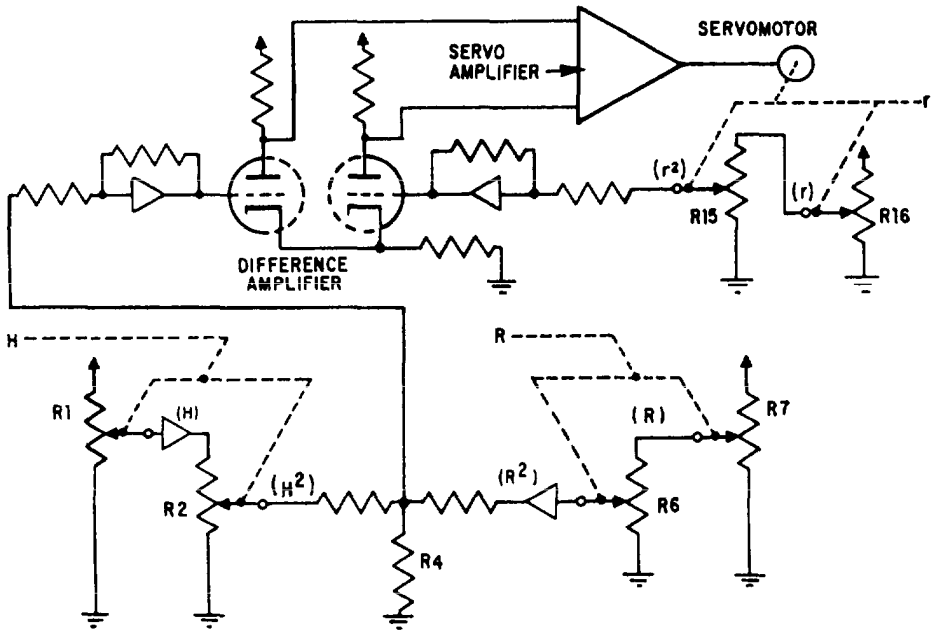


Figure 3-61.-Schematic diagram of a right triangle solver.

toward computers known as **hybrids.** These computers are a combination of both analog- and digital-computing devices. This arrangement will probably remain for some time since many of the input and output services must be analog. Input devices of the analog type are required to receive the data from a radar set, airspeed probe, or a shaft position because this type of data is analog in nature.

Q48. When grouping various devices to carry out a grouped operation, what type problems can develop?

Q49. Describe the problem of impedance matching.

Q50. Name two devices used between two computing circuits for impedance matching.

ANSWERS FOR REVIEW QUESTIONS Q48. THROUGH Q50.

A48. Change of representation, scale factor, impedance matching, and speed of computation.

A49. A mismatch may occur between stages of circuit input and output, which would cause an error in the computer.

A50. Emitter-followers and impedance-matching transformers.

CHAPTER 4

DIGITAL COMPUTERS

This chapter has been deleted. For information on digital computers, refer to Nonresident Training Course (NRTC) *Navy Electricity and Electronics Training Series (NEETS) Module 22*, NAVEDTRA 14194. For information on number systems and logic, refer to Nonresident Training Course (NRTC) *Navy Electricity and Electronics Training Series (NEETS) Module 13*, NAVEDTRA 14185.

CHAPTER 5

AVIATION SYSTEMS FUNDAMENTALS AND SUPPORT EQUIPMENT

Aviation Electronics Technicians (ATs) operate and maintain complex electronic installations in modern naval aircraft. To do this, the AT must know aircraft systems and support equipment (SE). Therefore, you, as an AT, must also understand the systems and SE of a typical aircraft, such as the power generation equipment, the conversion units, the power control, regulation, and protection devices, and the general power distribution systems.

AVIATION SYSTEMS FUNDAMENTALS

Learning Objective: *Identify systems characteristics for communications, navigation, radar, ECM, and ASW systems.*

In this chapter, you are introduced to a few equipments you may be responsible for maintaining. It includes coverage of displays, radar, IFF, air navigation, communications and data link, ECM, ESM, weapons control, and ASW acoustic and recorder systems. The *Aviation Electronics Technician* 2 *(Organizational),* NAVEDTRA 14030, and *Aviation Electronics Technician* 2 (Intermediate), NAVEDTRA 14029, contain a more in-depth coverage of these subjects. The specific maintenance instructions manuals (MIMs) contain in-depth information on specific systems and equipment.

DISPLAYS

Learning Objective: *Identify various types of displays used in aviation systems.*

To understand the basic fundamentals of any display system, you need to know the operation of cathode-ray tubes (CRTs), amplifiers, power supplies, and other solid-state devices. For more information about CRTs and related circuitry, you should refer to Navy Electricity and Electronics Training Series (NEETS), modules 6, 7, 8, 16, 18, and 21 for help in understanding electronics and troubleshooting many different types of display systems.

Display systems can range from a simple monitor to a highly sophisticated head-up display (HUD). They include radar and loran indicators as well as most systems that use a CRT or visual display. Most display systems contain a CRT and associated circuitry to present information using a PPI-scan, A-scan and/or graphics, alphanumerics, and conies generation. The next section of this chapter contains information about some typical radar indicators. The various types and operational principles of radar indicators, such as the A-scope, B-scope, and PPI-scope, are discussed in NEETS, module 18.

A-Scope

Figure 5-1 shows a simplified block diagram and scan presentation of a typical A-scope. The A-scope is only included to show you how scopes work. Then, the more advanced types are discussed.

In the operation of the A-scope, an initial trigger pulse from the timer is applied to both the radar transmitter and the one-shot (monostable) multivibrator. The one-shot multivibrator generates the following:

- A negative gate pulse that is fed to the range marker generator and the range sweep generators
- A positive gate pulse that is fed to the control grid of the CRT

The gate pulse to the range marker generator causes a series of equally spaced range marks to be generated. These range marks are added to the receiver output signal in the video mixer. The output of the video mixer is applied between ground and one vertical-deflection plate of the

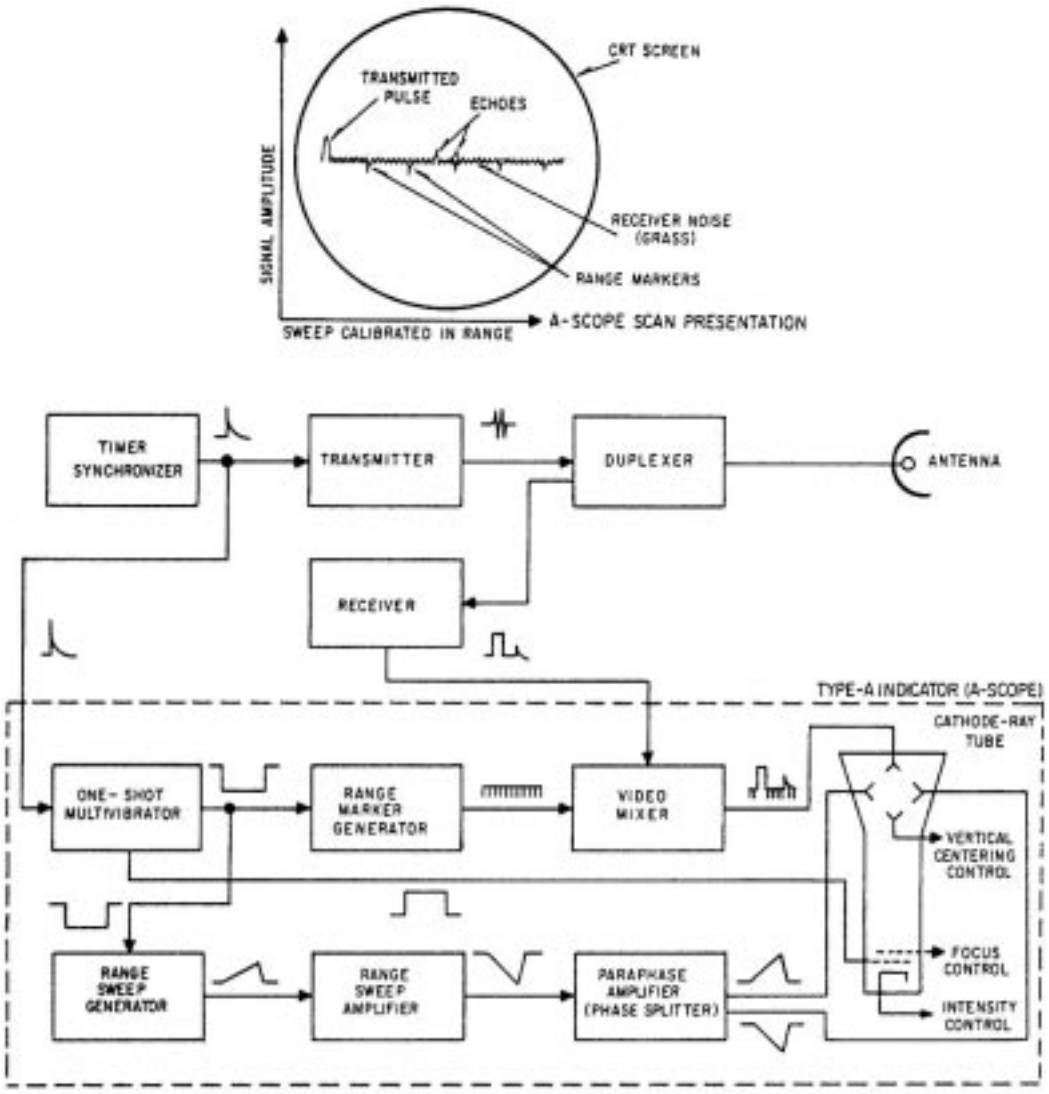


Figure 5-1.-Typical A-scope block diagram and scan presentation.

CRT. The other vertical-deflection plate is connected to the vertical-centering control.

The negative gate pulse fed to the range sweep generator causes a nearly linear sawtooth sweep voltage to be generated. The different timing capacitors in the one-shot multivibrator and in the range sweep generator are connected to a common range switch. Therefore, when the operating range is changed, the RC time constants of both circuits are simultaneously changed.

When the duration of the negative gate pulse is changed, the duration of the sawtooth sweep voltage is changed; but, the amplitude of the sweep voltage is unchanged. Therefore, at different operating ranges, the scanning spot travels about the same distance across the A-scope screen. However, the speed of the scanning spot increases as the range setting is decreased.

The sawtooth output of the range sweep generator is amplified by the range sweep amplifier. Then, it is applied to the paraphase amplifier (phase splitter). The paraphase amplifier outputs the sawtooth sweep voltage in push-pull fashion to the horizontal-deflection plates of the CRT. This reduces defocusing of the electron beam.

The positive gate pulse applied to the control grid of the CRT intensifies the electron beam during the sweep time, displaying the output of the video mixer on the A-scope screen. When the positive gate pulse is removed, blanking results (the electron beam is cut off).

Clamping circuits are frequently used with A-scopes. They keep the display properly positioned despite changes in the average (de) value of the sweep or signal voltages. Remember, clampers hold one part of the signal waveform at a constant voltage level. In some A-scopes, expanded sweep circuits are used. These circuits let a small section of the sweep expand to cover the A-scope screen. Thus, more accurate range measurements are made.

B-Scan

The B-scan represents a compromise between the extremes of simple and complex circuitry. When radar requirements call for simple circuitry and construction, the B-scan is used. In the B-scan, three variables are possible:

1. Range (a function of time)
2. Azimuth (a function of antenna rotation)
3. Intelligence received by the radar or associated equipment

B-scan circuitry involves the simplest circuitry construct ion of any two-dimensional presentation, yet it presents information as a reasonably faithful replica of the area scanned by the antenna (fig. 5-2). It works best under conditions where the antenna scans a sector of less than 180 degrees. However, it can be used in a situation where a 360-degree area is scanned.

Range is usually presented vertically by the use of a conventional sweep circuit. Azimuth is Presented horizontally by the use of a potentiometer mechanically connected to the antenna. The intelligence is presented on the indicator by intensity-modulating the sweep. The antenna scanning speed is approximately one scan per second, and the sweep speed is at the PRF rate; therefore, the intelligence has range and bearing.

C-Scope

C-scopes (fig. 5-3) present data on the bearing and elevation of targets. C-type indicators may

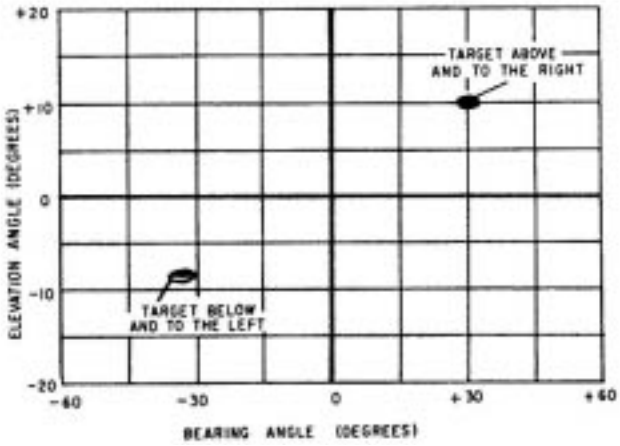


Figure 5-3.-C-scope presentation.

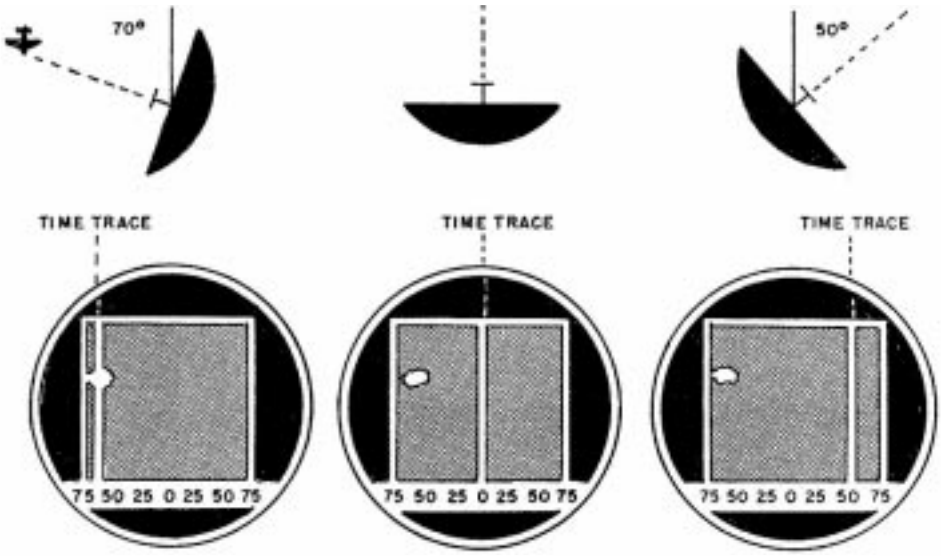


Figure 5-2.-B-scan presentation.

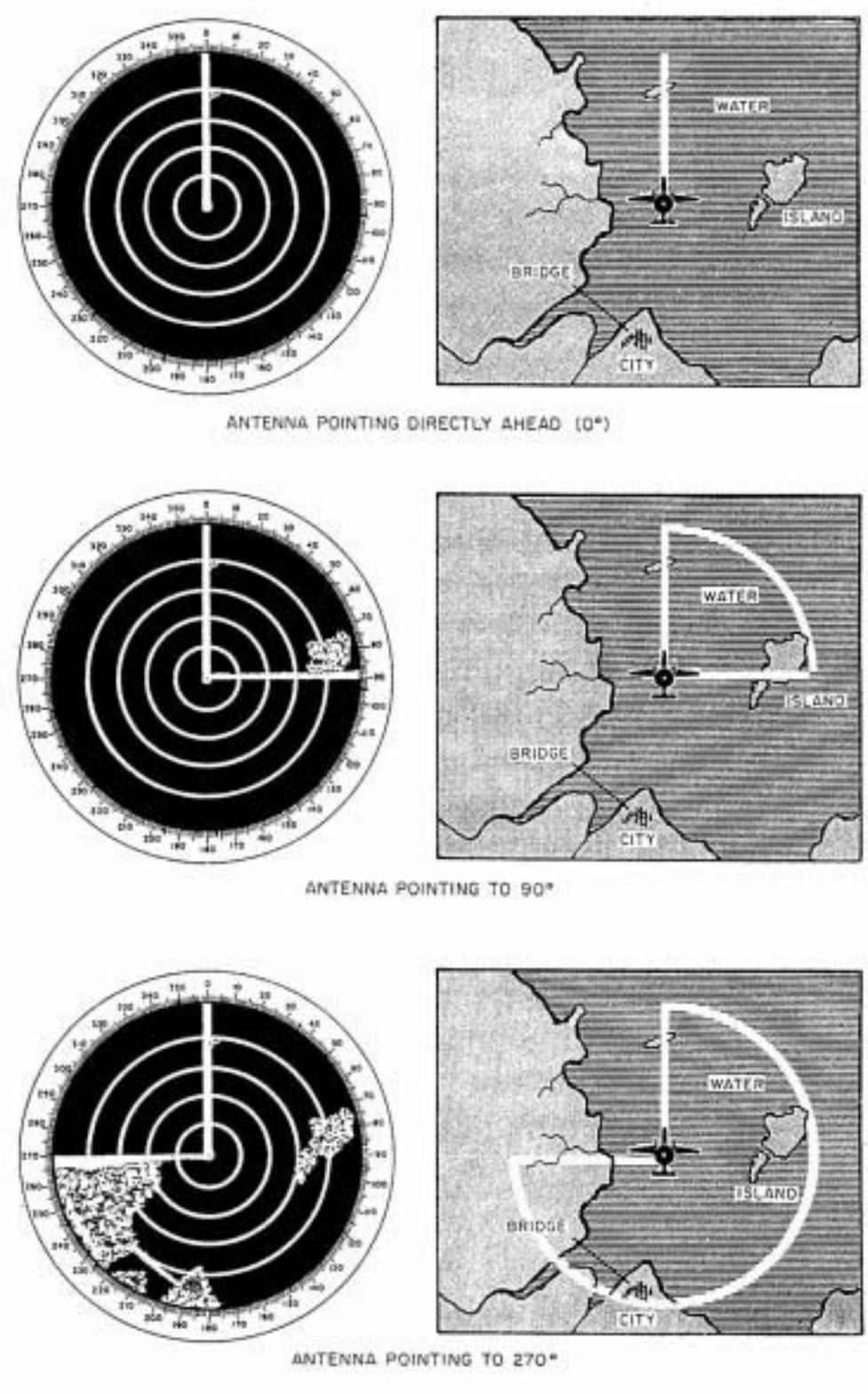


Figure 5-4.—PPI presentation.

sometimes be used in aircraft interception. Like B-scopes, C-scopes provide a rectangular display on their screens. However, in C-scopes, the vertical axis represents elevation and the horizontal axis represents bearing. Thus, in aviation fire control radar, targets may appear on either side of both the horizontal and vertical axes.

To get a rectangular display on the screen of a C-scope, both horizontal and vertical-sweep generators are used. Since the sweep frequencies are relatively low, potentiometers (like the azimuth sweep potentiometer of the B-scope) are generally used. These potentiometers are connected to the radar antenna,

When the antenna turns sideways, the scanning spot on the C-scope screen is deflected horizontally. When the antenna is tilted up or down, the scanning spot is deflected vertically. Echo signals, applied to the control grid (or cathode) of the CRT during the sweep period, cause the brightness of portions of the horizontal trace to be increased. The position of a bright spot indicates the elevation and bearing of a target.

Targets at different ranges, but with the same bearing and elevation, appear as a single spot on a C-scope. Targets of this kind cannot be distinguished individually on the C-scope. For this reason, an indicator that presents range data is generally used along with a C-scope. Once the range of a particular target is determined, a range gate pulse (rectangular pulse) is applied to the C-scope. This intensifies the electron beam only for the duration of the range gate pulse. Thus, only the desired target echo appears on the C-scope; all other signals are blanked out. By this means, the bearing and elevation of a particular target at a specific range is determined.

PPI-Scope

P-type indicators, known as *plan-position indicators (PPI* or *PPI-scopes),* are used to present the range and bearing data of targets. Like B- and C-scopes, PPI-scopes generally use CRTs with long-persistence screens.

The PPI presentation is practically an exact replica of the region scanned by the radar antenna. Distance along the radial sweep line represents target range. Rotation of the radial sweep line, synchronized with the antenna's rotation, produces a circular display.

When echo signals are applied to the control grid (or cathode) of the PPI CRT during the sweep period, the brightness of portions of the radial sweep line is increased, Like the B-scope, an increase in the brightness of portions of the PPI radial sweep line results in a maplike picture. Figure 5-4 shows a typical PPI presentation.

E-Scan (RHI)

The range-height indicator (RHI) (fig. 5-5) is another type of scan used to present range and height information. The RHI is also known as an *E-scan.* The E-scan is a modification of the B-scan on which an echo appears as a bright spot. The range is indicated by the horizontal coordinate and the elevation (height) by the vertical coordinate. This type of scan is used in directing aircraft during ground- and carrier-controlled approaches and in fire-control systems for terrain clearance.

Miscellaneous Presentations

Many other types of radar indicators are used. Often, more than one type of presentation is incorporated into one indicator. Most indicators in aviation fire control radar use two or more electron guns—one gun is used to develop a B-type presentation, and the other to develop the various elements of an attack presentation. These elements may consist of an elevation strobe, artificial horizon, steering information, acquisition circle, and range circle. Some of the systems and equipment that use displays include radar, IFF, and fire control.

RADAR

Learning Objectives: *Identify the characteristics of radar to include range, resolution, azimuth, and accuracy. Recognize the factors that affect radar performance. Identify the components of a pulse-modulated radar, and recognize the functions of the components within the system.*

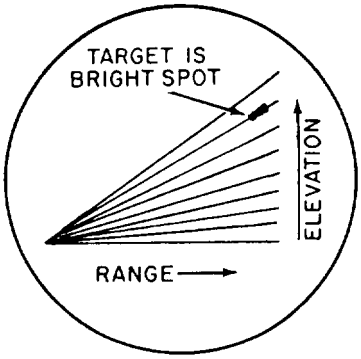


Figure 5-5.-E-scan presentation.

The word *radar* applies to electronic equipment used to detect the presence of objects. Radar determines an object's direction, altitude, and range by using reflected radio waves.

Characteristics of Radar

The characteristics of radar discussed in this section include the range, azimuth, resolution, and accuracy. Also, some of the factors that affect radar performance are discussed.

RANGE.– Radar measurement of range, or distance, is possible because radiated radio-frequency (RF) energy travels through space in a straight line at a constant speed. However, the straight path and constant speed are altered slightly by varying atmospheric and weather conditions.

Velocity.– RF energy travels at the speed of light, about 186,000 statute miles per second, 162,000 nautical miles per second, or 300 million meters per second. Radar timing is expressed in microseconds; the speed of radar waves is given as 328 yards or 984 feet per microsecond. One nautical mile is equal to about 6,080 feet. This means that it takes RF energy about 6.18 microseconds to travel 1 nautical mile.

Range Measurement.– The pulse-type radar set determines range by measuring the time it takes for the emitted pulse to travel to the target and return. (This is known as the *elapsed time.)* Since two-way travel is used in range measurement, the elapsed time for the pulse to leave the antenna, travel to the target, and return takes a total time of 12.36 microseconds per nautical mile. The range, in nautical miles, of an object is found—

1. by measuring the time that elapses during a round trip of the radar pulse (in microseconds), and
2. then dividing this quantity by 12.36.

Mathematically,

$$\text{range} = \frac{\text{elapsed time}}{12.36}.$$

The minimum range of a pulse radar is determined by adding the time of the transmitted pulse, or pulsewidth (PW), to the recovery time of the duplexer and the receiver. *Recovery time* is the time required for the receiver to become operative after the transmitter has fired. To find the minimum range (in yards) at which a target is detected—

1. add the PW (in microseconds) to the recovery time,
2. divide the result of step 1 by 2, and
3. multiply the result of step 2 by 328 yards.

Mathematically,

$$\text{minimum} = \frac{\text{PW} + \text{recovery time}}{2} \times 328 \text{ yd}$$

$$= (\text{PW} + \text{recovery time}) \times 164 \text{ yd}.$$

Targets closer than this range are not seen. The receiver is inoperative for the time necessary for a signal to travel this distance.

The maximum range of any pulse radar depends upon the transmitted power, PRF, and receiver sensitivity. The peak power of the transmitted pulse determines the maximum range that the pulse can travel to a target and return in usable echo strength. There must be enough time allowed between transmitted pulses for an echo to return from a target located at the maximum range of the system.

AZIMUTH.– The azimuth (bearing) of a target is its clockwise angular displacement in the horizontal plane with respect to true north. This angle is measured with respect to the aircraft heading. In this case, it is relative bearing. The angle is measured from true north, giving true bearing, if the installation contains azimuth stabilization equipment. The angle is measured by using the directional characteristics of a unidirectional antenna. Then the position of the antenna is determined when the strongest echo returns from the target.

RESOLUTION.– The range resolution of a pulse radar is the minimum resolvable separation, in range, of two targets on the same bearing, Range resolution is a function of the width of the transmitted pulse. The type and size of the targets and the characteristics of the receiver and indicator also affect resolution. With a well-designed radar, sharply defined targets on the same bearing are easy to resolve. Their ranges differ by the distance the pulse travels in one-half of the time of the pulsewidth (164 yards per microsecond of PW). If a radar set has a pulsewidth of 5 microseconds, the targets must

be separated by more than 820 yards before they could appear as two pips on the scope. The formulas for range resolution and minimum target separation are given below:

range resolution = PW x 328 yd

minimum target separation = PW x 164 yd

Azimuth resolution is the ability to separate targets at the same range but on different bearings. Azimuth resolution is a function of the antenna beamwidth and the range of the targets. The antenna beamwidth is the angular distance between the half-power points of an antenna's radiation pattern. Two targets at the same range appear as one target instead of two. They must be separated by at least one beamwidth to distinguish between them. Strong multiple targets appearing as one target are resolved in azimuth (bearing) by reducing the gain of the receiver.

ACCURACY.– The accuracy of a radar is a measure of its ability to determine the correct range and bearing of a target. To determine the degree of accuracy in azimuth, the effective beamwidth is narrowed. On a PPI scope, the echo begins to appear when energy in the edge of the beam first strikes the target. The echo is strongest as the axis of the beam crosses the target. The echo continues to appear on the scope as long as any part of the beam strikes the target. The target appears wider on the PPI than it actually is. The relative accuracy of the presentation depends on the width of the radar beam and range of the target.

The true range of a target is the actual distance between the target and the radar set (fig. 5-6). In airborne radar, the true range is called *slant range.* The term *slant range* indicates that the range measurement includes the effect of a difference in altitude.

The horizontal range of a target is a straight-line distance (fig. 5-6) along an imaginary line parallel to the earth's surface. This concept is important. An airborne target, or the observer's aircraft, only needs to travel the distance represented by its horizontal range to reach a position directly over its target. For example, an aircraft at a slant range of 10 miles at an altitude of 36,000 feet above the radar observer's aircraft has a horizontal range of 8 miles.

The timing sequence of a radar range-indicating device starts at the same instant that the transmitter starts operation. Therefore, with airborne surface-search radar, the first targets seen are those directly beneath the aircraft. However,

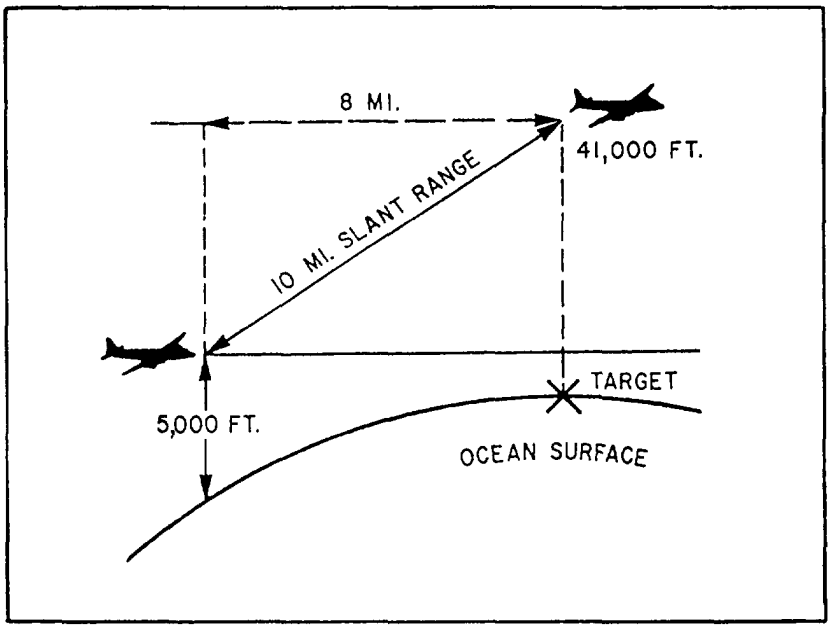


Figure 5-6.-Slant range versus horizontal range.

on the PPI scope, there is a hole in the middle of the picture (fig. 5-7), with a minimum radius corresponding to the altitude of the aircraft. The hole is known as the *altitude ring*. Objects directly beneath the aircraft appear on the scope at a distance equal to the distance between the aircraft and ground.

Factors Affecting Radar

Many factors affect radar performance; the principal one is **maintenance.** Keeping the equipment operating at peak efficiency affects the overall capabilities and limitations of the radar. A second factor is the radar operator's **knowledge** of the equipment. This knowledge must include the maximum and minimum ranges at which the operator can expect to pick up various targets, the range and bearing accuracy of the gear, and the range and bearing resolution. If the radar is a height finder, the operator must know the altitude determination accuracy and the altitude resolution. Some of the factors that affect radar are covered below. For more detailed information, you should refer to the maintenance instruction manual (MIM) for each radar.

PEAK POWER.—The peak power of a radar is its useful power. The range capabilities of the radar increase with an increase in peak power.

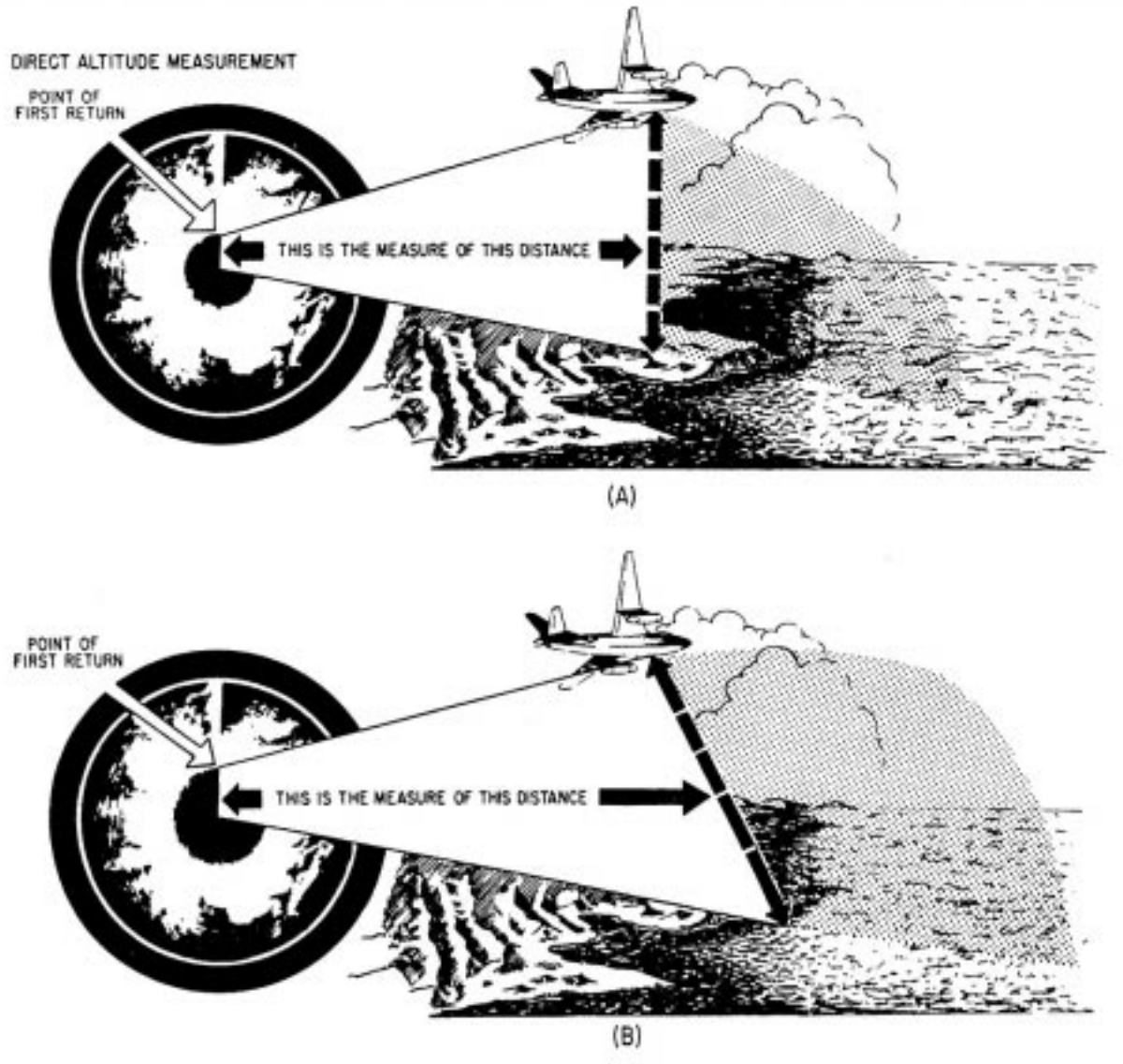


Figure 5-7.-Effect of altitude on radar. (A) Radar tilted down; (B) radar with zero tilt.

Doubling the peak power increases the range capabilities by about 25 percent.

PULSEWIDTH.– The longer the pulsewidth, the greater the range capabilities of the radar because of the greater amount of RF energy sent out in each pulse. In addition, because narrow bandpass receivers are used, the noise level is reduced. Remember though, an increase in pulsewidth increases the minimum range and reduces the range resolution capabilities of the system.

BEAMWIDTH.– The beamwidth is in degrees between the half-power points in the radiation pattern. The effective beamwidth of a radar is not a constant quantity, The receiver gain (sensitivity) and the size and range of the target affect it. The narrower the beamwidth, the greater the concentration of energy. The more concentrated the beam, the greater the range capabilities for a given amount of transmitted power.

RECEIVER SENSITIVITY.– The sensitivity of a receiver is a measure of the ability of the receiver to amplify a very weak signal. Increasing the receiver sensitivity increases both the detection range of the radar and the radar's ability to detect smaller targets. However, sensitive receivers are easier to jam, and interference shows on the scope more easily.

INDICATORS.– The choice of the type of scope used to display weak pips adds to the capabilities of the radar. A deflection-modulated A-scope would be more sensitive to weak echoes than the intensity-modulated PPI. A weak target is seen on the A-scope before it can be detected on the PPI.

ANTENNA ROTATION.– The more slowly the antenna rotates, the greater the detection range of the radar. Therefore, an antenna that is not rotating has the greatest range in the direction it is pointing. For tactical reasons, antennas are rotated. Pointing the antenna beam at the target momentarily allows you to gain information about the composition of a target.

Q1. The A-scope's positive gate pulse goes to the control grid of the CRT, causing the electron beam to _____.

Q2. What type of display works best under conditions where the antenna scans a sector of less than 180 degrees?

Q3. The PPI scope provides what type of presentation?

Q4. List the factors that affect the maximum range of pulse radars.

Q5. What are the characteristics of radar?

Q6. Define azimuth resolution.

Q7. Why does a long pulse width increase or decrease the range capabilities of a radar?

Functional Components of Pulse-Modulated Radar

The functional breakdown of a pulse-modulated radar can be divided into six essential parts (fig, 5-8).

1. The synchronizer (also known as the *timer* or *keyer)* supplies the synchronizing signals that time the transmitted pulses and the indicator. It also coordinates other associated circuits.
2. The transmitter generates the RF energy in the form of short, powerful pulses.
3. The antenna system takes the RF energy from the transmitter, radiates it in a highly directional beam, receives any returning echoes, and passes these echoes to the receiver.
4. The receiver amplifies the weak RF pulses returned by the target and reproduces them as video pulses, which are applied to the indicator.

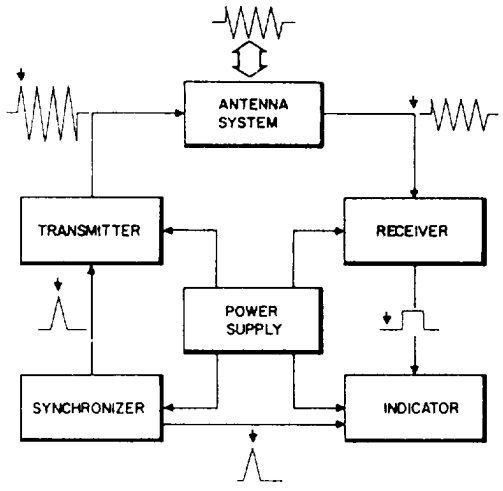


Figure 5-8.-Functional block diagram of a fundamental radar system.

5. The indicator produces a visual indication of the echo pulses in a manner that furnishes the required information.

6. The power supply provides the electrical power for the radar set.

The physical configuration of radar systems differ. However, the fundamental characteristics remain the same. Radar also works with the identification friend or foe (IFF) system. Normally, the IFF antenna is mounted on and shares the radar antenna, and its information is displayed on the same radar scope.

IDENTIFICATION FRIEND OR FOE (IFF)

Learning Objective: *Recognize IFF theory of operation to include interrogation and transponder functions.*

Identification friend or foe (IFF) was developed because of the destructive power of modern weapon systems and the speed of their delivery. You cannot wait to identify a detected radar target. Figure 5-9 shows a typical IFF system. It consists of an interrogator unit, a coder synchronizer unit, a search radar unit, and a

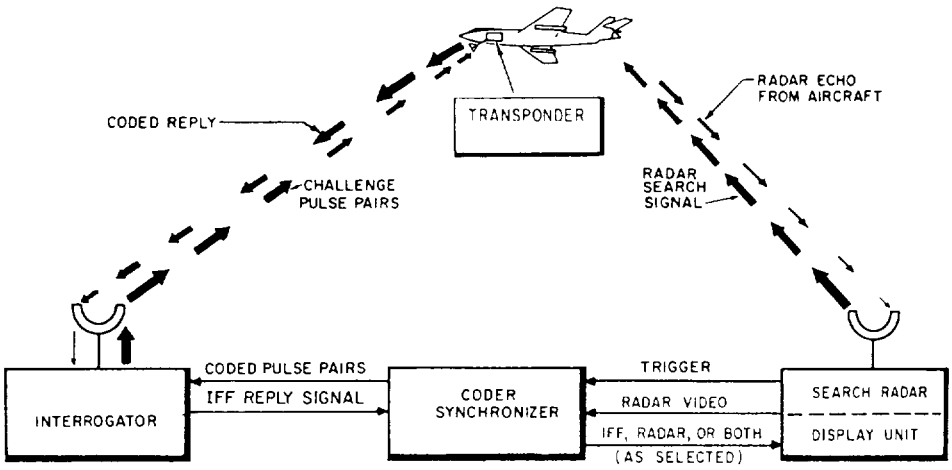


Figure 5-9.-IFF system block diagram.

ANSWERS FOR REVIEW QUESTIONS Q1. THROUGH Q7.

A1. To display the output of the video mixer.

A2. B-scan.

A3. A radial sweep line, maplike picture.

A4. Transmitted power, PRF, and receiver sensitivity.

A5. Range, azimuth, resolution, and accuracy.

A6. Azimuth resolution is the ability to separate targets at the same range but on different bearings.

A7. Because of the greater amount of RF energy sent out in each pulse.

transponder unit. The interrogator, synchronizer, and radar units make up the challenging station. The transponder unit is the responder station. By looking at figure 5-9, you can see that the challenging station can be a ground station, a ship, or another aircraft. The responder station is normally an aircraft.

There are five modes of IFF operation used by the air traffic control radar beacon system (ATCRBS) and naval aircraft–mode 1, mode 2, mode 3/A, mode C, and mode 4. In addition, there is a test mode used only by the aircraft transponder as a self-check of the transponder equipment.

Modes 1 and 2 are used exclusively by the military as tactical modes for target identification. Mode 3/A is used at military and civilian air traffic control stations. Mode C is used with an external pressure altitude digitizer to report the aircraft's altitude to an ATCRBS. Mode 4 is a military encrypted mode, which is controlled by an external computer. The operation of mode 4 is classified. Only interrogators and transponders using the same encrypted codes can respond.

NAVIGATION

Learning Objectives: *Recognize the navigation-related terms and definitions basic to inertial navigation system operation. Recognize the operating principles and characteristics of the inertial navigation system, to include Schuler loops and tuning. Recognize components and operating principles and features of airborne navigation systems used by the Navy.*

Navigation is the procedure by which you move from one point to another point. Air navigation is the process of directing the movement of an aircraft from one point to another. The function of air navigation is to locate positions and measure distance and time along the intended direction of flight.

Terms

As you read about air navigation, you must understand the terms that are being used. In this part of the TRAMAN, you will learn about some of these terms.

Position. Position is a point defined by stated or implied coordinates. One basic problem of navigation is to fix a position. If navigators do not know where they are, they can't direct the movement of the aircraft to its intended destination.

Direction. Direction is the position of one point in space relative to another, without reference to the distance between them. Direction may be either three-dimensional or two-dimensional. For example, the direction of San Francisco from New York is approximately west (two-dimensional). However, the direction of an aircraft from an observer on the ground may be west **and** 20° above the horizontal (three-dimensional). Direction is not itself an angle, but it is often measured in terms of its angular distance from a reference direction.

Course. Course is the intended horizontal direction of travel. For example, the direction of NAS Jacksonville from NAS Pensacola is east. This should be the intended direction of flight.

Heading. Heading is the horizontal direction in which an aircraft is pointing. Heading is the actual orientation of the aircraft's longitudinal axis at any instant. The term heading includes the following:

- True heading uses the direction of the geographic North Pole as the reference.
- Magnetic heading uses the direction of the earth's magnetic field at that location as the reference.
- Compass heading differs from magnetic heading by the amount of magnetic deviation.

Magnetic heading differs from true heading by the amount of magnetic variation at that location. Compass heading differs from true heading by the amount of compass error (deviation ± variation).

Bearing. Bearing is the horizontal direction of one terrestrial point from another. Bearings can be expressed by two terms—true north or the direction in which the aircraft is pointing. If true north is the reference direction, the bearing is a true bearing. If the reference direction is the heading of the aircraft, the bearing is a relative bearing. If you get a bearing by radio, it is a radio bearing; if visual, it is a visual bearing. You can accurately describe the direction between two

objects on or near the surface of the earth by saying: THE (RADIO, VISUAL) BEARING OF A FROM B IS X ± (RELATIVE/TRUE).

Distance. Distance is the separation between two points. To measure distance, you measure the length of a line joining the two points. This seems understandable enough. However, suppose that the two points are on opposite sides of a baseball. How do you draw the line? Does it run through the center of the ball or around the surface? If around the surface, what path does the line follow? You must **qualify** the term *distance* used in navigation to show how to measure the distance. The shortest distance on the earth's surface from NAS San Diego to Sydney, Australia, is 6,530 miles. If you travel via Honolulu and Guam, a frequently used route, it is 8,602 miles. You can express the length of a chosen line in various units, such as miles, kilometers, or yards.

Time. Time has many definitions. The two definitions used with navigation are—

1. the hour of the day, and
2. an elapsed interval.

The first appoints a definite instant, as *takeoff time is 0215.* The second definition appoints an interval, such as *time of flight, 2 hours 15 minutes.*

Poles. The earth's geographic poles are the extremities of the earth's axis of rotation. As the earth rotates, a man on the surface facing the direction of rotation has the North Pole on his left. East is in front of him, the South Pole is on his right, and west is behind him.

The earth has some of the properties of a bar magnet. The magnetic poles are the regions near the ends of the magnet. This is where the highest concentration of magnetic lines of force exist. However, the earth's magnetic poles are not at the geographic poles, nor are they opposite each other.

Great circles and small circles. The intersection of a sphere and a plane is a circle. The intersection is a great circle if the plane passes through the center of the sphere. It is a small circle if it does not.

Parallels and meridians. Look at figure 5-10. Here, the earth's equator is a great circle. If a second plane (fig. 5-11) passes through the earth parallel to the equator, its intersection is a small circle. If the small circles are perpendicular, then all points on the small circle are equidistant from the equator; that is, the circles are parallel to the equator. Such small circles, together with the equator, are *parallels.* Parallels are one component of a system of geographical coordinates,

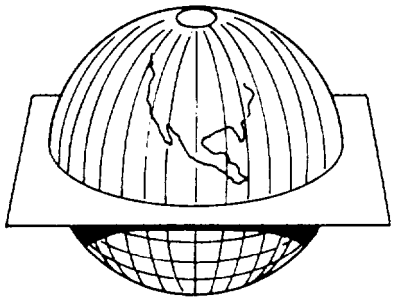


Figure 5-10.-The equator is a great circle whose plane is perpendicular to the polar axis.

Planes that pass through the earth's poles (fig. 5-12) form great circles. Great circles through the poles of the earth are *meridians.* All meridians are perpendicular to the equator. Meridians form the second part of a system of geographical coordinates. These coordinates are commonly used by navigators.

Latitude and longitude. Look at figure 5-13. You can identify any point on earth by the intersection of a parallel and a meridian. It is the same as an address *at the corner of Fourteenth Street and Seventh Avenue.*

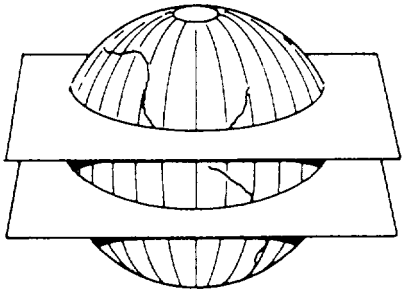


Figure 5-11.-The plane of a parallel is parallel to the equator.

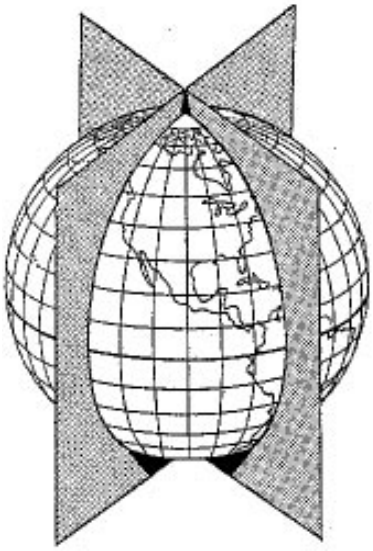


Figure 5-12.-Great circle through the poles form meridians.

You just use different names for identifying the parallels and meridians. Latitude is the north-south geographical coordinate and longitude is the east-west geographical coordinate.

Longitude is described as being east or west of Greenwich, England. This longitude at Greenwich is the *Prime Meridian* of 0°, the starting point. Longitude extends 180° east and west of the Prime Meridian, and it is broken down into degrees, minutes, and seconds.

A degree is divided into smaller units. However the common method of subdividing the degrees is by—

1. degrees—60 minutes (60'), and

2. minutes—60 seconds (60").

To convert minutes or seconds into decimals of degrees, divide by 6. Thus, 15°30' = 15.5°, and 15°30'24" = 15°30.4'.

Variation. The earth's true (geographic) poles and its magnetic poles are not at the same locations. Lines of magnetic force are not generally straight because of irregu-lar iron deposits near the earth's surface. Since a compass needle aligns to the lines of force at its location, it may not point to true or magnetic north. When connected together, lines connecting the locations on the earth where the compass does point to true north form an irregular line. This is the *agonic line.* At other locations, the angle between the direction of true north and the direction of the earth's magnetic field is the location's variation. Lines connecting locations having the same variation are known as *isogonic* lines. The earth's field direction may not be the same as the direction of the magnetic poles. This same angle is also often called the *angle of declination.* You label variation (or declination) east or west as the magnetic field direction

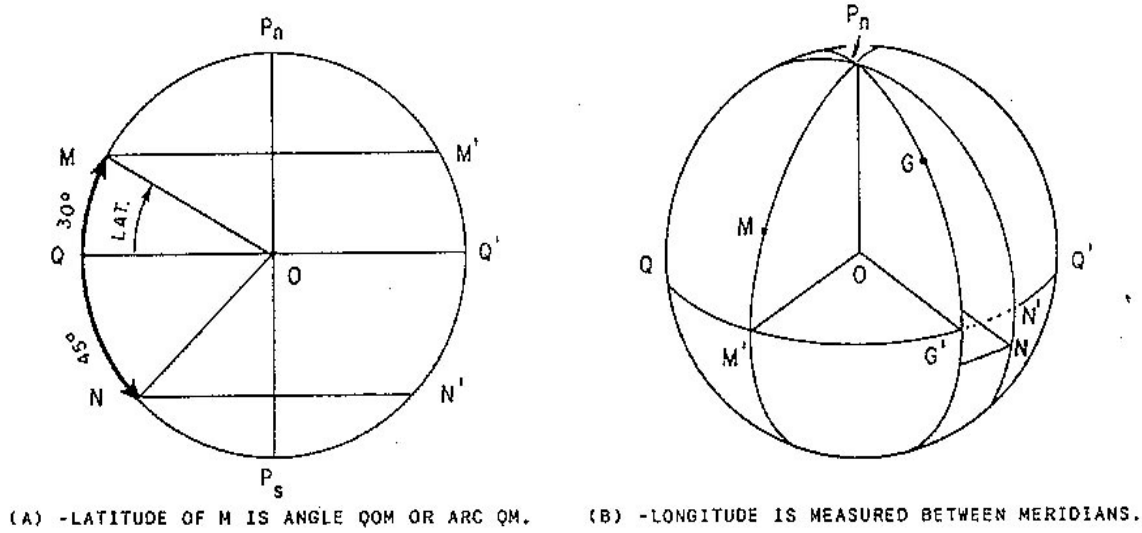


Figure 5-13.-Longitude and latitude.

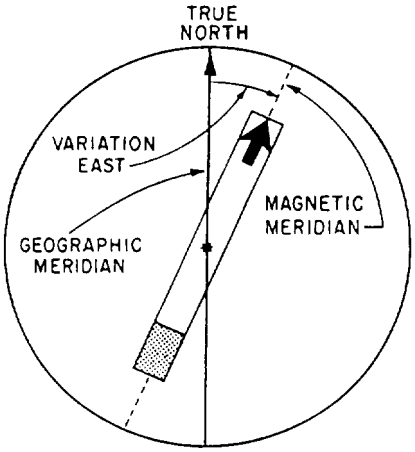


Figure 5-14.-Easterly magnetic variation.

is east or west, respectively, of true north. (See figures 5-14 and 5-15.)

Deviation. Deviation is the error in a magnetic compass caused by nearby magnetic influences. These influences may relate to magnetic material in the structure of the aircraft and to electrical (electronic) circuits. They deflect a compass needle from its normal alignment with the earth's magnetic field. These deflections are expressed as degrees. The deflection is east or west as the compass points east or west, respectively, of the earth's magnetic lines of force. Deviation varies with the heading of the aircraft. Figure 5-16 shows one reason for this deviation.

Compass error. The net result of both variation and deviation is the *compass error.* If

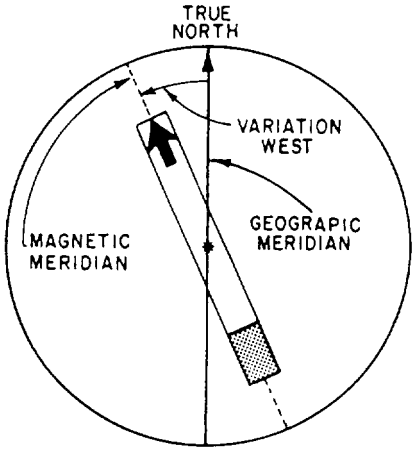


Figure 5-15.-Westerly magnetic variation.

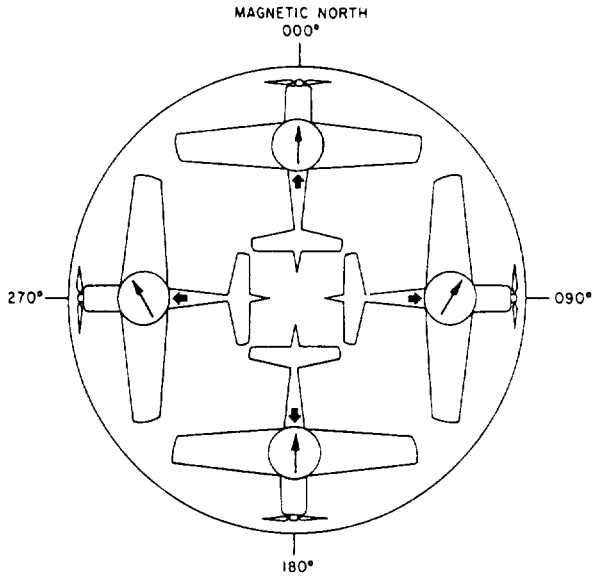


Figure 5-16.-Deviation changes with heading.

variation and deviation have the same name (east or west), you add to get compass error. If they have different names, subtract the smaller from the larger. Give the difference given as the name of the larger. (See fig. 5-17.) Label variation and deviation plus (+) if west, and minus (–) if east.

Example 1.

Given: Variation 7° west (W), deviation 2° west (W).

Required: Compass error.

Solution: 7°W + 2°W = 9°W. To fly a true course of 135°, this aircraft over this spot on the earth would fly a compass heading of 144°.

Example 2.

Given: Variation (–)2°, deviation (+)5°.

Required: Compass error.

Solution: (–)2° + 5° = (+)3°.

Magnetic dip. At the magnetic poles, the direction of the earth's magnetic field is vertical (perpendicular to the earth's surface). Along the *aclinic line* (sometimes called the *magnetic*

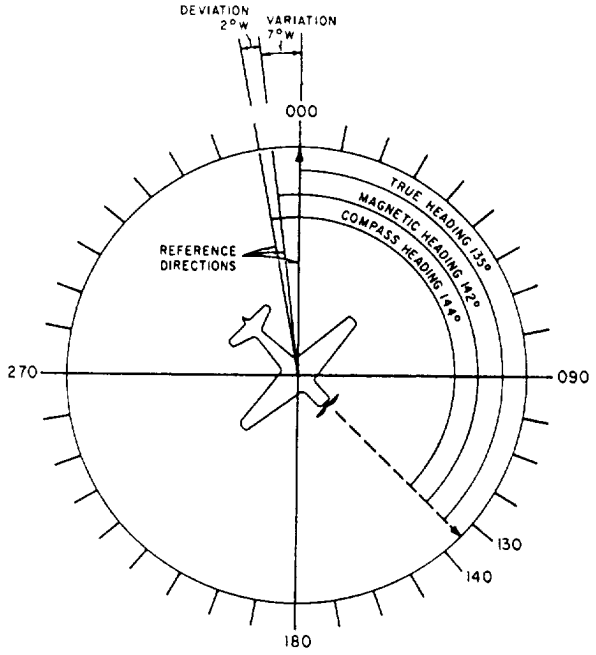


Figure 5-17.-Effect of compass error.

equator) roughly half way between the poles, the field's direction is parallel to the earth's surface (horizontal). The difference between the direction of the earth's field and the horizontal at any location is the *magnetic dip.* The magnetic dip varies from very small angles near the equator to very large angles near the poles. You can measure the angles with a dip needle, which is a magnetic needle free to turn about a horizontal axis. A line connecting all locations having equal dip angles is an *isoclinic line.*

Dead reckoning. Dead reckoning is the process of determining a position from the record of a previously known position, course, speed, and time traveled. To be accurate, every change of course and speed during the flight is considered. It does not matter whether the pilot or the air mass (wind) through which the aircraft is flying makes the changes.

Radar navigation. Modern radar is a valuable aid to navigation. Some radars present a maplike display of the terrain around the aircraft on the screen of a CRT. This lets the pilot go beyond some of the limitations of visual observations.

Radar transponders are devices that do not operate until interrogated or triggered into action by a signal from another radar transmitter. Then, they transmit their own signal, which the interrogating radar receives. These are used both as fixed navigational aids, such as radar beacon stations, and as airborne identification friend or foe (IFF) systems.

Doppler radar detects and shows actual ground speed and drift of an aircraft, regardless of wind speed or direction.

Radar altimeters give the actual distance from the aircraft to the surface below, The surface below can be a body of water or land mass far above sea level.

Radio navigation. Radio navigational aids vary from a fairly simple direction-finding receiver to complex systems using special transmitting stations. These special stations make it possible to fix the position of an aircraft with considerable accuracy. The usable range varies according to its intended use, and also with weather and ionospheric conditions. Beacon stations associated with an instrument landing system (ILS) are usually of low power. Long-range air navigation (loran) stations have a range extending to 1,400 miles under favorable conditions. Aviation Electronics Technicians (ATs) maintain the airborne portions of radio and radar systems.

Celestial navigation. Celestial navigation is the method of fixing the position of the aircraft relative to celestial bodies. Since the earth is constantly revolving, an accurate time device is necessary. In celestial navigation, three references are needed. The navigator tries, whenever possible, to select three bodies about 120 degrees apart in azimuth. This results in lines of position that cross cleanly and minimizes the effects of a constant error in the observations.

Inertial navigation. An inertial navigation system (INS) is a dead-reckoning device that is completely self-contained. It is independent of its operating environment, such as wind, visibility, or aircraft attitude. It does not radiate or receive RF energy; therefore, it is not affected by countermeasures. An INS makes use of the physical laws of motion that Newton described three centuries ago.

Air Navigation

Air navigation is the *process of determining the geographical position and maintaining the*

desired direction of an aircraft relative to the earth's surface. Certain conditions are unique to air navigation and have a special impact on the navigator.

- Continued motion. If necessary, a ship or land vehicle can stop and resolve any uncertainty of motion or wait for more favorable conditions. Most aircraft must keep going.

- Limited endurance. Most aircraft can remain aloft for only a relatively short time, usually a matter of hours.

- Greater speed. Navigation of high-speed aircraft requires detailed flight planning, navigation methods, and procedures that are quick and accurate.

- Effect of weather. Visibility affects the availability of landmarks. Wind directly affects the position of aircraft. Changes of atmospheric pressure and temperature affect the height measurement of aircraft using barometric altimeters.

The primary problem in air navigation is to determine the direction necessary to accomplish the intended flight, to locate positions, and to measure distance and time as means to that end. The following equipments are used in airborne navigation.

HORIZONTAL SITUATION INDICATOR (HSI).— Aircraft, such as the P-3, use the horizontal situation indicator to provide the pilot with a visual indication of the navigational situation of the aircraft.

BEARING-DISTANCE-HEADING INDICATOR (BDHI).— The BDHI is used with various navigation systems and provides information according to the mode selected. Some aircraft have more than one BDHI (fig. 5-18), wit h separate select switches for each instrument. The distance counter numerals may be in a vertical row or horizontal.

The lubber index is a fixed reference mark at the top of the instrument face. The compass card (read under the lubber index) shows the aircraft heading (either true or magnetic, depending on the mode used). Two pointers, a single bar and a double bar, can indicate the following:



Figure 5-18.-Bearing-distance-heading indicator.

- Bearing to a ground electronic station
- Bearing to destination
- Aircraft ground track
- Aircraft drift angle
- Heading error

The BDHI select switch selects the available combinations of these indications in a given aircraft configuration.

ATTITUDE HEADING REFERENCE SYSTEM (AHRS).— The AN/ASN-50 attitude heading reference system (fig. 5-19) generates and provides continuous roll, pitch, and heading signals. These signals go to the aircraft attitude indicator and other avionics equipment. Error signals develop in the displacement gyroscope as a result of displacement of synchro sensing devices from their null position. A remote compass transmitter supplies additional heading information to the system. For detailed information on the AN/ASN-50 system, you should refer to *Reference Altitude Heading,* NAVAIR 05-35LAA-1.

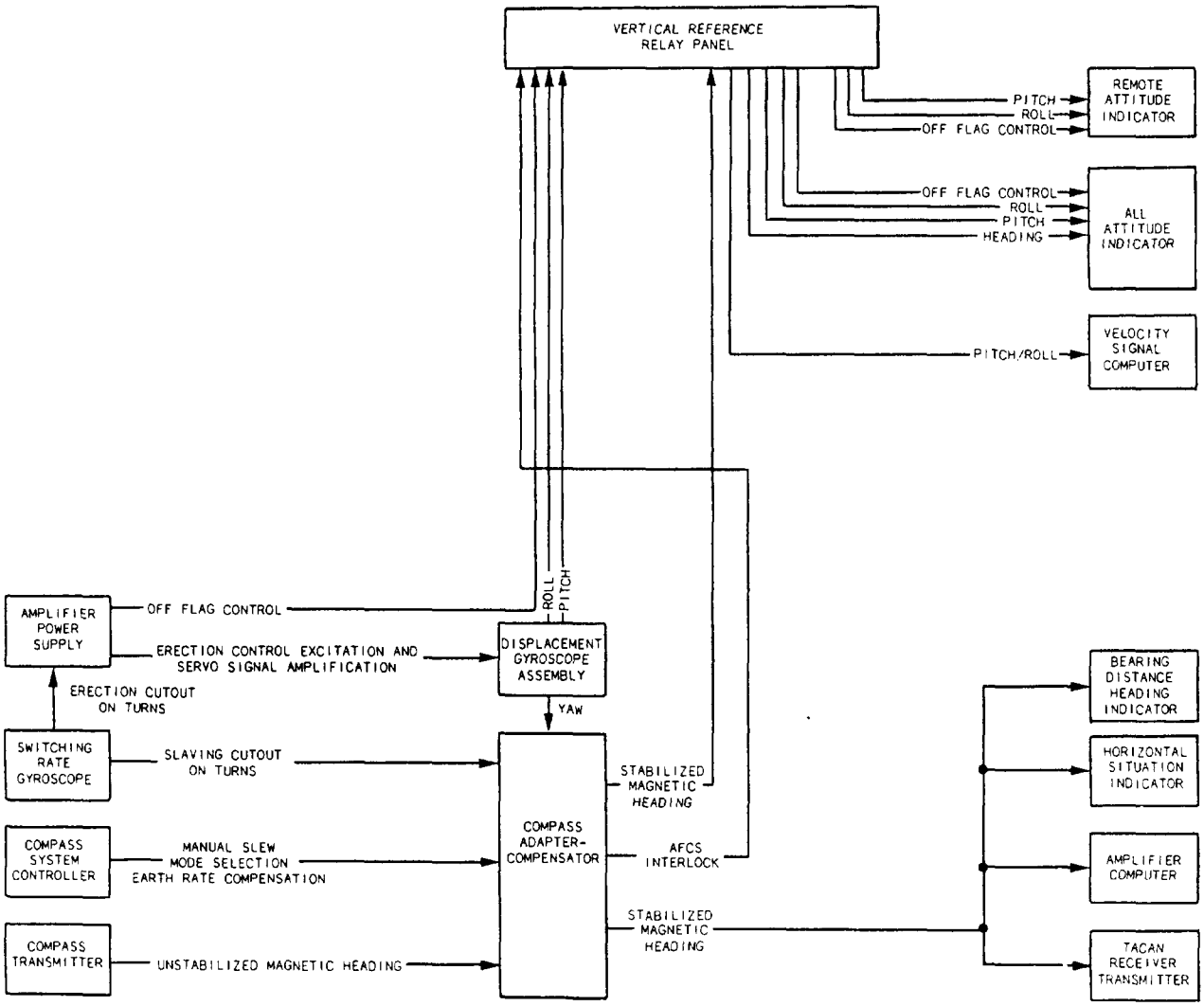


Figure 5-19.-Attitude heading reference system.

Q8. List the units in an IFF that make up the challenging station.

Q9. A point that is defined by stated or implied coordinates is known as a _____.

Q10. The intended horizontal direction of travel is known as _____.

Q11. In what two reference directions can you express bearings?

Q12. The east/west geographical coordinate is known as _____.

Q13. You measure longitude 180° east or west from what point?

Q14. The angle between true north and the direction of the earth's magnetic field is known as _____.

Q15. How do you label variation?

Q16. Magnetic influences cause what type of error in magnetic compasses?

Q17. The net result of both variation and deviation is known as _____.

Q18. You can determine a position from the record of a previously known position, course, speed, and time traveled by what process?

Q19. What navigation system makes use of the physical laws of motion that Newton described three centuries ago?

Q20. Describe navigation.

Inertial Navigation System

The inertial navigation system (INS) is sometimes maintained by personnel in the Aviation Electronics Technician (AT) rating. Some squadrons have an *integrated weapons team (IWT)*. It is composed of the three avionics/armament division (work center 200) ratings—AT, AO, and AE.

Navigation is defined as the process of directing a vehicle from one point to another. Navigation can be divided into two basic categories—position fixing and dead reckoning.

In position fixing, you determine position relative to positions of known objects such as stars and landmarks. The most common example of navigation by position fixing is celestial navigation. Loran is another example of navigation by periodic position fixes. Except for INS, navigation systems rely on some information that is external to the vehicle to solve its navigational problem.

Dead reckoning, the second category, is the process of estimating your position from the following known information:

- Previous position
- Course
- Speed
- Time elapsed

Two examples of navigation by dead reckoning are Doppler radar and inertial navigation systems.

BASIC PRINCIPLES.– The operating principle of the inertial navigation system (INS)

ANSWERS FOR REVIEW QUESTIONS Q8. THROUGH Q20.

A8. The interrogator, synchronizer, and radar.

A9. Position.

A10. Course.

A11. True north or the direction the aircraft is pointing.

A12. Longitude.

A13. Prime Meridian, 0 degree in Greenwich, England.

A14. Variation.

A15. You label variation east or west as the magnetic field direction is east or west, respectively, of true north.

A16. Deviation.

A17. Compass error.

A18. Dead reckoning.

A19. Inertial navigation.

A20. Air navigation is the process of determining the geographical position and maintaining the desired direction of an aircraft relative to the earth's surface.

is Newton's first law of motion. This law states *"Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed on it."* In laymans terms, this law says that a body at rest t ends to remain at rest. It also says a body in motion tends to remain in motion, unless acted upon by an outside force.

The full meaning of Newton's first law is not easy to visualize in the earth's reference frame. An inertial reference system can be defined as a nonrotating coordinate frame. It can be either stationary or moving linearly at a uniform speed in which there are no inherent forces such as gravity.

A true inertial system can exist only in empty space, far from any mass. A reference system attached to the earth can closely approximate an inertial system. For this system to work, you must balance the gravitational force on a body by a second force. For example, an object sliding on a flat, frictionless plane on the earth's surface moves in a **nearly** straight line. The object will have a **nearly** constant speed.

Newton's second law of motion is as important as his first law in an inertial navigation system because the inertial navigation system works on Newton's second law. Newton's second law of motion states *"Acceleration is proportional to the resultant force and is in the same direction as this force."* Written mathematically—

$$F = ma$$

where,

F = force

m = mass

a = acceleration

The physical quality in the equation that pertains to the inertial navigation system is acceleration. You can derive velocity and displacement from acceleration.

Differentiation is the process of investigating or comparing how one physical property varies with respect to another. *Integration,* the reverse of differentiation, is the process of summing all rate of changes that occur within the limits under investigation.

The inertial navigation system is an integrating system. Yet, before integration can be done, it must first have a rate of change. Therefore, the inertial navigation system is a detector and an integrator. It first detects changes of motion. It then integrates these changes of motion with time to arrive at velocity, and again with time to arrive at displacement.

DOPPLER RADAR PRINCIPLES.– Doppler radar uses continuous-wave (CW) radio-frequency (RF) transmission along with the *Doppler effect.* Pulse-type radar determines the distance to the target by measuring the period between transmission of a pulse and receipt of the reflected pulse. The CW Doppler radar senses velocity by measuring a proportional shift in frequency of the reflected signal. This frequency shift is the *Doppler effect.*

Airborne Navigation Systems

The airborne navigation systems now in use are classified as either self-contained or ground-referenced.

A self-contained system is complete in itself. It does not depend on the transmission of data from a ground installation. Some self-contained systems, such as search radar and Doppler radar, do require transmission of energy from the aircraft. Other self-contained systems, such as the inertial system and celestial-referenced aids, are completely passive in operation; they do not radiate energy from the aircraft.

Ground-referenced aids include all aids that depend on transmission of energy from the ground.

THE IDEAL SYSTEM.– Every navigation system has certain advantages and disadvantages. An ideal system would not have to contend with advantages of one system over another. Such an ideal system would have the following characteristics:

- Ground information. The system indicates the ground position of the aircraft.

- Global coverage. The system positions and steers the aircraft accurately and reliably any place in the world,

- Self-contained. The system does not rely on ground transmissions of any kind.

● Passive operation. The system does not betray the position of the parent aircraft by transmitting signals of any kind.

● Immune to countermeasures. The system is not susceptible to countermeasures of any type.

● Useless to enemy. The system does not provide navigational aid or intelligence of any kind to enemy forces.

● Flexible. The system is flexible. The system tracks the aircraft, even when unplanned deviations are made from the preflight course. The system also operates at any altitude and at any speed within the capability of the aircraft.

ADF.– Radio beacons transmit a nondirectional signal that is easily identified as a specific station. If an aircraft has automatic direction finding (ADF) equipment, the direction of the beacon from the aircraft can be determined. Most low-frequency, direction-finding equipment receives any frequency between 100 and 1750 kHz.

UHF/DF.– Some aircraft are equipped with automatic direction finders in the UHF frequency range (225.00 to 399.95 megahertz), which use loop and sensing (antennas) to give bearing information. Operation of the direction finder is controlled from the UHF radio panel. It is used to obtain a bearing to other aircraft and to emergency locator beacons that operate on 243.0 MHz and 282.0 MHz.

VOR/ILS.– The VHF omnidirectional range (VOR) is a radio aid that has practically eliminated interference due to atmospheric conditions. VOR stations operate between 108.00 and 117.95 MHz. Station identifiers for VOR navaids are given in code or voice or by alternating code and voice transmission. The VOR provides an infinite number of courses or radials from the station. The VOR also provides instrument landing system (ILS) capability. The transmission principle of the VOR is based on creating a phase difference between two signals.

RMI.– The RMI is a bearing indicator, usually with two pointers and a movable compass rose. The compass rose rotates as the aircraft turns, indicating the compass heading of the aircraft under the top of the index at all times. Therefore, all bearings taken from an RMI are magnetic.

BDHI.– The BDHI is similar to the RMI in that a pointer provides magnetic bearing information. Additional information concerning the BDHI is contained in the TACAN section.

HSI.– The HSI gives the pilot a visual indication of the navigational situation of the aircraft.

Tactical Air Navigation System (TACAN)

The tactical air navigation (TACAN) system provides the crew with information needed for precise positioning within 200 nautical miles. As with VOR, TACAN provides an infinite number of radials radiating outward from the station. In addition, distance measuring equipment (DME) provides continuous slant-range distance information.

TACAN operates in the UHF band and has 126 channels available in the X-mode pulse code. Pulse coding gives ground equipment the capability of an additional 126 channels in the Y mode. The station identifier is usually transmitted at 37.5-second intervals in international Morse code. Airborne DME transmits on 1025 to 1150 MHz; associated ground-to-air frequencies are in the 962 to 1024 MHz and 1151 to 1213 MHz ranges. Channels are separated at 1-MHz intervals in these bands.

TACAN DME is designed to provide range information to a maximum distance of 200 to 300 nmi, depending on aircraft equipment.

The air-to-air (A/A) function is provided to give distance information between two aircraft, working in the same manner as a regular ground-based TACAN station. Some sets provide only DME information. Newer sets provide both distance and bearing information to other aircraft. To obtain useful information, the A/A function should be selected by both aircraft with a 63-channel frequency separation, In addition, each aircraft must have the same mode (X or Y) selected. If one aircraft sets A/A channel 4 and the other sets A/A channel 67 in the X band, useful information should be obtained.

TACAN bearing is presented on an RMI (bearing), a BDHI, and a HSI (bearing and DME). The BDHI and HSI combine an RMI with a distance or range indicator, which saves space by displaying TACAN information on a single instrument.

Long Range Navigation (Loran)

The name loran is derived from the words long range navigation, which describes the hyperbolic system of electronic navigation, It provides lines of position over the surface of the earth. Over water, usable loran signals can be received at ranges up to 2,800 miles.

The loran system consists of a series of synchronized chain (set) of radio transmitting stations. These stations broadcast pulse signals similar to those used in radar with a constant time interval between them. The transmitting stations are the foci. The aircraft has a combination radio receiver and time difference measuring device. The measurements made by this equipment are used to make entries in tables or charts that identify the hyperbola on which the receiver is located.

The loran receiver is similar to an ordinary radio receiver, except that it has no speaker. The output of the receiver is fed to a loran base indicator. The base indicator is an electronic device capable of measuring the time difference between the receptions of the master and secondary signals with high precision. This indicator measures the time difference by one of the following methods:

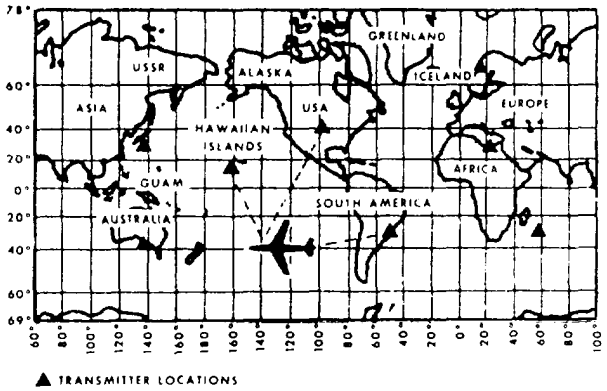
1. Using a CRT to provide a visual display of the incoming signals. By visually aligning these signals, a reading of the time difference measurement is obtained.
2. Automatically, by the loran set. It provides readings of the time difference.
3. Integrating with a computer to display latitude and longitude.

Readings obtained by these methods are plotted on a loran plotting chart, or, in the case of direct latitude/longitude readouts, they are plotted on any chart.

OMEGA Navigation System

Loran has significantly improved navigation over water and is very accurate up to 800 nmi. At distances over 1,000 nmi, sky waves must be used. Sky wave use causes a loss in position accuracy. Omega is an accurate long-range system that overcomes these problems.

The very low frequency (VLF) used by Omega transmitters increases range. To get an accurate fix, a navigator obtains simultaneous signals from three different Omega stations. There are only eight Omega stations worldwide; yet, they provide worldwide coverage (fig. 5-20). These eight



NAME	LATITUDE	LONGITUDE
NORWAY	N66°24'	E13°12'
LIBERIA	N06°18'	W10°36'
HAWAII	N21°24'	W157°48'
NORTH DAKOTA	N46°24'	W98°18'
LA REUNION	S21°00'	E55°18'
ARGENTINA	S43°06'	W65°12'
AUSTRALIA	S38°29'	E146°56'
JAPAN	N34°36'	E129°30'

Figure 5-20.-Omega transmitter locations.

stations actually operate at 10 to 13 kHz and use a signal phase difference rather than a time-of-arrival signal.

Omega transmitting stations operate in the internationally allocated very low frequency (VLF) navigational band between 10 and 14 kHz. The VLF lets Omega provide navigational signals at much longer ranges than other ground-based navigational systems. The eight transmitting stations provide worldwide coverage with an inherent potential fixing accuracy of 2 to 4 nautical miles 95 percent of the time.

Navigational Computer Systems

When automatic sensing devices are tied into a navigation computer system, the navigator is automatically provided current readings of present latitude and longitude, ground speed, and heading. The navigation computer system eases the navigator's workload and frees him or her to make the decisions that are beyond the capability of computers.

To handle the many flight conditions at the speed of sound or faster, the navigator uses automatic navigation computers. The navigational

computer system consists of the following components:

- The data-gathering units (sensors) such as radar, Doppler, INS, LORAN, and TACAN
- Computer units where the computations and comparisons are made
- Navigation panels containing the dials and controls that give the navigator a system-monitoring and control capability

SENSORS.– Sensors are data-gathering units such as radar, Doppler, INS, LORAN, and TACAN.

Radar.– When a radar set is incorporated into the computer system, movable electronic cross hairs are displayed on the radarscope so that range and direction of radar returns are measured and inserted into the computer (fig. 5-21). The cross hairs consist of a variable range mark and a variable azimuth mark. They are maneuvered with a cross hair control handle. On the radarscope, they resemble a single fixed-range mark and a heading mark. By moving the cross hair control handle, the navigator simultaneously changes the position of the cross hairs and the corresponding coordinate measurements (east-west and north-south) being fed to the navigation computers. The function is completed almost instantaneously.

When the navigator positions the cross hairs on a given return, the computers determine the distance between the aircraft and the return. If the coordinates of the return have been set in the computer, the computer can maintain a running account of the aircraft latitude and longitude.

Doppler.– Doppler radar's contribution to the computer system is ground speed and drift angle. These two outputs are put to several uses in the computer system. Doppler ground speeds is used to drive the present position latitude and longitude counters. Doppler outputs are used in platform leveling and in checking inertial ground speed in an inertial system. Doppler radar is an essential part of many navigation computer systems.

INS.– The INS is used to feed velocity information into the computers. Once the inertial sensor is leveled and in operation, it is used to continually update the present position counters.

Loran.– Loran fits in well with an automatic computer system. Some computer systems have

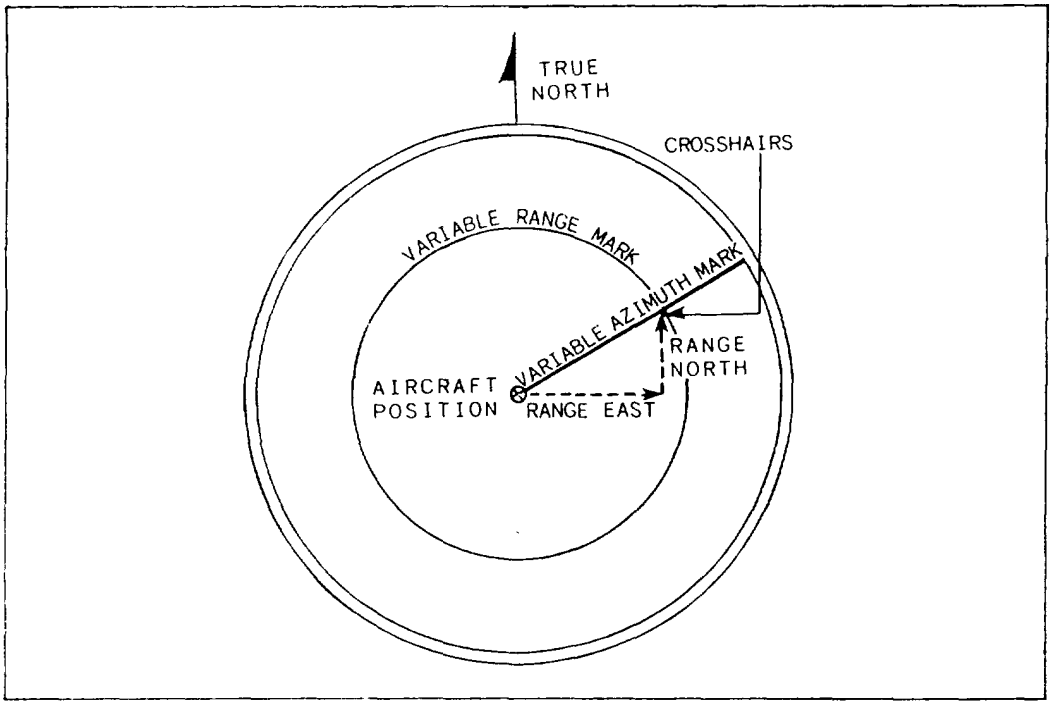


Figure 5-21.-Radar cross hairs.

the coordinates of loran stations stored in them. During flight, the navigator selects the stations, and the computer does the rest. Fixing is automatic and occurs in the same way that the navigator takes a celestial fix. An assumed position is determined by the computers; then, the loran position is applied to this assumed position. A series of credibility checks and approximations are applied automatically to the computer. The result is an accurate loran fix. When the computer functions in the loran mode, continuous present position and ground speed information is still available.

TACAN.– TACAN can easily be added to a computer system. Since the TACAN output is given in the form of a range and bearing, the computers only need the coordinates of the TACAN station being used. This data is set into the computer before the mission begins. Some corrections must be applied to TACAN outputs to increase accuracy. The bearings received from TACAN are magnetic; therefore, the computer must have an accurate magnetic variation value at all times. This is usually built into the computer. TACAN range output is expressed in slant range. The computer applies absolute altitude above the station to the slant range to produce exact ground range.

COMPUTER UNITS.– The two basic types of navigation computers are the analog and the digital computer.

Analog.– An analog computer is comparable to the navigator's handheld computer because a graphic replica of the problem to be solved is constructed to find the answer, The analog computer is generally larger than the digital computer because many components must be added to solve a wide variety of problems. The analog computer has one main advantage—it is not as sensitive to temperature and pressure changes as the digital system.

Digital.– The digital computer is generally lighter and more compact than the analog system. In some cases, the digital computer weighs less than 100 pounds. It computes navigation problems in the same way as the analog computer. It is unnecessary to design a digital computer expressly for the navigation problems it is to solve. Properly programmed, the same computer could be used in fields other than navigation. This is possible because the digital computer deals strictly with numbers. This requires that all inputs be changed to a numerical value before they are sent to the computer. Likewise, all outputs must be converted back to terms that are meaningful to the navigator.

NAVIGATION PANELS.– The navigation panels make up the greatest part of the computer system visible to the navigator. Panel appearance and operation vary with each computer system. The multitude of counters, dials, switches, buttons, control knobs, and selectors give the navigator maximum use and control of the system. Selectors that determine which sensors are used and which readouts are given let the navigator switch from one mode of operation to another, as shown in figure 5-22.

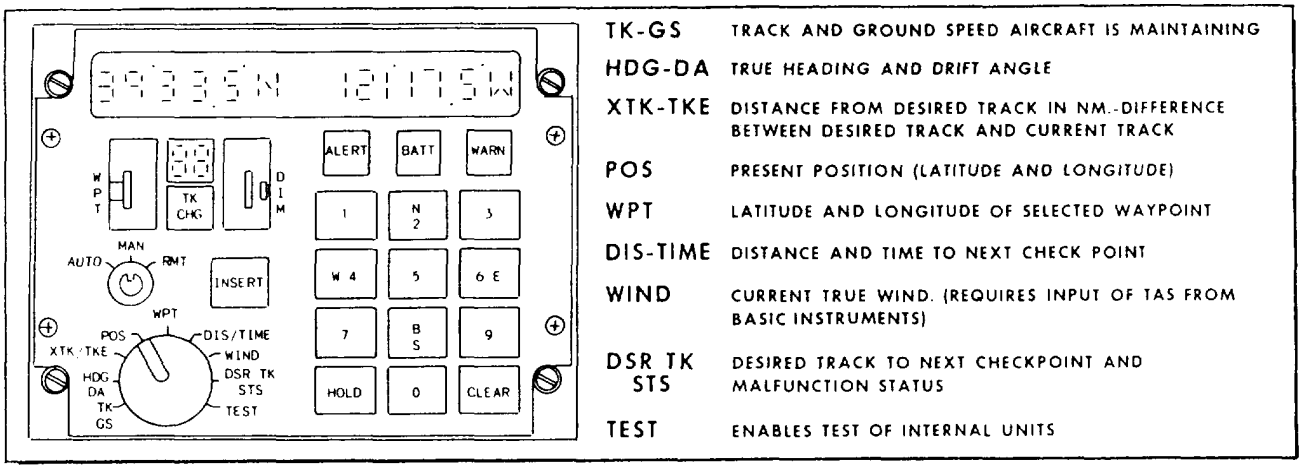


Figure 5-22.-Typical control display unit.

The computer system helps the navigator. Most modern computers have limits built into them so they will not accept unreasonable information. For instance, if the coordinates of a fix point are set 1 degree of latitude in error, the computer rejects the fix because the information is totally incompatible with information already in the computer. A rapid change in ground speed from a sensor might be rejected and that sensor output no longer used because it would be considered unreliable.

So far in this discussion, only basic navigation has been considered. A sophisticated computer system can solve ballistic problems and automatically release bombs and missiles. If the system is installed on a transport-type aircraft, cargo drops and notification of bailout time to paratroops can be controlled by the navigation computer.

Q21. Describe differentiation.

Q22. Define a self-contained navigation system.

Q23. State the transmission principle of the VOR.

Q24. What is the frequency range of the transmitted airborne TACAN DME?

Q25. With the addition of X and Y modes to the TACAN system, what total number of channels are available?

Q26. Loran determines the difference by measuring time intervals between the arrival of the first signal and the arrival of a second signal. What type of measurements can be used?

Q27. State the basic reason for incorporating the navigational computer in aircraft.

Q28. List the data-gathering units of a typical navigational computer system.

Q29. What other uses can the sophisticated computer system provide?

COMMUNICATIONS AND DATA LINK

Learning Objectives: *Identify communications and data link systems and recognize their purpose. Recognize the interface structure between, and the operating features of participating units of a data link system.*

Radio communications is a highly sophisticated field of electronics. Even small Navy aircraft have the capability to *come up* on the commonly used communication circuits. Some common circuits include ship-to-ship, ship-to-air, air-to-air, air-to-ground, and ship-to-shore.

Telecommunications refers to communications over a distance. It includes any transmission, emission, or reception of signs, signals, writings, images, or sounds. It also includes intelligence produced by visual means, oral means, wire, radio, or other electromagnetic systems. Electrical, visual, and sound telecommunications are all used in the Navy. The basic equipment used to communicate are the transmitter and receiver,

Transmitters and receivers each perform two basic functions. The transmitter generates a radio-frequency (RF) signal of sufficient power at the desired frequency and has a means of varying (or modulating) the basic frequency so it can carry an intelligible signal. The receiver selects the desired RF signal you want to receive and rejects all unwanted RF signals. In addition, the receiver detects the intelligence of the signal and amplifies the weak incoming signal to overcome the losses the signal suffers in its travel through space.

Navy Frequency Band Use

Table 5-1 shows the radio-frequency (RF) spectrum broken down into bands used by the

Table 5-1.-Radio-Frequency Spectrum

FREQUENCY	DESCRIPTION
30 GHZ—300 GHZ	extremely high frequency
3 GHZ—30 GHZ	superhigh frequency
300 MHZ—3 GHZ	ultrahigh frequency
30 MHZ—300 MHZ	very high frequency
3 MHZ—30 MHZ	high frequency
300 KHZ—3 MHZ	medium frequency
30 KHZ—300 KHZ	low frequency
3 KHZ–30 KHZ	very low frequency
300 HZ—3 KHZ	voice frequency
up to 300 HZ	extremely low frequency

military. Propagation of radio waves varies widely at different frequencies. Frequencies and equipment are chosen to meet the communications application desired. The frequency bands of particular interest to the Aviation Electronics Technician (AT) are discussed in the following paragraphs. For information on the other bands, refer to Navy Electricity and Electronics Training Series (NEETS), module 17, *Radio-Frequency Communications Principles.*

MEDIUM-FREQUENCY (MF) BAND COMMUNICATIONS.– The medium-frequency (MF) band of the radio-frequency spectrum includes the international distress frequencies (500 kHz and about 484 kHz). Only the upper and lower ends of the MF band have naval use. Frequencies in the lower portion of the MF band (300 to 500 Hz) are normally used for ground-wave transmission. They provide for transmission over moderately long distances over water and for moderate to short distances over land. Transmission in the upper MF band is generally limited to short-range communications (400 miles or less).

HIGH-FREQUENCY (HF) COMMUNICATIONS.– Successful transmission of HF signals over long distances depends on the refraction of radio waves by layers of the ionosphere. Ultraviolet radiation from the sun determines the height and density of these layers. They vary significantly with the time of day, season of the year, and the 11-year cycle of sunspot activity.

Naval communications within the HF band fall into groups of four general types of services. They include point-to-point, ship-to-shore, ground-to-air, and fleet broadcast. All of these services, except the fleet broadcast service, normally operate with two-way communications. Some of these services involve ships and aircraft that present special problems because of their physical characteristics and mobility. These special problems of HF performance are at least partially offset by powerful transmitters and sensitive receiving systems at the ship/shore terminals.

VERY-HIGH-FREQUENCY (VHF) AND ABOVE COMMUNICATIONS.– Normally, frequencies above 30 megahertz are not subject to refraction (bending) by the atmosphere, and ground-wave range is minimal. This normally limits the use of this frequency spectrum to line of sight. However, you can increase range through tropospheric scatter techniques, Some communications using VHF and above frequencies use a technique called *forward propagation by tropospheric scatter.*

Certain atmospheric and ionospheric conditions can also extend the normal line-of-sight range. Frequencies at the lower end of this band are capable of overcoming the shielding effects of hills and structures to some degree. However, as the frequency increases, the problem becomes more prominent. Reception is notably free from atmospheric and man-made static. The very-high-frequency (VHF) and ultra-high-frequency (UHF) bands are within the line-of-sight transmission bands.

Amplitude-Modulated Systems

Amplitude modulation (AM) is a method used to vary the amplitude of an electromagnetic carrier frequency according to the intelligence carried by the carrier. The carrier frequency is a radio-frequency (RF) wave suitable for modulation by the intelligence to be transmitted. One form of amplitude modulation is to interrupt the carrier using a prearranged code.

The on-off keying of a continuous-wave (CW) carrier (fig. 5-23) frequency is one way to modulate a carrier. The intervals of time when a carrier is present or absent carries the desired intelligence. As applied to a continuously oscillating RF source, on-off keying is known as *CW signaling,* or as an *interrupted continuous wave (ICW).*

The primary disadvantages of AM modulation are susceptibility to noise interference and the inefficiency of the transmitter. To overcome the susceptibility to noise interference, angle modulation was developed.

Angle Modulation

Angle modulation is modulation in which the angle of a sine-wave carrier is varied by a

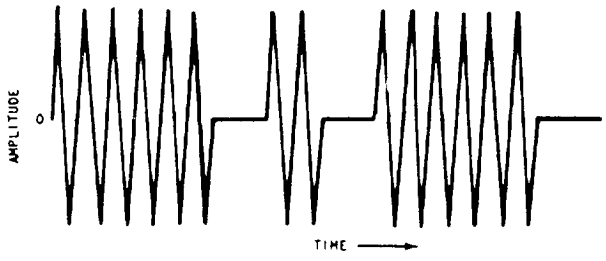


Figure 5-23.-Continuous-wave modulation.

modulating wave, Frequency modulation (FM) and phase modulation (PM) are two types of angle modulation. In FM, the modulating signal causes the carrier frequency to vary. These variations are controlled by both the frequency and amplitude of the modulating wave. In PM, the phase of the carrier is controlled by the modulating wave form.

In frequency modulation (FM), an audio signal is used to shift the frequency of an oscillator at an audio rate. Frequency-shift key (FSK) is the simplest form of FM, and it is similar to CW keying in AM transmissions.

For more information on AM, FM, and pulse modulation principles, refer to Navy Electricity and Electronics Training Series (NEETS), module 12, *Modulation Principles,* NAVEDTRA 14184.

General-Purpose Receiver

A typical general-purpose receiver, consisting of a receiver and its mounting, is a super-heterodyne receiver. It is capable of receiving RF signals from 190 kHz to 550 kHz and from 2 MHz to 25 MHz, in five frequency bands, A mechanical type counter, located on the front panel of the receiver (fig. 5-24), shows the frequency, in MHz, of received signals. It can receive signals that are of the amplitude modulated (AM), unmodulated

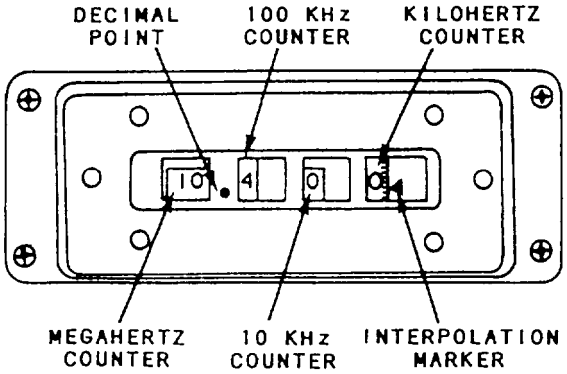


Figure 5-24.-Megahertz frequency indicator.

ANSWERS FOR REVIEW QUESTIONS Q21. THROUGH Q29.

A21. Differentiation is the process of investigating or comparing ho w one physical property varies with respect to another.

A22. A self-contained system is complete in itself; it does not depend on the transmission of data from ground installations.

A23. The VOR transmission principle is based on creating a phase difference between two signals.

A24. 1025 MHz to 1150 MHz.

A25. 126 channels in X and 126 channels in Y, 252 total channels available.

A26. CRT display, automatically by the loran set, integrating with the computer.

A27. To handle the many flight conditions at the speed of sound or above.

A28. Radar, Doppler, INS, loran, and TACAN.

A29. Solving of ballistic problems, automatic release of bombs and missiles, cargo drops, and notification of bailout times are just a few.

continuous wave (CW), or frequency shift keyed (FSK) types.

HF Transceiver

The typical HF transceiver transmits and receives communications in the high-frequency (HF) band and can operate on a frequency range from 2.0 to 29.999 MHz. The set may include a radio receiver-transmitter (RT), radio set control, and mounting. The RT unit is usually of modular construction and easy to maintain. In addition to the set components, the complete aircraft installation may require a headset, microphone, key, antenna coupler, and antenna.

VHF Transceivers

The main purpose of VHF transceivers is to provide two-way communications between aircraft, ships, and shore stations. They normally operate within the frequency range of 116 MHz to 149.95 MHz. Some VHF transceivers are dual purpose. Their receivers also work with the VHF omnidirectional rapid range (VOR) navigation systems. When used for this purpose, the frequency range of the receiver extends to cover 108 MHz to 151.95 MHz.

UHF Transceivers

There are two main types of UHF transceivers—frequency modulated (FM) and amplitude modulated (AM). Typical FM UHF transceivers operate between 225.0 MHz to 399.9 MHz, with channels spaced 100 kHz apart. Typical AM UHF transceivers operate between 225.0 MHz to 399.975 MHz, with a fixed guard frequency of 243. MHz.

Intercommunications Systems

All aircraft intercommunication systems perform essentially the same basic functions. They deliver audio to one or more selected stations on board the aircraft to permit crew members to speak to each other. They also provide control of the communication facilities so various members of the crew may receive incoming radio messages or transmit messages with the aircraft transmitters. It is also necessary for the intercommunication system to contain facilities for operating recording equipment. This lets you make permanent records of the various receptions and transmissions occurring during flight.

Communication Antennas

An antenna is a special type of electrical circuit intentionally designed to radiate and/or receive electromagnetic energy. In an ordinary circuit, the inductance (L), capacitance (C), and resistance (R) properties lump together and are constant. Therefore, the electromagnetic field is confined to the circuit where it performs useful work. In an antenna, the L, C, and R properties spread out, and the electromagnetic field tends to escape or radiate. It is this radiated field that provides the link between a transmitter and receiver.

While the simplest type of antenna is the bidirectional dipole, limitations in directivity, frequency bandpass, and gain somewhat restrict its use. Other dipole configurations such as the ram's horn and the corner reflector are for special applications.

Although the crossed dipole, the whip, the top-loaded vertical, or the **J** antennas are in use, the ground plane antenna is probably the most popular. This is especially true when reception or transmission must be equally effective in all directions (omnidirectional), For much higher frequencies, the biconical or the disc horn is an excellent antenna.

The log periodic, helical, and flat-spiral antennas have an extremely wide (as high as 20: 1) operating frequency range.

When space is not a controlling factor, the rhombic and the **V** type provide high gain and directivity. They can be unidirectional by terminating the ends of the legs with a non-inductive resistor. The **V** can be unidirectional by use of another **V** spaced an odd number of quarter wavelengths behind the original. Typical legs for the rhombic are three to four wavelengths; for the **V** type, legs of eight wavelengths are not uncommon.

The parabolic antenna can produce high gain and excellent directivity. Although screen mesh, or even a grid or rod, provides increased stability where wind resistance is a design factor, the reflector element generally consists of a solid surface. Physically, the reflector should be several wavelengths in diameter. The radiating element may be a dipole, a horn, or other suitable radiator. Mounting a hemispherical reflector in front of the dipole may increase gain providing its surface area does not appreciably shadow the rear parabolic reflector.

Data Link System Interfacing and Operation

The data link system is a communications link that provides computer-to-computer exchange of information. A typical link may include tactical ASW data between an aircraft and other participating units (PUS) and reporting units (RU) via RF transmission. Data link transmission includes communication and navigation information, voice communications, secure (coded) voice communications, sonobuoy information, and computer data.

A data link system is an integrated communications system that uses the functions and components of various communications systems to provide the data link capability. A modern data link system has the following components installed on the aircraft.

- A general-purpose digital computer (GPDC)
- A switching logic unit (SLU)
- A data terminal set (DTS)
- An integrated radio control (IRC)
- A secure data keyer
- A communication system (HF and UHF radio equipment discussed earlier)

ELECTRONIC COUNTERMEASURES (ECM), ELECTRONIC SUPPORT MEASURES (ESM), AND WEAPON CONTROL

Learning Objectives: *State the meaning and purpose of the two basic categories of ECM—electronic and nonelectronic. Identify various types of deception and jamming devices used in ECM and recognize their characteristics. Describe the weapon control fundamentals to include the primary problem, ballistics, and trajectory.*

The purpose of ECM equipment is to detect, analyze, locate, and degrade the use of an enemy's electronic warfare equipment. To do this, the Navy uses two basic categories of airborne ECM systems—passive ECM (PECM) or ESM and electronic and nonelectronic ECM (designed to jam or block an electronics system). Because ECM equipment is classified, no in-depth theory or circuitry is discussed in this TRAMAN.

ESM Indicator Units

ESM operations are not directly detectable by the enemy because they do not transmit. The purpose of ESM equipment is to detect (receive), plot (locate), and analyze the signal characteristics of a suspected enemy's communications, navigation, and radar equipments. To do this, an ESM system must have receivers that cover the entire frequency spectrum and a direction-finder (DF) type of antenna system. They also require indicators with circuitry to analyze and display the various signal characteristics. You may know ESM as passive electronic countermeasures (PECM). The terms *PECM* and *ESM* are synonymous.

ESM indicators give the operator a visual picture or digital readout of the received signal, let the operator analyze and determine the required signal characteristics, and plot the location of the transmitting station. There are three basic classes of indicators—panoramic adapters, digital display indicators, and pulse analyzers.

Electronic Countermeasures (ECM)

The design of defensive ECM equipment is primarily to protect a single aircraft from an enemy radar. This equipment is also referred to as a deceptive ECM system because it deceives rather than jams a radar system. The two basic categories of ECM equipment are electronic and nonelectronic ECM.

ELECTRONIC ECM EQUIPMENT.– Various types of electronic ECM equipments deceive various types of radars, such as search, fire-control, etc. The method of deception (such as time delay for search radar and frequency shifting for fire-control radar) may vary, but the operating concept is the same. For example, to deceive a threat radar signal, false information is injected, and the signal is retransmitted with increased power.

The ECM equipment receives the threat radar signal, amplifies it, detects the pulse, delays the pulse a few seconds, and retransmits the pulse. Some ECM equipment not only injects time delays, but transmits multiple pulses that show up as multiple targets on a radar's indicator.

Regardless of the type of deception used, the threat radar cannot plot the correct location of the aircraft. Fire-control radar will not be able to "lock-on" the aircraft,

ACTIVE ECM/JAMMING.– *Active ECM* is a term given to ECM electronic equipment designed to jam communications, navigation, and radar receivers. These *jammers* are high-power, noise-modulated transmitters that transmit random noise over a given band of frequencies. This high-powered noise overdrives (jams) the receiver of the target equipment and makes it useless. In threat radar, the jammer signal will cause the indicator to *blossom*. It blossoms because the jammer's powerful noise signal overdrives the radar receiver's circuits. When the radar receiver's circuits are overdriven, the receiver puts out a constant video signal for an area where the noise signal is stronger than the receiver's maximum sensitivity. In this way, one ECM jammer can protect (hide) a group of aircraft over a large area.

NONELECTRONIC ECM.– Another means of deceiving a threat radar is by using chaff. Chaff is the general name given to packaged strips of metal foil that resembles confetti. When chaff ejects from an aircraft, it disperses into the air and causes multiple echo signals (targets) on the radar's indicator. The metal foil is cut to the correct wavelength of the radar transmitting frequency, so it will reflect maximum echo signals back to the radar receiver.

Weapon Control Fundamentals

The primary problem of aircraft weapons systems is to accurately determine the correct position and attitude in which to place the aircraft. Correct positioning of the aircraft gives reasonable assurance of a hit on the target. No matter how difficult or how simple the problem, two terms are always present in the solution of the problem—ballistics and trajectory.

Ballistics refers to the science of the motion of projectiles. It is a study of all the various forces, both controllable and uncontrollable, that govern the movements of projectiles.

The study of ballistics includes two branches—interior and exterior. The study of interior ballistics involves the movement of projectiles inside a gun barrel or bore. The study of exterior ballistics involves the motion of the projectile in free air after it leaves the bore of the gun or the launcher.

Exterior ballistics is the branch of ballistics with which you are concerned. To understand exterior ballistics, you must fully understand the term *trajectory*. *Trajectory* is the curve a projectile describes in space as it travels to the target.

- For guns, trajectory is from the muzzle to the first point of impact.
- For rockets and missiles, the actual ballistic trajectory is that portion of the distance to the target under free flight (after burn time).
- For bombs, the trajectory is from the time of release to the time of impact.

Weapons Systems Concept

As aircraft altitudes increased and speeds reached the supersonic regions, the ability of the attacking aircraft to perform its mission became more difficult. To engage a target at supersonic speeds was impossible when depending only on the operator for accuracy. The result of solving these problems was the current aircraft—a completely integrated machine. Each of the separate systems are subsystems interconnected and dependent, to some extent, on each of the others. For example, the navigation system depends on the radar system; and the automatic flight control system depends on a computer. The computer depends on both the radar and navigation systems for proper operation. A weapons system includes the following:

- Units that detect, locate, and identify the target.
- Units that direct or control the delivery unit or the weapon, or both.
- Units that deliver or initiate delivery of the weapon to the target.
- Units that destroy the target when in contact with it or near it; these units are usually termed weapons.

Q30. To what NEETS module should you refer for information on radio frequency communications principles?

Q31. What two transmission bands are contained within the line-of-sight transmission band?

Q32. What is meant by the statement "some VHF transceivers are dual purpose?"

Q33. To what NEETS module should you refer for more information on AM, FM, and pulse modulation principles?

Q34. What type of communications antenna is excellent for higher frequencies?

Q35. What term is given to electronic ECM equipment designed to jam communications, navigation, and radar receivers?

Q36. Describe ballistics.

Q37. Define trajectory.

ASW ACOUSTIC AND RECORDER SYSTEMS

Learning Objectives: *Recognize the operating principles of magnetic anomaly detection (MAD). Recognize the classification, specifications, and operating principles of sonobuoys currently in use. Recognize the functions of and the relationship between components comprising magnetic tape recorder systems used on Navy ASW aircraft.*

The most feasible method of detecting a submerged submarine was to detect its disturbance of the local magnetic field of the earth. The development of the sonobuoy has made it possible to detect submarines using sound-ranging equipment (sonar) by aircraft.

Principles of Magnetic Detection

Light, radar, and sound energy cannot pass from air into water and return to the air in any degree that is usable for airborne detection. However, the lines of force in the earth's magnetic field pass through the surface of the ocean essentially undeviated and undiminished in strength. The change of medium from water to air or air navigation has little or no effect on magnetic lines of force. Consequently, detection of an object under the water can occur from a position in the air above it if the object has magnetic properties that distort the earth's magnetic field. A submarine has sufficient ferrous mass and electrical equipment to cause a detectable distortion (anomaly) in the earth's field. Detection of this anomaly is the function of magnetic anomaly detection (MAD) equipment.

The maximum range of submarine detection is a function of both the intensity of its magnetic anomaly and the sensitivity of the detector.

NOTE: A magnetometer is the detector in MAD equipment.

A submarine's magnetic moment (magnetic intensity) determines the intensity of the anomaly. The magnetic moment depends mainly on the submarine's alignment in the earth's field, its size, its detected latitude, and the degree of its permanent magnetization.

ANOMALY STRENGTH.– A submarine's anomaly is usually so small that MAD equipment must be capable of detecting a distortion of about one part in 60,000. This is because the direction of alignment of the earth's magnetic lines of force rarely change by more than one-half of 1 degree in a submarine anomaly.

COMPENSATION.– Regardless of its source, strength, or direction, any magnetic field may be defined in three axial coordinates. That is, it must act through any or all of three possible directions—longitudinal, lateral (transverse), or vertical—in relation to the magnetometer detector.

Compensation for magnetic noises is necessary to provide a magnetically clean environment. This ensures the detecting system will not be limited to the magnetic signal associated with the aircraft itself.

Under ideal conditions, all magnetic fields acting on the magnetometer head are completely counterbalanced. In this state, the effect on the magnetometer is the same as if there are no magnetic fields at all. This state exists only when the following ideal conditions exist:

1. The aircraft is flying a steady course (no maneuvers) through a magnetically quiet geographic area.
2. Electric or electronic circuits remain either on or off during compensation.
3. Direct current of the proper intensity and direction flow through the compensation coils, so all stray fields are balanced.

To approximate these conditions, the compensation of MAD equipment usually occurs in flight, well at sea. In this way, the equipment compensation occurs under operating conditions, which closely resemble those of actual ASW search flights.

Sonobuoys and Associated Receivers and Recorders

Sonobuoys are aircraft-deployed, expendable sonar sets that contain a VHF radio transmitter to relay acoustic information to the deploying aircraft. The detection, localization, and identification of potentially hostile submarines is the primary mission of the U.S. Navy airborne antisubmarine warfare (ASW) forces. The ASW capability of the fleet and the Navy operational readiness to deal with the submarine threat critically depends on sonobuoys. Sonobuoys detect underwater sounds, such as submarine noise and fish sounds. These audio frequency (AF) signals modulate an oscillator in the RF transmitter portion of the sonobuoy. The output of the transmitter is an FM-modulated, VHF signal that is transmitted from the sonobuoy antenna. The signal is received by the aircraft that dropped the sonobuoy. This signal is detected and processed by a sonobuoy receiver. By analyzing the detected sounds, the ASW operator can determine various characteristics (such as propeller shaft speed) of the detected submarine. The use of several sonobuoys operating on different VHF frequencies in a tactical pattern lets the ASW operator localize, track, and classify a submerged submarine.

Sonobuoys may be grouped into three categories—passive, active, and special-purpose. Passive sonobuoys are used in LOFAR and DIFAR systems. Active sonobuoys are used in CASS and DICASS systems, and special-purpose sonobuoys (BTS and DLC) are used for missions other than ASW.

PASSIVE SONOBUOY.– The passive sonobuoy is a *listen-only* sonobuoy. The basic acoustic sensing system that uses the passive sonobuoy for detection and classification is the low-frequency analysis and recording (LOFAR) system.

LOFAR System. In the LOFAR system, sounds emitted by the submarine are detected by a hydrophone from a passive omnidirectional sonobuoy. Data on the frequency and amplitude of these sounds are then transmitted by the sonobuoy antenna to a receiving station. At this station, normally located on board the deployment aircraft, the sound data is analyzed, processed, displayed, and recorded, The basic LOFAR display plots the frequency of the sound waves against the intensity of their acoustic energy and against the duration of the sound emission. This data can be displayed on a video screen and printed out. The data is also recorded on magnetic tape for storage and retrieval when desired.

DIFAR System. The directional low-frequency analysis and recording (DIFAR) system is an improved passive acoustic sensing system. Using the passive directional sonobuoy, DIFAR operates by detecting directional information, and then it frequency multiplexes the information (data) to the acoustic data transmitted by the sonobuoy to the deployment aircraft. This information undergoes processing by the aircraft's acoustic analysis equipment to compute a bearing and display it. Subsequent bearing information from the sonobuoy can pinpoint, by triangulation, the location of the sound or signal source.

ACTIVE SONOBUOY.– The active sonobuoy is either self-timed or commendable. The self-timed sonobuoy generates a sonar pulse at a fixed pulse length and interval. The commandable sonobuoy generates a sonar pulse, as determined by a UHF command signal from the controlling aircraft.

An active sonobuoy uses a transducer to radiate a sonar (sound) pulse that is reflected from the hull of the submarine. The time between the ping (sound pulse) and the echo return to the sonobuoy is measured. Taking into account the Doppler effect on the pulse frequency, this time-measurement data helps to calculate both range and speed of the submarine relative to the sonobuoy.

CASS sonobuoys. The command active sonobuoy system (CASS) allows the sonobuoy to remain silent until it receives a command signal from the aircraft to radiate a sound pulse. This technique allows the aircraft to surprise the submarine.

DICASS sonobuoy. A CASS sonobuoy, equipped with a directional hydrophone, is a directional commandable sonobuoy (DICASS). A DICASS sonobuoy lets the aircraft acoustic analysis equipment determine both range and bearing to the target with a single sonobuoy. DICASS sonobuoys are replacing the older RO and CASS sonobuoys.

SPECIAL-PURPOSE SONOBUOYS.– Currently there are two categories of special-purpose sonobuoys in use by the fleet—the bathythermobuoy (BTS), and the Down-Link Communication (DLC) special-purpose sonobuoys. These sonobuoys are NOT for use in submarine detection or localization.

Bathythermobuoy. The bathythermobuoy (BTS) measures the water temperature versus depth. The time of descent of a temperature probe determines the water depth. Once the BTS enters the water, this probe (fig. 5-25) descends automatically at a constant 5 feet per second.

The probe uses a thermistor, a temperature-dependent electronic component, to measure the temperature. The electrical output of the probe goes to a voltage-controlled oscillator, whose output signal frequency modulates the sonobuoy transmitter. The frequency of the transmit signal, which is recovered at the sonobuoy receiver in the aircraft, is linearly proportional to water temperature. The water temperature and depth are recorded on graph paper that is visible to the ASW operator.

DLC. The down-link communition (DLC) buoys are for communication between aircraft and submarines. The DLC buoy is not commanded and provides down-link communications only by a preselected code.

Sonobuoy Receivers

The sonobuoy receiver has many functions. It receives RF signals from deployed sonobuoys,

ANSWERS FOR REVIEW QUESTIONS Q30. THROUGH Q37.

A30. Module 17.

A31. UHF and VHF.

A32. Module 12, Modulation Principles.

A33. Their receivers also work with VHF and VOR.

A34. The biconical or disc horn.

A35. Active ECM.

A36. The science of motion of projectiles.

A37. The curve of a projectile describes in space as it travels to the target.

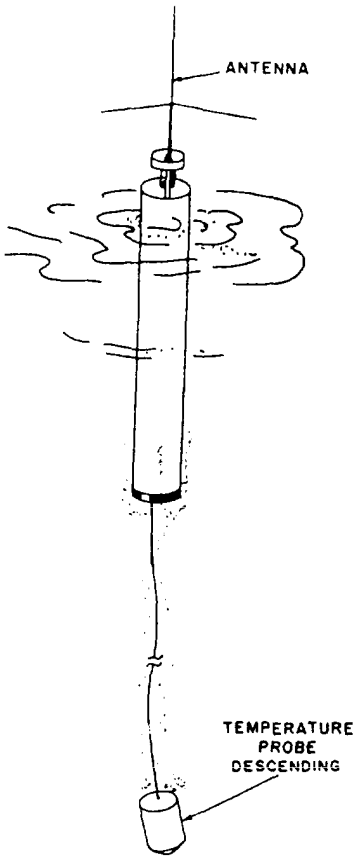


Figure 5-25.-Bathythermograph sonobuoy deployment.

detects intelligence on the signals, provides intelligence to various onboard equipment for acoustic analysis and recording and for navigating or navigation purposes.

SONOBUOY RECEIVER SET.– One commonly used sonobuoy receiver set includes 31 radio receivers that receive FM-modulated signals in the VHF range. Thus, simultaneous reception, demodulation (detection), and audio output of up to 31 RF channels are possible. These channels may each be any one of 31 preselected channels. Each audio output provides two levels—high audio and standard audio.

The equipment is primarily for (but not limited to) installation in either fixed- or rotary-wing aircraft. Although capable of being an independent operating unit, normally, the equipment is used with some combination of several types of sonobuoys and a signal processor.

Newer sonobuoy receiver groups provide the capability of simultaneously receiving 20 sonobuoy signals. To accomplish this they use 20 subassemblies. Each subassembly may be independently and automatically tuned to any 1 of 99 sonobuoy RF channels now in use, and those that are in development for future deployment.

SONAR COMPUTER-RECORDER GROUP.– The sonar computer-recorder group (DIFAR system) analyzes, records, and generates a permanent printed display of the passive and active sonobuoy signals processed by the receiver system. This display can provide information for identifying and locating the source of the sound. The system uses low-frequency analysis, directional-frequency analysis, broadband-frequency analysis, directional listening, and active ranging or Doppler techniques to detect, classify, and localize the underwater target,

The four basic modes of operation of the DIFAR system are as follows:

1. OMNISEARCH—omnidirectional signal from a passive buoy with NO directional capabilities
2. ALI-LOFAR—integrated omnisearch display using a directional or nondirectional passive buoy
3. DIFAR—directional frequency analysis and recording—will give a bearing to the target using directional buoys
4. Range—gives the range in yards to the target using an active range only buoy

Magnetic Recorders

Magnetic recorders are used throughout the Navy in various forms and types. They may be a simple audio recorder or the most complex data recorder; however, all of them provide a handy, compact means of storing and retrieving large amounts of information.

OPERATION OF A MAGNETIC RECORDER.– Operation of a magnetic recorder involves three basic processes—recording, reproducing, and erasing. In analog systems, reproducing is *playback* or *play*. In digital systems, record is write, and reproducing is *read back* or *read*. Keep in mind that analog recording and *digital* recording refer to recording techniques and not to the information recorded.

DIGITAL RECORDING.– The basic difference between analog and digital recording is in the method and degree of magnetizing of the recording media. For analog recording, linearity and low distortion are the primary requirements. However, for digital recording (as in most digital systems) there are only two states—0 or 1, ON or OFF, TRUE or FALSE, or whatever names are convenient.

ERASING.– The term *erasing* refers to an electromagnetic process, or demagnetizing procedure, that removes signals previously recorded without affecting the magnetic tape in any other way. The action is a realignment (or polarizing) of the oxide particles on the tape so all modulation (recorded data) is removed, making it possible to reuse the same tape.

Q38. What two factors determine the maximum detection range of a submarine?

Q39. What is the purpose of compensation?

Q40. What recorder system plots the frequency of the sound waves against the intensity of their acoustic energy and duration of the sound emission from an omnidirectional passive sonobuoy?

Q41. List the types of sonobuoys.

Q42. List the four basic modes of the DIFAR system.

SUPPORT EQUIPMENT

Learning Objective: *Identify various support equipment, including aircraft power generation, conversion, control, regulation, and protection equipment.*

Support equipment has become as important to the assigned mission of naval aviation activities as the aircraft itself. Many different types of support equipment are required for handling, servicing, loading, testing, and maintaining aircraft. Although your rating is not responsible for the upkeep and maintenance of support equipment, you, as a user, must have a basic knowledge of the equipment's capacity and operation.

You must understand the capabilities and limitations of the auxiliary power sources provided for use in ground servicing and maintenance of aircraft. You must observe and enforce all safety precautions and regulations concerning the use of the units,

You must also know the requirements for cooling the various electronic equipment while on the ground. You must be familiar with the sources of auxiliary air and cooling, and you must know the capabilities and limitations of the various cooling units.

This chapter discusses these topics. In most sections, the discussion is general. In a few instances, details are presented as they pertain to specific items of equipment. Coverage of the equipment is limited to those expected to be in common usage during the life of this training manual.

AIRCRAFT POWER

The electrical power system of an aircraft consists of the power source and its associated controls, the generation system and its associated controls and regulation, the conversion units, the feeder and distribution system and its component parts, and the various protective devices used throughout the installation.

As part of the overall effort to standardize aircraft and electronic installations, the supply and distribution of power offered a logical starting point. The first step was to standardize the supply voltages and power frequencies and to use generators that would provide the required power. Later in the standardization program, the generation of dc power was discontinued, and the primary power became exclusively ac. The dc requirement was supplied through transformer-rectifiers. This reduced the number of voltages generated, reduced the number of rotary devices, and allowed the use of smaller conductors in the distribution system. The result was a drastic decrease in the total weight of a given installation, which, in turn, permitted a more complex installation for a given weight allowance.

To be of any real value, a partial listing of the considerations involved in any discussion of aircraft electrical systems must include the following items:

1. A main generating source refers to all generator units driven by a specified engine; thus, a single-engine aircraft can have only one main source.

2. Multiengine aircraft may have a main generating subsystem for each engine. This is the usual practice, but it is not universally followed.

3. Adequate frequency regulation and stability in ac generation systems require some method of speed control of the generator's rotor drive mechanisms.

4. Provisions must be made to ensure that adequate power is available in each mode of operation. In the event of failure of the aircraft engine or its associated generation system, the maximum amount of power that can be produced is decreased. In the case of single-engine aircraft, this automatically constitutes an emergency situation.

5. The failure of a single generator or engine in a multiple installation does not constitute the same degree of emergency as the same failure in a single-engine installation. Although some restrictions are placed on operational capabilities, some degree of safety may usually be maintained with the remaining engines and generators.

6. Provisions should be made to enable use of external power sources for starting the engines while on the ground and for ground operation without using the aircraft engines. The aircraft electrical system must include provisions to prevent applying both internally generated power and externally furnished power to the system at the same time.

Aircraft Electrical Systems

The electrical system of each model aircraft has some features peculiar to it alone, while other features are common to most models. In this section, you are presented with a general discussion of the electrical system of a typical aircraft.

SOURCE OF POWER.— The basic source of power for the electrical system is the aircraft engine. An ac generator requires a constant rotational speed to produce a constant frequency output. In most modern aircraft, a constant-speed drive (CSD) unit is inserted between the aircraft engine and the ac generator for this purpose.

GENERATION SYSTEM.— The heart of the electrical generation system is the constant-speed, wye-connected ac generator. This unit normally produces a three-phase output voltage of about 120/208 volts at 400 Hz, which is subsequently regulated to 115/200 volts. The basic theory of ac generators is discussed in Navy Electricity and Electronics Training Series (NEETS), module 5.

DC Generator.— In most older aircraft, all electrical power was generated as dc voltage. In most of the newer aircraft, no dc voltage is generated. The dc requirements are met by transforming and rectifying the ac. In some operational aircraft presently in service, however, the main power generation system provides both ac and dc voltages from a common unit. In other aircraft models, a separate generator is used to provide the dc power required for operation of

the dc components. This method is not common in airborne applications because of the limited number of engines available. The basic theory of dc power generators is presented in NEETS, module 5.

Emergency Generators.— In the event of failure or shutdown of the aircraft engines or main generators, the electrical system becomes inoperative. The aircraft must have electrical power to maintain adequate flight control. All naval aircraft incorporate an auxiliary or emergency generator that operates independently of the aircraft engine.

System Voltage Regulation

Voltage regulators are incorporated in all electrical generation systems. Although similar in basic purpose, the configuration and details of operation vary with each type. A typical solid-state voltage regulator may consist of a sensing circuit with input rectifiers, a temperature-compensated Zener diode reference and error-detecting bridge, and a three-stage transistor amplifier. The output of the bridge circuit is a voltage inversely proportional to the difference between the generator voltage and the regulator set voltage, and it is referred to as the error signal.

External Power

All aircraft have provisions for application of electrical power from an external source for starting the aircraft engines and/or for ground servicing and maintenance without operating the engines. This power, while not generated within the aircraft, is part of the overall electrical system of the aircraft. All aspects must be compatible with the power generated within the aircraft. Under no circumstances may the internal and external power be used at the same time. This is one of the functions of the distribution system, which is discussed briefly in the following text, The equipment used to supply power in the external mode of the electrical system is discussed briefly in a later portion of this chapter.

Distribution Systems

Once the electrical power has been generated and some of it transformed, it must be distributed to the various components and equipment where it is to be used. In a simple system, with comparatively few equipment and requiring only a single form of electrical power, a simple distribution system could be used. In modern naval aircraft, however, with the complex electrical and electronic installations requiring many forms of power, an extremely complex distribution system is required.

Each model aircraft has different electrical requirements; therefore, each distribution system must differ from all others under individual requirements. The major area of difference between distribution systems of different model aircraft lies in the switching arrangement used to change electrical loads from one source to another in the event of a malfunction.

Power Conversion Devices

In most naval aircraft, the main electrical power generation system produces three-phase ac power at 400 Hz. All aircraft require various levels and quantities of dc power. In many instances, ac power of a different frequency is also required. In these cases, various devices are needed to

ANSWERS FOR REVIEW QUESTIONS Q38. THROUGH Q42.

A38. Its magnetic anomaly and the sensitivity of the detector.

A39. To provide a magnetically clean environment and ensure the detecting system will not be limited by the aircraft itself.

A40. LOFAR and DIFAR.

A41. Passive, active, CASS, DICASS, and special purpose.

A42. Omnisearch, ALI-LOFAR, DIFAR, and range.

convert the power from the forms generated into the forms required for the specific application. A few important conversion devices are discussed briefly in the following paragraphs.

TRANSFORMER-RECTIFIERS.— The most common conversion device for changing ac to dc is the transformer-rectifier. The three-phase, 115-volt ac is reduced in a step-down transformer, and then rectified to produce the 28-volt dc required for operation of various relays, lights, instruments, and mechanical devices. Specific transformer-rectifier units are discussed in the electrical section of the maintenance instructions manual (MIM) for each model aircraft. The fundamental theory of transformers is discussed in NEETS, module 2.

INVERTERS.— An inverter is a rotating electromechanical device used to convert low-voltage dc into ac. It consists essentially of a speed-governed dc motor, an armature and brush assembly, and a permanent magnet inductor-type ac generator all within a single unit. The armature and the permanent magnet rotor are usually mounted on a common shaft.

The inverter's output frequency and voltage should be checked periodically to assure that they are within prescribed limits. Should adjustment be required, the electrical shop is notified, since adjustment of inverters is a responsibility of the AE rating.

FREQUENCY CHANGERS.— When ac voltages of a frequency different from that produced by the main generator are required, suitable motor-generator combinations are used. Main electrical power frequency is usually 400 Hz, Many aircraft provide a 60-Hz source for test equipment and an 800-Hz source for certain instruments or components.

Q43. To what NEETS module should your refer for information on ac generators?

Q44. What is the purpose of external power?

Q45. List some power conversion devices.

CIRCUIT PROTECTION AND CONTROL

The electrical system of an aircraft is protected from damage and failure by fuses, current limiters, and circuit breakers. Control and distribution of power are accomplished by the use of switches and relays. Each of these components is available in many styles and sizes, some of which are ideally suited for use in aircraft, while others are limited to use in shop installations. In the following section, you will be presented with a brief discussion of these components.

Fuses

Fuses provide a controlled, intentionally weakened link in an electrical circuit. They serve as safety devices in the event of undesired overloads. Fuse sizes are available with ratings as low as a few milliamperes to several hundred amperes. Fuses of most ratings are available for normal, slow-acting, or fast-acting operation.

A fuse is a heat-sensitive, heat-operated device. When operated at the rated current, it consumes electrical power, and then dissipates this power in the form of heat. Under normal operating conditions, the dissipated heat is not sufficient to cause the fuse to open (blow). However, when the fuse is operated above the normal current rating, the overload current generates additional heat, which melts the fusible element.

1. **Voltage rating.** A fuse can be operated at any circuit voltage if it is mounted in a sufficiently well-insulated holder (as long as the fusible element is able to open without suffering arc damage). When a fuse blows due to excessive current, the full-circuit voltage appears across the open fuse. If inductance is present in the circuit, a surge is generated that may cause a destructive arc to be formed within the fuse. Under these conditions, intense heat and pressure develop, and the fuse may literally explode.

2. **Blow-time characteristics.** The blow-time characteristics of a fuse depend on the percent of rated current and thermal inertia of the fuse. Overload currents (currents larger than the maximum value for which the fuse is rated), when flowing through a fuse, heat the element beyond normal capacity. After a period of time, the fusible element opens.

Fuse elements with a large thermal inertia increase the length of time before blowing. Fuses containing such elements are known as slow-acting, slow-blow, or time-delay fuses. Slow-acting fuses are constructed with a compound element—a thermal cutout and a fusible link that melts on short circuits on very high overloads.

Small, light fuse elements reduce the thermal inertia; therefore, they are faster acting. This type of fuse is known as a fast-acting fuse and is used principally for the protection of sensitive instruments.

In the selection of blow-time characteristics, both the steady state and the transient or surge currents are considered. If currents of 200 to 400 percent above normal can be tolerated for periods of 1 to 10 seconds, a slow-acting fuse is specified. If the circuit requires immediate protection for any current above normal, a fast-acting fuse is specified. If the current must be limited to 200 percent of the rating for periods less than 1 second, then a normal or medium blow-time characteristic is specified. (See fig. 5-26.)

When possible, a fuse should be operated at about 75 percent of its rated value. This provides a good balance between protection and reliability.

3. **Vibration resistance.** Fuse protection for equipment subject to vibration can be provided by special vibration-resistant construction. This type of fuse has a spring formation, with winglike extensions that bear on the inside wall of the glass body to decrease vibration of the fuse element. For slow-acting fuses, a different construction is used. This construction consists of a compound spring and link structure. On moderate overloads, as the compound element reaches the melting point, the spring pulls away from the link, while on short circuits, the link fails.

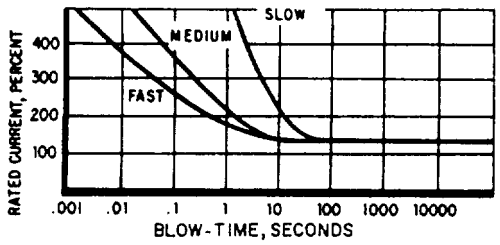


Figure 5-26.-Blow-time characteristics of fuses.

4. **Identification coding.** Fuses and their corresponding fuse holders are numbered according to a standardized system for easy identification. The numbering system is shown and explained in figure 5-27.

5. **Fuse holders.** The most common class of fuse holders used in Navy equipment is the post-type holder, shown in figure 5-28. It may be a screw in or a bayonet type. Both of these types are securely mounted to the chassis or front panel of the equipment. The purpose of the holder is the same, regardless of type—to hold the fuse securely with good electrical connection and physical stability for protection from mechanical vibration and electrical short circuit.

You should use care to ensure that the fuse is of a physical size compatible with the holder. Fuses that are undersized allow physical movement and arcing. This results in a blown fuse, erratic operation, or damaged holder. Fuses that are too large may cause cracking or breaking of the holder. Force should never be applied to either the fuse or the holder, since most are fragile devices.

Post-type fuse holders are normally series connected in the line, with the end connection to the power source and the center connection to the load. When connected in this fashion, the equipment is protected in the event of a broken holder. A short circuit from a fuse holder to chassis ground will result in a blown fuse and excessive current will not flow. Reversed connections will not furnish this protection. Connection is normally made by solder, although some fuse holders are connected by the use of a screw or lug method.

Current Limiters

Devices somewhat similar to fuses, called current limiters, are used in aircraft circuits that carry high currents. (See fig. 5-28.) The current limiter consists of a copper link of carefully predetermined sections. The sections melt when

ANSWERS FOR REVIEW QUESTIONS Q43. THROUGH Q45.

A43. Module 5.

A44. Starting aircraft engines and/or ground servicing and maintenance.

A45. Transformer-rectifier, inverter, and frequency changer.

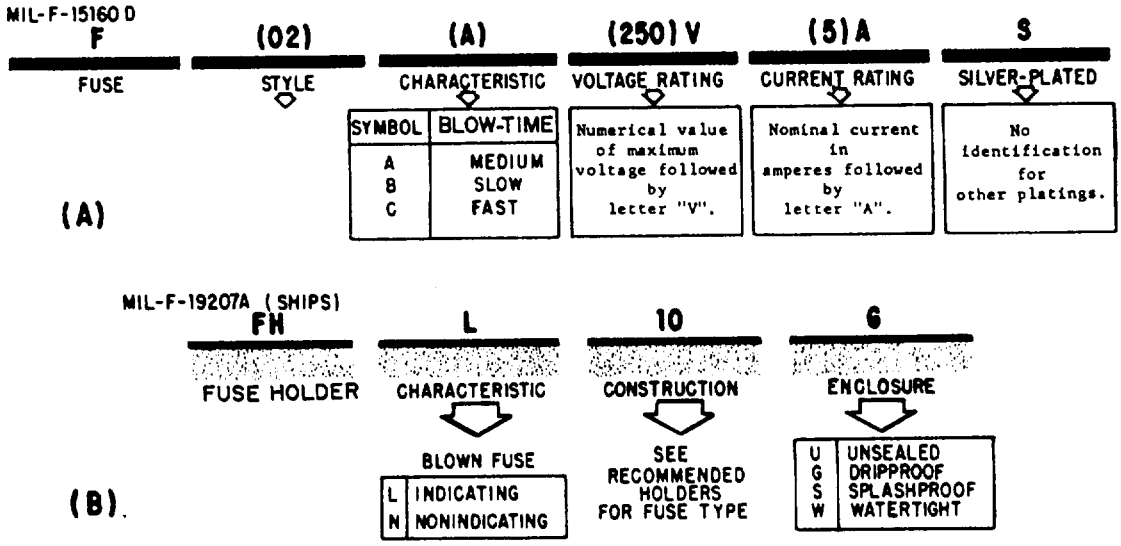


Figure 5-27.-Identification coding: (A) fuses; (B) fuse holders.

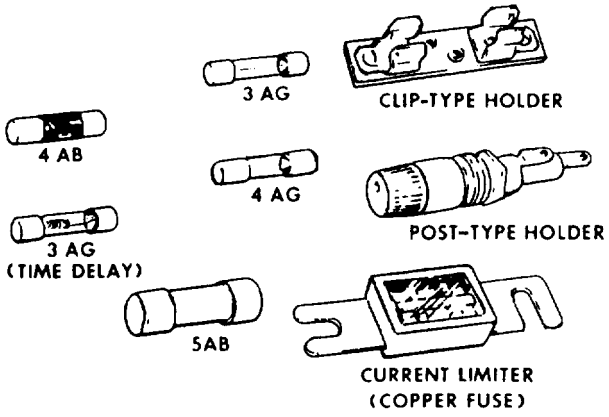


Figure 5-28.-Example of aircraft fuses and holders.

abnormally high currents start to flow. The melting sections have a high-arc resistance to keep the circuit current within the capacity of the limiter. If the excessive current is only a temporary surge, the melting ceases, and the circuit continues to operate as if no abnormal current had been present. Repeated applications of excessive current or uninterrupted application for a period of several seconds melt through the sections and cause the limiter to function in the same manner as a fuse.

Circuit Breakers

In modern naval aircraft, circuit breakers have replaced fuses as the circuit protection devices for most of the wires and cables making up the electrical system. The circuit breaker is designed to open the circuit under short-circuit or overload conditions without injury to itself. Thus, it performs the same function as the fuse, but it has the advantage of being reset and used again. Circuit breakers are rated in amperes and volts.

There are three basic types of circuit breakers—thermal, magnetic, and thermomagnetic. The following discussion is slanted toward the thermal type, because this type is more widely used. Circuit breakers are divided into three categories—the push-button reset type, the toggle type, and the automatic reset type (sometimes called a circuit protector).

The push-button reset type (fig. 5-29) consists of a bimetallic, thermally actuated, spring-loaded

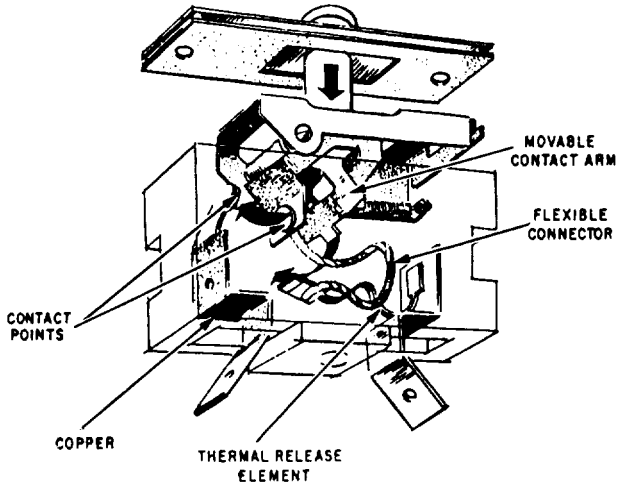


Figure 5-29.-Thermal circuit breaker.

device that connects two electrical contacts when set. An excessive current through the device causes an uneven expansion of the bimetallic mechanism (thermal release). This action releases a trigger escapement and permits the spring-loading to separate the contact members.

A visual indication of the automatic opening is provided by causing the push button to move to an easily noticed "tripped" position. In this position, the button is fully extended and the white ring on the button is showing. This type of push-button breaker has a pullout feature that permits manual opening of the circuit.

Another type of circuit breaker uses a toggle lever instead of the push button. It operates in the same manner as the push-button reset-type breaker, except that the tripped condition is indicated by the toggle lever being in the OFF position. This type of circuit breaker has the apparent advantage of also being used as a switch.

Manual resetting of the circuit breaker may be accomplished by means of the actuator (either push button or toggle lever) whenever the bimetallic thermal element cools sufficiently for the trigger to engage its latching mechanism. In connection with resetting, there are two classifications for circuit breakers—trip-free and nontrip-free.

In the trip-free class, the contacts cannot be kept closed by holding the actuator in the closed (or reset) position as long as an overload condition persists, which would otherwise cause normal tripping.

The nontrip-free circuit breakers can be prevented (by the operator's action) from tripping, even though a tripping condition exists. This should be done only in an emergency. Since this action is apt to change the calibration, the breaker should be replaced as soon as conditions permit. This type of breaker is no longer being installed in new aircraft, but it is still found on some older models.

A disk type of thermal circuit breaker is shown in figure 5-30. This breaker consists of a conductive, snap-acting bimetallic disk that bridges two electrical contacts. When the disk is heated by the excess current through it, it snaps to the reverse position, opening the contacts and breaking the circuit. In circuit breakers having low ratings, a resistance wire is inserted. Current through this wire provides the heat necessary to snap the disk. These breakers are reset by pressing a button that restores the disk to its original position. When circuit breakers of this type are closed, they cannot be reopened manually. They are also nonindicating; that is, the position of the break (open or closed) cannot be determined by visual inspection.

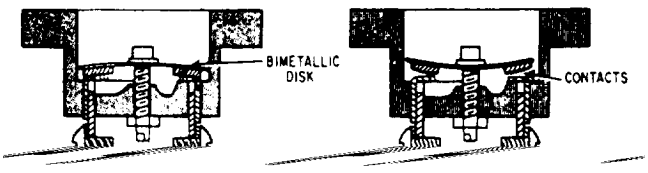


Figure 5-30.-Disk type of thermal circuit breaker.

The automatic reset type of circuit breaker is similar to the bimetallic-disk type just described, except that it has no reset push button. It resets itself automatically. After a short time, when the disk has cooled sufficiently, it will bend back and close the circuit, resetting itself. If a constant overload exists, the breaker will intermittently break the circuit.

Another type of circuit breaker is the switch toggle variety, which is based on magnetic instead of thermal operation. This type can be made to open almost instantly when more than the rated current flows in the circuit. An electromagnet is placed in series with the spring-loaded contacts. The contacts are mounted so that an armature acts as a latch to hold them closed. When an excess current flows, the armature is pulled toward the electromagnet, releasing the contacts and opening the circuit. To reset the circuit breaker, the contacts are closed manually, and the spring-loaded armature returns to its normal position.

MOBILE ELECTRIC POWER PLANTS

The electrical power requirements for starting and servicing modern aircraft are extremely high. Even in aircraft equipped with batteries, and with the batteries fully charged, the capacity is not sufficient to withstand the heavy load of starting an aircraft engine or the power drain of prolonged operational ground checks.

CAUTION

Batteries are not to be used to start aircraft reciprocating engines except in an extreme emergency. The purpose of an aircraft battery is to operate specific instruments and radios in case of a loss of aircraft generator power.

Aircraft are being manufactured that have no internal source of electrical power unless the

engines are operating. This presents problems when electrical power is required to perform maintenance. Running the aircraft engines to provide electrical power for maintenance purposes is also poor practice. There is the danger of turning propellers, jet intake and exhaust blast, or the expense of operating high-powered engines for long periods when only electrical power is required. To make maintenance easier and to provide instrumentation for monitoring engine performance during starts, an external source of electrical power is necessary.

Although the AT is not responsible for the upkeep and maintenance of mobile electric power plants (MEPPs), you must have a basic knowledge of their capacity and operation. On all of the mobile electric power plants described in this chapter, the ac frequency is automatically controlled by a governor that controls the speed of the power plant. The voltage is controlled by a voltage regulator. If the power plant does not regulate to the proper speed (frequency), it must be serviced by the support-equipment work center.

The term *mobile electric power plant (MEPP)* is limited to portable units not installed aboard the aircraft. The units may be self-propelled, towable, or merely transportable. They may be powered by diesel fuel, jet fuel, gasoline, or electricity.

Identification of MEPPs

There are four categories of MEPPs—(1) self-propelled vehicular, (2) gasoline- or diesel-engine driven trailer-mounted, (3) electrically driven trailer-mounted, and (4) gasoline-/diesel-engine or electrically driven dolly/skid-mounted. These power plants are further identified by prefix letters *NA, NB,* and *NC,* These letters indicate the type of power available from the unit as follows:

NA—dc output power only

NB—ac output power only

NC—ac/dc output power

The NC-2A is discussed here. For information on other MEPPS, you should refer to specific MIMs.

The NC-2A (fig. 5-31) is a self-propelled diesel-engine-powered unit. It is front-axle driven, steered by the two rear wheels, and easily maneuverable in congested areas. The front axle is driven by a 28-volt dc, reversible, variable-speed motor, capable of propelling the unit up to 14 mph on level terrain, and has a turning radius of approximately 11 feet.

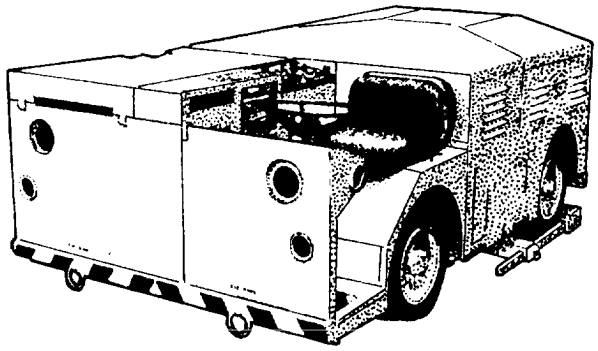


Figure 5-31.-MEPP NC-2A.

This unit supplies 30 kVA, 120/208-volt, 400-Hz, three-phase power for servicing, starting, and maintaining jet aircraft. A dc generator produces 28 volts up to 500 amperes.

Mobile Motor-Generator Sets

Mobile motor-generator sets (MMGs) perform the same function as the mobile electric power plants. However, they are not self-contained and require an external source of electrical power for operation. The MMGs are primarily used in hangars on shore stations or on the hangar decks of aircraft carriers where running an internal combustion engine is not practical, and where external power is readily available. Only the MMG-1A is described in this section. For information about other MMGs, refer to the applicable publications.

The MMG-1A (fig. 5-32) is a small, compact, trailer-mounted, electric-motor-driven generator

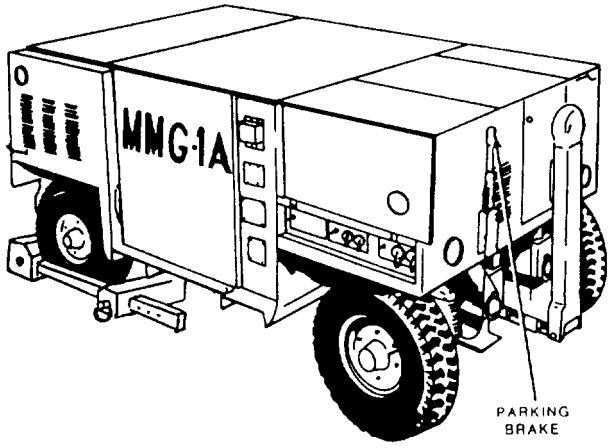


Figure 5-32.-MMG-1A.

set, used to provide 115/200-volt, three-phase, 400-Hz ac power for ground maintenance, calibration, and support for various types of aircraft systems and equipment. Operation oft he unit requires a three-phase, 60-Hz, 220- or 440-volt ac external power source. The unit must be towed or manually moved.

Additional Support Equipment

Other power systems and support equipments available to the AT include the deck-edge power system, the flight-line distribution system, and ground-cooling equipment.

DECK-EDGE POWER.— The primary function of the deck-edge electrical power system installed on aircraft carriers is to provide a readily accessible source of servicing and starting power to aircraft at almost all locations on the carrier's flight and hangar decks.

FLIGHT-LINE ELECTRICAL DISTRIBUTION SYSTEM.— The flight -line electrical distribution system (FLEDS) is an electrical distribution system for servicing aircraft on the flight line. Figure 5-33 shows the major parts of the FLEDS. It consists of three-way junction boxes, interconnecting ramps, aircraft service point castings, and aircraft connector plug assemblies. The total system capability is 24 aircraft. (See fig. 5-33.) Each service point can service one aircraft with 115/200-volt, three-phase, 400-Hz power,

The FLEDS accepts power from a mobile electrical power plant (MEPP) capable of supplying 115/200-volt, three-phase, 400-Hz power. Power is applied at the junction boxes and branches into the service point castings to the aircraft connector plug assemblies. The cables connecting the junction boxes, service point castings, and aircraft connector plugs are installed underneath the interconnecting ramps for protection.

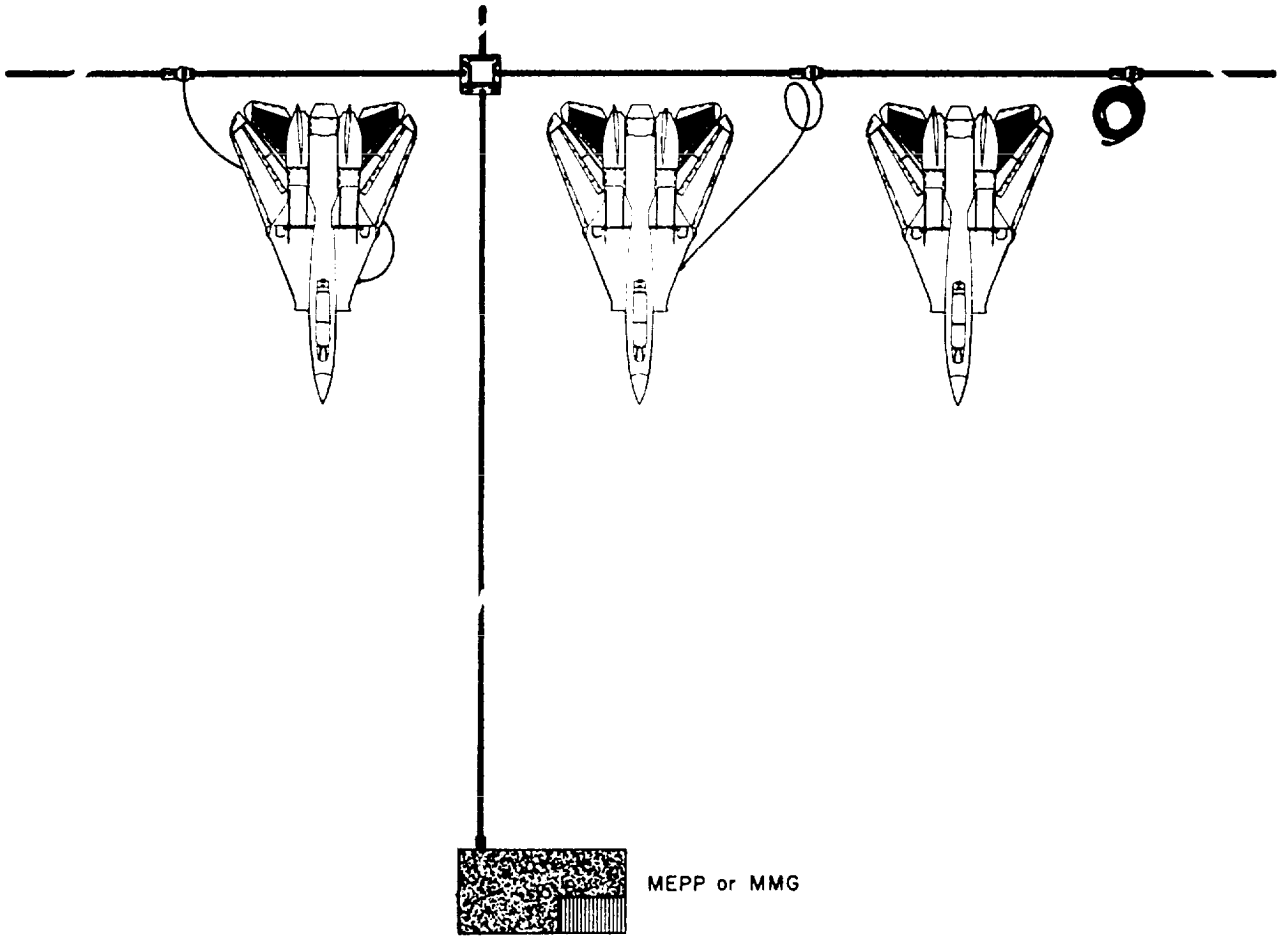


Figure 5-33.-FLEDS.

GROUND-COOLING EQUIPMENT.— The purpose and need for ground cooling varies. A primary reason for using ground-cooling equipment is that electronic equipment produces large quantities of heat. This heat must be dissipated or the equipment could get so hot that the equipment would be damaged and a fire hazard would be created.

When a large quantity of air is required for cooling, a common source for this air is the aircraft's ventilation system. Line maintenance, ground operational checks, and functional checks are usually performed without the aircraft's operating ventilation system since this system is driven by the aircraft engines. Therefore, a substitute air supply must be provided for the air distribution system. The mobile air-conditioner (fig. 5-34) was designed for this purpose. Mobile air-conditioners include the NR-2B, NR-5C, and NR-10A. For information about these air-conditioners, refer to the applicable MIM.

Additional SE information can be found in specific MIMs and *Airman,* NAVEDTRA 14014. OPNAVINST 4790.2 (series) has established the support equipment operator/organizational maintenance program. This program emphasizes and formalizes the responsibilities and procedures required in connection with the operation of support equipment (SE). (Support equipment is also referred to as ground support equipment [GSE], and you may see this terminology and abbreviation used in many publications.) During recent years, the improper use of SE has resulted in far too many ground-handling accidents, excessive repair and replacement costs amounting to millions of dollars annually, and reduced operational readiness. Investigation has shown the major reasons for improper use of this equipment to be lack of effective training for the individuals who operate and maintain the equipment. Also, the lack of effective supervision and leadership by the officers, chief petty officers, and petty officers/noncommissioned officers directly responsible for such operation and maintenance at the various activities contribute to the problem.

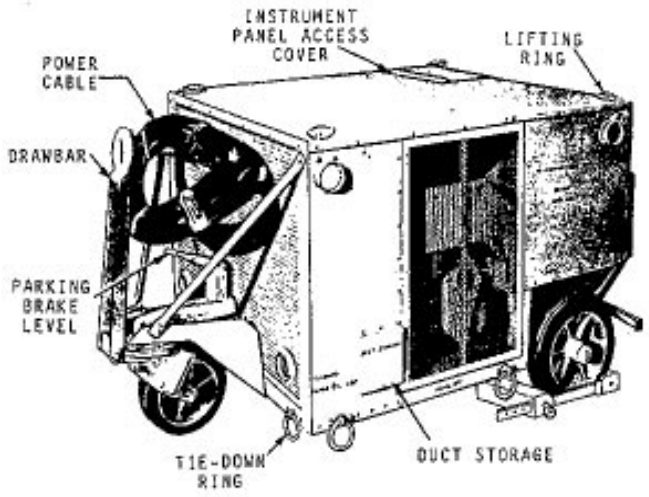


Figure 5-34.-NR-2B mobile air-conditioning unit.

CAUTION

An SE operator's license, OPNAV Form 4790/102, is required of all personnel who operate SE regardless of rate or rating.

It is emphasized that the SE training program is intended to teach support-equipment operation and organizational-level maintenance only. This training does not qualify the individual to operate equipment on the aircraft.

Q46. What components protect an aircraft electrical system?

Q47. At what potential should a fuse be operated? For what reason?

Q48. What advantage does a circuit breaker have have over a fuse?

Q49. List the three basic types of circuit breakers.

Q50. MEPP refers to what types of units? How are these units powered?

Q51. What MEPPs identification would indicate dc output power, as output power, and ac/dc output power, respectively?

Q52. What is the difference between an MEPP and an MMG?

ANSWERS FOR REVIEW QUESTIONS Q46. THROUGH Q52.

A46. Fuses, current limiters, and circuit breakers.

A47. At about 75 percent of its rated value, it provides a good balance between protection and reliability.

A48. They can be reset and used again.

A49. Thermal, magnetic, and thermomagnetic.

A50. Portable units not installed aboard aircraft; they are powered by either diesel fuel, jet fuel, gasoline, or electricity.

A51. NA, NB, and NC.

A52. MMGs are not self-contained and require an external electrical power source for operation.

CHAPTER 6

AVIONICS MAINTENANCE

In today's high-speed aircraft, the avionics systems must always be in top operating condition to ensure the aircraft can complete its mission. The effectiveness of the avionics systems depends on your ability to maintain them. You are only as good as the handtools and publications you use and your knowledge of general and specific maintenance procedures. This chapter covers general maintenance procedures and related information that apply to most avionics systems found in aircraft today.

MAINTENANCE CATEGORIES

Learning Objective: *Identify the maintenance categories and recognize the procedures for each.*

The maintenance performed on the equipment falls into the following two broad categories:

1. Preventive maintenance, which is actions taken to reduce or eliminate failure and prolong the useful life of the equipments.
2. Corrective maintenance, which is actions taken when a part or component has failed and the equipment is out of service.

In maintenance work of any kind, you will need two basic kinds of knowledge. First, you must have specific information that applies to the particular equipment you are repairing or keeping in good condition. Second, you must have and be able to use certain general skills and knowledges that apply to many kinds of equipment and types of work assignments.

Specific information consists of special procedures and processes and detailed step-by-step directions. This information is approved by the proper authority and recommended for a particular piece of equipment. Information is available in publications or checkoff lists from the Naval Air Systems Command (NAVAIRSYSCOM), type commanders, or other authorized sources. The general maintenance skills and procedures are not available in equipment manuals. These skills must be learned during on-the-job training.

PREVENTIVE MAINTENANCE

Maintenance performed to reduce the likelihood of future troubles or malfunctions is preventive maintenance. This form of maintenance consists mainly of visually checking the equipment before and during operation, cleaning the equipment and the various components, lubricating, and performing periodic inspections.

Visual Checks

Before you apply power to equipment, visually check equipment for loose leads, improper connections, and damaged or broken components. This type of check applies particularly to new equipment, equipment returned from overhaul, and preserved equipment. Also, it applies to equipment stored for long periods, and equipment that has been exposed to the weather. A close visual inspection of O-rings, gaskets, and other types of seals is necessary when the equipment under check is a pressurized component. This visual inspection often reveals easily correctable discrepancies with a minimum amount of labor and parts. Such discrepancies, if left uncorrected, might result in a major maintenance problem.

Cleaning

Cleaning the equipment and various components consists of removing dust, grease, and other foreign matter from the covers, chassis, and operating parts. Cleaning includes removing corrosion, fungus, and all other types of matter that could cause operating failure of the equipment. The methods used to clean the various parts and units will vary, but usually a vacuum cleaner

is good for removing the loose dust and foreign matter. Other types of foreign matter can be wiped off using a clean, lint-free cloth.

If you need to remove grease or other petroleum deposits, moisten the cloth with alcohol, dry-cleaning solvent, or some other approved degreaser. After removing the grease, wipe the part dry and clean before you apply power to the equipment.

NOTE: For more specific details on corrosion removal, you should refer to *Avionics Cleaning and Corrosion Prevention/Control,* NAVAIR 16-1-540.

Lubrication

Lubrication of electronic equipment consists of lubricating the mechanical parts that work with the electronic equipment. Equipment, such as unsealed bearings, antenna drives, and waveguide rot sting joints, may require lubrication as directed by the maintenance instructions manual (MIM) for the equipment. Using the correct specification number is very important because the viscosity of a lubricant changes with a change in operating temperature. High operating temperatures cause lubricants to become thin, while low operating temperatures cause lubricants to thicken or harden. Therefore, the lubricant for a particular job depends on operating characteristics and temperature. You should pay particular attention to equipment lubrication for aircraft that fly at high altitudes. At high altitudes, aircraft require a special lubricant that will not harden. This reduces any physical overload on the drive motors and shafts and any electrical overload on the circuits involved.

CORRECTIVE MAINTENANCE

When finding defective parts or unsatisfactory operation occurs, you must analyze the equipment, determine the defective part or parts, and replace or repair. In general, the most effective method for this analysis is a logical step-by-step troubleshooting procedure.

TROUBLESHOOTING

Learning Objectives: *Identify correct troubleshooting techniques; recognize the procedures used to determine malfunctions in aircraft systems and equipment; and identify color coding for electronic components.*

Most of your maintenance time is spent troubleshooting the equipment within the squadron's aircraft. Your job is to maintain several units and systems. Many systems are complex and might seem, at first glance, to be beyond your ability to maintain. However, the most complex job usually becomes much simpler if it is broken down into successive steps. Any maintenance job should be performed in the following order:

1. Analyze the symptom
2. Detect and isolate the trouble
3. Correct the trouble and test the work

Remember, you should follow the six-step troubleshooting procedure found in Navy Electricity and Electronics Training Series (NEETS), module 16, *Introduction to Test Equipment,* NAVEDTRA 14188.

AIRCRAFT PROCEDURES

In troubleshooting, there is no substitute for common sense. Most beginners make a common mistake; they remove major units from the aircraft unnecessarily. The first step you should take when receiving a discrepancy is to determine if the equipment in question is actually faulty. Very often, a preliminary check of the system will show a faulty control box, frayed or broken wiring, or corroded or wet connectors. In some cases, you may find someone using an improper operating procedure—especially with new equipment. (Improper operating procedures are especially common when the reported discrepancy involves new equipment or when operating personnel are undergoing indoctrination.)

If there is no power present at the input to the equipment, you may assume (temporarily) that the set is not broken. You should check all applicable switch positions, circuit breakers, fuses, and other common problems. Then, check for power at the electrical bus that feeds the equipment. Check the tightness of connections and the physical condition of interconnecting cables. Using the wiring diagrams in the applicable manuals, you should check at successive tie points and splices for continuity, short circuits, or grounds.

If a circuit breaker trips or if a fuse blows, it indicates a circuit malfunction. Turn off power to the circuit containing the open, and do not reapply power until you locate and correct the malfunction. The most common causes of tripped

or blown circuit protectors are short circuits, faulty grounds, or overload conditions. However, circuit protectors sometime fail because of age or other conditions. If, after a thorough check, there is no clear reason for the failure, reset the breaker or replace the fuse. Make sure the replacement fuse is the proper size and type, then reapply the power.

The analysis may not indicate the existence of a short circuit, faulty ground, or overload condition. If the equipment still does not operate, you should continue to take measurements with power applied. **Observe all safety precautions.** Systematically take these measurements at progressive checkpoints. Particular faults that can interrupt current through a circuit include broken wiring, loose or faulty terminal or plug connections, faulty relays or switches, and uncoupled splices. Be alert for these conditions!

Sometimes, you cannot determine the defective unit while its still installed in the aircraft. You may need to turn off the power and replace units, one at a time, with units that operate properly. After replacing each unit, reapply power and check the system for proper operation. If the system operates normally, you have found the faulty unit. You may then take the bad unit to the shop for corrective maintenance. At this stage of the overall maintenance process, you should try to determine the reason for the failure of the unit. It is possible the new unit may also become damaged if the basic cause has not been corrected.

After you have removed the defective unit and further analyzed it, reinstall all other items of the original installation and safety wire. Then, perform a complete operational check. During the operational check, readjust or calibrate as necessary. This should be done before clearing the discrepancy on the original VIDS/MAF.

The rules shown here are a guide you can use when making the tests described in this section.

1. Always connect an ammeter in series.

2. Always connect a voltmeter in parallel.

3. Never connect an ohmmeter to an energize circuit.

4. Select the highest range first, and then switch to lower ranges, as needed.

5. When using an ohmmeter, select a scale that will result in a midscale reading.

6. Do not leave the selector switch of a multimeter in the resistance position when the meter is not in use. The leads may short together and discharge the internal battery. There is less chance of damaging the meter if you leave it on a high ac voltage setting or in the OFF position. Meters that have an OFF position dampen the swing of the needle by connecting the meter movement as a generator. This prevents the needle from swinging wildly when moving the meter.

7. View the meter from directly in front to eliminate parallax.

8. Observe polarity when measuring dc voltage or direct current.

9. Do not place meters in the presence of strong magnetic fields.

10. Never try to measure the resistance of a meter or a circuit with a meter in it. The high current required for ohmmeter operation may damage the meter. This also applies to circuits with low-filament current tubes and some types of semiconductors.

11. When measuring high resistance, be careful not to touch the test lead tips or the circuit. Your body resistance will shunt the circuit and cause an erroneous reading.

12. Connect the ground lead of the meter first when making voltage measurements. Work with one hand whenever possible.

Continuity Test

Open circuits are circuits that interrupt current flow, either from a broken wire, defective switch, or any other means that stops current flow. To check for opens (or to see if the circuit is complete or continuous) you conduct a *continuity test.*

An ohmmeter, which contains its own batteries, is an excellent tool to use when you perform a continuity test. (In an emergency, a flashlight can function as a continuity tester.) Normally, you make continuity checks in circuits where the resistance is very low (such as the resistance of a copper conductor). A very high or infinite resistance indicates an open circuit. Such a condition would be an open conductor.

Look at figure 6-1. It shows a continuity test of a cable. When using an ohmmeter, make sure you disconnect both connectors and connect the ohmmeter in series with the conductor under test. The power must be off. When you are checking conductors A, B, and C, the current from the ohmmeter flows through plug No. 2, the conductor, and plug No. 1. From this plug, it passes through the jumper to the chassis ground and to the aircraft's structure. The structure serves as the return path of the current to the chassis of unit 2, completing the circuit to the ohmmeter. The ohmmeter will indicate a low resistance.

Checking conductor D (fig. 6-1) reveals an open. The ohmmeter indicates maximum resistance because current cannot flow. With an open circuit, the ohmmeter needle is all the way to the left, since it is a series-type ohmmeter (reads right to left).

You cannot use the aircraft structure as the return path; use one of the other conductors. For example, to check D (fig. 6-1), connect a jumper from pin D to pin A of plug 1 and the ohmmeter leads to pins D and A of plug 2. By the process of elimination, this technique will also reveal the open in the circuit.

Grounded Circuit Test

Grounded circuits may be caused from either direct or indirect contact between some conducting part of the circuit and the metallicframework of the aircraft. Grounds may have many causes. Perhaps the most common cause of a ground is frayed wire insulation that allows the bare wire to come into contact with the metal ground.

Grounds are usually indicated by blown fuses or tripped circuit breakers. Blown fuses or tripped circuit breakers, however, may also result from a short other than a ground. A high-resistance ground may also occur where enough current does not flow to rupture the fuse or open the circuit breaker.

Ohmmeters provide a good test for grounds. You may also use other continuity testers. By measuring the resistance to ground at any point in a circuit, you can determine if the point is at ground potential. Look at figure 6-1 again. It shows a way to test a cable for grounds. If you remove the jumper from pin D of plug No. 1, a test for grounds can be made for each conductor of the cable. This is done by connecting one meter lead to ground and the other to each of the pins of one of the plugs. A low-resistance reading on the ohmmeter indicates a grounded pin. You must remove both plugs from their units. If you remove only one plug, a false indication is possible. This false indication occurs because the other conductor receives a ground through the unit.

Short Test

A short-circuit test is a test to determine whether two conductors have accidentally touched

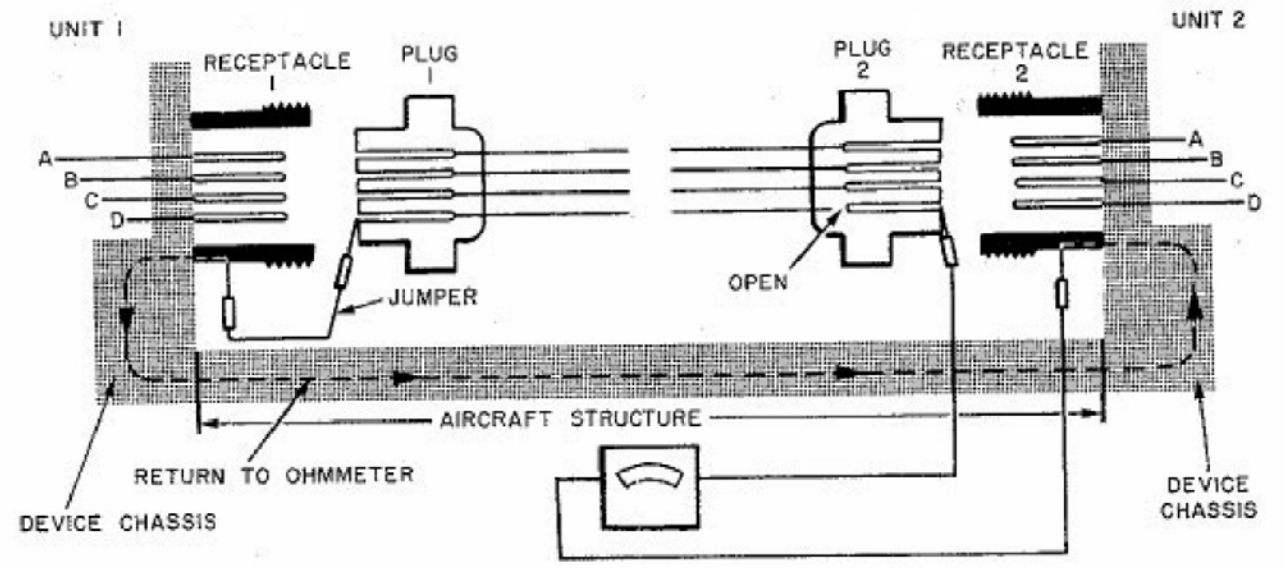


Figure 6-1.-Continuity test.

each other, directly or through another conducting element. Two conductors with frayed insulation may touch and cause a short. Too much solder on one pin of a connector may short it to an adjacent pin. In a short circuit, sufficient current may flow to blow a fuse or open a circuit breaker. However, it is entirely possible to have a short between two cables carrying signals and not blow a fuse.

The device used to check for a short is the ohmmeter. By measuring the resistance between two conductors, you may detect a short between them. A low-resistance reading usually indicates a short. Look at figure 6-1. You may perform a short test by removing the jumper and disconnecting both plugs. This is done by measuring the resistance between the two suspected conductors.

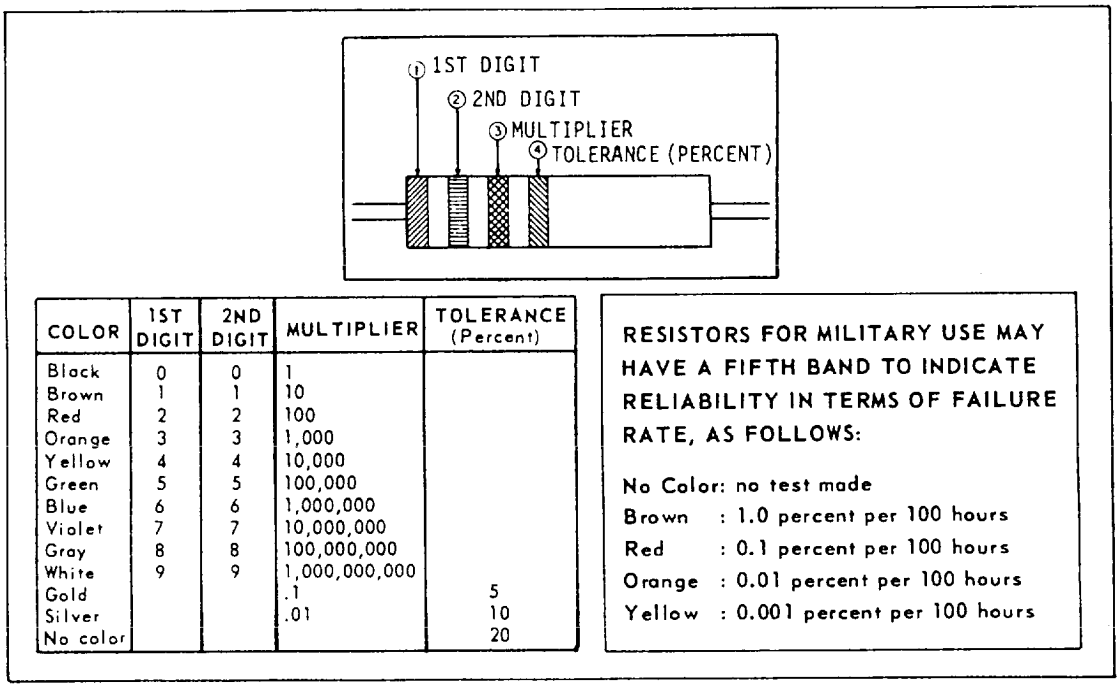
Shorts can occur in many components, such as transformers, motor windings, and capacitors. The major method for testing such components is to take a resistance measurement and then compare the indicated resistance with the resistance given on schematics or in maintenance manuals. You may also make comparisons with identical operational equipment.

Voltage Test

You make voltage tests with the power applied. **Therefore, you must follow the prescribed safety precautions to prevent injury to yourself and others or damage to the equipment.** Making voltage tests is an important part of maintenance work. It lets you isolate discrepancies to major components, and you can use these tests in the maintenance of subassemblies, units, and circuits. Before checking a circuit voltage, you should check the voltage of the power source to make sure normal voltage is being input to the circuit.

COLOR CODING

As an AT, you need to know the different color codes that identify resistors, capacitors, wiring, and other components. Resistor color codes (fig. 6-2) lets you quickly identify size (in ohms) and tolerances. You can use color codes, along with MIL-STD-199C (which contains a complete part number breakdown), to identify or find suitable replacements.



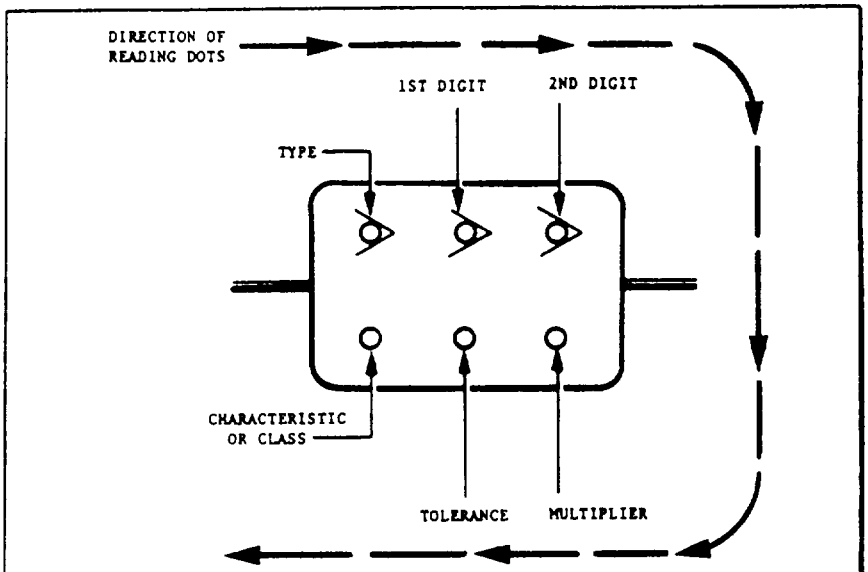
COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (Percent)
Black	0	0	1	
Brown	1	1	10	
Red	2	2	100	
Orange	3	3	1,000	
Yellow	4	4	10,000	
Green	5	5	100,000	
Blue	6	6	1,000,000	
Violet	7	7	10,000,000	
Gray	8	8	100,000,000	
White	9	9	1,000,000,000	
Gold			.1	5
Silver			.01	10
No color				20

RESISTORS FOR MILITARY USE MAY HAVE A FIFTH BAND TO INDICATE RELIABILITY IN TERMS OF FAILURE RATE, AS FOLLOWS:

No Color: no test made
Brown : 1.0 percent per 100 hours
Red : 0.1 percent per 100 hours
Orange : 0.01 percent per 100 hours
Yellow : 0.001 percent per 100 hours

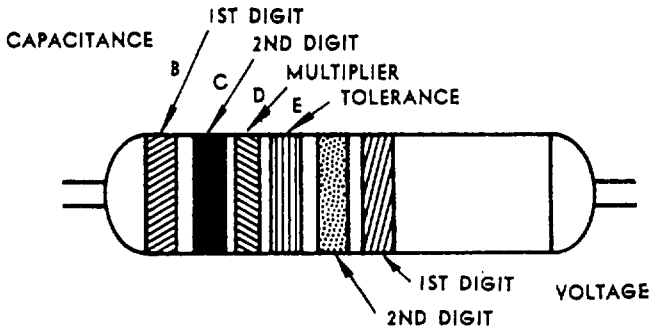
Figure 6-2.-Resistor color codes.

Capacitor color coding is one of two methods used to identify capacitors. Figures 6-3, 6-4, 6-5, and 6-6 are several examples of capacitor color coding for different styles of capacitor. The other method is the typographical method where a number is stamped on the capacitor. For more information on capacitor identification, you should refer to NEETS, module 19, NAVEDTRA 14191, and specific military standards and specifications.



TYPE	COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (PERCENT)	CHARACTERISTIC OR CLASS
JAN, MICA	BLACK	0	0	1.0	±20	APPLIES TO
	BROWN	1	1	10		TEMPERATURE
	RED	2	2	100	± 2	COEFFICIENT
	ORANGE	3	3	1,000		OR METHODS
	YELLOW	4	4	10,000		OF TESTING
	GREEN	5	5	100,000		
	BLUE	6	6	1,000,000		
	VIOLET	7	7	10,000,000		
	GRAY	8	8	100,000,000		
EIA, MICA	WHITE	9	9	1,000,000,000		
	GOLD			.1	± 5	
MOLDED PAPER	SILVER			.01	±10	
	BODY				±20	

Figure 6-3.-Six-dot color code for mica and molded paper capacitors.



COLOR	CAPACITANCE			TOLERANCE (PERCENT)	VOLTAGE RATING	
	1ST DIGIT	2ND DIGIT	MULTIPLIER		1ST DIGIT	2ND DIGIT
BLACK	0	0	1	±20	0	0
BROWN	1	1	10		1	1
RED	2	2	100		2	2
ORANGE	3	3	1,000	±30	3	3
YELLOW	4	4	10,000	±40	4	4
GREEN	5	5	100,000	± 5	5	5
BLUE	6	6	1,000,000		6	6
VIOLET	7	7			7	7
GRAY	8	8			8	8
WHITE	9	9		±10	9	9

Figure 6-4.-Six-band color code for tubular paper dielectric capacitors.

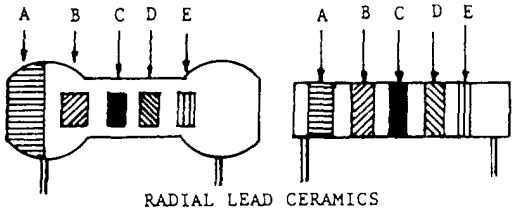
B - A - TEMPERATURE COEFFICIENT

B - 1ST DIGIT

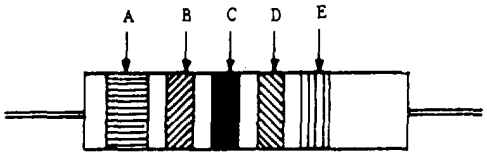
C - 2ND DIGIT

D - MULTIPLIER

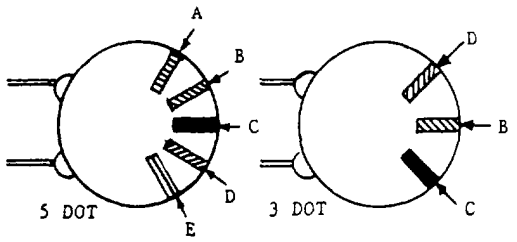
E - TOLERANCE



RADIAL LEAD CERAMICS



AXIAL LEAD CERAMIC

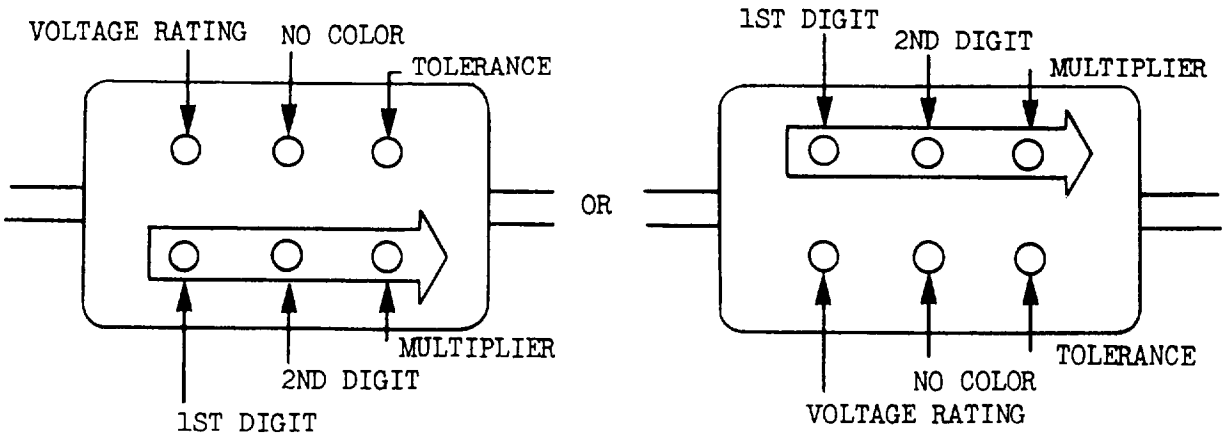


CERAMIC DISC CAPACITOR MARKING

COLOR	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE		TEMPERATURE COEFFICIENT*
				MORE THAN 10 pF (IN PERCENT)	LESS THAN 10 pF (IN pF)	
BLACK	0	0	1.0	±20	±2.0	0
BROWN	1	1	10	± 1		-30
RED	2	2	100	± 2		-80
ORANGE	3	3	1,000			-150
YELLOW	4	4	10,000			-220
GREEN	5	5		± 5	±0.5	-330
BLUE	6	6				-470
VIOLET	7	7				-750
GRAY	8	8	.01		±0.25	+30
WHITE	9	9	.1	±10	±1.0	+120 TO -750 (EIA)
						+500 TO -330 (JAN)
SILVER						+100 (JAN)
GOLD						BYPASS OR COUPLING (EIA)

*PARTS PER MILLION PER DEGREE CENTIGRADE.

Figure 6-5.-Ceramic capacitor color code.



COLER	1ST DIGIT	2ND DIGIT	MULTIPLIER	TOLERANCE (PERCENT)	VOLTAGE RATING
BLACK	0	0	1.0		
BROWN	1	1	10	± 1	100
RED	2	2	100	± 2	200
ORANGE	3	3	1,000	± 3	300
YELLOW	4	4	10,000	± 4	400
GREEN	5	5	100,000	± 5	500
BLUE	6	6	1,000,000	± 6	600
VIOLET	7	7	10,000,000	± 7	700
GRAY	8	8	100,000,000	± 8	800
WHITE	9	9	1,000,000,000	± 9	900
GOLD			.1		1000
SILVER			.01	± 10	2000
BODY				± 20	*

*WHERE NO COLOR IS INDICATED, THE VOLTAGE RATING MAY BE AS LOW AS 300 VOLTS.

Figure 6-6.-Mica capacitor color code.

Semiconductor diodes and transformers also have color-coding identification. See figures 6-7 and 6-8.

BENCH PROCEDURES

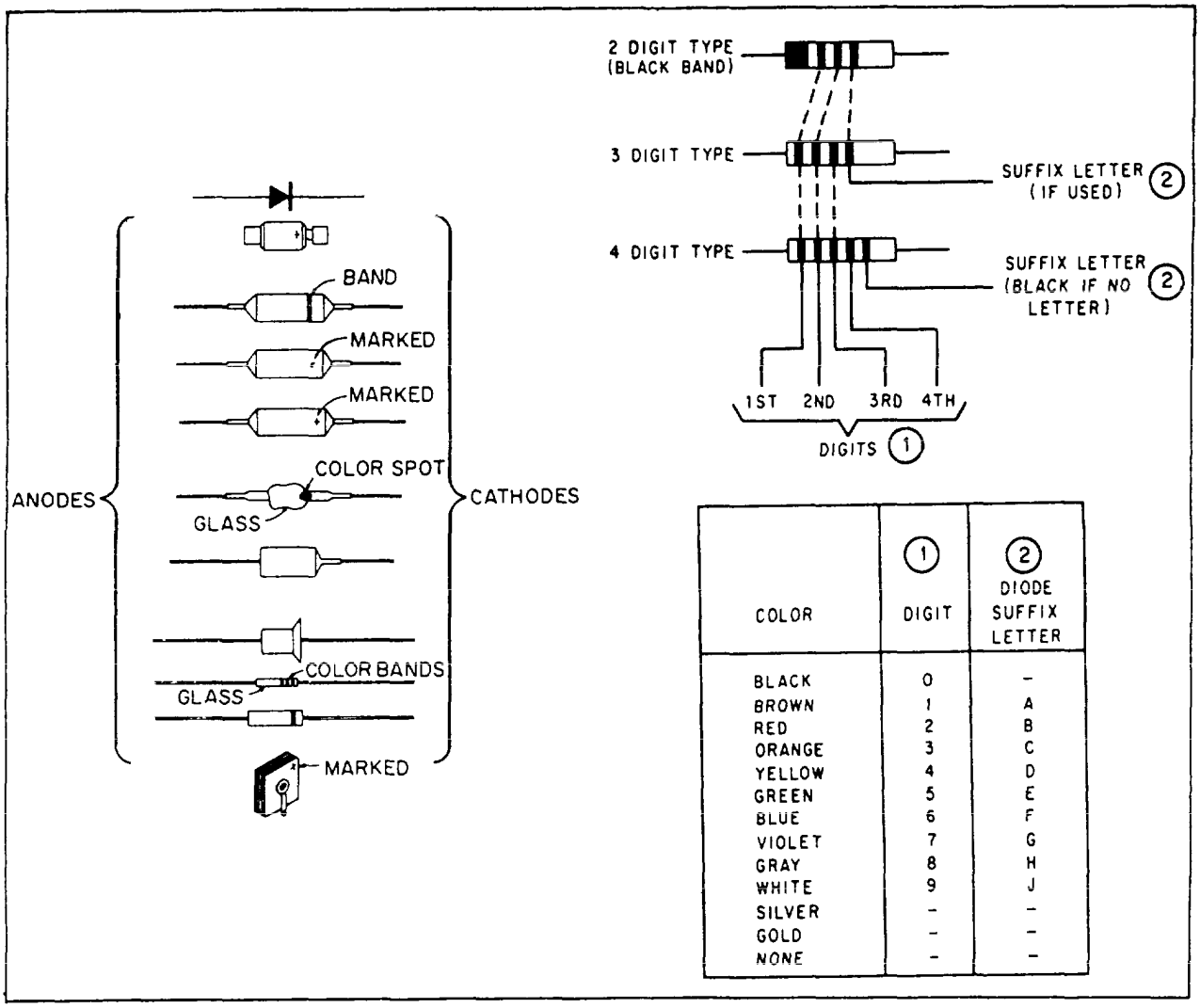
The visible condition of a unit is usually the first check in any troubleshooting process. If certain parts are obviously not in good condition, correct them before you resume testing. Such faults include burned parts, loose, disconnected, dented, broken, or otherwise obviously faulty parts. Check the visible condition of a unit before installing and connecting the unit at the test bench.

The sense of smell can help pinpoint certain troubles. A part that overheats usually gives off an odor that is sometimes readily detectable. However, location of a burned part does not necessarily reveal the cause of the trouble.

To determine the cause of the trouble, you should refer to the MIM for the given equipment. The MIM is a source of valuable information for performing maintenance on electronic equipment. (Few technicians are so thoroughly familiar with an electronic unit that they do not have to use the MIM when performing maintenance.)

Signal Tracing

Signal tracing is one method used in trouble-shooting. It is a good method for tracing signals in RF receivers and audio amplifiers. However,



COLOR	(1) DIGIT	(2) DIODE SUFFIX LETTER
BLACK	0	–
BROWN	1	A
RED	2	B
ORANGE	3	C
YELLOW	4	D
GREEN	5	E
BLUE	6	F
VIOLET	7	G
GRAY	8	H
WHITE	9	J
SILVER	–	–
GOLD	–	–
NONE	–	–

Figure 6-7.-Semiconductor diode markings and color-code system.

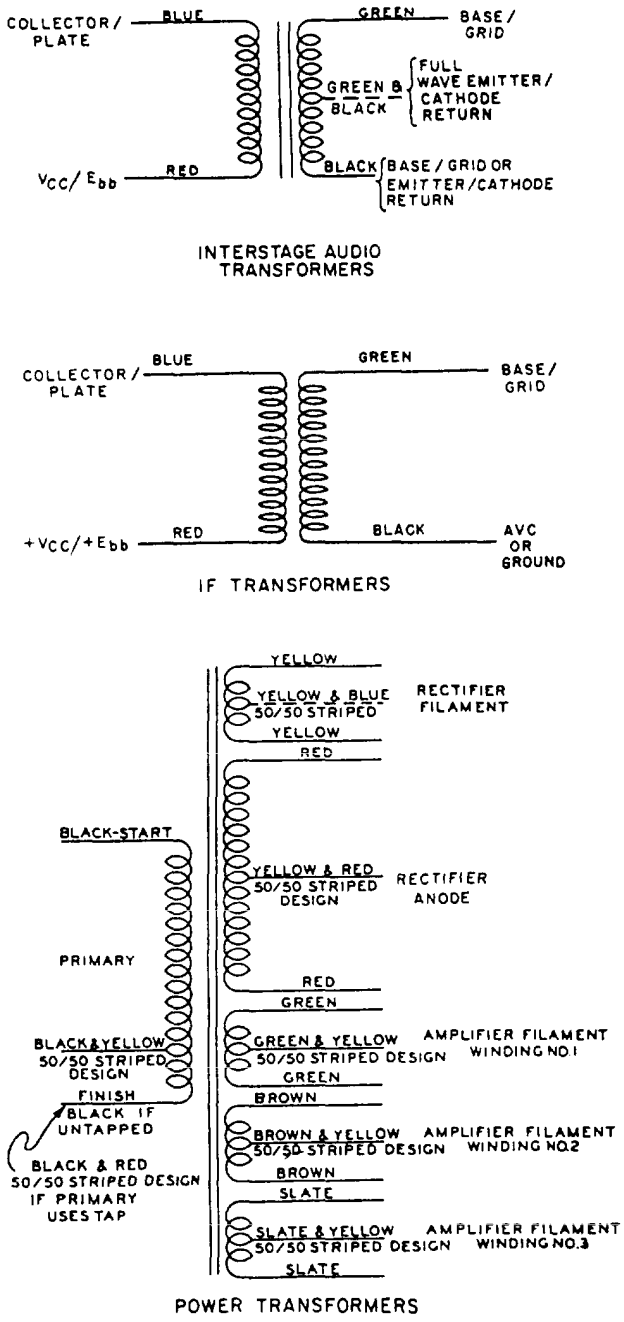


Figure 6-8.-Color codes for transformers.

in radar, the frequencies are higher, the methods of signal application differ, and the output in the final stage is video (viewed). The applicable MIM contains detailed procedures for testing most units or circuits.

Signal tracing is a very effective method for locating defective stages in many types of electronic sets. It is especially useful when servicing equipment that normally contains no built-in meters. In signal tracing, a signal voltage (similar to that present under operating conditions) from a signal generator is input to the circuit in question. The signals that result are then checked at various points in the stage, using a high-impedance test instrument. The particular test equipment, such as a vacuum tube voltmeter, an oscilloscope, or an output meter, depends on circuit application and other parameters, as appropriate. (The test instrument should have high impedance so that it will not change the operation of the circuit under test.)

When using the signal-tracing to measure ac signals, you should make sure the test instruments are adequately isolated from any dc potential present in the circuit. Some test instruments have special ac probes that incorporate a capacitor in series with the input. Before using any item of test equipment, you must know the characteristics and proper use of the test equipment as well as the equipment under test.

By using the signal-tracing method, you can measure the signal gain or loss of amplifiers. You can also locate the points of origin of distortion, hum, noise, and oscillation that occur in the amplifiers.

The gain measurement is a good example of an important method in signal tracing. By this procedure, you can quickly isolate a discrepancy to the defective stage. A signal generator, with the output attenuator calibrated to microvolt, and an output meter can measure gain. It is helpful to have data on the normal gain of the various stages of the device. You can find this data in the MIM for the receiver under test.

To measure gain, you connect the output meter across the headset (or the voice coil of a speaker) or across the secondary of the output transformer. Connect the output of the signal generator to the grid circuit of the stage under test. Then, adjust the attenuator of the signal generator until the output meter reads a value appropriate to serve as a reference figure. After adjustment, connect the output of the signal generator to the output of the stage under test (or to the input of the next stage). Adjust the attenuator until registering the same reference value on the output meter. To determine the gain of the stage, divide the second value of the signal (taken from the calibrated attenuator) by the value of the signal applied to the input of the stage. For example, suppose the signal generator supplies a voltage of 400 microvolt to the grid of an IF amplifier. This voltage causes the output meter to indicate some

value you can use as a reference. When the generator signal is input to the following grid, the signal strength must be increased (4,000 microvolt) to cause the output meter to indicate the same reference value. The gain of the stage is equal to

$$\frac{E_{in}\ \text{2nd stage}}{E_{in}\ \text{1st stage}};$$

that is,

$$\frac{4{,}000}{400} = 10.$$

If similar measurements made in the remaining stages of the receiver reveal one stage in which the gain is lower than normal or is zero, a faulty stage is indicated. Then, you can check that stage thoroughly by measuring voltage or resistance or by replacing parts until you find the defective one.

Test Probe Substitution

Do not use a test equipment probe with equipment other than that for which it is designed. Errors may result. Any differences in the internal resistance of the probe and input circuitry of the equipment make substitution impossible without calibration. For example, the internal resistance of a 10:1 probe is usually nine times higher than the input circuitry of the equipment. You should note that 2:1, 50:1, and 100:1 probes are also available.

Use the test probe that is designed for the equipment. Do not use a probe that is not specifically designed for the equipment under test. An improper test probe may not have sufficient capacitive adjustment to preserve the waveshape of the observed signal.

Voltage Checks

You should make voltage measurements at various points in the stage suspected of being faulty. Compare the observed voltage values with the normal voltage values given in the MIM. When making voltage checks for comparison with a chart, you should use a voltmeter with the proper ohms-per-volt rating (sensitivity). **Always connect voltmeters in shunt with the circuit elements under test.** This results in circuit loading. (For an explanation of circuit loading, refer to NEETS, module 3, NAVEDTRA 172-03-00-79.) The sensitivity of the test instrument must be the same as that of the instrument used in making the readings on the chart. This ensures the loading effect will be the same in both cases, and your meter readings should be reliable. Remember, if the meter sensitivity is too low, the loading effect may be so severe that it will prevent proper operation of an otherwise normally functioning circuit.

By comparing observed voltages with the voltages given in the MIM, you can often isolate the defect. Voltage checks are most effective when applied within a single stage after you have made checks to localize the defect. This is true because modern electronic equipment is complex, and requires time to check all the voltages present in all the stages.

Some electronic sets have built-in meters or plugs for front panel application of meters. These meters usually work with a selector switch and read voltage or current values at set points. Normally, you can isolate a defective stage in this manner.

After isolating the defective stage, it becomes a matter of point-to-point checking to isolate the fault within the stage itself. A voltmeter will pinpoint the trouble, but it often becomes necessary to use an ohmmeter to determine the exact cause of trouble; for example, shorted capacitors, open resistors or transformers, or a wire grounded to chassis.

Resistance Checks

Like voltage measurement, resistance checks are most effective after you isolate the trouble to a particular stage. After isolating the trouble, the ohmmeter is a very useful instrument, and often quickly leads you, the technician, to the cause of the trouble. Resistance checks are made like voltage checks, except you must remove power from the set. You measure resistance and compare your readings to the normal values given in the maintenance publications. Reliance on resistance measurement alone is too time-consuming to be efficient.

NOTE: To prevent damage to the ohmmeter, always be sure there are no voltages present in the equipment before beginning the resistance checks. Turn off the power switches, discharge the power supply and other large capacitors, and bleed off any other residual charges in the set. Also observe proper precautions when connecting or disconnecting the ohmmeter across large inductors.

The ohmmeter method of checking electrolytic capacitor serves as an example of how to make a routine resistance check. You make a resistance measurement on the discharged capacitor using the high resistance range of the ohmmeter. When you first apply the ohmmeter leads across the capacitor, the meter pointer rises quickly and then drops back to indicate high resistance. Now, if you reverse the test leads and reapply them, the meter pointer rises again, even higher than before, and again drops to a high value of resistance. The battery of the ohmmeter charges the capacitor and causes the meter to deflect. When reversing the leads, the voltage in the capacitor adds to the applied voltage, resulting in a greater deflection than at first.

WARNING

Do not leave the ohmmeter connected across an electrolytic capacitor for any length of time. Electrolytic capacitors are polarity sensitive, and reverse polarity of voltage (even from an ohmmeter) may cause excessive current, which could result in overheating and possible explosion of the capacitor.

If the capacitor is open-circuited, no deflection will occur. If the capacitor is short-circuited, the ohmmeter indicates zero ohms. The resistance values registered in the normal electrolytic capacitor result from the slight current leakage between the electrodes. Because the electrolytic capacitor is a polarized device, the resistance is greater in one direction than the other.

If a capacitor indicates a short circuit, you must disconnect one end of it from the circuit. Then, take another resistance reading to determine if the capacitor is actually at fault.

Unless the ohmmeter has a very high resistance scale, you will not be able to see any meter deflection when you are checking small capacitors. Even a scale of R x 10,000 is not enough for very small capacitors. The smaller the capacitor, the less leakage across the plates; therefore, the more resistance.

When making resistance checks, you need to determine what circuits connect to the checkpoints. The MIM indicates the proper resistance at various checkpoints throughout the set. Also, the MIM contains a complete schematic of the set, as well as a circuit schematic of the stage under test. The schematics may set up conditions for performing voltage and resistance measurements. These conditions may include the positions of switches and control knobs, relays energized or de-energized, and tubes in sockets. These conditions duplicate the initial measurement conditions with which you are comparing your readings. Typical instructions might read "Power switch OFF—all controls on the control box full CCW (counterclockwise)." By following these instructions, you should get accurate values to compare with the specified values. Otherwise, you may get incorrect values.

Defective Components

Before you replace a defective part, determine if such an operation is within your activity's capability. The maintenance that you can perform is a function of your activity's assigned level of maintenance. Because electronic equipment is complex and compact, the trend in the Navy is toward replacement of subassemblies instead of individual parts. This trend stems from the necessity of exact parts replacement and the difficulty of working in small spaces. Even the amount of solder used on a connection is important. However, there are many parts that you may replace at any level of maintenance. The general rule is to replace any defective part with an exact duplicate.

You should refer to the specific MIM, IPB, and supply publications to help get information (such as stock number and description) about a particular part. The publication that you will use most often when ordering parts for the particular equipment under repair is the illustrated parts breakdown (IPB). For an explanation on how to use the IPB, you should refer to Aviation *Maintenance Ratings Fundamentals,* NAVEDTRA 14318.

If it becomes necessary to substitute parts, you need to make sure the substitute part is a proper replacement. When replacing resistors, you must consider ohmic value, wattage rating, tolerance, physical dimensions, and type of construction. If you are replacing capacitors, you must consider physical dimensions, capacity, tolerance, temperature coefficient, and voltage rating. Plugs and connectors almost always have to be exact because it is difficult to find items of this type that are interchangeable. Familiarity with the IPB is a definite asset to the technician who must determine exactly what part to order.

Checking After Repair

No repair job is complete until you reinstall the repaired unit or component and actually check to see that it is operating properly. The component must be bench checked after correcting the trouble. Before completely reassembling the component, you should make any alignment or adjustments that are necessary for the proper operation of the component. After reassembly of the component, replace dust and shielding covers, install the component in the outer case (and pressurize, if necessary), and perform a final bench operational check. Often, when installing a shield or plate, it touches a bare wire or other contact and makes the component inoperative or causes substandard operation. It is much better to discover such a fault at the bench than in the aircraft.

After installing the component in the aircraft and properly securing it for flight, you must give it a final operational test. You cannot assume that because the component operated properly on the bench it will do so in the aircraft. The most important test is an operational check under exact operating conditions. When the component performs properly in the aircraft and is secure, you may sign off the discrepancy sheet (VIDS/MAF). This signature indicates that the electronic component should operate properly under normal flight conditions.

Figure 6-9 summarizes the troubleshooting information described in the preceding paragraphs. The directions given in blocks 1 through 5 are steps for locating a trouble. The directions given in blocks 6 and 7 are steps in repairing the set and should always occur. However, steps 2, 3,4, and/or 5 may sometimes be eliminated.

Q1. What are the two broad categories of maintenance?

Q2. Describe preventive maintenance.

Q3. What is the first step you should take when receiving a discrepancy?

Q4. Describe the use of continuity tests.

Q5. Describe the major method for testing shorts in transformers, motor windings, and capacitors.

Q6. What is the proper color code for a 100-ohm resistor with a 10-percent tolerance?

Q7. What must you consider when substituting a resistor to ensure it is a proper substitution?

REPAIR INFORMATION

Learning Objective: *Describe repair techniques for soldering microelectronics, including modules, maintenance aids, and printed circuits (construction, repair techniques, and parts replacement).*

The trend toward replaceable units has led to several new methods of construction of electronic equipment. Two examples of replaceable units are *microelectronic* and *printed circuits.* These circuit designs provide speed and economy of manufacture and speed and ease of maintenance, as well as for saving space and weight.

NOTE: Only certified microminiature component repair (MMCR) personnel are authorized to make microelectronic repairs.

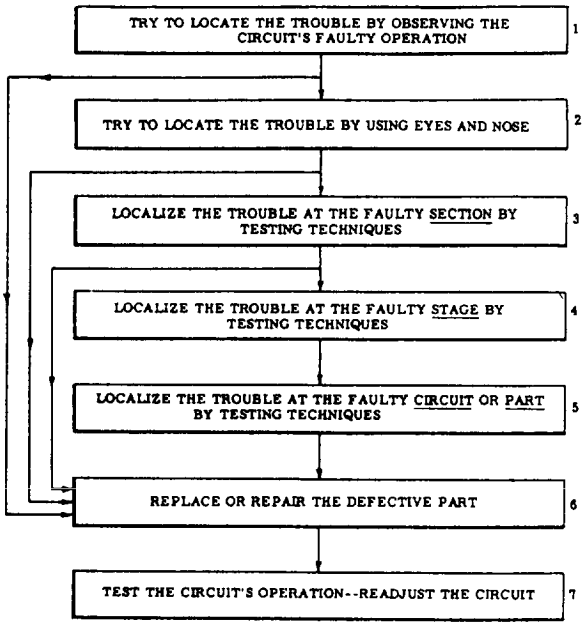


Figure 6-9.-Troubleshooting procedures.

SOLDERING

Soldering operations are a vital part of electronics maintenance procedures. Soldering is a manual skill that all personnel assigned electronics maintenance shop duties must learn. Practice is necessary to develop proficiency in the techniques of soldering. However, practice serves no useful purpose unless it is based on an understanding of basic principles, For a discussion on soldering materials and practices, you should refer to NEETS, module 4, NAVEDTRA 14176.

MICROELECTRONIC MAINTENANCE

Microelectronic technology by itself does not solve the maintenance problem. In spite of the increased reliability, failures still occur. When they do, the faulty items must be isolated and repaired or replaced.

With the discrete miniature component (transistor, resistor, capacitor, etc.), you can test individual circuit elements. Thus, you can determine the cause of failure, and repair it by replacing the faulty component.

With the integrated circuit, you cannot replace an individual part because the unit exists only as a complete functional element. The maintenance process then becomes a matter of isolation and replacement of the defective chip, flat-pack, board, or module.

Modules

Modular assemblies are mechanically more rugged than conventional circuits. However, they are susceptible to damage from improper handling, electrical overload, or overheating. Techniques used to maintain and service modules are similar to those used for conventional circuits, but they require somewhat more care in execution. The small size and close spacing of the parts within the modular assembly require smaller tools than those used for conventional maintenance. Additional devices and maintenance aids help with the precision needed for such close work.

Many components are susceptible to damage from various causes, especially maintenance. Component damage during maintenance usually results from excess heat during repair, reversed polarity of ohmmeters while checking for continuity, excessive voltage application or signal strength during testing, rough handling, or use of the wrong tools or materials.

Do not loosen connections, disconnect parts, insert or remove transistors, or change modular units with the power on or while the circuit is under test. A loose connection of any type causes an inductive kickback, which may damage the component.

You should remove any capacitive charge from parts, tools, or test equipment before connecting them to any modular unit. Connect a grounding clip from the item to the modular chassis before you make any other contact. When disconnecting the equipment, you should remove the grounding clip last.

Damage easily occurs to transistor leads, printed circuit boards, etc., as well as many miniature components, during handling, stowage, or shipping. You should always observe proper precautions. If you use adequate care and proper techniques, you can repair these miniature components.

Maintenance Aids

To maintain microcircuits, you need special devices to extend your vision, aid your reach, and act as a third hand. The special tools and devices you use will depend on the equipment you are servicing and on the maintenance operations involved. Many of the tools and devices discussed in this section are useful in all maintenance activities, while others have limited applicability. Keep the assortment of tools to the minimum required for effective and efficient maintenance of assigned equipment.

Many dental tools, no longer usable for their original purpose, make excellent tools for your use. These tools include various knives for scraping protective coatings and excess solder, brushes for cleaning, probes, and mirrors for inspecting crowded spaces. Drills and drill bits are useful when making small repairs. You can use tweezers and surgical hemostats to grasp and hold small parts. They also provide good heat shunts for soldering, but their effectiveness is limited. (A more desirable heat shunt is described later in this section.) Hypodermic syringes can be used to oil hard-to-reach points.

You should use a pin vise when drilling through plastic or Bakelite, or when drilling through the copper-ribbon conductor strips on printed circuit boards. You may also use it when cleaning solder from hollow receptacles and terminals. In addition, the pin vise can hold many sizes and shapes of hooks and probes made from spring wire. These attachments are useful when

you are inspecting and servicing equipment and components in confined spaces.

A magnifying device is essential for inspecting minute parts. If the magnifier is on a stand, you will have both hands free for other tasks.

When you work on a removed printed circuit or terminal board, the item must remain still. You can use a module holder or module jig for this purpose. The jig provides support and prevents flexing or slipping. Securing the jig to the worktable leaves both of your hands free to work on the board.

For any resoldering operation, mount the part so the terminals point out and down. Place the soldering iron under the terminals so the solder flows away from the joint. To resolder the joint, invert the part.

Some technicians use a drawer or box with a white cloth to catch (trap) any small parts dropped during maintenance. (See fig. 6-10.)

NOTE: This procedure is no longer recommended since the cloth and/or box may contain an electrostatic charge. The static charge may damage solid-state components when they fall on the cloth. Ensure you and your fellow workers DO NOT use this unless approved by proper authority.

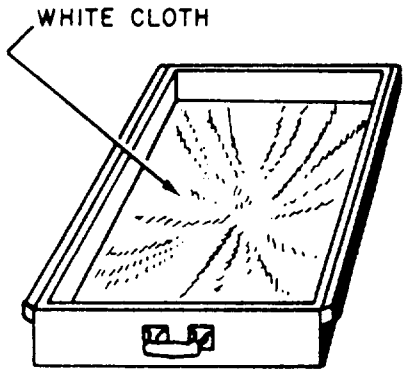


Figure 6-10.-Trap for catching small dropped parts.

For further information on procedures to follow when resoldering components, refer to *Assembly Electronics Repair, Standard Maintenance Practices,* NAVAIR 01-1A-23.

PRINTED CIRCUITS

The trend toward replaceable units has led to several new methods of construction of electronic equipment. An example of such a unit is the printed circuit. This type of circuit provides for speed and economy of manufacture and speed and ease of maintenance, as well as for saving space and weight.

ANSWERS FOR REVIEW QUESTIONS Q1. THROUGH Q7.

A1. Preventive and corrective maintenance.

A2. Preventive maintenance is maintenance performed to reduce the likelihood of future troubles or malfunctions.

A3. Determine if the equipment in question is actually faulty.

A4. To check for opens or to see if a circuit is complete or continuous.

A5. The major method for testing these components is to take resistance measurements and compare them with schematics, MIMs, or identical operational equipment.

A6. 1st Digit: Brown; 2nd digit: Black; Multiplier: Brown; Tolerance: Silver; see figure 6-2.

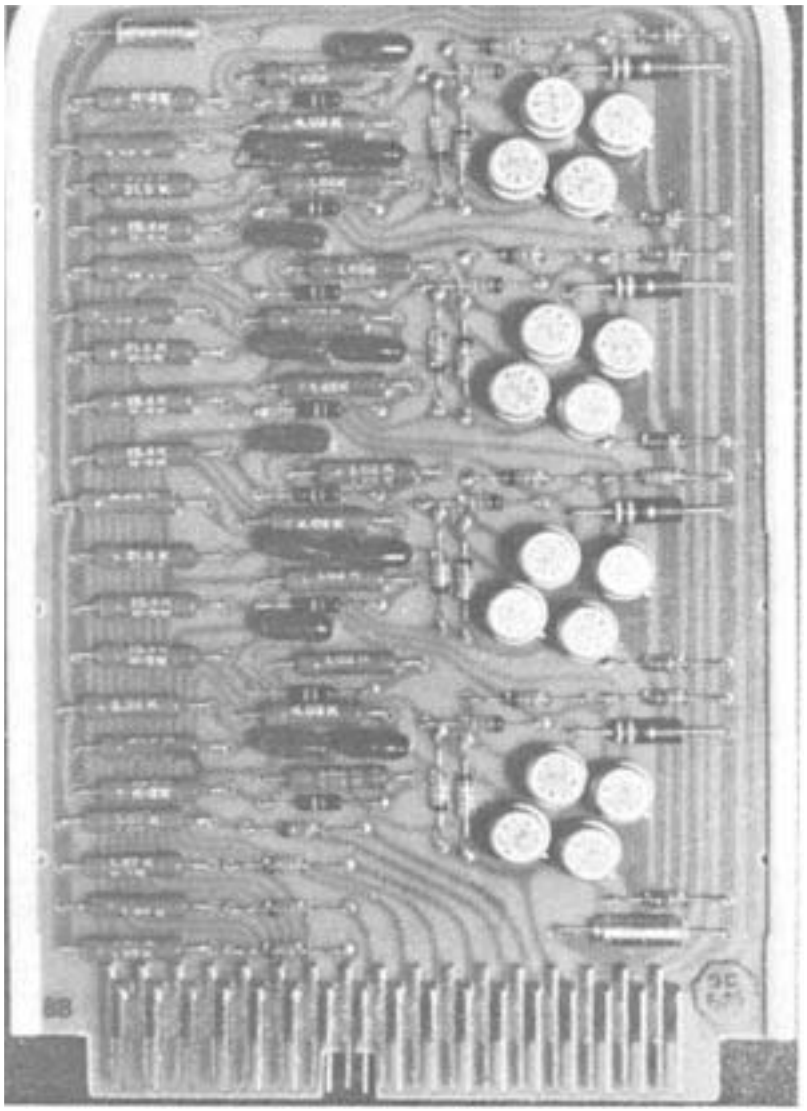
A7. You must consider ohmic value, wattage rating, tolerance, physical dimensions, and type of construction.

Circuit Construction

One method of manufacturing a printed circuit is the *photoetching process.* During this process, a plastic or phenolic sheet is coated with a thin layer of copper. A light-sensitive enamel covers the copper coating. A template of the circuit that will eventually appear on the plastic sheet is placed over it. Then, the entire sheet is exposed to light. The area of the exposed copper reacts to the light. This area is then removed by an etching process. The enamel on the unexposed circuit protects the unexposed copper from the etching bath that removes the exposed copper. After the etching bath, the enamel is removed from the printed circuit. This leaves the surfaces in a condition for soldering of parts and connections.

Some manufacturers use machinery to mount standard parts like capacitors, resistors, and transistor sockets—further speeding manufacture. These circuits operate as well as conventional circuits and are as easily repairable.

Look at figure 6-11, which shows an improved type of construction, from the troubleshooter's standpoint. This construction is a removable subassembly, known as a *module.* Modules are removable and have many internal and external



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Figure 6-11.—Electronic module construction.

test points to make troubleshooting easier. The modules are built of standard parts that are easily replaceable. Most test racks have plug extensions that permit raising any module, making all parts accessible for checking and repairing. The module is not expendable, but it is easy to repair, since all the parts are of conventional design. Miniature and subminiature parts are so common in today's electronic equipment that they are considered to be conventional.

Soldering Repair Techniques

Soldering techniques used to repair the printed circuit board differ from those used on the conventionally wired circuits. You can repair printed circuits with a little care and common sense. If a printed circuit becomes broken, repair it by placing a short length of bare copper wire across the break and soldering both ends to the print. If the break is small, simply flow solder across it (fig, 6-12). When you perform these operations, you do not apply too much heat and don't let solder flow to other printed areas.

The phenolic boards used for printed circuits are similar to the phenolic strips used for conventional terminal strips and mounting boards. There has been no difficulty in soldering to the metal connectors on these terminal strips and mounting boards, so there should be none in soldering printed circuits. In rare cases where excessive heat causes separation of printed conductors from the phenolic board, jumper wires are used for repair (fig. 6-13).

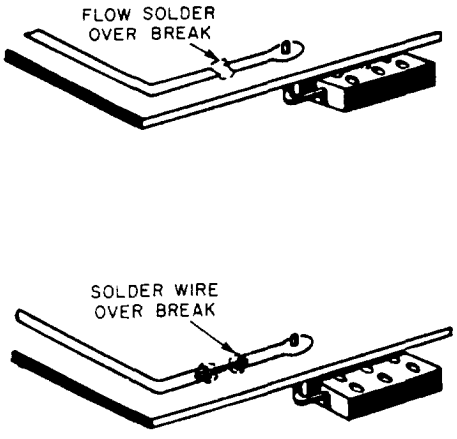


Figure 6-12.-Repairing breaks in foil.

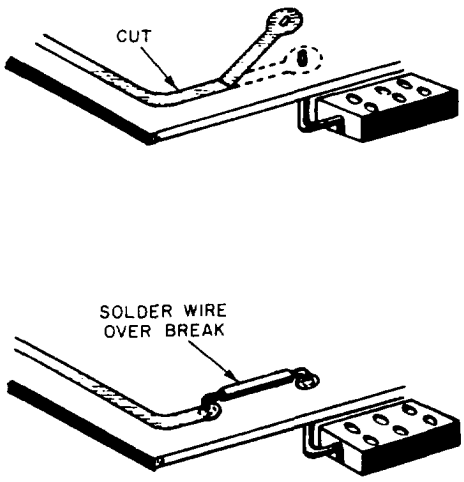


Figure 6-13.-Repairing raised portion of foil.

NOTE: The repair procedures described above will result in satisfactory INTERIM repairs. Normally, however, you will turn most faulty printed circuit boards requiring repair in to a certified repair facility—either to a miniature component repair (MCR) facility or to a certified micro-miniature component repair (MMCR) facility.

Parts Replacement

Removing (resoldering) a part from a printed circuit board without damaging the printed circuit or the associated parts requires precision and skill. When it is necessary to unsolder a component, you will probably use a pencil iron and special tips. Figure 6-14, view A, shows how to use special tips to unsolder multiple terminals. It is possible to unsolder boards using a jury rig (view B). A ground lead connected from the tip of the soldering iron to the frame or chassis prevents damage to transistors and other parts due to leakage current in the soldering iron. Often it is more convenient, and always safer, to remove the module and work on it on an insulated surface.

The general procedure recommended for removing soldered parts is applicable to most connections. A chassis-holding jig holds the printed circuit boards. Position the board so the terminals to be unsoldered are facing out and down. Place the tip of a hot pencil soldering iron under and against the terminal. The solder will flow to the soldering tip, and you may remove it from the tip by wiping it. Remove sufficient

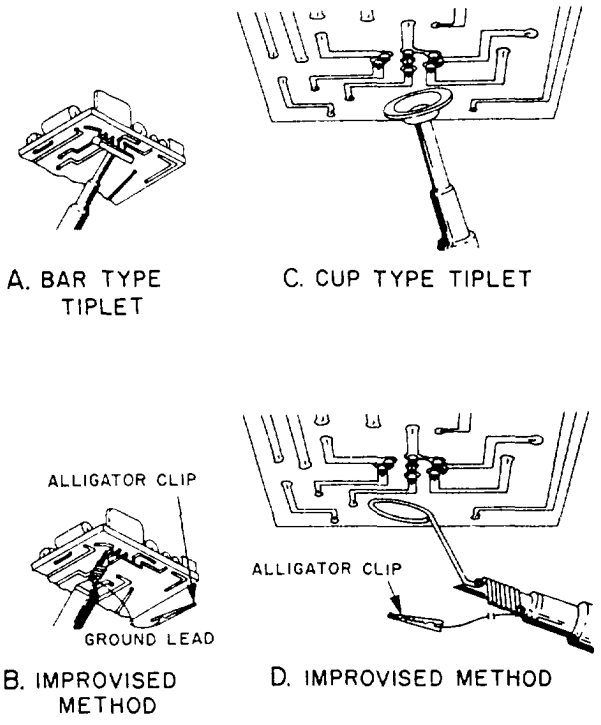


Figure 6-14.-Unsoldering multiple terminals.

solder from each of the terminals to free the part. When the terminals are loose, lift the part from the board. The part should **NEVER** be pried or forced loose. Any attempt to force a part loose may result in a broken or separated printed circuit panel. If the terminals do not pass easily through their holes, chances are that some solder still remains. After removing the leads, remove any solder left in the terminal hole by applying the soldering iron to the hole just long enough to soften the solder. Then, poke the softened solder out with a toothpick, scribe, or small brush.

You should use these special tips whenever possible. Use slotted tiplets to simultaneously melt solder and straighten bent leads, tabs, or small wires against the board or terminal.

Parts such as resistors and small capacitors are easier to remove if you cut them first to free their leads. It requires much less heat to remove a part if the leads are free. Sometimes it is inconvenient to remove a board for access to the wiring side. However, it is usually possible to cut the leads of small resistors and capacitors so a small portion of the lead is accessible. You can then solder the new part to the old leads. See figure 6-15.

The bar tiplet will remove straight-line multiterminal parts quickly and efficiently, as shown in figure 6-14, view A. You can also do

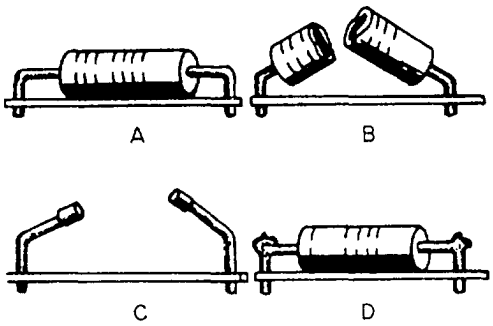


Figure 6-15.-Replacement of a resistor on a printed circuit board.

this by heating each solder connection and brushing away the melted solder. If you use the latter method, be careful that loose solder does not stick to other parts or to the printed panel, where it may cause a short.

You can also improvise a tip that will cover all the connections simultaneously, as shown in figure 6-14, view B. If you use this method, make sure that the tool contacts only the terminals you need to unsolder and nothing else. Do not allow the tool to remain in contact for too long a period of time.

The cup tiplet (fig. 6-14, view C), the triangle tiplet, and the hollow cube tiplet are special designs used to withdraw solder from circular or triangular-mounted parts in one operation. If these tools are not available, you can improvise a tip by shaping it to cover the terminals, as shown in view D. The same procedures and precautions given for unsoldering straight-line terminals apply here.

Most printed circuit board components can be removed by following the methods just described. However, if an unfamiliar situation occurs, spend some time and think about the best way to remove the part. Planning saves you time.

In some cases, excess solder at a printed circuit connection makes removal difficult. You may find the following method helpful: Coat a piece of clean copper braid (such as a ground strap or length of coaxial shield) with a noncorrosive solder flux and apply it to the connection. Heating the braid with a soldering iron causes the excess solder to transfer to the braid. Be careful not to overheat the braid.

The proper methods of solder removal and application are shown in figure 6-16, views A, B, and C. View A shows the correct and incorrect methods of solder application. The correct method for removing solder from a component without damaging the printed wiring circuits is shown in view B, View C shows the correct method of applying solder to a replaced component.

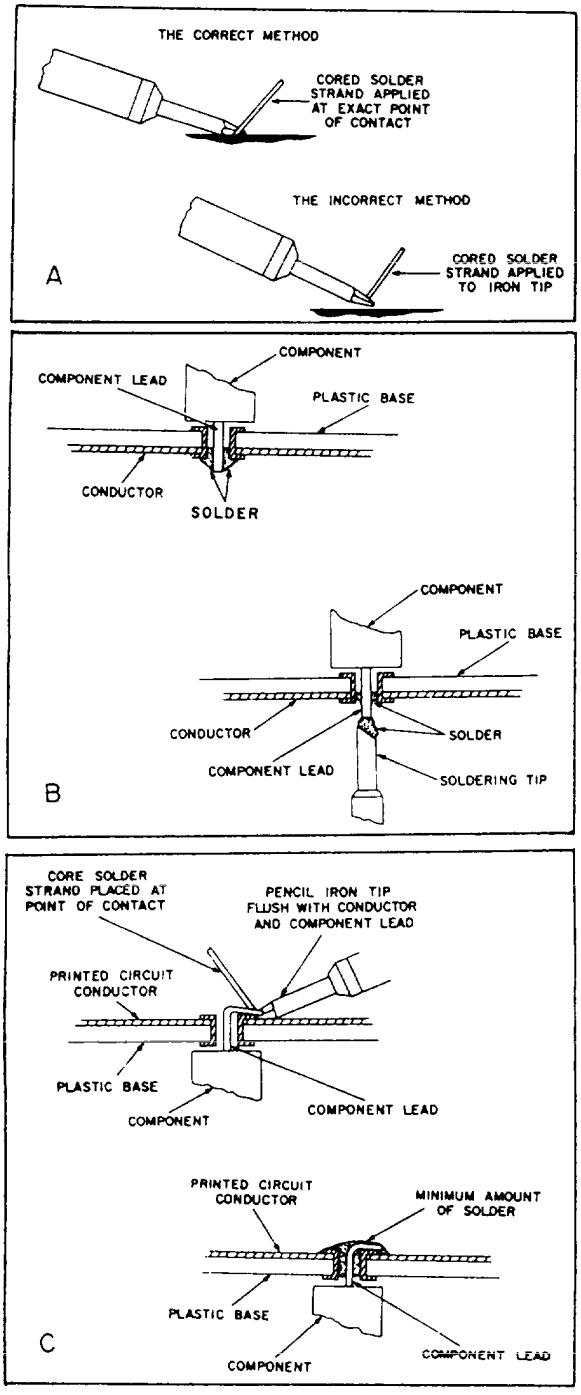


Figure 6-16.-Soldering techniques.

Resistors

One of the most important considerations when replacing a resistor is the wattage value of the resistor. The wattage rating is a measure of the ability of the resistor to dissipate heat. The wattage value is a function of the dimensions of the resistor.

The selection of a resistor with a safe wattage value is based on a consideration of the working conditions of the resistor in the circuit. Consider, for example, the replacement of an 850-ohm resistor with one of equal ohmic value but with a tolerance of ±20 percent. Suppose the normal voltage existing across the resistor is 40 volts. Because of the 20-percent tolerance, the actual resistance of the replacement may be as much as 1,020 ohms or as little as 680 ohms. If the resistor with the lesser value is chosen (the more unfavorable from a heat-dissipating standpoint), the power that may be developed in the resistor under circuit conditions is found as follows:

$$W = \frac{E^2}{R}$$

$$W = \frac{40 \times 40}{680}$$

$$W = 2.35 \text{ watts, approximately.}$$

To allow a sufficient safety margin, a resistor should be capable of dissipating from 1.5 to 2 times the power it will actually meet. In the above example, this value is not more than 4.7 watts. Since a 5-watt resistor is the next standard size above the 4.7-watt value, this is a desirable wattage rating for the replacement.

Under emergency conditions, you may need to combine resistors in series or in parallel to get a desired resistance value. When doing this, you should avoid a voltage distribution (or current distribution) that would cause any low-wattage resistor in the combination to dissipate an excessive amount of heat. Suppose, for example, that you combine two 10-watt resistors of 1-ohm value with a 2-watt resistor of 10-ohm value in a series circuit with 12 volts applied. The total wattage now being dissipated by the 10-ohm, 2-watt resistor would be 10 watts, a value far more than its capabilities. Therefore, you must consider

each resistor in the combination and select a wattage value based on the voltage that will develop across the individual unit.

Q8. Who can make microelectronic repairs?

Q9. Describe the causes of component damage during maintenance.

Q10. What manual should you refer to for further information on procedures for desoldering components?

AIRCRAFT AND EQUIPMENT WIRING

Learning Objective: *Identify the purpose and use of various components when wiring aircraft and equipment.*

Aircraft wiring is identified by a system of numbers and letters stamped on each wire. The MIM for the aircraft or equipment gives the number of each wire used in electronic equipment cabling. If you need to trace and repair a wire in an aircraft, refer to the MIM to determine the routing of the wire.

You can find the wiring data for all electrical and electronic systems in each model aircraft in the wiring data section of the applicable MIM. The diagrams are prepared separately for each circuit. They provide all data necessary to understand the construction of each circuit, to trace each circuit within the system, and to make continuity and resistance checks. They also provide specific troubleshooting performance data on inoperative or malfunctioning circuits. The schematic diagrams for circuits and related components are in those volumes of the MIM that specifically cover a system or systems.

CONNECTORS

When you inspect major units, inspect their connectors. During this inspection, separate the mating parts of the connectors and examine the contacts for corrosion. If corrosion is present, clean the surfaces with a brush or clean rag and a noncorrosive solvent. Inspect the coupling ring for battered threads, and replace it if the threads are not in good condition. When attaching or detaching the connector, be careful not to damage the coupling or bend the coupling nut.

If the connector does not contain a moisture-proofing compound, inspect the conductors where they are soldered to the pin contacts. Short circuits often occur because a frayed strand of one conductor touches the solder cup of another conductor within the plug. In this case, you may clip the frayed strand. You should check to see that all soldered connections are adequate and that no cold solder joints exist.

Connectors do not require lubrication except the coupling ring threads. Occasionally, they should receive a light coat of antiseize compound to ensure smooth operation.

At times, operating conditions demand that ordinary electrical connectors receive a moisture-proofing treatment. Moistureproofing reduces failure of electrical connectors and reinforces the wires at the connectors against failure caused by vibration and lateral pressure. Both of these failures fatigue the wire at the solder cup. The basis of moistureproofing is the application of a sealing compound.

Sealing compound also protects electric connectors from corrosion and contamination by excluding metallic particles, moisture, and aircraft liquids. As a result of its improved dielectric characteristics, sealing compound reduces the chance of arcover between pins at the back of electric connectors.

The sealant is available in kit form through the normal supply channels. Sealing (or potting) is not necessary on environmentproof E connectors or connectors located in areas where the temperature exceeds 200°F. The sealing compound deteriorates after long exposure to ambient temperatures above 200°F.

For detailed instructions on how to perform sealing operations, refer to current electronic material changes and to *Installation Practices for Aircraft Electrical and Electronic Wiring,* NAVAIR 01-1A-505. A summary of the procedures that you should follow when sealing a connector is as follows:

1. Prepare a used connector by removing existing sealants and by cleaning. The cleaning solvent used must clean thoroughly, evaporate quickly, and leave no residue. Remove all sleeving from the wires. Resolder loose or poorly soldered connections, and add a length of wire about 9 inches long to each unused pin. The purpose of soldering a short length of wire to each spare pin is to allow for circuit growth. Use a stiff-bristle brush to remove any excess rosin from around the

pins. Now, repeat the cleaning, and then separate the wires evenly.

2. Thoroughly mix the accelerator and base compound (fig. 6-17). The ratio of accelerator to base compound is critical; therefore, you must add the entire quantity of accelerator furnished to the base compound.

3. Place the plugs or receptacles on a table, arranging them so gravity will draw the sealer to the bottom of the plug. Box receptacles of plugs without back shells require fittings with a mold made of masking tape, cellophane tape, or its equivalent (fig. 6-18, view A). This will retain the

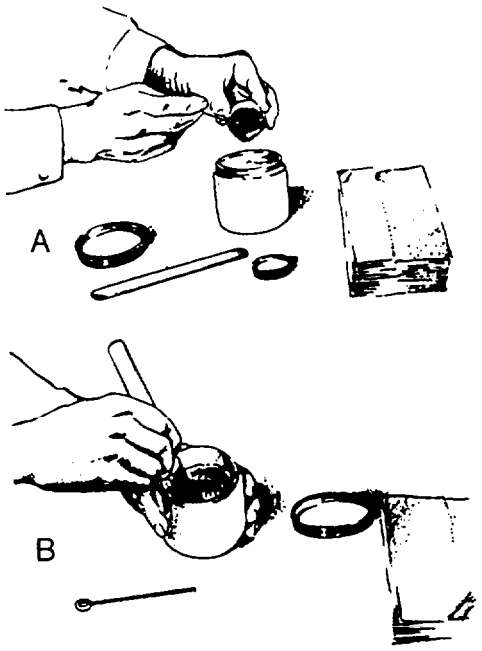


Figure 6-17.-Combining accelerator with base compound.

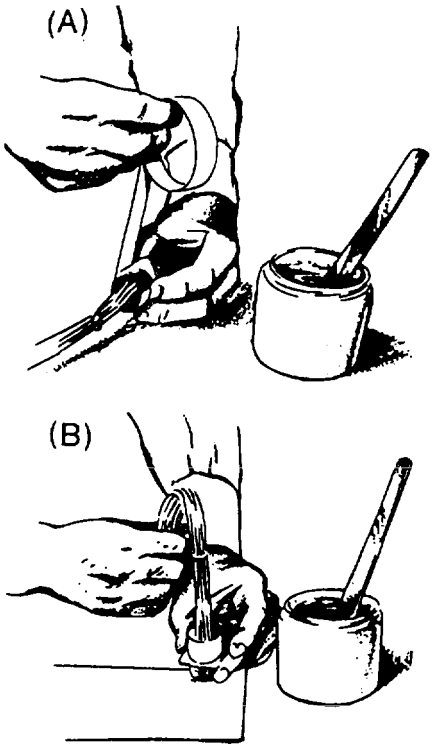


Figure 6-18.-(A) Making a mold from masking tape; (B) finished potted plug.

sealant during the curing process. If using the back shell, apply a slight amount of oil to the inner surface to prevent the compound from adhering to it.

4. Use a spatula, putty knife, or paddle to apply the compound. Ensure good packing around the base of the pins. When potting, completely fill the part, or at least fill it to a point where you can cover about three-eighths inch of insulated wire. Now, allow the compound to cure.

ANSWERS FOR REVIEW QUESTIONS Q8. THROUGH Q10.

A8. Only certified microminiature component repair (MMCR) personnel.

A9. Component damage during maintenance usually results from excess heat during repair, reversed polarity of ohmmeters while checking for continuity, excessive voltage application or signal strength during testing, rough handling, or using the wrong tools or materials.

A10. Assembly Electronics Repair, Standard Maintenance Practices, NAVAIR 01-1A-23.

The normal curing time is about 24 hours. Temperature affects the curing time.

Sometimes you may need to seal the entire connector assembly (plug and receptacle) to prevent fluid from entering or collecting between the two parts. You may fit a rubber O-ring over the barrel of the plug. This will provide a seal when connecting the two parts securely. If properly installed, this seal prevents moist air from entering during variations in temperature, altitude, or barometric pressure on the ground. Rubber packing O-rings are available for this purpose through normal supply channels. Examine O-rings every time you disassemble the connecter because O-rings age during service. If you find that the O-rings have deteriorated, replace them.

CONDUCTORS AND TERMINALS

Although printed circuits and microelectronic components are used in contemporary electronic equipment, conductors are still important as a signal- or current-carrying device. In this discussion, the term *conductor* refers to both wire and cable. As a significant part of operating equipment, conductors deserve appropriate attention.

Wire

When you are replacing wire, consult the MIM for the particular aircraft or equipment, since it normally lists the wire used. When this information is not available from the MIM, you must determine the correct conductor needed for the job. The three major selection factors (in descending order of importance) are size, insulation, and the characteristics required to satisfy the specific environment in which the wire must function.

CONDUCTOR SIZE.— For dc applications, the allowable voltage drop and current-carrying capacity govern the choice of size. At radio frequencies, the skin effect and inductance may become a controlling factor. Although normally (except in inductors or RF transformers) these parameters are not considered. Therefore, wire size is basically a function of the current or the allowable resistance, except when this results in a very small conductor size.

Small conductors are difficult to handle and break easily when soldered or from vibration. Using No. 22 or No. 24 American Wire Gage (AWG) wire for general circuit wiring lessens these problems. Also, you should use at least No. 20 AWG wire for connecting tube filaments in parallel. Only use solid wire for short jumper connections, not exceeding 3 inches in length. However, you may use longer runs of solid wire when connecting parts that are solidly mounted and not subject to vibration. Clamps or dress lugs are recommended for long leads. In other words, use stranded copper wire whenever possible. Under extreme conditions of vibration or in areas that require high flexibility, maintenance procedures may specify the use of oxygen-free copper. Copper-clad steel is another possibility for applications requiring greater strength and rigidity.

INSULATION.— A wide variety of insulating material is available, which makes its specification particularly important. Since each type of insulation has its peculiar characteristics, no single type is always suitable for general usage. The major insulation requirements include the following:

- Good dielectric strength
- High insulation resistance (internal and surface)
- Wide temperature range (with high softening and low brittle points)
- Flexibility
- Color stability
- Resistance to abrasions, crushing, moisture, fungus, burning, radiation, oil, and acids

Insulation requirements for electronic, as opposed to power, applications are somewhat more exacting because of the higher frequencies and impedances and often higher voltages involved. Insulation resistance and dielectric strength are the prime considerations, although, for RF application the figure of merit, Q, becomes important.

Some of the insulations used for general-hookup wire include lacquered cotton, high-temperature rubber, butadiene styrene copolymers, fiber glass, nylon, and vinyl. Also, polyvinyl chloride, cellulose acetate, polystyrene, polyethylene, and various silicon-treated materials are used as general hookup wire. The recommended

insulation wall thickness for all wiring within the confines of an enclosure or with mechanical protection is less than 0.013 inch. Exposed wiring or wiring that is subject to wear or abrasion requires heavier insulation.

ENVIRONMENT.— You must consider environmental factors such as temperature, humidity, altitude, vibration, radiation, fungus, contaminants, and corrosive elements when selecting conductors. These requirements are part of the specification for the equipment where the wire is to be used.

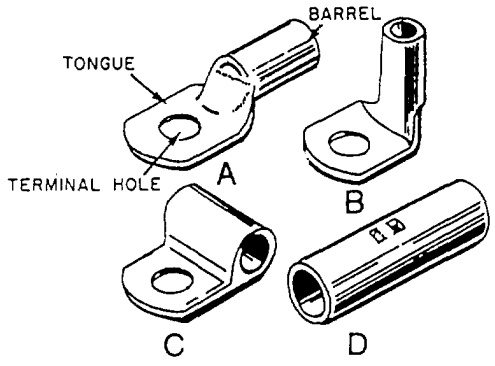


Figure 6-19.-Types of solderless terminals.

Terminals

Since most aircraft have stranded wires, you use terminal lugs to hold the strands together and make it easier to fasten wires to terminal studs. The types of terminals used in electrical wiring are either of the soldered or crimped. Terminals used in repair work must be the size and type specified on the electrical wiring diagram for the particular models. You may use soldered- and crimped-type terminals interchangeably, but both must have the same amperage capacity and the same size hole in the lug.

The increased use of crimp-on terminals is, to a large degree, due to the limitations of soldered terminals. The quality of soldered connections depends upon the operator's skill. Such factors as temperature, flux, cleanliness, oxides, and insulation damage caused by heat contribute to defective connections,

The crimp-on solderless terminals require relatively little operator skill. Another advantage is that the use of a crimping tool eliminates the necessity of supplying power to a soldering iron. This allows installing terminals in an aircraft with a minimum of time and effort. The connections are made more rapidly, are cleaner, and are more uniform. Because of the pressures exerted and the materials used, the crimped connection or splice (when properly made) has an electrical resistance that is less than that of an equivalent length of wire.

The basic types of terminals are shown in figure 6-19. View A shows the straight type, view B the right-angle type, view C the flag type, and view D the splice type. There are also variations of these types. Variations may include the use of a slot instead of a terminal hole, three- and four-way splice-type connectors, and others.

Since present-day aircraft have both copper and aluminum wiring, both copper and aluminum terminals are necessary. There are various size terminal and stud holes for each of the different wire sizes. A further refinement of the solderless terminals is the insulated type, where insulation encloses the barrel of the terminal. The crimping process compresses the insulation along with the terminal barrel, but does not damage it in the process. This eliminates the need for taping or tying an insulating sleeve over the joint.

Cable Splicing

A cable splice (other than one made with the crimp-on splice or connector) is an emergency measure only. You may or may not use solder, as the condition warrants. However, the splice should give a good electrical and mechanical joint without solder. Tape the splice enough to provide insulation equivalent to that in the rest of the cable. You must make permanent repairs as soon as possible.

You should refer to NAVAIR 01-1A-505 for detailed information about attaching cable terminals, forming terminals for emergency use, and repairing damaged or broken cables, including fiber optic cables.

Terminal Blocks and Junction Boxes

Terminal blocks are an insulating material that supports and insulates a series of terminals from each other and from ground. They give you a means of installing terminals within junction boxes and distribution panels.

Two methods of attaching cable terminals to terminal blocks are shown in figure 6-20. View A shows one of the standard nonlocking nut methods. In this installation method, lockwashers are used. The preferred method is shown in

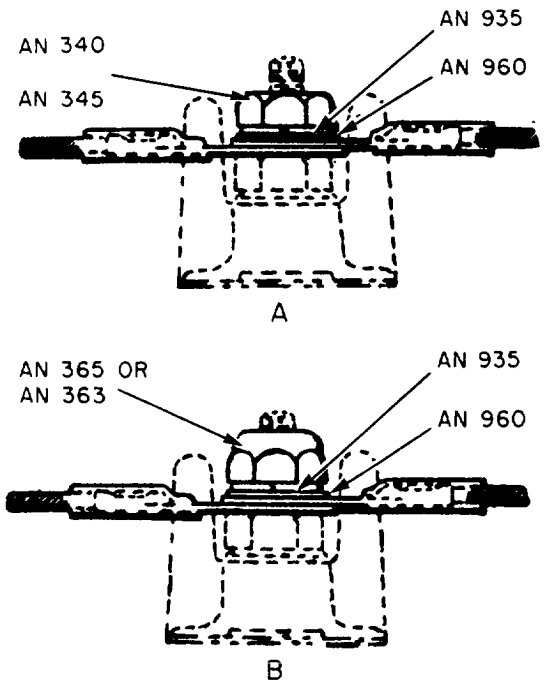


Figure 6-20.-Installation of cable terminals on terminal block.

view B. Here, an anchor nut (or self-locking nut) and the lockwasher are used for additional security. The use of anchor nuts is especially desirable in areas of high vibration. In both installation methods, you must use a flat washer, as shown in the drawing.

Junction boxes are used to hold electrical terminals or other equipment, such as relays and transformers. Individual junction boxes are named according to their function, location, or equipment with which they work. Junction boxes usually have a drain hole (except boxes labeled vaportight) located at the lowest point. This allows water, oil, condensate, or other liquids to drain out.

Insulating Sleeving

Electronic maintenance operations in many aviation activities use insulating sleeving (commonly called *spaghetti)* or shrink tubing. You will use sleeving when fabricating cable connectors and connections to relays and terminal strips. Crimped or soldered terminal lugs or splices and tie points on terminal strips or terminal boards also require insulating sleeving.

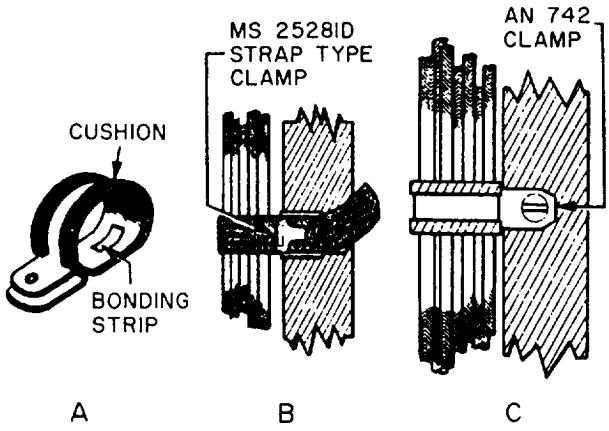


Figure 6-21.-Cable clamps.

Support Clamps

Clamps provide support for open wiring and serve as (or in addition to) lacing on open wiring. They usually come with a rubber cushion. When used with shielded conduit, the clamps are of the bonded type (fig. 6-21, view A); that is, they provide for electrical contact between the clamp and conduit. Unbended clips provide for the support of open wiring.

To support long runs (lengths) of cable between panels, you should use either a strap-type clamp (view B) or a clamp of the type shown in view C. The preferred method of supporting cables for all types of runs is with the type shown in view C. When using the strap-type clamps, you should make sure they hold the cables firmly away from lines, surface control cables, pulleys, and all movable parts of the aircraft. Use these clamps as an emergency measure only.

When cables pass through lightening holes, the installation should conform to the examples shown in figure 6-22. You should route the cable

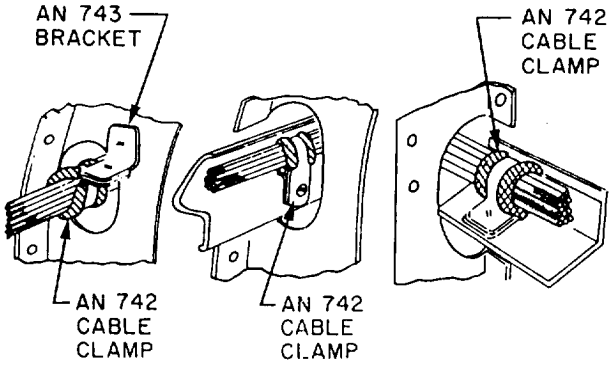


Figure 6-22.-Routing cables through lightening holes.

clear of the edges of the lightening hole to avoid any chance of chafing the insulation.

Replacing Wiring

When you install or replace wire or wire bundles, make sure there is no excessive slack between cable clamps. Normally, there should be no more than a one-half inch deflection with normal hand pressure. However, you should allow sufficient slack at each end of the wire or wire bundles for the following reasons:

- To allow easy removal and connection of plugs
- To allow replacement of terminals two times
- To prevent mechanical strain on the wires
- To permit free movement of shock- and vibration-mounted equipment
- To allow movement of equipment for maintenance

Normally, bends in individual wires should have a minimum bend radius of 10 times the diameter of the bundles. However, where the wire has suitable support at each end of the bend, a minimum bend radius of three times the diameter of the bundle is acceptable.

Never bend coaxial cable to a radius smaller than six times its outside diameter. Damage will result. Route coaxial cables as directly as possible, avoiding any unnecessary bends.

Wires passing through a bulkhead require support at each hole by a cable clamp. If the clearance between the wires and the edge of the hole is less than one-fourth inch, you should use a suitable grommet in the hole. See figure 6-23.

You must maintain a minimum clearance of 3 inches between wiring and control cables. If this cannot be done, install guards to prevent the wiring from contacting the control cables. When the wiring must be parallel to plumbing carrying flammable fluids or oxygen, maintain as much separation as possible. Support the wiring so it cannot come closer than one-half inch to the plumbing. Never support any wire or wire bundle from a plumbing line that carries combustible liquids or oxygen.

Install cable clamps so the mounting screws are above the wire bundle (fig. 6-24). Otherwise,

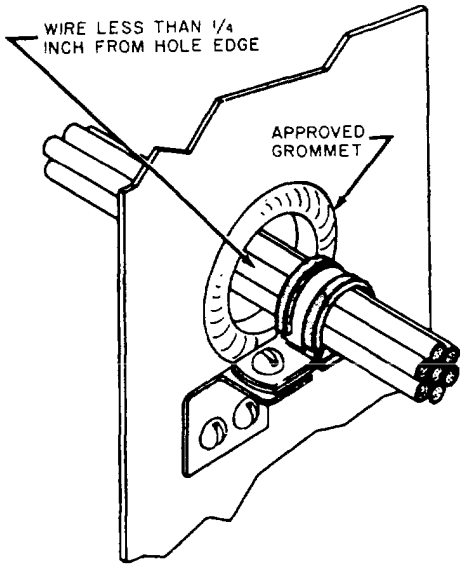


Figure 6-23.-Cable clamp and grommet at bulkhead hole.

the weight of the cable may bend and break the clamp. It is also desirable that the back of the clamp rest against a structural member, if practical. Be careful not to pinch wires in the cable clamp.

TYING AND LACING WIRE GROUPS AND BUNDLES.— A wire group is two or more wires tied or laced together to give identity to an individual system. A wire bundle is two or more wires or groups tied or laced together to provide

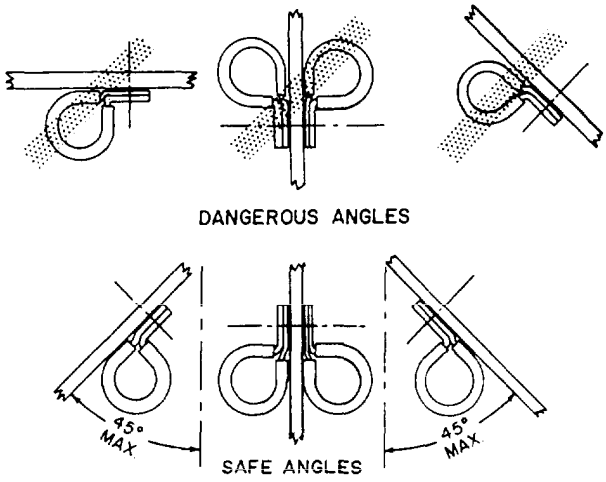


Figure 6-24.-Safe angles for cable clamps.

easier maintenance. Wire groups and bundles should be laced or tied together. This makes it easier to install, maintain, and inspect them. Also, it keeps the cables neatly secured in groups and bundles to help avoid damage from chafing or equipment operation.

Tying is the securing together of a group or bundle wires by individual pieces of cord tied around the group or bundle at regular intervals.

Lacing is the securing together of wires inside enclosures by a continuous piece of cord, forming loops at regular intervals around the wire group or bundle.

Wherever possible, you should use a narrow, flat, nonadhesive tape for lacing and tying. You may use round cord; however, it has a tendency to cut into wire insulation. Therefore, it is not the preferred method. Use cotton, linen, nylon, or glass-fiber cord or tape, according to the temperature requirements. Prewax cotton or linen cord or tape to make it moisture- and fungus-resistant. Nylon cord or tape may be waxed or unwaxed. Glass-fiber cord or tape is usually not waxed.

PRECAUTIONS FOR LACING AND TYING WIRE GROUPS.— When lacing or tying wire groups and bundles, use the following precautions:

1. Lace or tie bundles tightly enough to prevent slipping, but not so tightly that the cord cuts into or deforms the insulation. This applies especially to coaxial cable, which has a soft dielectric insulation between the inner and outer conductors.

2. Do not place ties on that part of a wire group or bundle located inside a conduit.

3. Lace wire groups or bundles only inside enclosures, such as junction boxes. Use double cord on groups or bundles larger than 1 inch in diameter. Use single or double cord for groups or bundles 1 inch or less in diameter.

NOTE: Coaxial cables can be damaged from lacing materials or methods of lacing or tying wire bundles that cause a concentrated force on the cable insulation. Elastic lacing materials, small-diameter lacing cord, and excessive tightening deform the innerconductor insulation, which may result in short circuits or impedance changes. Flat, nylon, braided, waxed lacing tape is recommended for coaxial cables.

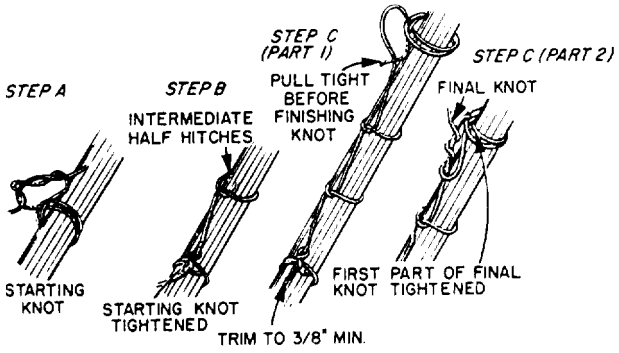


Figure 6-25.-Single-cord lacing.

PROCEDURES FOR LACING WITH A SINGLE CORD.— The procedures you should use to lace a wire group or bundle with a single cord are as follows:

1. Start the lacing at the thick end of the wire group or bundle with a knot consisting of a clove hitch with an extra loop. See figure 6-25.

2. At regular intervals along the wire group or bundle and at each point where a wire or wire group branches off, continue the lacing with half hitches. Space half hitches so the group or bundle is neat and securely held.

3. End the lacing with a knot consisting of a clove hitch with an extra loop.

4. Trim the free ends of the lacing cord to three-eighths inch minimum.

PROCEDURES FOR LACING WITH A DOUBLE CORD.— The procedures you should use to lace a wire group or bundle with a double cord are as follows:

1. Start the lacing at the thick end of the wire group or bundle with a bowline on a bight. See figure 6-26.

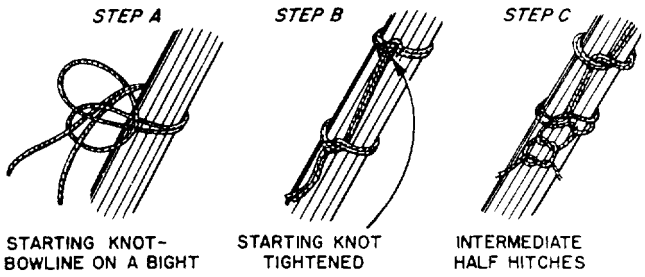


Figure 6-26.-Double-cord lacing.

2. At regular intervals along the wire group or bundle and at each point where a wire group branches off, continue the lacing with half hitches, holding both cords together. Space half hitches so the group or bundle is neat and securely held.

3. End the lacing with a knot consisting of a half hitch, using one cord clockwise and the other counterclockwise, and then tie the cord ends with a square knot.

4. Trim the free ends of the lacing cord to three-eighths inch minimum.

PROCEDURES FOR LACING A BRANCHING WIRE GROUP.— The procedures you should use to lace a wire group that branches off the main wire bundle are as follows:

1. Start the branch-off by lacing with a starting knot located on the main bundle just past the branch-off point. See figure 6-27. When using single-cord lacing, make the starting knot the same as regular single-cord lacing. When using double-cord lacing, use the double-cord lacing starting knot.

2. End the lacing with the regular knot used in single- and double-cord lacing.

3. Trim the free ends of the lacing cord to three-eighths inch minimum.

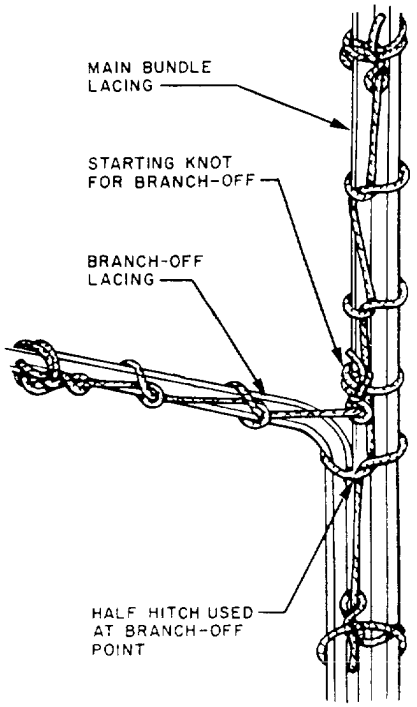


Figure 6-27.-Lacing a branch-off.

TYING WIRE GROUPS WHEN SUPPORTS ARE MORE THAN 12 INCHES.— Tie all wire groups or bundles (fig. 6-28) when supports are more than 12 inches apart. Space the ties so they are 12 inches or less

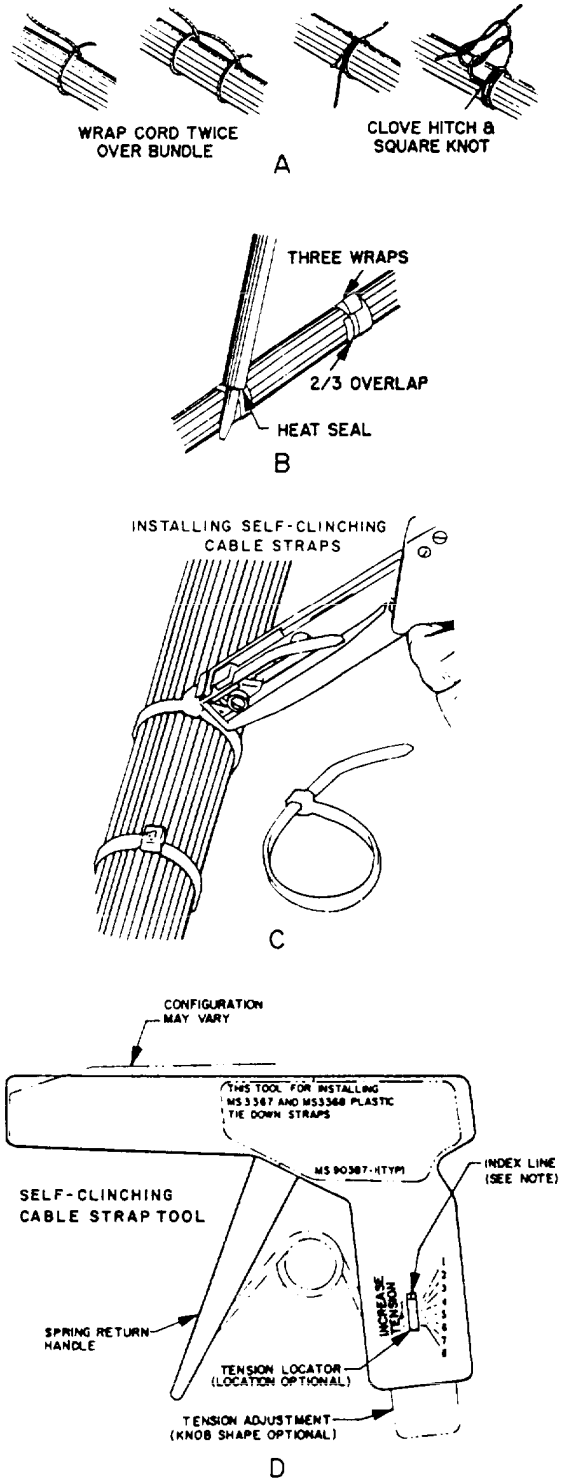


Figure 6-28.-Tying groups or bundles.

apart. To make a tie, you should perform the following:

1. Wrap cord around wire group or bundle, as shown in figure 6-28, view A.
2. Make a clove hitch, followed by a square knot with an extra loop.
3. Trim free ends of cord to three-eighths inch minimum.

When tying sleeves to wire groups or wire bundles, make the ties the same as for wire groups and bundles.

USING TAPE.— When it is permissible to use tape, you should use the following method:

1. Wrap tape around the wire group or bundle three times, with a two-thirds overlap for each turn. See figure 6-28, view B.
2. Heat-seal the loose tape end with the side of a soldering iron heating element. Do not use tape to secure wire groups or bundles that require frequent maintenance.

SELF-CLINCHING CABLE STRAPS

Self-clinching cable straps are adjustable, lightweight, flat nylon strips. They have molded ribs or serrations on the inside surface to grip the wire. You may use them instead of individual cord ties for quickly securing wire groups or bundles. The straps are of two types—a plain cable strap and one that has a flat surface for identification of cables.

CAUTION

Do not use nylon cable straps over wire bundles containing coaxial cable. Do not use straps in areas where failure of the strap would allow the strap to fall into movable parts.

Installing self-clinching cable straps is done with a military standard handtool (fig. 6-28, view C). An illustration of the working parts of the tool is shown in figure 6-28, view D. You should follow the manufacturer's instructions when using the tool.

WARNING

Use proper tools and make sure the strap is cut flush with the eye of the strap. This prevents painful cuts and scratches caused by protruding strap ends. Do not use plastic cable straps in high-temperature areas (above 250°F).

BONDING

A bond is any fixed union between two metallic objects that results in electrical conductivity between them. Such a union results either from physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them. Aircraft electrical bonding is the process by which the necessary electrical conductivity between the component and metallic parts of the aircraft is gotten. An isolated conducting part of an object is one that is physically separate (by intervening insulation) from the aircraft structure and from other conductors bonded to the structure. A bonding connector provides the necessary electrical conductivity between metallic parts in an aircraft where electrical contact is insufficient. Examples of bonding connectors are bonding jumpers and bonding clamps. See figure 6-29.

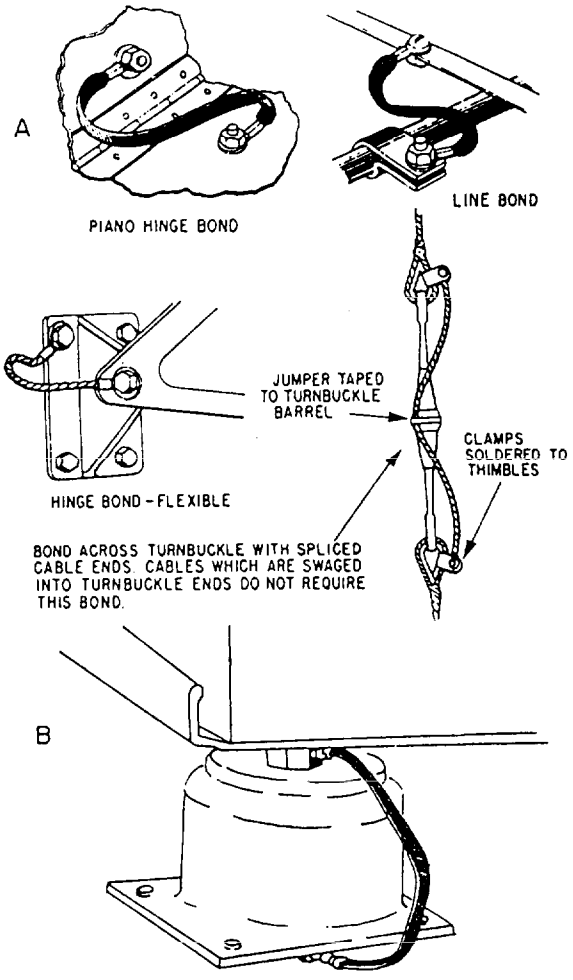


Figure 6-29.-Bonding methods.

An aircraft can become highly charged with static electricity while in flight. In an improperly bonded aircraft, all metal parts will not have the same amount of charge, and a difference of potential will exist between various metal surfaces. Charges flowing through paths of variable resistance, such as moving control surfaces, will produce electrical disturbances (noise) in the radio receiver. If the resistance between isolated metal surfaces is large enough, charges can accumulate until the potential difference becomes sufficiently high to cause a spark, creating a fire hazard. If lightning strikes an aircraft, a good conducting path is necessary for the heavy current. This reduces severe arcs and sparks, which would damage the aircraft and possibly injure its occupants.

The aircraft structure is also the ground for the radio. For the radio to function properly, a proper balance between the aircraft structure and antenna is required. This means the surface area of the ground must be constant. Control surfaces, for example, may at times become partially insulated from the remaining structure because of a film of lubricant on the hinges. This will affect radio operation if the condition is not taken care of by bonding.

Bonding also provides the necessary low-resistance return path for single-wire electrical systems. This low-resistance return path also aids the effectiveness of the shielding and provides a means of bringing the entire aircraft to the earth's ground potential.

In summary, aircraft are electrically bonded for the following reasons:

- To reduce radio and radar interferences by equalizing static charges that accumulate
- To eliminate a fire hazard by preventing static charges from accumulating between two isolated members and creating a spark
- To reduce lightning damage to the aircraft and injury to its occupants
- To provide the proper ground for proper functioning of the aircraft radio
- To provide a low-resistance return path for single-wire electrical systems
- To aid in the effectiveness of the shielding
- To provide a means of bringing the entire aircraft to the earth's potential, and keeping it that way while it is grounded to the earth

Bonding connections are made so vibration, expansion or contraction, or relative movement incidental to normal service use will not break the bonding connections. Bondings should not loosen to such an extent that the resistance will vary during the movement. The bonding of most concern is the bonding jumpers that go across shock mounts used to support electronic equipment.

A primary aim of bonding is to provide an electrical path of low dc resistance and low RF impedance. Therefore, the jumper should be a good conductor of ample size for the current-carrying capacity, have low resistance, and be as short as possible. If practical, you should bond parts directly to the basic aircraft structure rather than through other bonded parts. Install bonding jumpers so they do not interfere with the operation of movable components of the aircraft.

Contact of dissimilar metals in the presence of an electrolyte, such as salt water, produces an electric action (battery action) that causes a pitting in one of the metals. The intensity of this electric action varies with the kinds of metals. Frequently, bonding involves the direct contact of dissimilar metals. In such cases, the metals used produce a minimum amount of corrosion. The connections are also made so that if corrosion does occur, it will be in replaceable elements, such as jumpers, washers, or separators, rather than the bonded or bonding members. Thus, use washers made of the same material as the structural member against the structural member. Also, use washers of the same material as the bonded member that is in contact with that item.

Self-tapping screws should not be used for bonding purposes, nor should jumpers be compression-fastened through plywood or other nonmetallic material. When performing a bonding operation, you should remove contact surface films before assembly, and then refinish the completed assembly with a suitable protective finish.

For more detailed information about bonding, you should refer to *Installation Practices, Aircraft Electric and Electronic Wiring,* NAVAIR 01-1A-505.

SHOCK MOUNTS

Electronic equipment is sensitive to mechanical shock and vibration. Therefore, units of electronic equipment are normally shock mounted to provide some protection against in-flight vibration and against launching and landing shock. The

specific type of prescribed shock mount will be in the MIM for the specific aircraft, and you should not use a substitute.

Shock mounts require periodic inspections. Replace any defective mounts as soon as possible. In the inspection, you should check for chemical decay of the shock-absorbing material, stiffness and resiliency of the material, and overall rigidity of the mount. If the mount is too still or too rigid, it may not provide adequate protection against the shock of launching and landing. If it is not stiff or rigid enough, it may permit prolonged vibration following an initial shock. When determining the limits of rigidity and resiliency, you should consider the weight of the mounted unit as well as the possible amounts of positive and negative acceleration the unit may receive.

Shock-absorbing materials commonly used in shock mounts are usually electrical insulators. For safety, each electronic unit mounted in this manner is electrically bonded to a structural member of the aircraft (fig. 6-29, view B.) The inspection of the shock mounts should include the bonding straps. Replace or redo any defective or ineffective bonds as soon as possible.

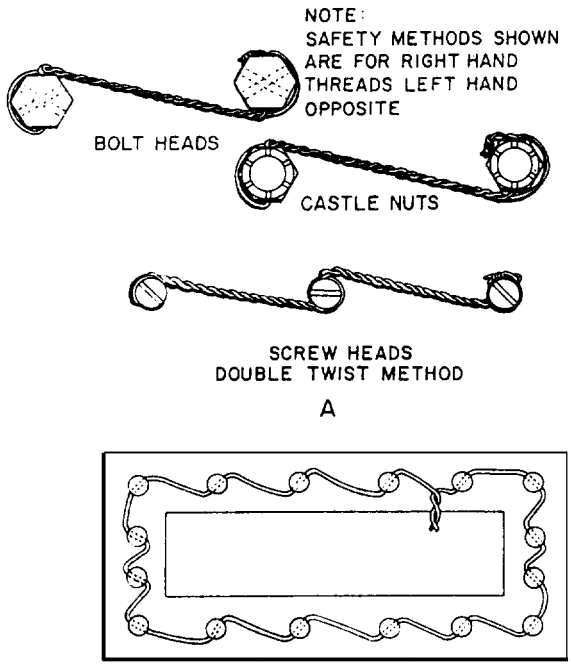


Figure 6-30.-Safety wiring nuts, bolts, and screws.

SAFETY WIRING

Some equipment parts require a positive safety locking device. The use of safety wire is one accepted method of providing this safety measure. Two of the most common reasons for safety wiring nuts, bolts, screws, and connector parts are

1. to prevent them from coming loose due to aircraft vibration, and
2. to prevent accidental engagement of a guarded switch.

You will learn about some of the methods of applying safety wire in the following paragraphs.

The most common method of safetying nuts, bolts, and screws is the double-twist method. You can do this by hand or with special safety wire pliers. (See figure 6-30, view A.) If you make the twists by hand, make the final few twists using pliers so there is enough tension to secure the ends of the wire properly. The safety wire should always be installed and twisted so that the loop around the head stays down and does not tend to come up over the bolt head. When you twist the wires together, be extremely careful to ensure they are tight, but do not overstress them to the point where they will break under a slight load or vibration. You should always use new safety wire on every job. Be careful to use pliers only on the ends of the wire so you don't nick the wire. If safety wire becomes nicked, discard it and use a new piece. After you make the final twists with pliers, cut off the nicked loose ends and bend the end of the wire around the bolt or screw head. This will protect personnel from the sharp ends.

You may use the single wire method of safety wiring (fig. 6-30, view B) on small screws in a closely spaced area provided the screws form a closed geometrical pattern. Note that any loosening tendencies will pull against the tension of the wire. Never *back off* or overtorque to align holes for safety wiring.

Safety wire electric connectors only when specified on engineering drawings or when experience has shown that the connector will not stay tight. Electric connectors are usually safety wired in engine nacelles, in areas of high vibration, and in locations not readily accessible for periodic maintenance inspection.

When you must safety wire electrical connectors, you should use 0.032-inch-diameter safety wire wherever possible. On small parts with holes 0.045 inch nominal diameter or smaller, use 0.020-inch-diameter safety wire. Sometimes the

connector to be safety wired does not have a wire hole. If there is no wire hole, remove the coupling nut and drill a No. 56 (0.045-inch-diameter) hole diagonally through the edge of the nut. Figure 6-31 shows a properly safety-wired connector.

An example of safety wiring a guarded switch is shown in figure 6-32. You can see that the wire is not twisted tightly. Use very soft wire; the wire may be either aluminum or copper. This soft wire (called *shear wire)* lets the operator break the wire easily when necessary to engage the switch,

Q11. To what NAVAIR manual should you refer for detailed instructions on potting or sealing operations?

Q12. What are the three major factors to consider when you have to determine the correct conductor you need for a job?

Q13. When may you use a cable splice (other than one made with the crimp-on splice or connector) and to what manual should you refer?

Q14. Why should you install cable clamps so the screws are above a wire bundle?

Q15. Describe the difference between a wire group and wire bundle.

Q16. When should you NOT use nylon cable straps?

Q17. Describe the primary aim of bonding.

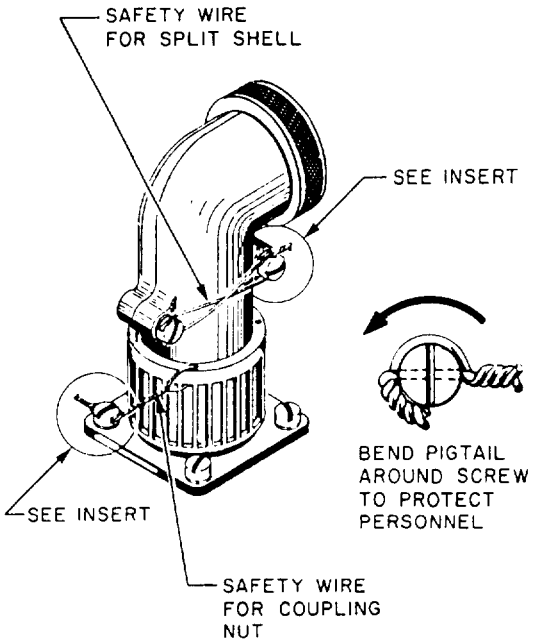


Figure 6-31.-Safety wiring a connector.

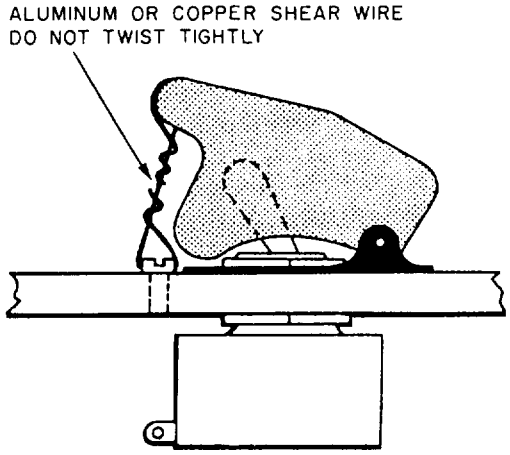


Figure 6-32.-Shear wire on a switch guard.

ENVIRONMENTAL PROBLEMS

Learning Objective: *Recognize the various environmental effects on electronic equipment and the methods used to combat these effects.*

The complexity of avionics equipment and environmental conditions are among the chief causes of equipment failure. For these reasons, you need to know how environmental conditions affect the equipment. Some of the environmental factors that affect the design characteristics of equipment include temperature, humidity, pressure, abrasive conditions, and shock, vibration, and acceleration.

TEMPERATURE

Research has resulted in the development of component parts that are able to withstand operation under extreme temperatures. Extremely low temperatures cause brittleness in metal and loss of flexibility in rubber, insulation, and similar materials. Extremely high temperatures cause deformity and decay of these items.

Most internal component parts cannot withstand extreme temperatures. Because equipment is normally in confined spaces aboard aircraft, the generated heat causes the temperature to rise; therefore, many units have fans installed to increase the air circulation. This reduces the temperature within the unit. Most new models of aircraft use an electronic equipment compartment concept. Also, blast air from outside the aircraft

or from the aircraft's air-conditioning system may provide cooling.

HUMIDITY

Humidity is a term that defines the measure of water content in the air. Humidity is a possible cause of avionics equipment or component failure. High humidity (a high water content in the air) provides a possible environment for corrosion and fungus growth. Humid air can cause short circuiting between points of high potential.

In certain cases, the removal of heat from equipment requires the use of external air. If this external air has a high moisture content, cooling may occur using one of two methods. First, the high-humidity air may go through an air jacket that surrounds the equipment. In this case, the heat is removed without allowing the humid air to come in contact with the internal equipment components. Second, when the internal equipment components require direct air for heat removal, the direct air passes through silica-gel crystals (a desiccant), removing the moisture from the air.

PRESSURIZATION

When operating high-voltage electrical equipment at high altitudes, there is always the problem of arcing. At high altitudes, arcing is caused by the reduced dielectric strength of the air as it becomes thinner. The pressurized equipment case reduces the possibility of arcing. All components inside the case are subjected to pressurization, which reduces the chance of arcing. In radar operation at high altitudes, the waveguides and parts of the antenna are also pressurized.

Pressurization is usually not a big maintenance problem, but occasionally it can cause trouble. The problems that do arise in the pressurization system are usually the result of poor scheduled maintenance. For a trouble-free pressure system, all seals and gaskets (located at the points of separation, waveguide joints, and case covers) must undergo careful installation to provide an airtight seal. When pressurization troubles do occur, they may be difficult to detect, since a very small leak may make the system inoperable. Before you try to pressurize a system to check for leakage, consult the MIM for the amount of safe pressure for that system. If excessive pressure is applied, it could possibly rupture the seals or gaskets or cause mechanical damage to parts of the equipment.

ABRASIVE CONDITIONS

Sand, dust, and other substances that are abrasive affect many components. Normally, these components are not sealed off from atmospheric conditions. In some cases, the abrasive material may form even though the unit is sealed. This material may come from generators, motors, and dynamotors that use brushes. Also, the protective coating may wear off a part by the movement of the abrasive material in the cooling air. Removing the protective coating may allow the unprotected metal to corrode.

Modern aircraft configurations use air-conditioning systems to cool avionics equipments. The external air cools the heat exchanger, while the internal air that removes heat from the equipment may be pressurized. The use of the pressurized air for equipment heat removal reduces the undesired environmental effects of temperature, humidity, arcover, and abrasive conditions.

SHOCK, VIBRATION, AND ACCELERATION

Since acceleration effects are directly proportional to mass, the smaller the object, the less the mass and inertia, all other factors being equal. The extended use of miniaturized components on printed circuits will, to some extent, counteract the trouble due to increased accelerations and shocks.

Vibration effects are directly proportional to the resonant mechanical frequency of the equipment. Shock and vibration effects are reduced by locating the heavier components as closely as possible to the mounting points to reduce the length of the moment arm.

The decision to mount entire equipments on shock and vibration mounts or to mount each component individually depends on the overall mass. Using vibration mounts for components and then mounting the entire chassis on shock mounts would probably amplify any vibration.

Q18. What causes arcing at high altitudes?

Q19. How do we reduce the possibility of arcing?

ELECTROSTATIC DISCHARGE (ESD)

Learning Objective: *Recognize the hazards to ESD-sensitive devices, to include proper handling and packaging techniques.*

The sensitivity of electronic devices and components to electrostatic discharge (ESD) has recently become clear through use, testing, and failure analysis. The construction and design features of current microtechnology have resulted in devices being destroyed or damaged by ESD voltages as low as 20 volts. The trend is toward greater-complexity, increased packaging density, and thinner dielectrics between active elements. This trend will result in devices even more sensitive to ESD.

Various devices and components are susceptible to damage by electrostatic voltage levels commonly generated in production, test, operation, and by maintenance personnel. These devices and components include the following:

- All microelectronic and most semiconductor devices, except for various power diodes and transistors
- Thick and thin film resistors, chips and hybrid devices, and crystals

All subassemblies, assemblies, and equipment containing these components/devices without adequate protective circuitry are ESD-sensitive (ESDS).

You can protect ESDS items by implementing simple, low-cost ESD controls. Lack of implementation has resulted in high repair costs, excessive equipment downtime, and reduced equipment effectiveness.

The operational characteristics of a system may not normally show these failures. However, under internal built-in test monitoring in a digital application, they become pronounced. For example, the system functions normally on the ground; but, when placed in an operational environment, a damaged PN junction might further degrade, causing its failure. Normal examination of these parts will not detect the damage unless you use a curve tracer to measure the signal rise and fall times or check the parts for reverse leakage current.

ANSWERS FOR REVIEW QUESTIONS Q11. THROUGH Q19.

A11. You should refer to the current electronic material changes and to Installation Practices, Aircraft Electric and Electronic Wiring, NAVAIR 01-1A-505.

A12. Conductor size, insulation, and the environment for the conductor.

A13. As an emergency measure only. You must make permanent repairs as soon as possible. For detailed information, you should refer to NAVAIR 01-1A-505.

A14. The weight of the cable may bend and break the clamp.

A15. A wire group is two or more wires tied or laced together to give identity to an individual system. A wire bundle is two or more wires or groups tied or laced together to provide easier maintenance.

A16. Do not use nylon cable straps over wire bundles containing coaxial cable or in areas where failure of the strap would allow the strap to fall into moveable parts.

A17. The primary aim of bonding is to provide an electrical path of low dc resistance and low RF impedance.

A18. At high altitudes, arcing is caused by the reduced dielectric strength of the air as it becomes thinner.

A19. Pressurization of the equipment case.

STATIC ELECTRICITY

Static electricity is electrical energy at rest. Some substances readily give up electrons while others accumulate excessive electrons. When two substances are rubbed together, separated, or flow relative to one another (such as a gas or liquid over a solid), one substance becomes negatively charged and the other positively charged. An electrostatic field or lines of force radiate between a charged object to an object at a different electrostatic potential (such as more or less electrons) or ground. Objects entering this field will receive a charge by induction.

The capacitance of the charged object relative to another object or ground also has an effect on the field. If the capacitance is reduced, there is an inverse linear increase in voltage, since the charge must be conserved. As the capacitance decreases, the voltage increases until a discharge occurs via an arc.

CAUSES OF STATIC ELECTRICITY

Generation of static electricity on an object by rubbing is known as the *triboelectric effect.* Table 6-1 lists substances in the triboelectric series.

The size of an electrostatic charge on two different materials is proportional to the separation of the two materials. Typical prime charge generators commonly encountered in a manufacturing facility are shown in table 6-2.

Electrostatic voltage levels generated by nonconductors can be extremely high. However, air slowly dissipates the charge to a nearby conductor or ground. The more moisture in the air the faster a charge dissipates. Table 6-3 shows typical measured charges generated by personnel in a manufacturing facility. You can see that the generated voltage decreases with an increase in humidity levels of the surrounding air.

NOTE: The triboelectric series is arranged in an order so that when any two substances in the list contact one another and are separated, the substance higher on the list assumes a positive charge.

EFFECTS OF STATIC ELECTRICITY

The effects of ESD are not always recognized. Failures due to ESD are often misanalyzed as being caused by electrical overstress due to transients other than static. Many failures, often classified as *other, random, unknown, infant mortality, manufacturing defect, etc.,* are actually caused by ESD. Misclassification of the defect is often caused by not performing failure analysis to the proper depth.

Table 6-1.-Triboelectric Series

POSITIVE (+)
ACETATE
GLASS
HUMAN HAIR
NYLON
WOOL
FUR
ALUMINUM
POLYESTER
PAPER
COTTON
WOOD
STEEL
ACETATE FIBER
NICKEL, COPPER, SILVER
BRASS – STAINLESS STEEL
RUBBER
ACRYLIC
POLYSTYRENE FOAM
POLYURETHANE FOAM
SARAN
POLYETHYLENE
POLYPROPYLENE
PVC (VINYL)
KEL F
TEFLON
NEGATIVE (–)

NOTE: THE TRIBOELECTRIC SERIES IS ARRANGED IN SUCH AN ORDER THAT WHEN ANY TWO SUBSTANCES IN THE LIST CONTACT ONE ANOTHER AND ARE SEPARATED, THE SUBSTANCE HIGHER ON THE LIST ASSUMES A POSITIVE CHARGE.

COMPONENT SUSCEPTIBILITY

All solid-state devices (all microcircuits and most semiconductors), except for various power

Table 6-2.-Typical Charge Generators

WORK SURFACES	● FORMICA (WAXED OR HIGHLY RESISTIVE) ● FINISHED WOOD ● SYNTHETIC MATS
FLOORS	● WAX FINISHED ● VINYL
CLOTHES	● COMMON CLEAN ROOM SMOCKS ● PERSONNEL GARMENTS (ALL TEXTILES EXCEPT VIRGIN COTTON) ● NONCONDUCTIVE SHOES
CHAIRS	● FINISHED WOOD ● VINYL ● FIBERGLASS
PACKAGING AND HANDLING	● COMMON POLYETHYLENE — BAGS, WRAPS, ENVELOPES ● COMMON BUBBLE PACK, FOAM ● COMMON PLASTIC TRAYS, PLASTIC TOTE ● BOXES, VIALS
ASSEMBLY, CLEANING, TEST AND REPAIR AREAS	● SPRAY CLEANERS ● COMMON SOLDER SUCKERS ● COMMON SOLDER IRONS ● SOLVENT BRUSHING (SYNTHETIC BRISTLES) ● CLEANING, DRYING ● TEMPERATURE CHAMBERS

Table 6-3.-Typical Measured Electrostatic Voltages

MEANS OF STATIC GENERATION	VOLTAGE LEVELS @ RELATIVE HUMIDITY	
	LOW-10-20%	HIGH-65-90%
WALKING ACROSS CARPET	35,000	1,500
WALKING OVER VINYL FLOOR	12,000	250
WORKER AT BENCH	6,000	100
VINYL ENVELOPES FOR WORK INSTRUCTIONS	7,000	600
COMMON POLY BAG PICKED UP FROM BENCH	20,000	1,200
WORK CHAIR PADDED WITH URETHANE FOAM	18,000	1,500

transistors and diodes, are susceptible to damage by discharging electrostatic voltages. The discharge may occur across their terminals or by subjecting these devices to electrostatic fields.

LATENT FAILURE MECHANISMS

ESD overstress can produce a dielectric breakdown of a self-healing nature when the current is unlimited. When this occurs, the device may retest good. However, it contains a hole in the gate oxide. With use, metal will eventually migrate through the puncture, resulting in a shorting of this oxide layer.

Another structure mechanism involves highly limited current dielectric breakdown from which no apparent damage is done. However, this reduces the voltage at which subsequent breakdown occurs to as low as one-third of the original breakdown value. ESD damage can result in a lowered damage threshold at which a subsequent lower voltage ESD will cause further degradation or a functional failure.

ESD ELIMINATION

The heart of an ESD control program is the ESD-protected work area and ESD-grounded work station. When you handle an ESD-sensitive (ESDS) device outside of its ESD protective packaging, you need to provide a means of reducing generated electrostatic voltages below the levels at which the item is sensitive. The greater the margin between the level at which the generated voltages are limited and the ESDS item sensitivity level, the greater the probability of protecting that item.

PRIME GENERATORS

Look at table 6-2. It lists ESD prime generators. All common plastics and other prime generators of static electricity should be prohibited in the ESD-protected work area. Carpeting should also be prohibited. If you must use carpet, it should be of a permanently anti-static type. Perform weekly static voltage monitoring where carpeting is in use.

CAUTION

Anti-static cushioning material is acceptable; however, the items cited need to be of conductive material to prevent damage or destruction of ESDS devices.

PERSONAL APPAREL AND GROUNDING

An essential part of the ESD program is grounding personnel and their apparel when they handle ESDS material. Means of doing this are described in this section.

Smocks

Personnel handling ESDS items should wear long-sleeve ESD-protective smocks, short-sleeve shirts or blouses, and ESD-protective gauntlets banded to the bare wrist and extending toward the elbow. If these items are not available, use other anti-static material (such as cotton) that will cover sections of the body that could contact an ESDS item during handling.

Personnel Ground Straps

Personnel ground straps should have a minimum resistance of 250,000 ohms. Based on limiting leakage currents to personnel to 5 milliamperes, this resistance protects personnel from shock from voltages up to 125 volts RMS. The wrist, leg, or ankle bracelet end of the ground strap should have some metal contact with the skin. Bracelets made completely of carbon-impregnated plastic may burnish around the area in contact with the skin, resulting in too high an impedance to ground.

ESD-PROTECTIVE MATERIALS

There are two basic types of ESD-protective materials-conductive and anti-static. Conductive materials protect ESD devices from static discharges and electromagnetic fields. Anti-static material is a nonstatic generating material. Other than not generating static, anti-static material offers no other protection to an ESD device.

CONDUCTIVE ESD-PROTECTIVE MATERIALS

Conductive ESD-protective materials consist of metal, metal-coated, and metal-impregnated materials (such as carbon particle impregnated, conductive mesh or wire encased in plastic). The most common conductive materials used for ESD protection are steel, aluminum, and carbon-impregnated polyethylene and nylon. The latter two are opaque, black, flexible, heat sealable, electrically conductive plastics. These plastics are

composed of carbon particles, impregnated in the plastic, which provides volume conductivity throughout the material.

ANTI-STATIC ESD PROTECTIVE MATERIALS

Anti-static materials are normally plastic materials (such as polyethylene, polyolefin, polyurethane, nylon) that are impregnated with an anti-static substance. This anti-static substance migrates to the surface and combines with the humidity in the air to form a conductive sweat layer on the surface. This layer is invisible and, although highly resistive, is conductive enough to prevent the buildup of electrostatic charges by triboelectric (or rubbing) methods in normal handling. Simply stated, the primary asset of an anti-static material is that it will not generate a charge on its surface. However, this material won't protect an enclosed ESD device if it comes into contact with a charged surface.

Anti-static material is tinted pink, a symbol of its being anti-static. Anti-static materials are used for inner-wrap packaging. However, anti-static trays, vials, carriers, boxes, etc., are not used unless components and/or assemblies are wrapped in conductive packaging.

HYBRID ESD-PROTECTIVE BAGS

Hybrid ESD-protective bags area laminate of different ESD-protective materials. They are made from conductive and anti-static materials. The hybrid ESD-protective bag provides the advantages of both types of materials in a single bag.

ESDS DEVICE HANDLING

The following are general guidelines that you should follow when handling ESDS devices:

- Ground all containers, tools, test equipment, and fixtures used in ESD-protective areas before and/or during use, either directly or by contact with a grounded surface.

- Avoid physical activities around ESDS items that are friction-producing; for example, removing or putting on smocks, wiping feet, sliding objects over surfaces, etc.

- Wear cotton smocks and/or other anti-static treated clothing.

- Avoid the use or presence of plastics, synthetic textiles, rubber, finished wood, vinyls, and other static-generating materials, especially when handling ESDS out of their ESD-protective packaging.

- Place the ESD protective material containing the ESD item on a grounded work bench surface to remove any charge before opening the packaging material.

- Attach personnel grounding to ground themselves before removing ESDS items from their protective packaging.

- Remove ESDS items from ESD-protective packaging with fingers or metal grasping tool only after grounding, and place on the ESD-grounded work bench surface.

- Make periodic electrostatic measurements at all ESD-protected areas. This assures the ESD-protective properties of the work station and all equipment contained there have not degraded.

- Perform periodic continuity checks of personnel ground straps (between skin contact and ground connection), ESD-grounded work station surfaces, conductive floor mats, and other connections to ground. Perform this check with a megohmmeter to make sure grounding resistivity requirements are met.

ESDS DEVICE PACKAGING

Before an ESDS item leaves an ESD-protected area, package the item in one of the following ESD-protective materials:

- Ensure shorting bars, clips, or noncorrective conductive materials are inserted correctly in or on all terminals or connectors.

- Package ESD items in an inner wrap of type II material and an outer wrap of type I material that conform to MIL-B-81705. You may use a laminated bag if it meets the requirements of M-B-81705. Cushion-wrap the item with electrostatic-free material conforming to PPP-C-1842, type III, style A. Place the cushioned item into a barrier bag made from MIL-C-131 and heat-seal closed, using method 1A-8. Place the wrapped, cushioned, or pouched ESDS item in bags conforming to MIL-B-117, type I, class F, style I. Mark the packaged unit with the ESD symbol and caution (fig. 6-33).

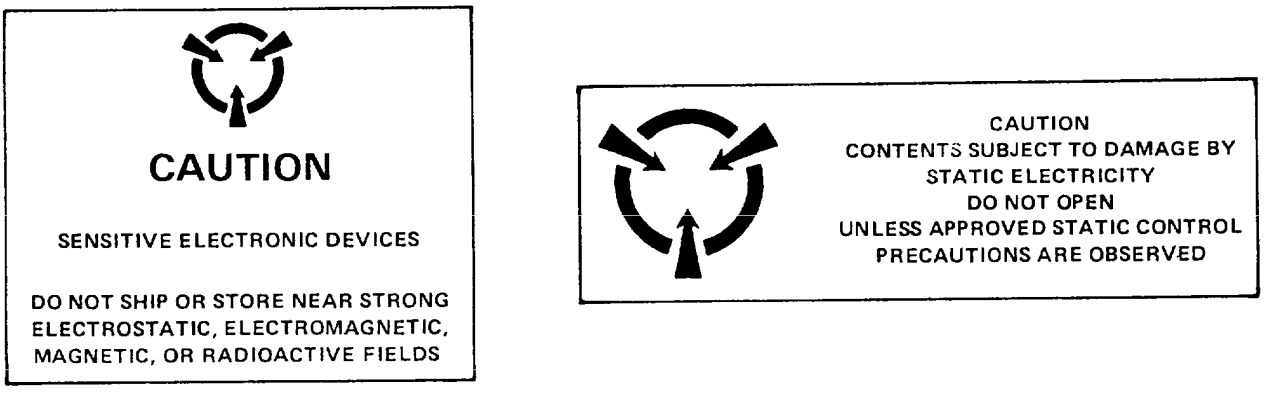


Figure 6-33.-ESDS markings.

TESTING/REPAIR

Before you work on ESDS items, make sure you meet the following precautions/procedures:

- Ground the work area, equipment, and wrist strap assembly.

- Attach the wrist strap and place metal tools, card extractors, test fixtures, etc., on a grounded bench surface.

- Place conductive container on the bench top. Remove the component/assembly from packaging. Remove shorting devices, if present. Handle components by their bodies and lay them on the conductive work surface or test fixtures.

- Test through the connector or tabs only.

- Do not probe assemblies with test equipment.

- After testing, replace shorting devices and protective packaging.

- Do not use a Simpson Model 260 or equivalent to test parts or assemblies. You must use a high input impedance meter such as a Fluke 8000A multimeter.

- Do not permit or perform dielectric strength tests.

Q20. ESD-sensitive devices can be damaged by electrostatic voltages as low as _____ _____.

Q21. When handling ESDS devices, personnel and their apparel should be connected to _____.

Q22. What is the minimum resistance for personnel ground straps?

Q23. What color is a symbol of material that is antistatic?

ELECTRICAL/ELECTRONIC NOISE

Learning Objective: *Recognize the types and effects of radio noise, including natural and man-made interference.*

The electrical noise generated within a radio or radar receiver is not the same as the electrical noise generated external to the receiver that couples into the receiver. The internally generated noise is the result of circuit deficiencies in the receiver itself. Normally, replacing the defective components in the receiver or replacing the entire receiver will eliminate internally generated noise. Externally produced electrical noise enters the receiver by various means. The noise causes interference in and poor reception by the receiver.

In early naval aircraft, electrical noise interference was not a major problem because there were fewer external sources of electrical noise. Receiver sensitivities were low, and the aircraft control components were manual. In today's aircraft, there are considerably more sources of externally generated electrical noise. The aircraft now contains many receivers with higher sensitivities, and the aircraft controls are from various electrical and/or mechanical devices. These devices include control surface drive motors, fuel and hydraulic boost pumps, ac inverters, and cabin pressurization systems. In addition, pulsed electronic transmitters, such as tacan, radar, and IFF, can be sources of electrical noise interference. Listening to electrical noise interference in the output of a radio receiver can cause nervous fatigue in aircrew personnel. Electrical noise may also reduce the performance (sensitivity) of the receiver. For these reasons, electrical noise must be kept at the lowest possible level.

TYPES AND EFFECTS OF RECEIVER NOISE INTERFERENCE

There are two types of electrical noise interference that enter aircraft receivers—natural interference and man-made interference.

Natural Interference

The three types of natural electrical noise that cause radio interference are atmospheric static, precipitation static, and cosmic noise.

ATMOSPHERIC STATIC.— Atmospheric static is the result of the electrical breakdown between masses (clouds) of oppositely charged particles in the atmosphere. An extremely large electrical breakdown between two clouds or between the clouds and ground causes lightning. Atmospheric static is completely random in nature. Both its rate of recurrence and intensity of individual discharges are random. Atmospheric static produces irregular popping and crackling in audio outputs and grass (noise floor) on visual output devices. Its effects range from minor annoyance to complete loss of a receiver's usefulness. The intensity of atmospheric interference is seldom crippling at frequencies from 2 MHz to 30 MHz, but it can be annoying. Above 30 MHz, the noise intensity decreases to a very low level. At frequencies below 2 MHz, natural static is the main limiting factor on usable receiver sensitivity.

The intensity of atmospheric static varies with location, season, weather, time of day, and the receiver's tuned frequency. It is strongest at the lower latitudes, during the summer, during weather squalls, and at the lower radio frequencies. Many schemes are available for reducing the effect of atmospheric static. However, the best technique is to avoid those frequencies associated with intense static, if possible.

PRECIPITATION STATIC.— Precipitation static is a type of interference that occurs during dust, snow, or rain storms. The main cause of precipitation static is the corona discharge of high-voltage charges from various points on the

ANSWERS FOR REVIEW QUESTIONS Q20. THROUGH Q23.

A20. 20 volts.

A21. Ground.

A22. 250,000 ohms.

A23. Pink.

airframe. These charges may reach several hundred thousand volts before discharge occurs. The charge can build up in two ways. First, an electrostatic field existing between two oppositely charged thunderclouds induces bipolar charges on the surfaces of the aircraft as it passes through the charged clouds. Second, a high unipolar charge on the entire airframe occurs from frictional charging. This occurs from collision of atmospheric particles (low altitudes) or fine ice particles (high altitudes) with the aircraft's surface. The effects of corona discharge vary with temperature. The effects increase as altitude and airspeed increase. Doubling airspeed increases the effect by a factor of about 8; tripling airspeed increases the effect by a factor of about 27.

The effect of precipitation static is a loud hissing or frying noise in the audio output of a communication receiver. A grassy indication may also appear on a visual output device, such as a radar receiver. The radio frequency ranges affected by 'precipitation static are nearly the same as for atmospheric static. When present, precipitation interference is severe and often disables all receivers tuned to the low- and medium-frequency bands.

COSMIC NOISE.— Cosmic noise usually affects the UHF band and above. However, it occasionally affects receivers operating at frequencies as low as 10 MHz. Cosmic noise is caused by radiation of stars. Its effect is normally unnoticed. However, at peaks of cosmic activity, cosmic-noise interference could be a limiting factor in the sensitivity of navigational and height-finder radar receivers.

Man-Made Interference

The general categories of man-made interference are tied to their spectrum of influence, such as broadband and narrow band.

BROADBAND INTERFERENCE.— Broadband interference occurs when the current flow in a circuit is interrupted or varies radically from a sinusoidal rate. A current whose waveform is a sine wave can interfere at only a single frequency. Any other waveform contains harmonics of the basic sinewave frequency. The steeper the rise or fall of current, the higher the upper harmonic frequency will be. A perfect rectangular pulse contains an infinite number of odd harmonics of the frequency represented by its pulse recurrence rate. Typical types of electrical disturbances that generate broadband interference are electrical impulses, electrical pulses, and random noise signals.

In this chapter, the term *impulse* describes an electrical disturbance. An impulse may be a switching transient that is an incidental product of the operation of an electrical or electronic device. The impulse recurrence rate may or may not be regular. The term *pulse* describes an intentional, timed, momentary flow of energy produced by an electronic device. The pulse recurrence rate is usually regular.

Switching transients or impulses result from the make or break of an electrical current. They are extremely sharp pulses. The duration and peak value of these pulses depend on the amount of current and the characteristics of the opening or closing circuit. The effects are sharp clicks in the audio output of a receiver and sharp spikes on an oscilloscope trace. The isolated occasional occurrence of a switching transient has little or no significance. However, when repeated often enough and with enough regularity, switching transients are capable of creating intolerable interference to audio and video circuits. They degrade receiver performance. Typical sources of sustained switching transients are ignition timing systems, commutators of dc motors and generators, and pulsed navigational lighting.

Pulse interference is normally from pulsed electronic equipment. This type of interference presents a popping or buzzing in the audio output device and noise spikes on an oscilloscope. The interference level depends on the pulse severity, repetition frequency, and regularity of occurrence. Pulse interference can trigger beacons and IFF equipment and cause false target indications on radar screens. In certain types of navigational beacons, these pulses cause loss of reliability.

Random noise consists of impulses that are of irregular shape, amplitude, duration, and recurrence rate. Normally, the source of the random noise is an intermittent contact between brush and commutator bar or slip ring. Another source can be an imperfect contact or poor isolation between two surfaces.

NARROW BAND INTERFERENCE.— Narrow band interference is almost always from oscillators or power amplifiers in receivers and transmitters. In a receiver, the cause is usually a poorly shielded local oscillator stage. In a transmitter, several of the stages could be at fault. The interference could be at the transmitter operating frequency, a harmonic of its operating

frequency, or at some false frequency. A multichannel transmitter that uses crystal-bank frequency synthesizing circuits can produce interference at any of the frequencies present in the synthesizer. Narrow-band interference in a receiver can range from an annoying heterodyne whistle in the audio output to the complete blocking of received signals. Narrow-band interference affects single frequencies or spots of frequencies in the tuning range of the affected receiver.

SOURCES OF ELECTRICAL NOISE

Learning Objective: *Recognize the various sources of electrical noise and the operating characteristics of each.*

Any circuit or device that carries a varying electrical current is a potential source of receiver interference. The value of the interference voltage depends on the amount of voltage change. The frequency coverage depends on the abruptness of the change. The main sources of man-made interference in aircraft include rotating electrical machines, switching devices, pulsed electronic equipment, propellers systems, receiver oscillators, nonlinear elements, and ac power lines.

Rotating Electrical Machines

Rotating electrical machines are a major source of receiver interference because of the many electric motors used in the aircraft. Rotating electrical machines used in aircraft are of three general classes—dc motors, ac motors and generators, and inverters.

DC MOTORS.—Modern aircraft use many dc motors as flight control actuators, armament actuators, and flight accessories. Most electronic equipment on the aircraft includes one or more dc motor for driving cycling mechanisms, compressor pumps, air circulators, and antenna mechanisms. Each of these motors can generate voltages capable of causing radio interference over a wide band of frequencies. The following is a list of the types of interfering voltages generated by dc motors:

1. Switching transients generated as the brush moves from one commutator bar to another (commutation interference)
2. Random transients produced by varying contact between the brush and the commutator (sliding contact interference)
3. Audio-frequency hum (commutator ripple)
4. Radio frequency and static charges built up on the shaft and the rotor assembly

The dc motors used in aircraft systems are of three general types—series-wound motors, shunt-wound motors, and permanent-magnet (PM) motors. The field windings of both series- and shunt-wound motors afford some filter action against transient voltages generated by the brushes. The PM motor's lack of such inherent filtering makes it a very common source of interference. The size of a dc motor has little bearing upon its interference generating characteristics. The smallest motor aboard the aircraft can be the worst offender.

AC GENERATORS AND MOTORS.—The output of an ideal ac generator is a pure sine wave, A pure sine-wave voltage is incapable of producing interference except at its basic frequency. However, a pure waveform is difficult to produce, particularly in a small ac generator. Nearly all types of ac generators used in naval aircraft are potential sources of interference at frequencies other than the output power frequency. Interference voltages come from the following sources:

- Harmonics of the power frequency. Normally, the harmonics are due to a poor waveform.
- Commutation interference. This condition starts in a series-wound motor.
- Sliding-contact interference. This condition starts in an alternator and in a series-wound motor.

Normally, an ac motor without brushes does not create interference.

INVERTERS.— An inverter is a dc motor with armature taps brought out to slip rings to supply an ac voltage. The ac output contains some of the interference voltages generated at the dc end as well as the brush interference at the ac end of the inverter.

Switching Devices

A switching device makes abrupt changes in electrical circuits. Such changes are accompanied by transients capable of interfering with radio

operation and other types of electronic receivers. The simple manual switch (occasionally operated) is of little concern as a source of interference. Examples of switching devices (frequently operated) capable of causing interference are the relay and the thyratron.

RELAYS.— A relay is an electromagnetic remote-control switch. Its main purpose is to switch high-current, high-voltage, or other critical circuits. The relay is used almost exclusively for controlling large amounts of power with relatively small amounts of power. Therefore, the relay is always a potential source of interference, especially so if the relay controls an inductive circuit. Relay-starting circuits are also possible interference sources. Even though the actuating currents are small, the inductances of the actuating coils are usually quite high. It is not unusual for the control circuit of a relay to produce more interference than the controlled circuit.

THYRATRONS.— A thyratron is a gas-filled, grid-controlled, electronic switching tube used mainly in radar modulators. The current in a thyratron is either **on** or **off;** there is no in-between. The time required to turn a thyratron ON is only a few microseconds. Therefore, the current waveform in a thyratron circuit always has a sharp leading edge. As a result, the waveform is rich in radio interference energy. The voltage and peak power in a radar modulator are usually very high. The waveforms are intentionally sharp and flat as possible. These factors are essential for proper radar operation, but they do increase the production of interference energy.

Pulsed Electronic Equipment

Pulse interference is from pulsed electronic equipment. Types of systems that fall within this category include radar, beacons, transponders, and coded-pulse equipment.

RADAR.— In radar equipment, range resolution depends largely on the sharpness of the leading and trailing edges of the pulse. The ideal pulse is a perfect square wave. Target definition also depends on the narrowness of the pulse. Both the steepness and narrowness of a pulse determine the number and amplitudes of harmonic frequencies. The better the shape of a radar pulse, the better the radar is working, and the greater the interference it can produce. Most of the interference is from frequencies other than those leaving the radar antenna, except in receivers operating within the radar band.

Radar interference at frequencies below the antenna frequency severely affects all receivers in use. Principal sources of such interference are the modulator, pulse cables, and transmitter.

CODED-PULSE EQUIPMENT, BEACONS, AND TRANSPONDERS.— This group includes IFF, beacons, tacan, teletype, and other coded-pulse equipment. The interference energy produced by this group is the same as that produced by radar-pulsing circuits. The effects of this interference energy are smaller because the equipment is usually self-contained in one shielded case, and uses lower pulse power. However, the effects also increase because the radiating frequencies are lower. This permits fundamental frequencies and harmonics to fall within frequency bands used by other equipment. Each piece of equipment is capable of producing interference outside the aircraft where other receiver antennas may pick it up.

Propeller Systems

Propeller systems, whether hydraulic or electric, are potent generators of radio interference. The sources of interference include propeller pitch control motors and solenoids, governors and associated relays, synchronizers and associated relays, deicing timers and relays, and inverters for system operation.

Propeller control equipment generates clicks and transients as often as 10 per second. The audio frequency envelope of commutator interference varies from about 20 to 1000 Hz. The propeller deicing timer generates intense impulses at a maximum rate of about 4 impulses per minute.

Values of current in the propeller system are relatively high. Therefore, the interference voltages generated are severe. They are capable of producing moderate interference at frequencies below 100 kHz and at frequencies above 1 MHz. However, the interference voltages can cause severe interference at intermediate frequencies.

Receiver Oscillators

Either directly or through frequency multipliers or synthesizers, the local oscillator in a superheterodyne receiver generates an RF signal at a given frequency. The local oscillator signal

mixes with another RF signal to produce an intermediate frequency (IF) signal. Depending on receiver design, the frequency of the local oscillator signal is either above or below the frequency of the RF signal by a frequency equal to the IF.

The amount of interference leaving the receiver through its antenna is roughly proportional to the ratio of the tuned input frequency to the intermediate frequency. For any tuning band on the receiver, oscillator leakage is highest at the low end of the band. Also, the lower the intermediate frequency, the greater the leakage chance.

Although the receiver antenna is the principal outlet of oscillator leakage, leakage can occur from other points. Any path capable of introducing interference into a receiver is also capable of carrying internally generated interference out of the receiver. The paths of entry are discussed more fully later in this chapter.

Oscillator leakage from a single communications receiver in an aircraft is not likely to be a direct source of interference. However, oscillator leakage is a direct source in very large aircraft using two or more frequencies in the same band simultaneously. However, high-order harmonics of the oscillator frequency can become troublesome in the VHF band and above.

Oscillator leakage from a swept-tuning receiver can produce interference in any receiver aboard the aircraft. This is done directly (on harmonics) or by nonlinear mixing, as shown in the following example:

- Receiver A, operating at a frequency of 2100 kHz, with an IF of 500 kHz, has oscillator leakage at 2600 kHz (or 1600 kHz).

- Receiver B, operating at 150 MHz, with an IF of 10 MHz, has oscillator leakage at 160 MHz (or 140 MHz).

- Receiver C, sweeping a frequency band from 200 to 300 MHz, with an IF of 30 MHz, has oscillator leakage across the band 170 to 270 MHz (or 230 to 330 MHz).

Each receiver can interfere with the other receivers at the oscillator frequency and its harmonics. In addition, with the presence of a nonlinear detector, the leakage signals from the three receivers can be mixed and interfere with the following frequencies:

- Receiver A and B, after nonlinear mixing, can produce interference at 160 ±2.6 MHz.

- Receivers A and C can similarly produce interference at any frequency from 200 ±2.6 to 300 ±2.6 MHz; receivers B and C between 200 ±60 to 300 ±160 MHz.

Nonlinear Elements

A nonlinear element is a conductor, semiconductor, or solid-state device whose resistance or impedance varies with the voltage applied across it. Therefore, the resultant voltage is not proportional to the original applied voltage. Typical examples of nonlinear elements are metallic oxides, certain nonconducting crystal structures, semiconductor devices, and electron tubes. Nonlinear elements that could cause radio interference in aircraft systems are overdriven semiconductors and vacuum tubes, oxidized or corroded joints, cold-solder joints, and unsound welds.

In the presence of a strong signal, a nonlinear element acts like a detector or mixer. It produces sum and difference frequencies and any harmonics from the signal applied to it. These false frequencies are called *external cross modulation.* These frequencies (sum, difference, and harmonics) can cause interference problems when the combined product of their field strengths exceeds 1 millivolt.

A common example of this action is the entry of a strong off-frequency RF voltage into the mixer stage of a superheterodyne receiver. By the time the interfering signal has passed through the preselector stages of the receiver, it has undergone distortion by clipping. Therefore, the interfering signal is essentially a rectangular wave that is rich in harmonics. Frequency components of the wave beat both above and below the local oscillator frequency and its harmonics. This produces signals at the output of the mixer that are acceptable to the IF amplifier.

Power Lines

Alternating current power sources are broadband sources of receiver interference. Even though they are conducting a nearly sinusoidal waveform, ac signals on power lines are capable of interfering with audio signals in receivers. In

such cases, only the power-line frequency appears. However, where multiple sources of ac power are present, these signals are capable of mixing in the same manner as receiver radiation. Sum and difference frequencies appear.

In ac-powered equipment, ac hum can appear at the power frequency or at the rectification ripple frequency. The rectification ripple frequency is twice the power frequency times the number of phases. Normally, aircraft systems use only single- and three-phase sources at a nominal 400 Hz. Full-wave rectification with single-phase, 400-Hz power gives a ripple frequency of 800 Hz; a three-phase source yields 2400 Hz. This ripple produces interference that varies from simple annoyance to complete unreliability of equipment, depending on its severity and its coupling to susceptible elements.

INTERFERENCE COUPLING

Learning Objective: *Identify the various types of electrical interference caused by coupling, and recognize means used to reduce the interference.*

Openings in the outer shields of equipment are necessary for the entrance of power leads, control leads, mechanical linkages, ventilation, and antenna leads. Interference entering these openings is amplified by various amounts, depending on the point of entry into the equipment's circuits. Coupling between the entry path and the sensitive points of the receiver can be in any form.

Conductive Coupling

Interference often couples from its source to a receiver by metallic conduction. Normally, this is done by way of mutual impedance, as shown in figure 6-34. In the figure, A is the power source, B the receiver, and C the interference source. The interference is maximum at the interference source (C) and decreases rapidly to a relatively low value at battery (A) because of the very low impedance of the battery. The size of the arrows indicate that the nearer the power tap of the receiver (B) is to the interference source (C), the greater the amplitude of interfering current in the BC loop.

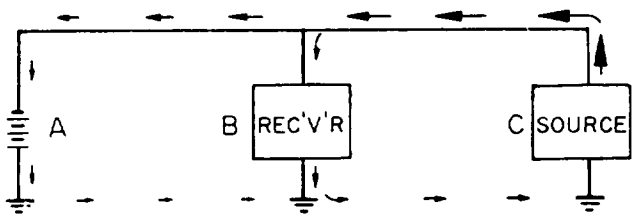


Figure 6-34.-Path of conducted interference.

Inductive-Magnetic Coupling

Every current-carrying conductor is within a magnetic field whose intensity variations are faithful reproductions of variations in the current in the conductor. When another parallel conductor is cut by the lines of force of this field, the conductor has a current induced into it. The amplitude of the induced current depends on the following factors:

- The strength of the current in the first conductor
- The nearness of the conductors to each other
- The angle between the conductors
- The length through which the conductors are exposed to each other

The amount of the variation in the current that directly affects variation in the magnetic field surrounding the conductor depends on the nature of the current. When the conductor is a power lead to an electric motor, all the frequencies and amplitudes associated with broadband interference are present in the magnetic field. When the lead is an ac power lead, a strong sinusoidal magnetic field is present. When the lead is carrying switched or pulsed currents, extremely complex broadband variations are present. As the magnetic field cuts across a neighboring conductor, a voltage replica of its variation is induced into the neighboring wire. This causes a current to flow in the neighboring wire. When the neighboring wire leads to a sensitive point in a susceptible receiver, serious interference with that receiver's operation can result. Similarly, a wire carrying a steady pure dc current of high value sets up a magnetic field. This field is capable of affecting the operation of equipment that uses the earth's magnetic field.

Shielding a conductor against magnetic induction is both difficult and impractical. Nonferrous shielding materials have little or no

effect upon a magnetic field. Magnetic shielding that is effective at low frequencies is too heavy and bulky.

In aircraft wiring, the effect of induction fields must be reduced. This can be done by using the proper spacing and coupling angle between wires. The degree of magnetic coupling diminishes rapidly with distance. Interference coupling is least when the space between active and passive leads is at a maximum, and when the angle between the leads approaches a right angle.

Inductive-Capacitive Coupling

Capacitive (electric) fields are voltage fields. Their effects depend on the amount of capacitance existing between exposed portions of noisy circuits and noise-free circuits. The power transfer capabilities are directly proportional to frequency. Thus, high-frequency components couple more easily to other circuits. Capacitive coupling is relatively easy to shield out by placing a grounded conducting surface between the interfering source and the sensitive conductor.

Coupling by Radiation

Almost any wire in an aircraft system can, at some particular frequency, act like an antenna through a portion of its length. Inside an airframe, however, this occurs only at very high frequencies. At high frequencies, all internal leads normally have good shielding against pickup of moderate levels of radiated energy. Perhaps the only cases of true inside-the-aircraft radiation at HF and below occur with unshielded or inadequately shielded transmitter antenna leads.

Complex Coupling

Complex coupling involves more than one type of interference (conduction, induction, or radiation). When more than one coupling occurs simultaneously, we need corrective actions, such as bonding, shielding, or filtering. Sometimes the corrective action for one type of coupling can increase the coupling capabilities of another type of coupling. The result may be an increase in the transfer of interference. For example, an unbended, unfiltered dc motor can transfer interference to a sensitive element by conduction, inductive coupling, capacitive coupling, and by radiation. Some frequencies are only transmitted by one form of coupling, and some frequencies by others. At still other frequencies, all methods of transmission are equally effective. On a motor, bonding almost always eliminates radiation from the motor shell. It also increases the intensity in one of the other methods of transmission, usually by conduction. The external placement of a low-pass filter or a capacitor usually reduces the intensity of conducted interference. At the same time, it may increase the radiation and induction fields. This occurs because the filter appears to interference voltages to be a low-impedance path across the line. Relatively high interference currents then flow in the loop formed between the source and the filter. For complex coupling problems, multiple solutions may be necessary to prevent the interference.

RADIO INTERFERENCE REDUCTION COMPONENTS

Learning Objective: *Recognize various methods and components used to reduce radio interference caused by electrical noise.*

Radio interference reduction at the source may include, to varying degrees, one or more of the following methods—short circuiting, dissipation, open circuiting, or a combination of all three.

Using discrete components will normally achieve interference reduction at the source. The use of capacitors, resistors, and inductors are to short circuit, dissipate, and open circuit the interference, respectively.

Capacitors

Short circuiting of interference is done by using capacitors connected across the source. The perfect capacitor looks like an open circuit to dc or the power frequency, and progressively as a short circuit to ac as the frequency increases.

FUNCTION.— The function of a capacitor in radio interference filtering is to provide a low-impedance radio-frequency path across the source. When the reactance of the capacitor is lower than the impedance of the power lines to the source, high-frequency voltages see the capacitor as a shorter path to ground. The capacitor charges to the line voltage. It then tends to absorb transient rises in the line voltage and to provide energy for canceling transient drops in the line voltage.

LIMITATIONS.— The efficiency of a perfect capacitor in bypassing radio interference increases in direct proportion to the frequency of the interfering voltage. Its efficiency is also in direct proportion to the capacitance of the capacitor. All capacitors have both inductance and resistance. Any lead for connecting the capacitor has inductance and resistance as a direct function of lead length and an inverse function of lead diameter. Some resistance is inherent in the capacitor itself in the form of dielectric leakage. Some inductance is inherent in the capacitor. Inherent inductance is usually proportional to the capacitance.

The effect of the inherent resistance in a high-grade capacitor is negligible as far as its filtering action ability. The inherent inductance plus the lead inductance seriously affects the frequency range over which the capacitor is useful. The bypass value of a capacitor with inductance in series varies with frequency.

At frequencies where inductive reactance is much less than capacitive reactance, the capacitor looks very much like a pure capacitance. As the frequency approaches a frequency at which the inductive reactance is equal to the capacitive reactance, the net series reactance becomes smaller. This continues until reaching its resonant frequency, a point of zero impedance. At this point, maximum bypass action occurs. At frequencies above the resonant frequency, the inductive reactance becomes greater than the capacitive reactance. The capacitor then exhibits a net inductive reactance whose value increases with frequency. At frequencies much higher than the resonant frequency, the value of the capacitor as a bypass becomes lost.

The size of the capacitor and the length of the leads control the frequency at which the reversal of reactance occurs. For instance, the installation of a very large capacitor frequently requires the use of long leads. As an example of the influence of lead length upon the bypass value of a capacitor, the following data is presented for a typical 4-microfarad capacitor whose inherent inductance is 0.0129 henrys.

Lead Length	Crossover Frequency
1 inch	0.47 MHz
2 inches	0.41 MHz
3 inches	0.34 MHz
4 inches	0.30 MHz
6 inches	0.25 MHz

You can see that for the 4-μF capacitor, each additional inch of lead causes the capacitance-inductance crossover point to decrease.

By looking at figure 6-35, you can see the capacitance-to-inductance crossover frequencies

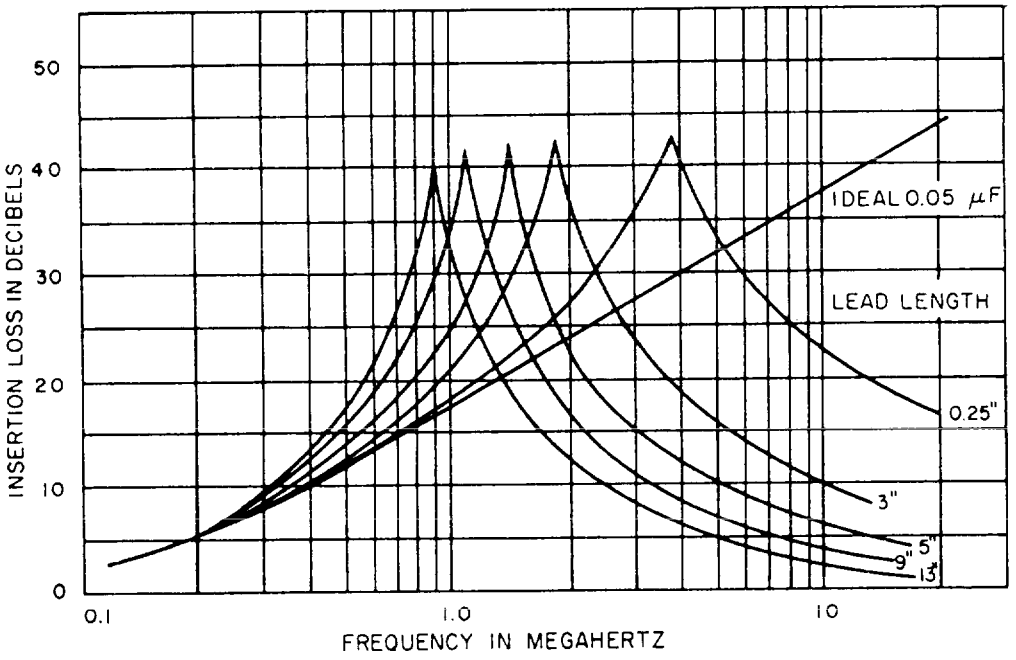


Figure 6-35.-Crossover frequency of a 0.05-microfarad capacitor with various lead lengths.

for various lead lengths of a 0.05 µF capacitor. Notice the difference in the crossover frequencies for the 3-inch lead of the 4-microfarad capacitor and the 3-inch lead of the 0.05-µF capacitor in figure 6-35.

COAXIAL FEEDTHROUGH CAPACITORS.— Coaxial feedthrough capacitors are available with capacitances from 0.00005 to about 2µF. These capacitors work well up to frequencies several times those at which capacitors with leads become useless.

The curves shown in figure 6-36 compare the bypass value of a feedthrough capacitor of 0.05 µF with that of a theoretically perfect capacitor of the same capacitance. The feedthrough capacitor differs from the capacitor with leads. The feedthrough capacitor forms a part of both the filtered circuit and the shield used to isolate the filtered source. Lead length has been reduced to zero. The center conductor of the feedthrough capacitor must carry all the current of the filtered source, and it must have an adequate current rating to prevent dc loss or power frequency insertion loss. Figure 6-37 shows the internal constructions of feedthrough and conventional capacitors. Notice the differences in the two types.

SELECTION OF CAPACITORS.— The selection of capacitors for filtering circuits in aircraft depends on characteristics such as physical size, high temperature and humidity tolerances, and physical ruggedness. The capacitors should have at least twice the voltage rating of the circuit to be filtered. When installing capacitors use minimum lead length.

APPLICATION OF CAPACITIVE FILTERS.— Bypass every circuit carrying an unintentionally varying voltage or current capable of causing radio interference to ground by using suitable capacitors. When variations cause

Lead Length	Crossover Frequency
1″	0.47 MHz
2″	0.41 MHz
3″	0.34 MHz
4″	0.30 MHz
6″	0.25 MHz

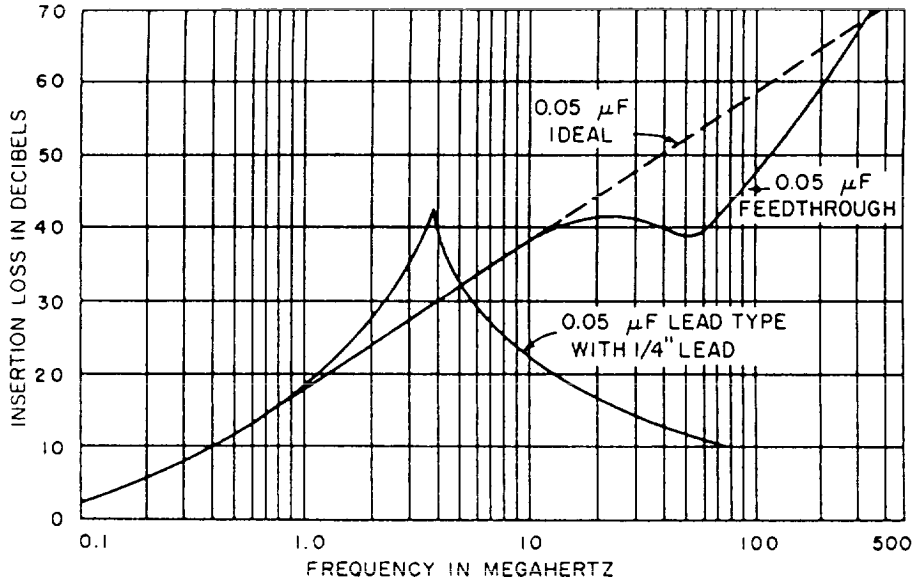


Figure 6-36.-Crossover frequency of a 0.05-microfarad feedthrough capacitor.

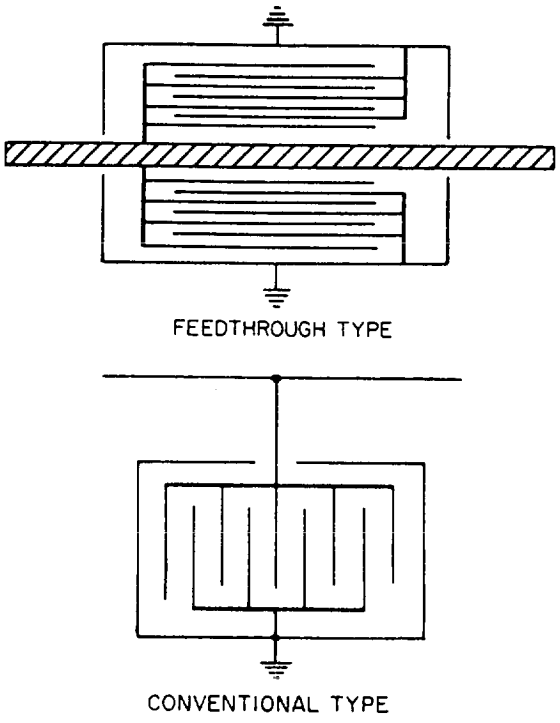


Figure 6-37.-Internal construction of feedthrough and conventional capacitors.

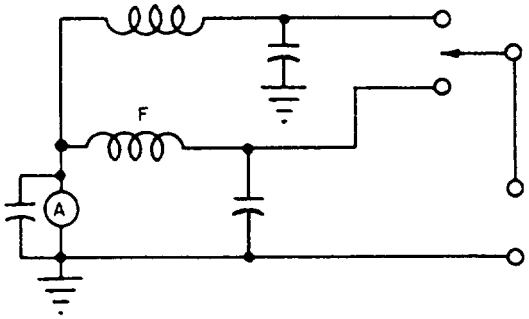


Figure 6-38.-Capacitive filtering of a reversible dc series motor.

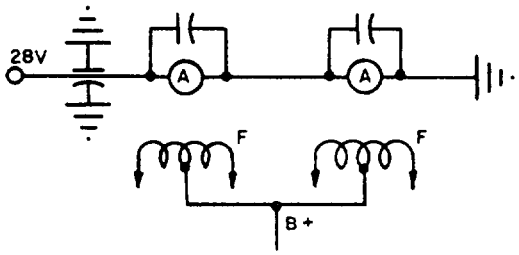


Figure 6-40.-Capacitive filtering of a servomotor.

interference at both high and low frequencies, chose and install a capacitor that provides an adequate insertion loss at the lowest interfered frequency. The overall capacitance required at low frequency may provide inadequate insertion loss at high frequencies. Therefore, you may need to bridge the capacitor in the shortest and most direct manner possible by a second capacitor.

Install a capacitive filter as near as possible to the actual source of interference. Hold lead length to an absolute minimum for two reasons. First, the lead to the capacitor carries interference that must not radiate. Second, the lead has inductance that tends to lower the maximum frequency for which the capacitor is an effective bypass.

When possible, a filter capacitor should be installed to make use of any element of the filtered circuit that provides a better filtering action. Figures 6-38, 6-39, and 6-40 show the proper use of filter capacitors.

CAPACITIVE FILTERING IN AN AC CIRCUIT.— Radio interference from slip ring ac motors and generators is transient noise caused by sliding contacts plus high-frequency energy from other internal sources. For this reason,

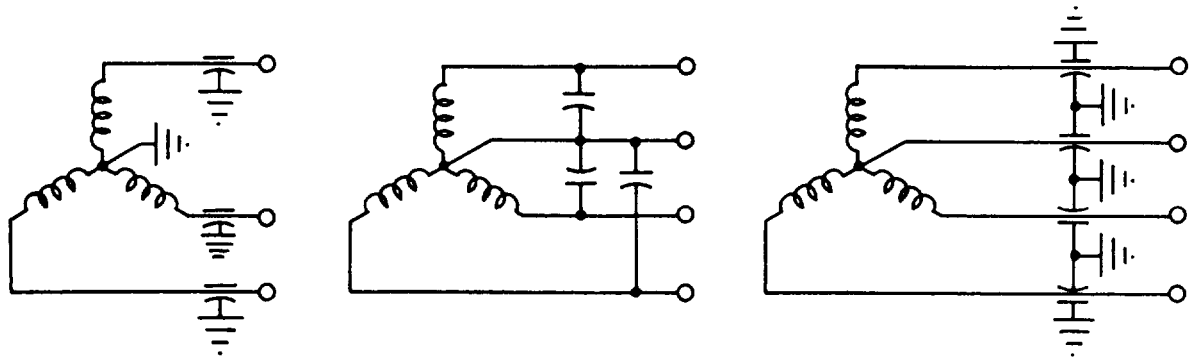


Figure 6-39.-Capacitive filtering of a three-phase attenuator.

filtering should attempt to reduce HF and VHF noise components. This requires the use of low-capacitance, high-grade capacitors. Wherever possible use feedthrough capacitors. Capacitances should be chosen low enough in value to represent a high impedance at the power frequency and to avoid resonance with the internal inductances of the filtered unit. Voltage ratings should be at least twice the peak voltage across the capacitors.

In a four-wire electrical system, the neutral lead carries all three phases. A large quantity of the third harmonic of the power frequency is present. This frequency must be considered in setting capacitance limits and in filtering the return lead. Normal values of capacitance for filtering 400-Hz leads vary from 0.05 to 0.1 µF.

CAPACITIVE FILTERING OF SWITCHING DEVICES.— Normally, a capacitor should not be used by itself as a filter on a switch in a dc system. In the open position, the capacitor bridging the switch assumes a charge equal to the line voltage. When the switch closes, the capacitor discharges at such a rapid rate that it generates a transient. The transient interference value exceeds that caused by the opening of the unfiltered circuit. The capacitor across a switch should have enough series resistance to provide a slow discharge when the switch shorts the capacitor.

Resistive-Capacitive Filters

A resistive-capacitive (RC) filter is an effective arc and transient absorber. The RC filter reduces interference in two ways—by changing the waveform of transients and by dissipating transient energy. Figure 6-41 shows how an RC filter is connected across a switch.

Without the RC filter, the voltage appearing across the switch at the instant the switch opens is equal to the line voltage plus an inductive voltage of the same polarity. The amplitude of the inductive surge depends upon the inductance of the line and the amplitude of the closed-circuit current.

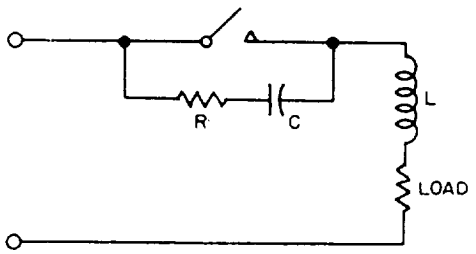


Figure 6-41.-An RC filter connected across a switch.

When the sum of the voltages appearing across the switch is large enough, arcing occurs. When the capacitance is large enough, the capacitor absorbs enough transient energy to reduce the voltage below arcing value. During the charging time of the capacitor, the resistor is passing current and dissipating some of the transient energy.

For maximum absorption of the circuit opening transients, resistance should be small and capacitance should be large. Good representative values are R = 1/5 load resistance and C = 0.25 µF.

Figure 6-42 shows two RC filters used to absorb the transient interference resulting from the opening of a relay field. In circuit A, the value of R_a should provide a low resistance path to ground less than the line impedance and high enough to lower the Q sufficiently. The capacitor should be at least 0.25 µF, with a voltage rating several times the line voltage. Circuit B has the advantage of reducing the capacitor and coil leads to absolute minimum and reducing the relay field current. It also has the disadvantage of carrying the dc coil current. Normal values of each resistance (R_b) in circuit B is 5 percent of the dc resistance of the coil. The capacitor is normally 0.25 µF. Circuit B serves as both a damping load and a high-loss transmission line.

Inductive-Capacitive Filters

Filtering radio interference is done through an inductor inserted in series with the ac power source. The inductor offers little impedance to the ac or power-line frequency and an increasing high impedance to transient interference as frequency increases. Combinations of inductance and capacitance are widely used to reduce both broadband and narrow-band interference.

Filters used to reduce radio interference transmissions are available in the Navy supply system. The filters come in a large variety of types and sizes. Filters are classified as to their frequency characteristics—low-pass, high-pass, bandpass, and band-reject filters. Also, you can distinguish filter classes by their applications, such as power-line, antenna, and audio filters. The type most often used in aircraft is the low-pass, power-line filter.

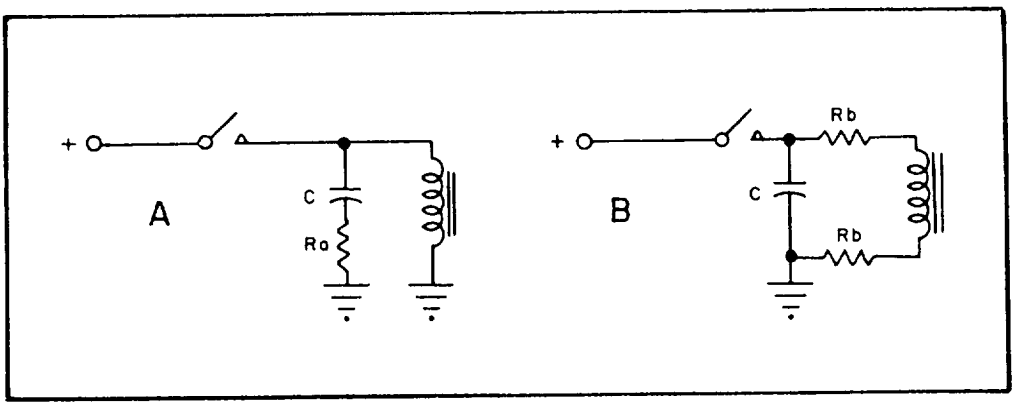


Figure 6-42.-Methods for using RC filters in relay circuits.

LOW-PASS FILTERS.— A low-pass filter in an aircraft filters power leads coming from interference sources. The filter prevents the transmission of interference voltages into the wiring harness. It also blocks transmission or reception of radio-frequency energy above a specified frequency.

The ideal low-pass filter has no insertion loss at frequencies below its cutoff frequency, but has an infinite insertion loss at all higher frequencies. Practical filters fall short of the ideal in three ways. First, a filter of acceptable physical size and weight has some insertion loss, even under dc conditions. Second, because of the lack of a pure inductor, the change from low to high impedance is gradual instead of abrupt. Third, the impedance is held to a finite value for the same reason. Figure 6-43 compares the insertion loss of a typical low-pass filter with that of the hypothetical ideal filter.

Figure 6-44 shows the arrangement and typical parameters of a low-pass filter having a design cut off frequency of 100 kHz. Inductor L must carry load current. It must be wound of wire large enough that its dc insertion loss is negligible. Therefore, maximum current is one parameter for rating filters. The capacitors C1 and C2 must withstand the line voltage. Therefore, maximum voltage is another parameter for rating filters.

At frequencies immediately below cutoff, the filter looks capacitive to both the generator and the load. Inductive reactance (X_L) has very little influence, and no filtering action takes place. However, at frequencies above cutoff, the series reactance of coil L becomes increasingly higher. The series reactance of coil L is limited only by the resistance of the coil and its distributed capacitance. Coil L then functions as a high-frequency disconnect. The bypass values of both C1 and C2 become increasingly higher, and are limited only by the inductance of the capacitors

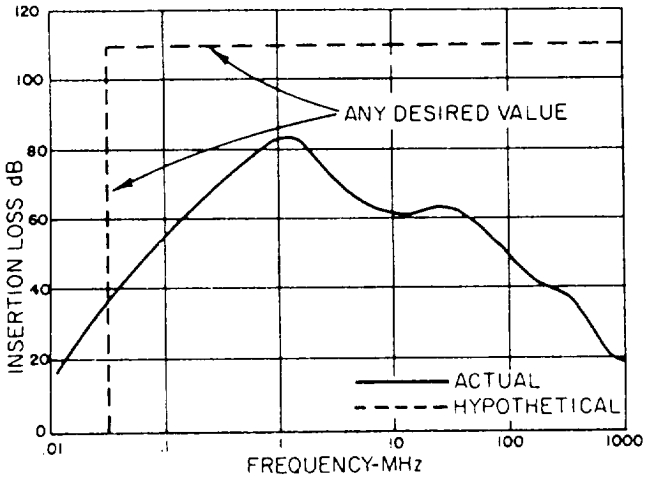


Figure 6-43.-Insertion-loss curve of a commercial low-pass power-line filter.

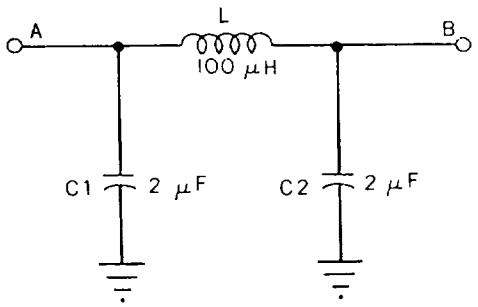


Figure 6-44-Low-pass filter circuit.

and their leads. As a result of these two actions, high-frequency isolation between points A and B occurs.

HIGH-PASS FILTERS.— In most radio transmitters operating at high frequencies (HF) and above, the master oscillator generates a signal at a submultiple of the output frequency. The use of one or more frequency multipliers raises the basic oscillator frequency to the desired output frequency. At the input to the antenna, an overdriven output amplifier may output the output frequency and harmonics of the output frequency. A high-pass filter is very effective in preventing the undesired harmonics from radiating or reaching the antenna.

High-pass filters are also useful for isolating a high-frequency receiver from the influence of energy of signals of lower frequencies. Figure 6-45 shows the use of a typical high-pass filter to reduce radio-noise interference. In symmetrical high-pass filter sections ($Z_{in} = Z_{out}$), the series combination of Cl and L should resonate at 2 times the desired cutoff frequency. The L/C ratio that is chosen should have a square root equal to the terminal impedance.

BANDPASS FILTERS.— Bandpass filters provide a very high impedance above and below a desired band of frequencies. They also provide a very low impedance to frequencies within that band. Bandpass filters find their greatest application in (1) decoupling the receiver from shock and overload by transmitters operating above and below the receiver pass band, and (2) multiplexing or decoupling two or more receivers or transmitters using the same antenna.

A bandpass filter can have many forms and configurations, depending on its application. For filtering antennas, a bandpass filter normally consists of one or more high-pass filter sections followed by one or more low-pass filter sections. The section configuration is normally selected so the upper limit of the pass band approaches or exceeds twice the frequency of the lower limit of the pass band. Figure 6-46 shows typical arrangements for bandpass filters.

BAND-REJECTION FILTERS.— A band-rejection (band-stop) filter rejects or blocks a band of frequencies from passing. This filter allows all frequencies above and below this band to pass with little or no attenuation.

The band-stop filter circuit consists of inductive and capacitive networks combined and connected to form a definite frequency response characteristic. The band-stop filter's design attenuates a specific frequency band and permits the passage of all frequencies not within a specific band. The frequency range over which attenuation or poor transmission of signals occurs is the attenuation band. The frequency range over which the passage of signals readily occurs is the bandpass. The lowest frequency at which the attenuation of a signal starts to increase rapidly is the lower cutoff frequency (f_1). The highest frequency at which the attenuation of a signal starts to increase rapidly is the upper cutoff frequency (f_2). The basic configuration arrangement or assembly of the band-reject filter elements are the L- or half-section, the T-section,

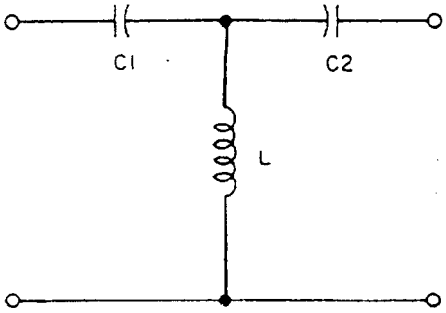


Figure 6-45.-Schematic diagram of a high-pass filter.

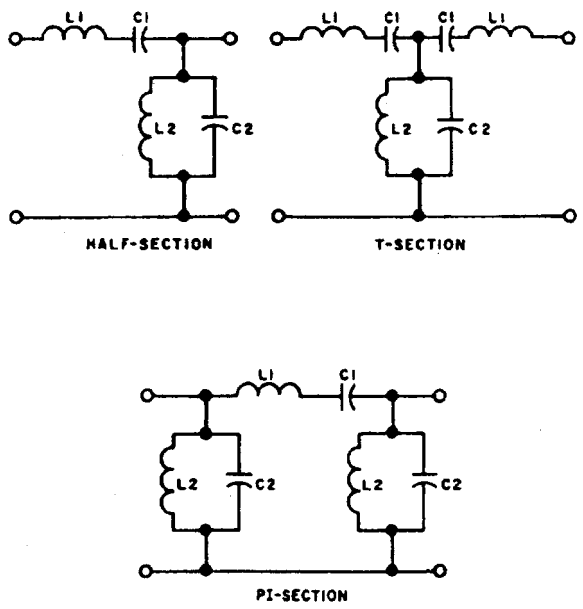


Figure 6-46.-Examples of bandpass filter circuits.

and the Pi-section configurations. (See figure 6-47.) For a more in-depth discussion on the various filters discussed in this chapter, you should refer to *Installation Practices for Electrical and Electronic Wiring,* NAVSHIPS 0967-000-0120, section 4.

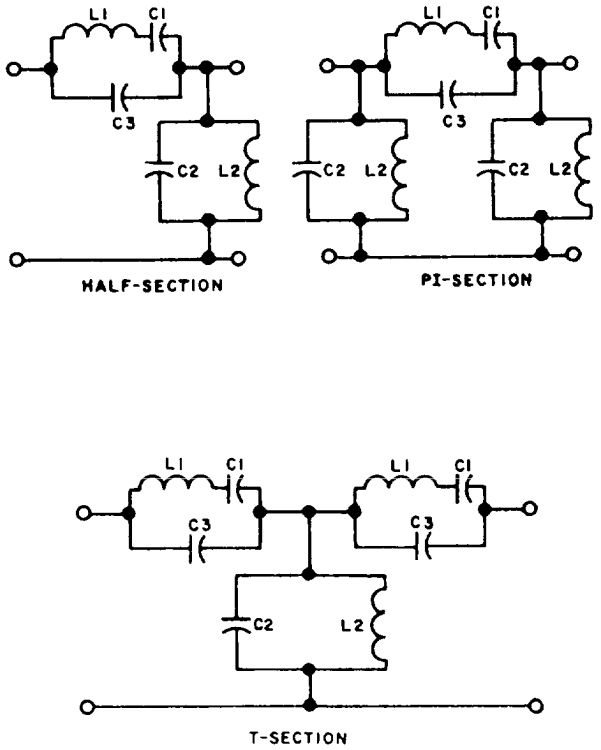


Figure 6-47.-Examples of band-reject filter circuits.

Q24. Name the two types of electrical noise interference that enter aircraft receivers.

Q25. Of the three types of natural interference, which is caused by radiation of stars?

Q26. Why are rotating electrical machines a major source of receiver interference?

Q27. Does the size of an electric dc motor determine its interference capability?

Q28. Name the types of equipment that can cause pulse interference.

Q29. Describe rectification ripple frequency.

Q30. In aircraft wiring, the effect of induction fields is reduced by using proper spacing and coupling angle between wires. When is interference coupling at its least?

Q31. What methods may be used to reduce radio interference at the source?

Q32. Capacitors and capacitive filter circuits make good filters for reducing and eliminating noise. What characteristics are used in selecting capacitors for filtering circuits in aircraft?

Q33. How does an RC filter reduce interference?

Q34. How can you distinguish filter classes?

ANSWERS FOR REVIEW QUESTIONS Q24. THROUGH Q34.

A24. Natural and man-made interference.

A25. Cosmic noise.

A26. Because there are so many electric motors used in the aircraft.

A27. No. The smallest motor could be the worst offender.

A28. Radar, beacons, transponders, and coded-pulse equipment.

A29. The rectification ripple frequency is twice the power frequency times the number of phases.

A30. Interference coupling is least when the space between active and passive leads is maximum and when the angle between the leads approaches a right angle.

A31. Short circuiting, dissipation, open circuiting, or a combination of all three.

A32. Physical size, high temperature, humidity tolerances, and physical ruggedness.

A33. The RC filter reduces interference in two ways—by changing the waveform of transients and by dissipating transient energy.

A34. Filters are classified as to their frequency characteristics—low-pass, high-pass, bandpass, and band-reject; however, they are also distinguished by their applications, such as power-line, antenna, and audio filters. For example, the most common type used in aircraft is the low-pass, power-line filter.

CHAPTER 7

AVIONIC DRAWINGS, SCHEMATICS, HANDTOOLS, AND MATERIALS

The theory of operation of avionic equipment is a small part of the knowledge you need to successfully perform maintenance on these equipments. You need to know how to use avionic drawings, schematics, handtools, and material.

As an AT, you use many publications to properly maintain a weapons system. The weapons systems in modern-day aircraft are so complex that maintenance is difficult or impossible without the use of technical publications. Just the list of the electronics equipment installed in modern-day aircraft is quite long. It is impossible for you to be thoroughly familiar with all the various types of electronics equipment presently in use. However, with a good general background of electronic principles and circuit theory and a little study, you can become familiar with any specific system or test equipment.

The material presented in this chapter includes general and specific types of publications and drawings, illustrations, diagrams, charts, and tables. It also includes identification of handtools and materials common to the Aviation Electronics Technician.

DRAWINGS AND SCHEMATICS

Learning Objective: *Recognize types of and uses for various avionics-related symbols, diagrams, illustrations, charts, and tables.*

Nearly all technical manuals make extensive use of drawings and diagrams. As an AT, you will use these drawings and diagrams in nearly every phase of your work. You will use them in the location and identification of units and components, troubleshooting, signal and/or circuit tracing, installation, calibration and adjustment, testing, operation, and evaluation. You will also use these figures when you study the operating principles of circuits and equipments.

No one particular type of illustration is suitable for all applications; therefore, many different types exist. Several different types of illustrations are discussed in the following paragraphs. Each type has its own advantages and disadvantages.

NOTE: *Blueprint Reading and Sketching,* NAVEDTRA 14040, provides many details on the construction of illustrations and drawings. You should review that manual before continuing the study of this chapter. The Navy Electricity and Electronics Training Series (NEETS), module 4, contains additional information on drawings and schematics.

ILLUSTRATIONS

Illustrations present the idea of a text visually; therefore, they are used in many forms. A few of these are the photograph, line drawing, shaded sketch, blueprint, etc. However, you will learn about some of the more common illustrations, such as pictorial, cutaway view, location and dimension, and assembly drawings in this chapter.

Pictorial

Pictorial illustrations normally show physical appearance. They may present details on location, size, construction, physical relationships of size and location, or parts arrangement. Pictorial illustrations appear throughout all types of manuals, and you can use them to locate and identify systems, equipments, components, or parts. You will use them to install, inspect, service, operate, adjust, calibrate, troubleshoot, and repair equipment.

A pictorial illustration may be an accurate, detailed representation or a generalized indication, depending on its purpose. They may be photographs, halftone or shaded sketches, or line drawings.

Cutaway View

A cutaway view is an illustration used to show some detail of construction that would be extremely difficult or impossible to show by conventional pictorial views. It is often used in connection with discussions of physical construction and the operation of mechanical devices. You will frequently find them in assembly diagrams and in construction details.

Location and Dimension

Location diagrams show physical position relationships, and they may or may not be sufficiently detailed to show physical appearance. They are primarily used for familiarization, and are commonly found in flight manuals or Naval Air Training and Operating Procedures Standardization (NATOPS) manuals. Location diagrams are also contained in the general information and servicing section of maintenance instruction manuals (MIMs), illustrated parts breakdown (IPB) manuals (fig. 7-1), and in the operation and maintenance instruction manuals for equipments.

Dimension diagrams show physical size and distance. They are useful in planning the layout of bench stations, making equipment installations, or packing materials for reshipment. They are frequently used in the general information sections of technical manuals and in those sections covering equipment familiarization, installation, and shipment. They are also found in change-type technical directives.

Sometimes, location and/or dimension diagrams are combined with other types of illustrations, giving additional details without increasing the number of illustrations.

Assembly Diagrams

Assembly diagrams, as the name implies, provide details of construction that you use to assemble parts into a unit. They are also used to explain the operating procedures of mechanical or electromechanical devices.

BLOCK DIAGRAMS

Block diagrams present a generalized explanation of overall functional operation. They do not show physical shape, size, or location. They range from the very simple to very complex, depending on the type of equipment, the quantity and quality of details, and the purpose of the information. Nearly all manuals that deal with basic or detailed operational theory contain block diagrams. The more complex the equipment, the more probable the need for block diagrams.

Manuals for many electromechanical devices, as well as electrical or mechanical systems, contain block diagram descriptions. By using this type of diagram, you can increase your understanding of functional relationships and operations.

Symbols

Since block diagrams provide a general analysis of functional operation, symbols represent individual circuits or functional components. To use block diagrams successfully, you must recognize the symbols and understand their meanings and limitations. Appendix II of this manual contains many of the common symbols found on block diagrams. As you read this chapter, you should refer to this appendix.

Signal Flow Diagram

One special type of block diagram is the signal flow diagram or signal flow chart. It is usually associated with overall operation of complicated systems, such as fire control computers, ASW systems, aircraft control or power distribution systems, or search or navigation radar systems. The signal flow diagram includes all features normally associated with block diagrams. In addition, it includes considerable detail on signal paths, signal wave shapes, timing sequences, and relationships and magnitudes of potentials, signals, and frequencies.

WIRING DIAGRAMS

The wiring diagram presents detailed circuitry information on electrical and electronics systems. A master wiring diagram is a single diagram that shows all the wiring in a complete system or in an aircraft. Usually, this diagram is too large to use. It is normally broken down into logical functional sections, each of which maybe further

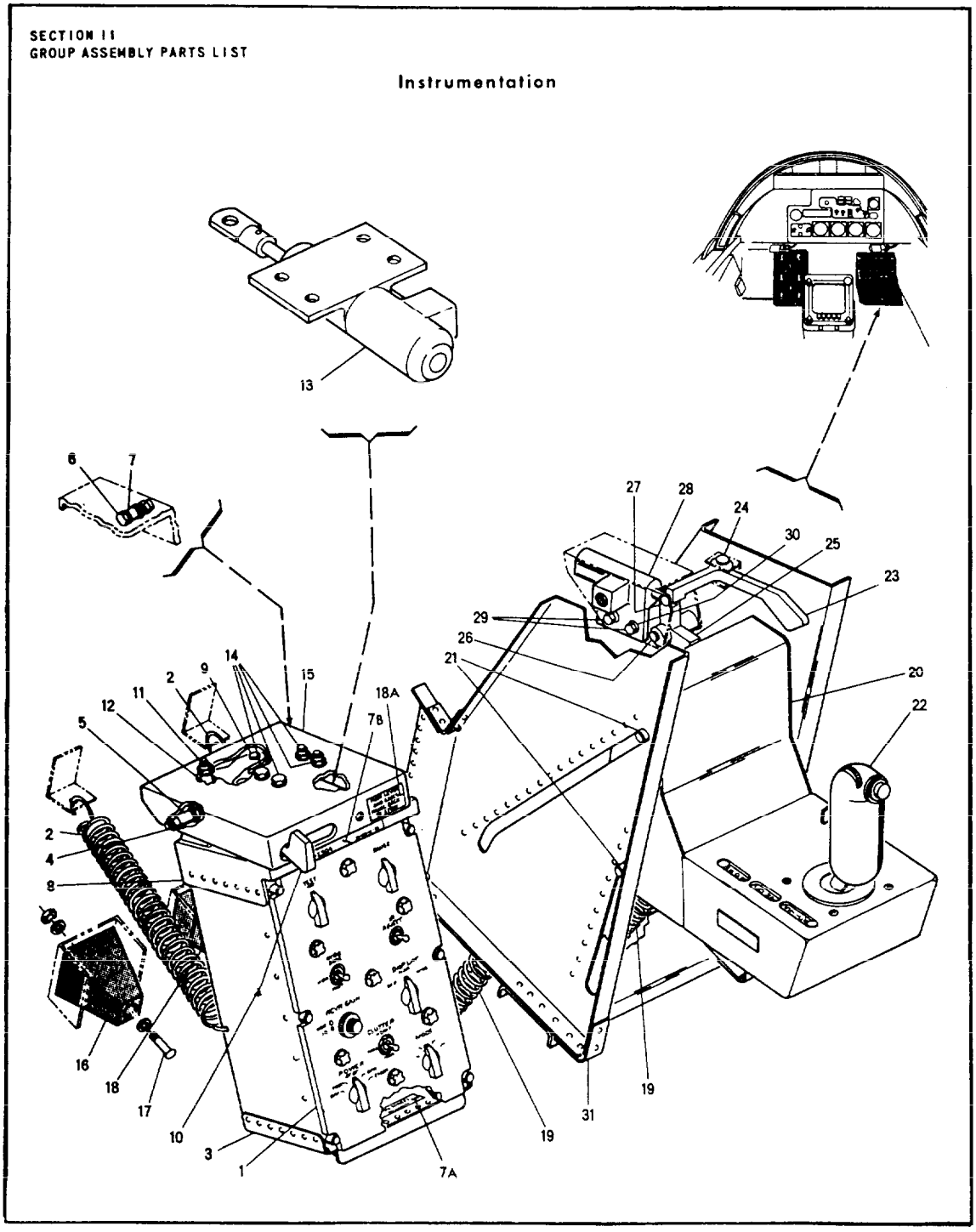


Figure 7-1.-IPB sample figure, radar control panal installation and stick assembly.

subdivided into circuit diagrams. When a diagram of a system is broken down into individual circuit diagrams, each circuit is presented in greater detail. The increased detail lets you trace, test, and maintain circuits more easily.

Wiring diagrams fall into two basic classes—chassis wiring and interconnecting diagrams. Each class has specific purposes and many variations in appearance (depending on application). Wiring diagrams are not normally used in discussions of the operational theory of specific circuits.

View A of figure 7-2 is an example of one type of chassis wiring diagram commonly used. This drawing shows the physical layout of the unit, and all component parts and interconnecting tie points. Each part has a reference designation number, thus enabling use of the IPB to determine values and other data. The values of resistors, capacitors, or other components are normally not on wiring diagrams. However, the polarity of semiconductor diodes and the polarized capacitor are on wiring diagrams. Also, the lead numbers for the transistor (Q101) in figure 7-2 are for convenience. Since this specific diagram

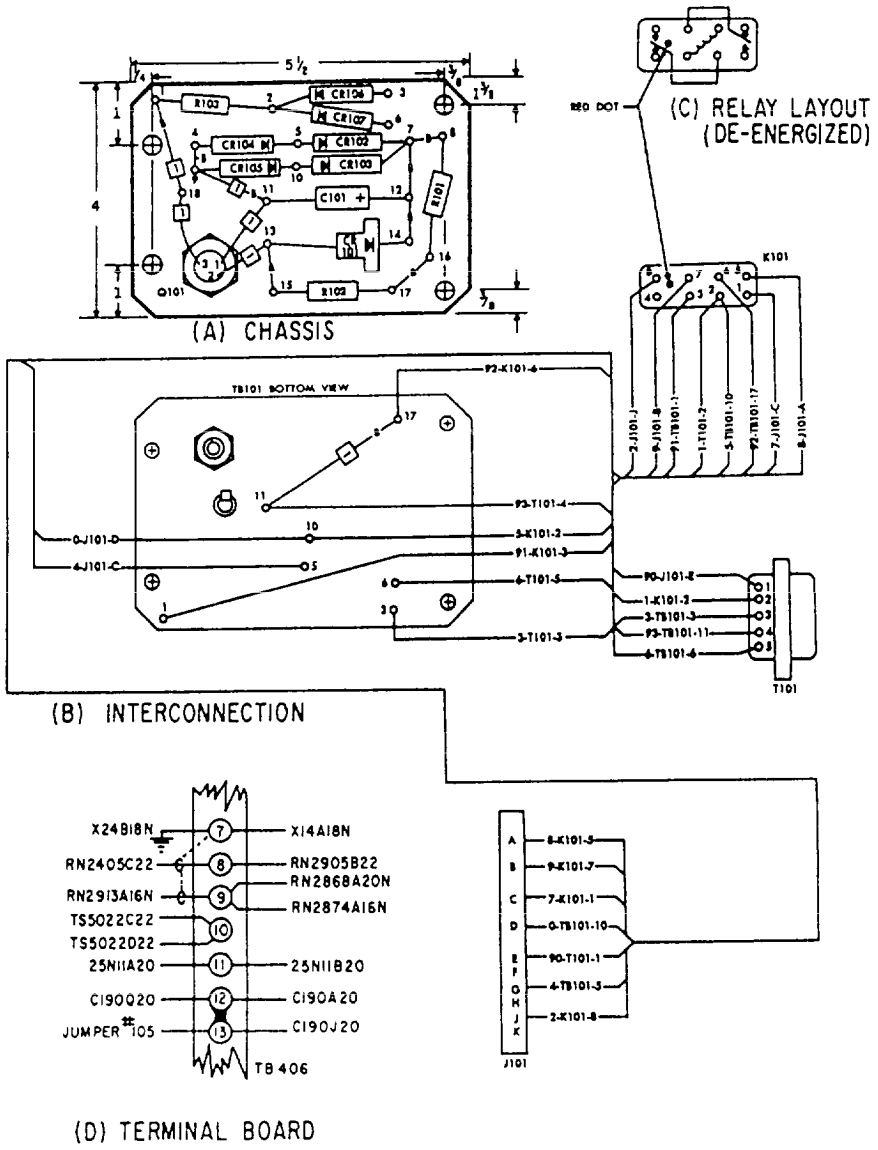


Figure 7-2.-Wiring diagrams. (A) Chassis wiring; (B) interconnection wiring; (C) sealed component parts layout; (D) terminal board connections.

shows physical layout and dimensional details for mounting holes, it could also function as an assembly drawing and an installation drawing.

View B of figure 7-2 shows the reverse side of the same mounting board. It also shows the wiring interconnections to other components. However, it does not show actual positioning of circuit components, and wire bundles are represented by single lines, with the separate wires entering at an angle.(The angle indicates the direction to follow in tracing the circuit to locate the other end of the wire.)

The wire identification coding on this diagram consists of a three-part designation. See figure 7-2, view B, (3-T101-3). The first part (3) is a number representing the color code of the wire according to military specification. (Many other chassis wiring diagrams designate color coding by abbreviations of the actual colors.) The second (T101) is the reference part designation number of the item to which the wire is connected. The last (3) is the designation of the specific terminal to which the wire connects.

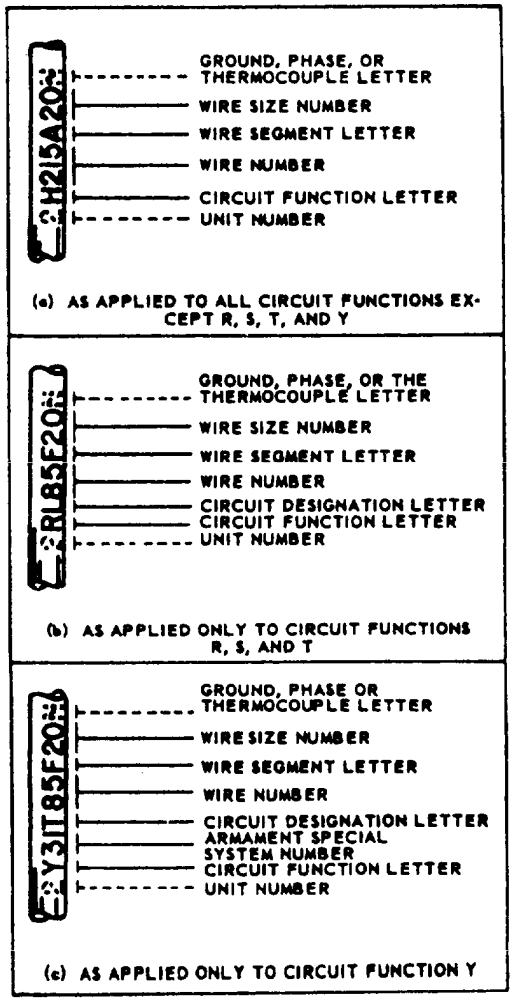


Figure 7-3.-Example of wire identification coding using circuit function letter coding.

View C of figure 7-2, while not a wiring diagram, illustrates a method commonly used to show some functional aspect of sealed or special components. View D of figure 7-2 shows several methods used to indicate connections at terminal strips.

Normally, wiring diagrams are the major content of the last volume of a MIM set, and the last section of most other maintenance manuals. This volume, or section, contains wiring diagrams for all electrical and electronic systems of the aircraft. The diagrams are prepared separately for each circuit and provide all data necessary for the following:

- To understand the construction of each circuit
- To trace each circuit within the system to make continuity and resistance checks
- To perform specific troubleshooting on inoperative or malfunctioning circuits

Aircraft Wire Identification Coding

To make maintenance easier, all aircraft wiring that appears on the wiring diagrams are exactly as marked in the aircraft. Identification of each wire is coded by a combination of letters and numbers imprinted on the wire at prescribed intervals along its entire run. Look at figure 7-3 as you read this section, which explains the codes used in aircraft wiring installation.

The unit number (shown in dashed outline) is only when there is more than one given unit installed in an identical manner in the same aircraft. The wiring concerned with the first such unit is labeled prefix 1. Corresponding wires for the second unit have exactly the same designation, except they carry prefix 2.

The circuit function letter identifies the basic function of the unit. Look at table 7-1. Note that circuit function R, S, and T wiring may bear a second letter to designate the functional breakdown of the circuit.

On new aircraft, the equipment identification code replaces the circuit function letters R, S, T, and Y. The equipment identification code is the part of the AN nomenclature following the diagonal (/), excluding the hyphen (-) and suffix letters. For example, wires of an AN/APS-115(V) unit will have an equipment identification code of APS115. Those of an AN/ARC-52A unit will use ARC52 (fig. 7-4), and those of an AN/MX-94 unit use MX94 as there equipment identification codes.

Each wire within a given circuit function group has a separate wire number. Wires that have segments of splices, plug and receptacle connectors, terminal strip tie points, etc., have a letter segment designation. Passage through a switch, relay, circuit breaker, etc., requires assignment of a new number.

Wire size numbers identify the size of the wire or cable, but are not on coaxial cables. Wire size numbers are replaced by a dash and coded designator when part of a thermocouple arrangement.

A suffix is added to designate the phase (or ground) in three-phase ac power wiring. A thermocouple has a suffix that denotes the metal element involved.

For further information on aircraft wiring codes, you should refer to *Installation Practices, Aircraft Electric and Electronic Wiring,* NAVAIR 01-1A-505.

Table 7-1.-Wiring Circuit Function Code

Circuit function letter	Circuits
A	Armament
B	Photographic
C	Control surface
D	Instrument
E	Engine instrument
F	Flight instrument
G	Landing gear
H	Heating, ventilating, and de-icing
J	Ignition
K	Engine control
L	Lighting
M	Miscellaneous
P	DC power Wiring in the dc power or power control system will be identified by the circuit function letter P.
Q	Fuel and oil
R	Radio (navigation and communication) RN—Navigation RP—Intercommunications RZ—Interphone, headphone
S	Radar SA—Altimeter SN—Navigation SQ—Track SR—Recorder SS—Search
T	Special electronic TE—Countermeasures TN—Navigation TR—Receivers TX—Television transmitters TZ—Computer
V	DC power and dc control wires for ac systems will be identified by the circuit function letter V.
W	Warning and emergency
X	AC power Wiring in the ac power system will be identified by the circuit function letter X.
Y	Armament special systems (except those listed under A)
Z	Experimental circuits (reserved for NATO, not for U.S. use)

Cable Construction

Cable construction diagrams present details about the fabrication and construction of cables. These details usually include designation of the type connectors or terminals, identification of wires for each terminal, and method of connecting wire to terminal. The details also include potting requirements, length of wires, lacing or sleeving specifications, and any other specifications or special considerations.

Cable Routing

Diagrams of major systems usually include an isometric shadow outline of the aircraft, showing the approximate location of equipment components and the physical routing of

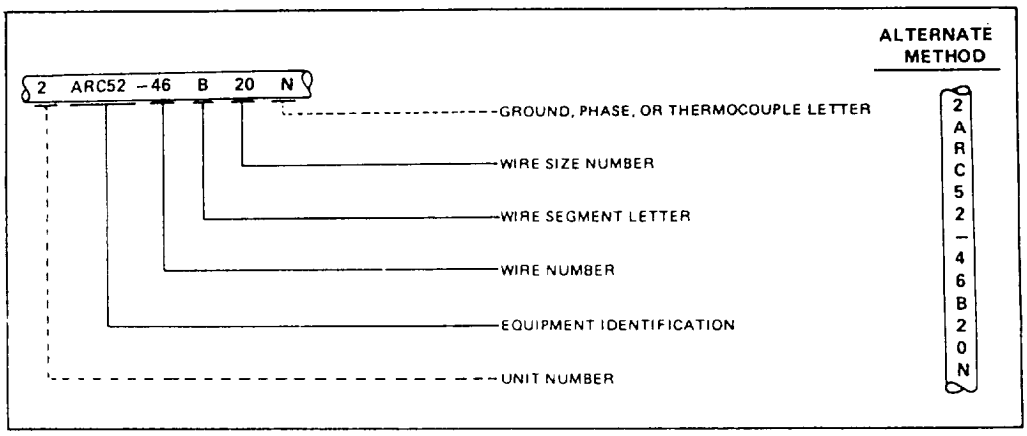


Figure 7-4.-Example of wire identification coding (circuit function letters R, S, T, and Y) using equipment identification coding.

interconnecting cables. A cable, regardless of the number of conductors, is represented by a single line on an isometric wiring diagram. No attempt is made to show individual connections at equipment units or in connection boxes. An isometric drawing shows, at a glance, a picture of the layout of the entire system.

SCHEMATIC DIAGRAMS

The major purpose of the schematic diagram is to show the electrical operation of a particular system. The system schematic is not drawn to scale, and the diagram shows none of the actual construction details of the system unless the construction details are essential to understanding circuit operation.

Schematic diagrams differ from block diagrams because they present more detail about each circuit. While the block diagram deals with functional units of the system, the schematic diagram shows each part that contributes to the functional operation of the circuit.

Simplified Schematic

In large or complex equipments, a complete schematic diagram may be too large for practical use. For this reason, most technical manuals present partial or simplified schematics for individual circuits or units.

Simplified schematic diagrams normally leave out parts and connections that are not essential to understanding circuit operation. In studying or troubleshooting equipment, you will frequently make and use simplified drawings. In these cases, you should include only those items that contribute to the purpose of the drawing, and you need to be careful to include **all** such items. Many techniques for simplifying schematics are presented in this TRAMAN, and you will see them as you read the course. Pay special attention to those techniques maintenance personnel find useful. They are important tools in your work.

Electromechanical Drawings

Electromechanical devices such as synchros, gyros, accelerometers, autotune systems, and analog computing elements are quite common in avionics systems. Neither an electrical drawing nor a mechanical drawing is adequate for a complete understanding of these units. You might be confused if you only use these two drawings. Therefore, you need to use a drawing that combines the two—using some aspects of each type. Electromechanical drawings are usually simplified both electrically and mechanically, and usually show only those items essential to the operation.

CHARTS AND TABLES

Charts and tables present factual data in a clear, concise form. Many types of charts and tables are used in all types of technical publications. In this discussion, a chart contains information in lists, pictures, tables, or diagrams. A table is one type of chart that presents or lists information in a very condensed form.

Tables are valuable when presenting the same general type of information about many items.

The list of details for the items maybe in columns. The columns are arranged so that by reading across them, you find details about a specific item, while reading down presents a comparison of items about a specific detail. One very common and useful table of this type is found in the IPB (fig. 7-5). For more detail about using information in publications and IPBs, you should refer to *Aviation Maintenance Rating Fundamentals,* NAVEDTRA 14022.

Q1. In what publication can you find more information about illustrations, drawings, and schematics?

Q2. Describe some uses for dimension diagrams.

Q3. *What type of diagram presents detailed circuitry information on electrical and electronic systems?*

Q4. List the two basic classes of wiring diagrams.

Q5. In what publication can you find more information on aircraft wire identification codes?

Q6. Describe the major purpose of a schematic diagram.

VOLUME, FIGURE & INDEX NO.	PART NUMBER	1 2 3 4 5 6 7 DESCRIPTION	UNITS PER ASS'Y	USABLE ON CODE
4-61-	32-87291-301	PANEL INSTALLATION, RADAR CONTROL (see figure 4-46-29 for next higher assembly)	Ref	14
	32-87291-1	PANEL INSTALLATION, RADAR CONTROL (see figure 4-46-29 for next higher assembly)	Ref	19 & up
-1	C-2452/APQ-72	. PANEL ASSEMBLY, RADAR SET CONTROL (GFAE) (see NAVWEPS 16-30APQ72-8 for bkdn)	1	14,19 & up
-2	32-87294-3	. SPRING, HELICAL, EXTENSION (when exhausted use 32-87294-5)	2	14,19-191
	32-87294-5	. SPRING, HELICAL, EXTENSION (suitable substitute for 32-87294-3)	2	14,19 & up
-3	32-87295-15	. FRAME ASSEMBLY, RADAR CONTROL PANEL (when exhausted use 32-87295-301)	1	14
	32-87295-301	. FRAME ASSEMBLY, RADAR CONTROL PANEL (suitable substitute for 32-87295-15)	1	14,19 & up
		(ATTACHING PARTS)		
		.		14,19-265
		.		266 & up
-4	AN3-12A	. BOLT, MACHINE	1	14,19-265
	NAS464P3A13	. BOLT, SHEAR	1	266 & up
	AN960D10	. WASHER, FLAT	1	14,19-265
	AN960D10	. WASHER, FLAT	1	
	AN36-01050	. WASHER, FLAT (Mfd by 76301)	2	
	AN36-01050	. WASHER, FLAT (Mfd by 76301)	1	266 & up
	NAS1197-616L	. WASHER, FLAT	6	
	NAS679A3	. NUT, SELF-LOCKING, HEXAGON	1	
-5	NAS72-3E007	. BUSHING, SLEEVE	1	
-6	AN3-12A	. BOLT, MACHINE	1	32-87295-15
	AN3-11A	. BOLT, MACHINE	1	32-87295-301
	AN960D10	. WASHER, FLAT	1	32-87295-15
	AN36-01050	. WASHER, FLAT (Mfd by 76301)	2	
	NAS1197-616L	. WASHER, FLAT	6	
	NAS1021C3	. NUT, SELF-LOCKING, HEXAGON	1	
-7	NAS72-3E007	. BUSHING, SLEEVE	1	
		----*----		
-7A	32-89110-78	. . PLATE, IDENTIFICATION (for reference designation 61-Z304)	1	48-95
-7B	32-89110-78	. . PLATE, IDENTIFICATION (for reference designation 61-Z304)	1	96 & up
-8	32-87317-1	. . FITTING ASSEMBLY, STRUCTURAL	1	32-87295-15
	32-87317-301	. . FITTING ASSEMBLY, STRUCTURAL	1	32-87295-301
	AN45-6-26	. . BUSHING, SLEEVE (Mfd by 76301)	2	
-9	AN393-15	. PIN, FLATHEAD	1	
	AN960D10L	. WASHER, FLAT	1	
	AN380-2-1	. PIN, COTTER	1	
-10	32-87061-301	. LEVER ASSEMBLY, RADAR CONTROL PANEL STOWAGE	1	18
	32-87061-7	. LEVER ASSEMBLY, RADAR CONTROL PANEL STOWAGE	1	19 & up
		(ATTACHING PARTS)		
-11	NAS1303-16W	. BOLT, MACHINE	1	
	AN36-01050	. WASHER, FLAT (Mfd by 76301)	1	
	AN960D10	. WASHER, FLAT	2	
	NAS1197-10L	. WASHER, FLAT	1	
	NAS679A3	. NUT, SELF-LOCKING, HEXAGON	1	
-12	NAS72-3E006	. BUSHING, SLEEVE	1	
		----*----		
	AN42786-31	. BOLT, MACHINE, SLEEVE (Mfd by 76301)	1	
-13	32-7236[illegible]	. WASHER, FLAT, RADAR CONTROL PANEL RELEASE PNEUM	2	
		. WASHER, FLAT	10	
		. NUT, SELF-LOCKING, HEXAGON	4	
		----*----		
-15	32-87312-5	. SUPPORT ASSEMBLY, RADAR CONTROL PANEL	1	14
	32-87312-1	. SUPPORT ASSEMBLY, RADAR CONTROL PANEL	1	19 & up
-16	32-87330-3	. BUMPER, RADAR CONTROL PANEL	1	14,19-96
		(ATTACHING PARTS)		
-17	AN23-18	. BOLT, CLEVIS	1	
	AN960D10L	. WASHER, FLAT	1	
	AN960D10	. WASHER, FLAT	1	
	AN310-3	. NUT	1	
	AN[illegible]	. PIN, COTTER	1	
		----*----		
		BUMPER, RADAR CONTROL PANEL	1	14

Figure 7-5.-IPB sample.

HANDTOOLS

Learning Objective: *Identify common handtools used in avionics maintenance, including their proper operation and care.*

Tools are a costly investment. Therefore, you need to take care of them and use then correctly. There is something about a good tool that helps the technician turn out good work. This fact more than justifies the slightly higher cost of quality tools. Even more important, low quality tools become defective sooner, and can result in injury to the user or damage to the equipment. In the same manner, by properly using quality materials, the quality of any maintenance task is improved and chances of new failures are reduced.

In this TRAMAN, the term *handtools* refers to small, portable or fixed-power tools, as well as those normally classified as nonpowered handtools. Handtools are tools commonly available in electronics maintenance shops or used by electronics maintenance personnel during work on aircraft.

SAFETY, USE, AND CARE OF HANDTOOLS

Carelessness is the greatest menace in any shop. It comes from the technician; the machine alone cannot inflict injury. Lack of care causes most of the accidents in electrical and electronics shops today. **Remember, all moving machinery is potentially dangerous!** Do not lean against any machine that is in motion, or that may be started in motion by anyone else. Treat a machine with respect and there is no need to fear it. Do not start a machine until you know how it operates and understand the safety precautions you are to follow.

Information about accident prevention is contained in chapter 9 of this TRAMAN. You should refer to it frequently. Other sources of information on the use and care of handtools can be found in *Airman,* NAVEDTRA 14014, and *Tools and Their Uses,* NAVEDTRA 14256. Since these manuals are basic to all aviation ratings, the material they cover is not contained here. If you have not done so, you should review this material before proceeding with this manual.

The safe use of tools cannot be overemphasized. The following two safety precautions are basic to most situations when using tools:

1. Use the proper tool for its designed function, and use it in the proper manner.
2. Maintain all tools in proper working order and in a safe condition. Sharpen or replace dull cutting tools. Replace broken or defective tools. Protect tools from damage while in use or storage.

When you use tools and/or materials, arrange them so you can reach them easily, and so they won't interfere with your work. This arrangement increases efficiency as well as safety.

You should inventory tools before starting a job. After completing a job, you should clean and inspect the tools. Next, inventory the tools again. Finally, return the tools to their proper storage place. If any tool is missing, you must report it immediately to maintenance control. Refer to OPAVINST 4790.2 (series) and your local procedures for specific procedures and guidance.

GENERAL TOOL PROCEDURES

The basic manuals provide a lot of information about commonly used general tools. In this section, you will read about procedures you should or should not follow.

You should never use a center punch on extremely hard metals, or use it to remove bolts by force. If you do, you will dull the point. **Never** use a pin punch as a starting punch; a hard blow may cause the slim shank to break. **Always** use the largest starting and pin punch that will fit the hole. When using punches, do not strike a glancing blow because the punch may break, and broken pin punches are difficult to remove.

Do not hammer on a screwdriver. If an obstruction is in the slot, apply a driving force with the heel of the hand or remove the obstruction with a file. **Never** use a screwdriver as a pry bar, lever, or chisel. **Do not** use pliers or wrenches on a screwdriver to increase torque.

When using a grinding wheel, make sure that the guard is in place. If you must use the wheel with the guard removed, stand to one side to avoid flying particles of emery or metal. **Use** safety goggles when using a grinding wheel to grind screwdriver blades or any metal object. **Use** the

rest stand when possible, but ensure that the rest is close to the grinding wheel.

WARNING

NEVER use the grinding wheel on nonferrous metals. When used with this type of material, the grinding wheel could, in effect, explode. This could result in serious injury to or death of personnel.

When drilling, you should **never** use your hand to hold the work being drilled. **Use** a vise or a clamp. The same idea applies when you are soldering, filing, or sawing.

You should **always** use the right type of screwdriver. If you use a Reed and Prince screwdriver on Phillips head screws (or vice versa), you may ruin the tool. Also, using the wrong screwdriver may round out the screwhead, making it difficult to remove the screw. **Do not** use the screwdrivers interchangeably. In general, Reed and Prince screws are used for airframe structural applications, while Phillips screws are usually used in component assemblies.

Figure 7-6 shows the difference between the two screwdrivers. The Phillips screwdriver has flukes that are about 30 degrees with a blunt end. However, the Reed and Prince has 45-degree flukes and a sharper, pointed end. The Phillips screw has beveled walls between the slots, while the Reed and Prince has straight, pointed walls.

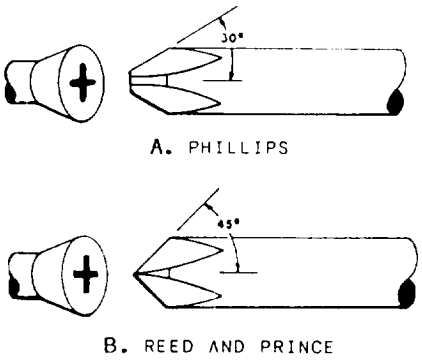


Figure 7-6.-Matching cross-slot screws and drivers.

In addition, the Phillips screw is not as deep as the Reed and Prince.

Use the following methods to identify the right screwdriver for the job.

- If the screwdriver stands up unassisted when the point is put in the head of a vertical screw, it is probably the proper one.
- The outline of the end of a Reed and Prince screwdriver is approximately a right angle, as seen in figure 7-6.
- The best way is to know the descriptions of both types.

ANSWERS FOR REVIEW QUESTIONS Q1. THROUGH Q6.

A1. Blueprint Reading and Sketching, NA VEDTRA 14040, and NEETS module 4.

A2. Dimension diagrams are useful in layout of bench stations, making equipment installations, or packing materials and equipment for reshipment.

A3. A wiring diagram.

A4. Chassis wiring and interconnecting diagrams.

A5. Installation Practices, Aircraft Electric and Electronic Wiring NAVAIR 01-IA-505.

A6. The major purpose of a schematic diagram is to show the electrical operation of a particular system.

Remember, if you use the right tool, you will save time and avoid trouble.

Q7. What training manuals contain information on handtools, their use, and care?

SPECIAL TOOLS

Learning Objective: *Identify specialized tools used by AT personnel to include proper use and purpose.*

The manufacturers of aircraft, engines, and related equipment furnish a wide variety of special tools. These tools are listed in special allowance lists. Their use is explained in the maintenance or service instructions manuals covering the specific aircraft, engine, or item of equipment for which they were designed. Other tools are peculiar to the maintenance of electronic equipment. Although the following discussion is not complete, it represents some of the special tools most commonly used in aircraft electronics maintenance work.

NONMAGNETIC TOOLS

Tools made of nonmagnetic materials are available through normal supply channels. They are primarily used when performing specific maintenance functions on certain classes of equipment or components. These tools are expensive tools. They are normally made of beryllium-copper or plastic, and they are not as rugged as steel tools, and are more easily damaged. If you use them for their intended purpose, you will prolong their useful life and increase their usefulness. In addition to possible damage of the tool itself, improper use of these tools could allow them to transfer foreign particles to locations where they could cause problems. In either case, the results could be of considerable inconvenience to you. Some of the general uses of nonmagnetic tools are described in the following paragraphs.

Always use nonmagnetic tools near magnetrons and other components containing permanent magnets. Magnetic tools may attract with enough force to cause damage to the magnet or injury to the technician. The tool could also become magnetized and transfer this magnetic condition.

Also, use nonmagnetic tools in tuning RF circuits, which are susceptible to frequency changes resulting from the introduction of new magnetic fields (or the distortion of the existing magnetic fields). Many RF circuits are slug tuned to avoid this potential trouble.

A good general maintenance practice to follow is to wipe the tools before and after use. This is especially true for nonmagnetic tools. Use a lint-free cloth, dampened with a suitable cleaning solvent for this purpose.

INSULATED TOOLS

Safety considerations require you to use insulated tools whenever the danger of electrical shock or short circuit exists. Many types of insulated tools are available directly through supply channels. You should obtain these tools and use them whenever available. However, many types of insulated tools are not readily available (or are available only at considerable added expense). If essential, procure these tools or modify conventional tools. Insulated sleeving may be put on the handles of pliers and wrenches and on the shanks of screwdrivers. Use tools modified in this manner for low-voltage circuits only because of the limitations of the insulating materials. For use on higher voltages, special insulating handles are available for many of the common types of tools.

At times, you will need to use tools that are made of insulating material, rather than just having an insulating handle. In these instances, you should requisition the tools through normal supply channels.

TORQUE WRENCHES

Sometimes, for engineering reasons, a specific torque must be applied to a nut or bolt head. In such cases, you must use a torque wrench. The torque wrench is a precision tool, consisting of a torque-indicating unit and an appropriate adapter or attachments. It measures the amount of turning or twisting force you are applying to a nut, bolt, or screw.

The three most commonly used torque wrenches are the deflecting-beam, dial-indicating, and micrometer-setting types (fig. 7-7). When using deflecting-beam and dial-indicating torque wrenches, you read the torque visually from a dial or scale mounted on the handle of the wrench.

The most accurate and reliable torque wrench is the micrometer-setting type. The next most accurate and reliable is the dial-indicating type. The least accurate and reliable is the deflecting-beam type. You should not use the deflecting-beam type (because of the high probability of operator error) unless it is absolutely necessary.

To use the micrometer-setting torque wrench, unlock the grip and adjust the handle to the desired setting on the micrometer-type scale, and then relock the grip. Install the required socket or adapter to the square drive of the handle. Place the wrench assembly on the nut or bolt and pull in a clockwise direction with a smooth, steady motion. (A fast or jerky motion results in an improperly torqued unit.) When the applied torque reaches the torque value indicated on the handle setting, the handle automatically releases or "breaks" and moves freely for a short distance. The release and free travel is easy to feel, so there is no doubt when the torquing process is complete.

To make sure the correct amount of torque is gotten on fasteners, all torque handles require periodic testing under the metrology program.

You should take the following precautions when using torque wrenches.

- Always ensure proper calibration.
- Do not use the torque wrench as a hammer.
- When using the micrometer-setting type, do not move the setting handle below the lowest torque setting. However, you should place it at its lowest setting before returning it to storage.
- Do not use the torque wrench to apply greater amounts of torque than its rated capacity.

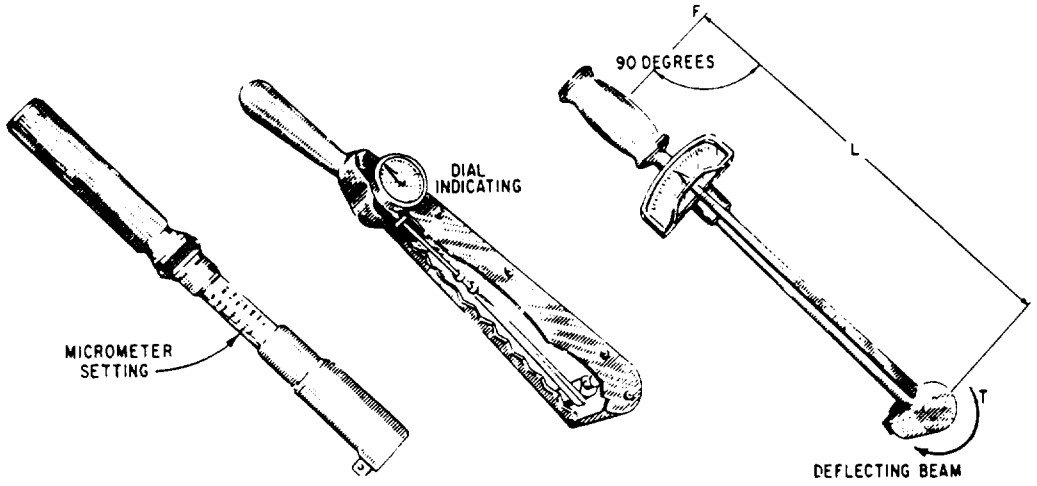


Figure 7-7.-Torque wrenches.

ANSWER FOR REVIEW QUESTION Q7.

A7. TRAMAN, NAVEDTRA 12000, and Tools and Their Uses, NAVEDTRA 14256.

- Do not use the torque wrench to break loose bolts.
- Never store a torque wrench in a toolbox or in an area that may cause damage to it.
- Do not drop the wrench because it will affect its accuracy.

RELAY TOOLS

You may damage or ruin relay tools if you use sandpaper or emery cloth to clean the contact points. Use of abrasives as a cleaner causes the cent acts to bend. Trying to straighten them with long-nose pliers causes further damage, eventually requiring replacement of the relays. You can avoid the whole problem by using a burnishing tool to clean dirty contact points. Figure 7-8, view A, shows the use of a burnishing tool on a relay. Burnishing tools are available through normal supply channels. Before using this tool, you should clean it thoroughly with alcohol; do not touch the tool surface with your fingers before use. Burnishing burned and pitted contacts will not repair them. You must replace burned and pitted contacts.

Another tool useful in relay maintenance is a point bender (fig. 7-8, view B). It can help to straighten bent relay contacts. You can make this tool locally using a 0.12-inch diameter rod stock, shaping it as shown in figure 7-8.

WIRE AND CABLE TOOLS

An innovation in electrical connectors is the taper pin electrical connector for aircraft. The taper pin works on the principle of driving a taper wedge into a tapered hole, and depends on friction to keep the pin in the hole. The taper pin connector makes a very good electrical and mechanical connection because of the high metal-to- metal contact pressure developed during the driving action of the insertion tool. Taper pins let you make circuit changes quickly and easily without using a soldering iron. Tests show that vibration and corrosion over time can improve the electrical continuity and increase the mechanical pulling force required to remove a taper pin. Another advantage of taper pins is the accessibility of test points for voltage and circuit continuity checks.

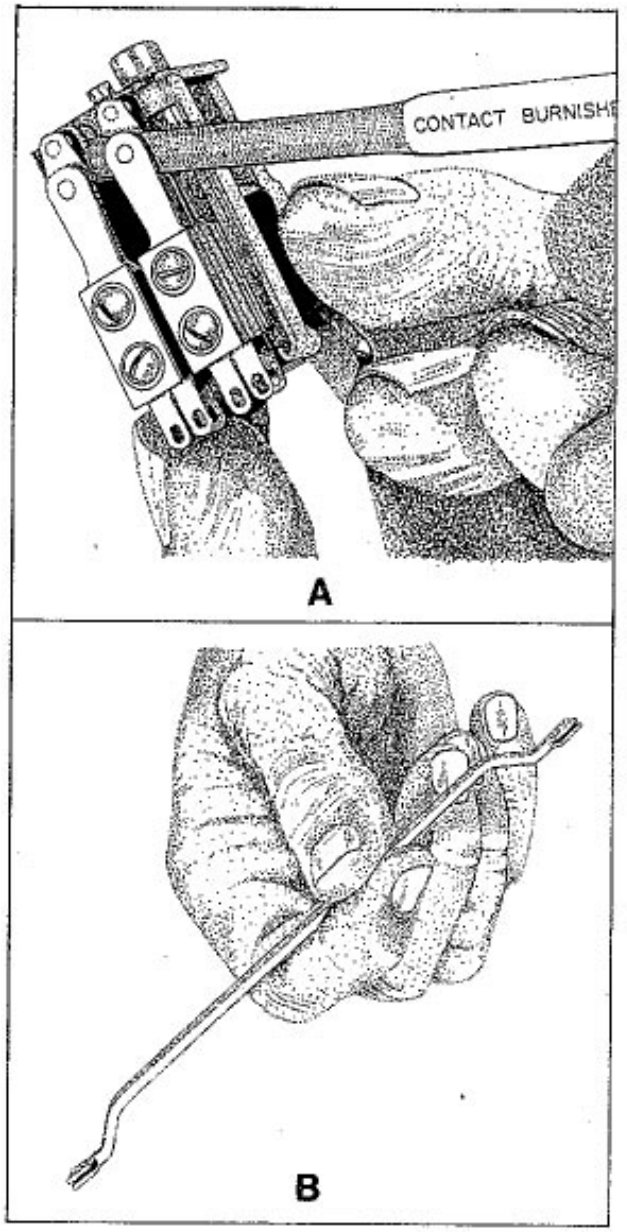


Figure 7-8.-View A, burnishing tool; view B, point bender.

You use a special tool (fig. 7-9) to properly insert the taper pin into a terminal block socket. Internally, the insertion tool has a calibrated driving spring, a calibrated pull test spring, and a taper pin captive key.

The driving spring adjusts to apply the proper driving impact to the pin. The pull test spring adjusts to apply the correct pull force on the pin to check for proper pin insertion. The captive key ensures that each taper pin has a 100-percent pull test before removing the tool from the pin. You need to rotate the removal lever to remove the taper pin from the terminal block socket,

It is important that you properly insert the taper pin into the terminal block sockets. By doing this, you maintain the reliability of the system. Pushing the pins into the sockets with your fingers or pliers will not make them stay. You must drive them in with the insertion tool. The tool must be calibrated for you to apply the proper pressure. When inserting the taper pins, hold the insertion tool at right angles to the terminal block. Then, push it straight toward the terminal block, without twisting the tool. (The pins are very sensitive to twists, which could cause a faulty connection or a broken pin.) By installing the pin correctly, you can install and remove a taper pin as many as 25 times before you must replace it. If you properly install the taper pin, it will pass the pull test of the insertion tool. Always replace bent or broken pins.

Three different sizes of taper pins are used to terminate wires from size 16 through size 22. The sizes are identified by color coding-the insulating sleeves. A crimping tool is used to attach the taper pin to the wire. The taper pin crimping tool is similar to other wire terminal crimping tools.

DIAGONAL PLIERS

Diagonal pliers are described briefly in *Tools and Their Uses,* NAVEDTRA 14256. The following discussion describes a modification to diagonal pliers when they are used to maintain equipment aboard aircraft.

The diagonal pliers (fig. 7-10, view A) have been modified by adding potting compound to the jaws. This prevents loss of small pieces of wire into the equipment when you are cutting wire. The potting compound also lets you cut the wire without holding onto the piece being cut away. (Figure 7-10, view B, shows the diagonals before modification.) If you do not have a pair of these modified diagonal pliers, make your own by adding potting compound. Before applying the potting compound, clean the diagonals with solvent; then secure the handles with a rubber band (fig. 7-10, view C), and apply the compound. Let the compound dry for 24 hours. You can seperate the jaws by slicing them apart with a single-edged razor blade.

SAFETY WIRING PLIERS

When you install equipment in aircraft, it is necessary to lockwire (usually referred to as safety wire) certain parts of the installation. You can lockwire parts faster and more neatly by using special pliers. **Use these pliers with extreme care.**

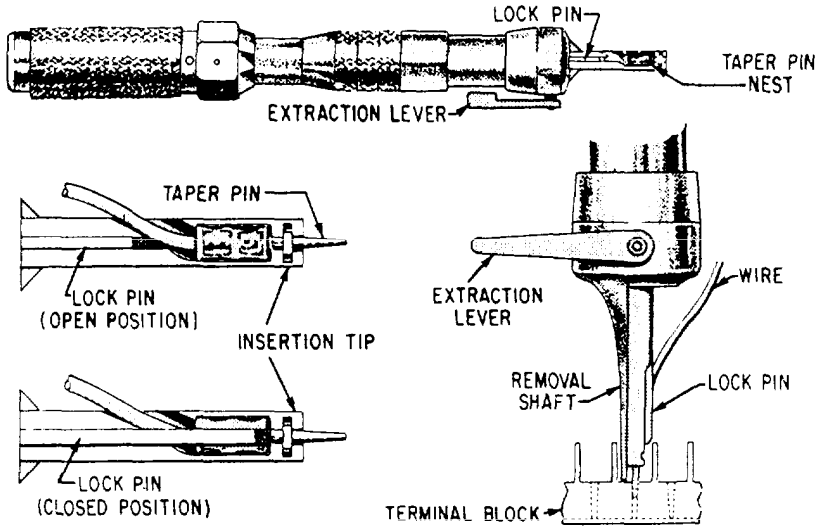


Figure 7-9.-Taper pin insertion and removal tool.

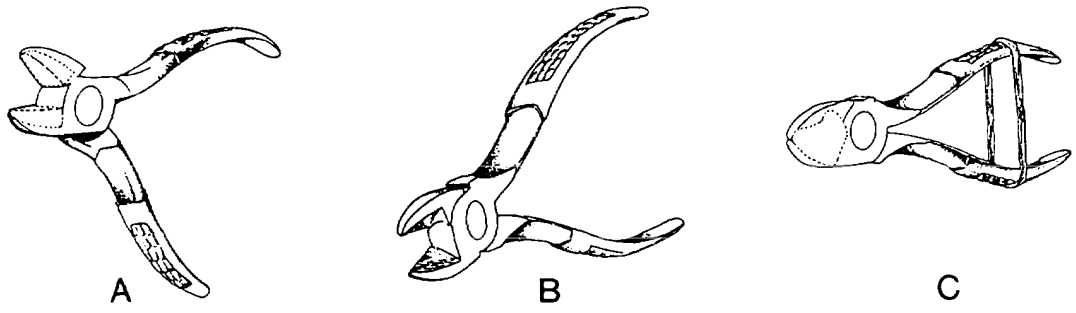


Figure 7-10.-Diagonal pliers. View A, compound; View B, without compound; View C, apply compound.

The wire must be installed snugly, but not so tight that any part of the wire is overstressed. The appropriate MIM normally prescribes the proper routing of the twisted wire for the particular installation.

Safety wiring pliers (wire twister) (fig. 7-11) are three-way pliers that hold, twist, and cut. They reduce the time used in twisting safety wire on nuts and bolts. To use them, grip the wire between the two diagonal jaws, and the thumb will bring the locking sleeve into place. A pull on the knob twirls the twister, making uniform twists in the wire. You may push the spiral rod back into the twister without unlocking it, which lets you pull on the knob again and gives a tighter twist to the wire. Squeezing the handle unlocks the twister, and the wire can be cut to the desired length with the side cutter. You should occasionally lubricate the spiral of the twister.

WIRE AND CABLE STRIPPERS

Nearly all wire and cable used as electrical conductors have some type of insulation cover. To make electrical connections with the wire, you must remove a part of this insulation, leaving the end of the wire bare. You should use a wire and cable stripping tool similar to the one shown in figure 7-12 when stripping electrical cable.

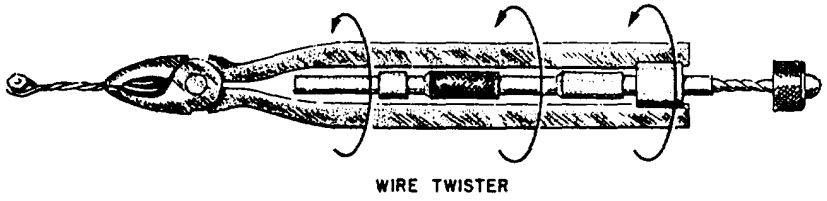


Figure 7-11.-Safety wiring pliers.

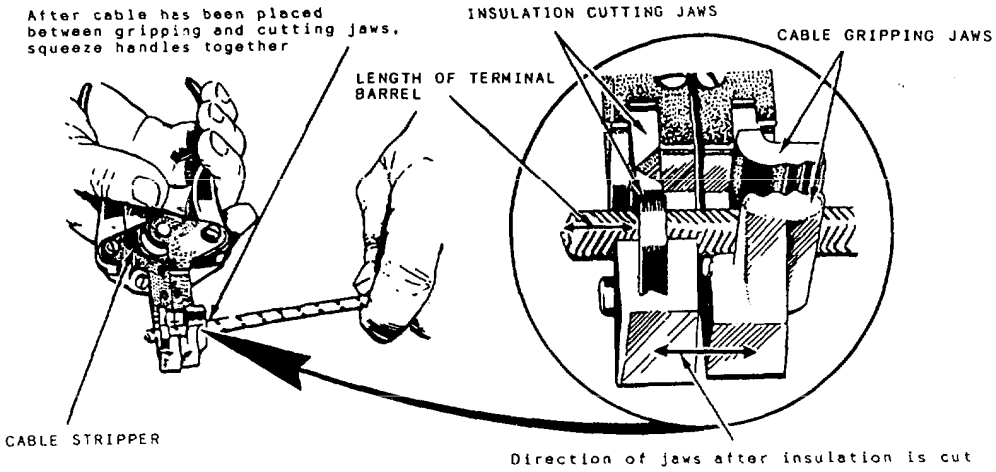


Figure 7-12.-Wire and cable stripper.

Although several variations of this basic tool are available, the most efficient and effective type is shown in figure 7-12. Its operation is extremely simple: You insert the end of the wire in the proper direction to the depth you need stripped. Position the wire so it rests in the proper groove for that size wire and squeeze. The tool functions in three steps as follows:

1. The cable gripping jaws close, clamping the insulated wire firmly in place. You must insert the wire so the jaws clamp the main section of the wire rather than the end to be stripped.

2. The insulation cutting jaws close, cutting the insulation. If the wire is not inserted in a groove, the conductor will also be cut. If the wire is positioned onto too small a groove, you may cut some of the strands. If the groove is too large, the insulation will not be completely cut. Inserted into the correct groove, the insulation will be cut neatly and completely, and the wire will not be damaged.

3. The two sets of jaws separate, removing the clipped insulation from the end of the wire.

CRIMPING TOOLS

The two types of crimping tools described in this section are the MS 25037-1 and the MS 3191-3.

Type MS 25037-1

The standard tool issued for crimping solderless terminals is MS 25037-1. It is used with standard insulated copper terminal lugs manufactured according to MS 25036. The standard tool uses a double jaw to hold the terminal lug or splice. One side of the jaw applies crimping action to fasten the terminal to the bare wire when inserting the terminal, as shown in figure 7-13, view A. When using the tool correctly, a deep crimp is made in the B area of terminal lugs and splices (fig. 7-13, view C). This also makes a shallow crimp to the portion of the terminal or splice that extends over the insulation of the wire (fig. 7-13. view C, area A). This clamping action comes from a recessed portion in the other side of the divided jaw. A guard, which should be in the position shown when crimping terminals, helps to properly position the terminal. However, the guard must be moved out of the way when using the tool for crimping splices.

The MS 25037-1 tool should be checked occasionally. A No. 36 (0.106) drill rod should **not** be able to enter the smaller (red or blue) nest when the tool is fully closed. If it does enter, have the tool repaired.

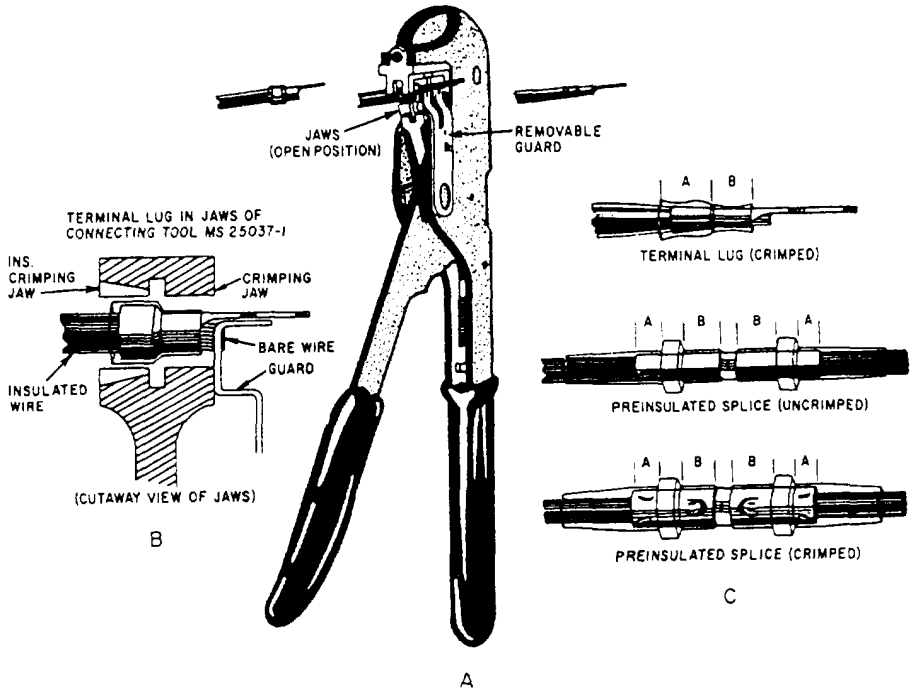


Figure 7-13.-Crimping tool MS 25037-1.

Instruction in the proper crimping procedure should be given to all who need to make solderless terminal connections. *Installation Practices, Aircraft Electric and Electronic Wiring,* NAVAIR 01-1A-505, contains detailed procedures for using many solderless connector tools.

Type MS 3191-3

MS 3191-3 is the latest standard crimping tool designed specifically for use with MS 3191 contacts for electrical connectors. It features interchangeable heads that fit various size terminals. You may use it with the turret (fig. 7-14, view A) for normal use or without the turret (fig. 7-14, view B) for eyeball crimping (when material alignment does not allow use of the turret).

Before you use the tool, you must select the correct position on the positioner head and also on the indentor gap selector plate. To release the turret for indexing, press the trigger and the spring-loaded turret snaps out to its indexing position. Select the desired position from the color-coded nameplate, and rotate the turret to align the selected positioner with the index. Depress the turret until flush, and it automatically locks into place. To prevent further indexing, insert the lockwire through the hole in the trigger.

To crimp a terminal, select the proper size and type terminal. Insert the prepared wire into the contact pocket until the wire seats on the bottom. The wire should be visible through the inspection hole, and the insulation should enter the contact insulation support. Then, insert the contact and wire into the terminal crimping tool, making sure that the contact seats properly in the positioner. Close the crimping tool handles to crimp the contact and wire. At the completion of the stroke, the ratchet releases, and you can open the handles and remove the crimped contact from the tool.

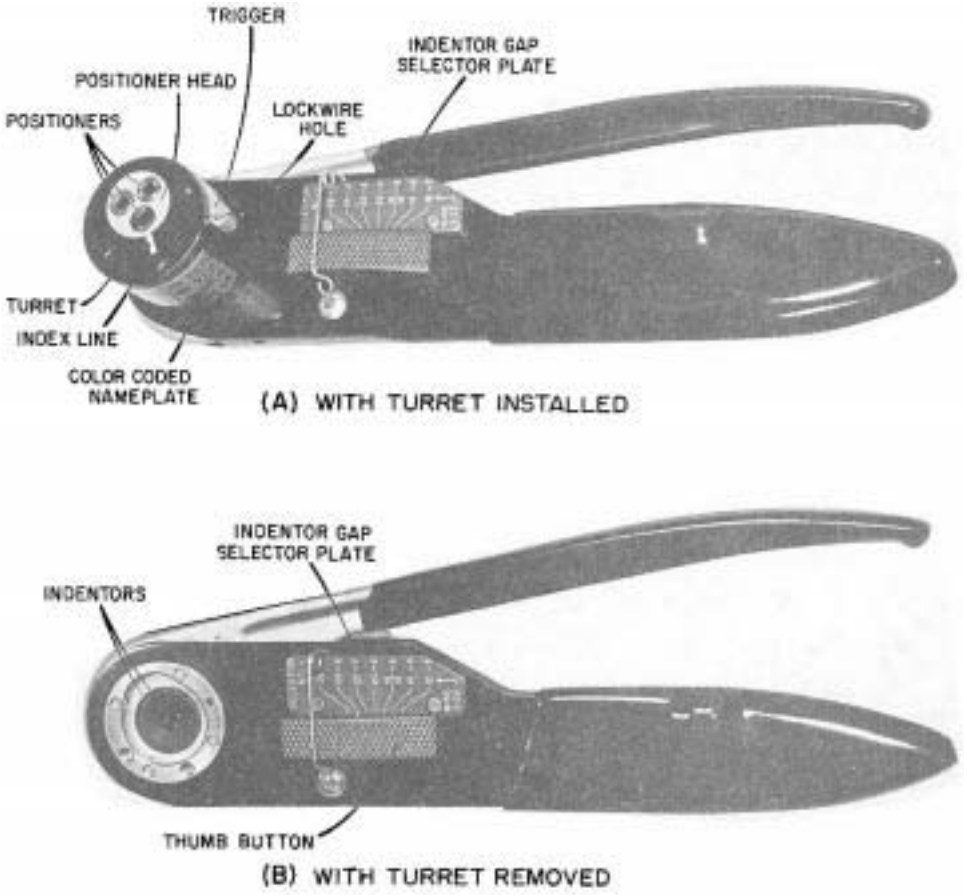


Figure 7-14.-Crimping tool MS 3191-3.

Inspect the crimped terminal and wire. The wire must be visible through the inspection hole. The insulation must be inside the insulation support. The crimping indents must be positioned between the inspection hole and the front of the insulation support. The contact must not bend. The crimped contact is now ready to be installed into a connector.

For eyeball crimping, remove the head assembly from the tool. Select the proper wire size and move the thumb button until the pointer aligns with the selected wire size on the indentor gap selector plate. Holding the contact in the crimping tool, slowly close the handles. At the same time, position the contact so the indenters are positioned midway on the contact barrel. Insert the wire, making sure it bottoms in the contact, and then close the handles fully. After releasing the handles, remove and inspect the crimped contact. The contact must not be fractured, and the conductor must be visible in the inspection hole.

SOLDERING GUNS, IRONS, AND TIPS

The soldering tools for aviation maintenance activities come in many sizes and models. They may be of the gun type or of the common iron type. Soldering irons come in a wide range of wattage ratings and may operate on 28 volts dc or 115 volts ac.

The soldering iron most commonly used in avionics maintenance is the pencil soldering iron (fig. 7-15). You should use this tool and its special tips when the applied heat must remain low. These operations include all cases involving transistors, printed circuit repair, miniaturized components, and so forth.

Because of its rapid heating and cooling, the soldering gun has gained great popularity in recent years. It is especially useful when maintaining and troubleshooting work where only a small part of your time is spent actually soldering. A continuously hot iron oxidizes rapidly and is difficult to keep clean.

A transformer in the gun supplies about 1 volt at high current to a loop of copper that serves as the tip. It heats to soldering temperature in 3 to 5 seconds, and it will heat to as high as 1,000°F if left on longer than 30 seconds. Because it operates for short periods, very little oxidation occurs. Thus, it is one of the easiest soldering tools to keep well tinned. (Tinned refers to the tin alloy protective coating on soldering tips.) However, this tip is pure copper with no plating, so pitting occurs easily. Offsetting this disadvantage, however, is the low cost of replacement tips. You should NEVER use a soldering gun when working on solid-state equipment. Serious damage to diodes, transistors, and other solid-state components can result from the strong electromagnetic field surrounding the tip of the soldering gun.

To get the best results from a soldering gun or iron, keep the tip free of oxide and scale. Most technicians wipe the tip on a cloth, and then file and retin as necessary.

A faster way to clean the tip is the *damp sponge* method. Keep a dampened cellulose sponge in a container, such as a soap dish or metal ashtray. (The sponge is more effective than the cloth in keeping the tip clean, and it presents no safety problems.) The damp sponge prevents splattering that sometimes occurs when wiping the heated tips off in the usual way. It will also absorb particles that can injure your face. The sponge

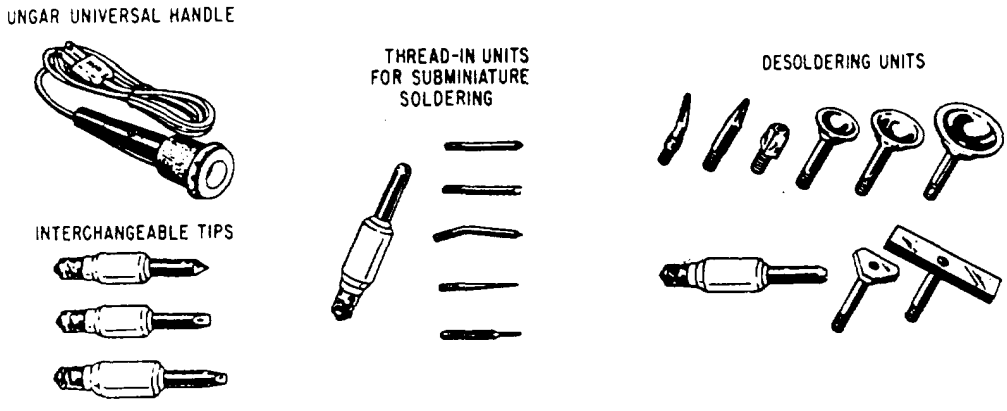


Figure 7-15.-Pencil iron with special tips.

eliminates oxide and scale, which keeps filing and retinning to a minimum.

A time-controlled resistance soldering set (fig. 7-16) is especially useful for soldering cables of-AN plugs and similar connectors, even the smallest types. The set consists of a transformer that supplies 3 or 6 volts at high current to stainless steel or carbon tips. The transformer is turned ON by a foot switch and OFF by an electronic timer. You can adjust the timer for as long as 3 seconds of soldering time.

When in use, adjust the double-tip probes of the soldering unit to straddle the connector cup to be soldered. One pulse of current heats it for tinning and, after inserting the wire, a second pulse of current completes the job. Since the soldering tips are hot only during the brief period of actual soldering, your chances of burning the wire insulation and melting connector inserts are less.

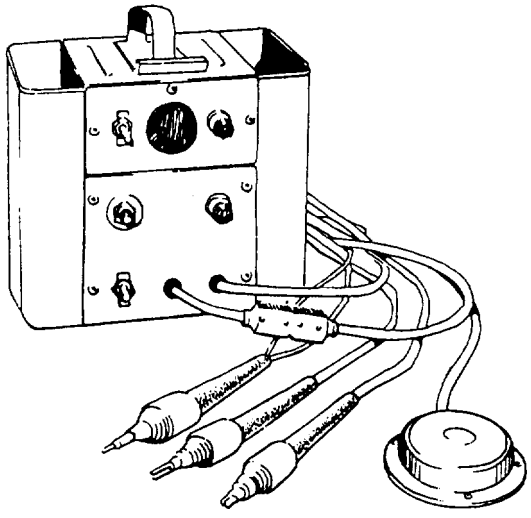


Figure 7-16.-Resistance soldering unit.

MECHANICAL FINGERS

You use mechanical fingers to reach and retrieve small articles that fall into places you can't reach. This tool can be used to start nuts or bolts in difficult areas. Mechanical fingers (fig. 7-17) have a tube containing flat springs that extend from the end of the tube to form clawlike fingers, much like the screw holder of a screwdriver. The springs are attached to a rod that extends from the outer end of the tube. A plate is attached to the end of the tube, and a similar plate is attached to the end of the rod. A coil spring placed around the rod between the two plates holds them apart and retracts the fingers into the tube.

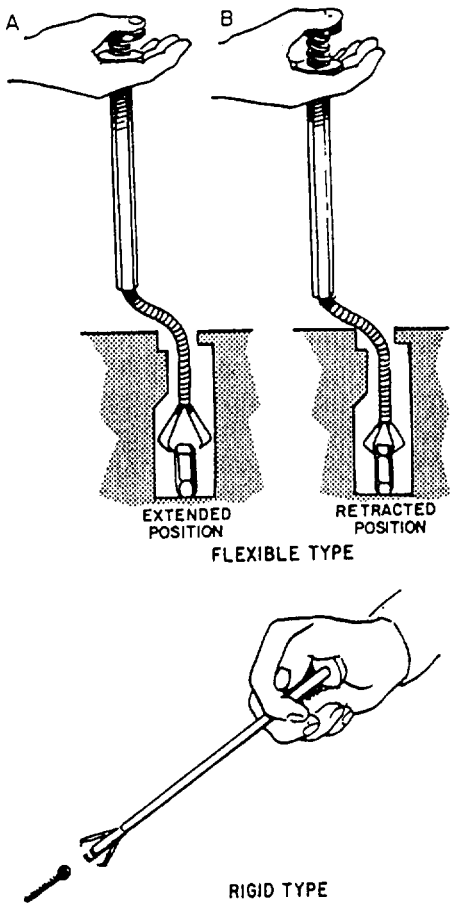


Figure 7-17.-Mechanical fingers.

When you grasp the bottom plate between your fingers, and you apply enough thumb pressure to the top plate to compress the spring, the tool fingers will extend from the tube in a grasping position. See figure 7-17, view A. When you release the thumb pressure, the tool fingers retract into the tube as far as the object they hold will allow. There is enough pressure on the object to hold it securely. Some mechanical fingers have a flexible end on the tube to let you use them in close quarters or around obstructions.

NOTE: You should not use mechanical fingers as a substitute for wrenches or pliers. The fingers are made of thin sheet metal and are easily damaged by overloading.

STEEL SCALE

The steel scale (fig. 7-18) is a measuring device most technicians keep in their toolbox. It has graduated divisions of one-eighth and one-sixteenth inch on one side and one thirty-second and one sixty-fourth inch on the other side. The steel scale most commonly used is 12 inches long. You should take measurements with the steel scale by holding it on its edge on the surface of the object you want to measure. This will prevent you from making errors that might be caused by the thickness of the scale. Such thickness causes the graduations to be a slight distance away from the surface of the object. Read measurements at the graduation that coincides with the distance you are measuring.

FLASHLIGHT

Your toolbox should contain a standard Navy vaporproof two-cell flashlight. You will use it during all phases of maintenance. Installed in both ends of the flashlight are rubber seals that keep out all vapors. You should inspect the flashlight periodically for the installation of these seals, the spare bulb, and the blue lens. (The spare bulb, lenses, and filters should be available in the end cap.)

NOTE: Do not throw away any filters; you may need them for night operations.

INSPECTION MIRROR

There are several types of inspection mirrors used in aircraft maintenance. The mirror comes in a variety of sizes and may be round or rectangular. The mirror connects to the end of a rod and may be rigid or adjustable (fig. 7-19).

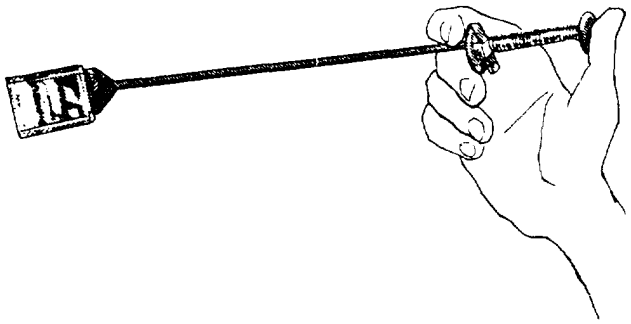


Figure 7-19.-Typical inspection mirror.

The inspection mirror helps you make detailed inspections where you cannot directly see the inspection area. By angling the mirror, and using a flashlight, it is possible to inspect most areas.

CANNON PLUG PLIERS

Figure 7-20 shows a set of special pliers you should use to remove electrical connectors when they are on so tight that you cannot remove them by hand. These pliers, when properly used, will prevent damaging or destroying electrical connectors.

FIBER OPTICS

Special tools for fiber optic equipment and cable repair include optical time-domain reflectometers, optical multimeter, optical ohmeters, optical power meters, radiometer/photometer, and automatic test equipment. Furthur information is available in NEETS, module 21, NAVEDTRA 14193, and *Installation Practices, Aircraft Electric and Electronic Wiring,* NA 01-1A-505.

Q8. You should use nonmagnetic tools when tuning RF circuits susceptible to frequency changes. How do some RF circuits avoid this potential frequency change problem?

Q9. List the three common types of torque wrenches in order of their accuracy and reliability from most to least.

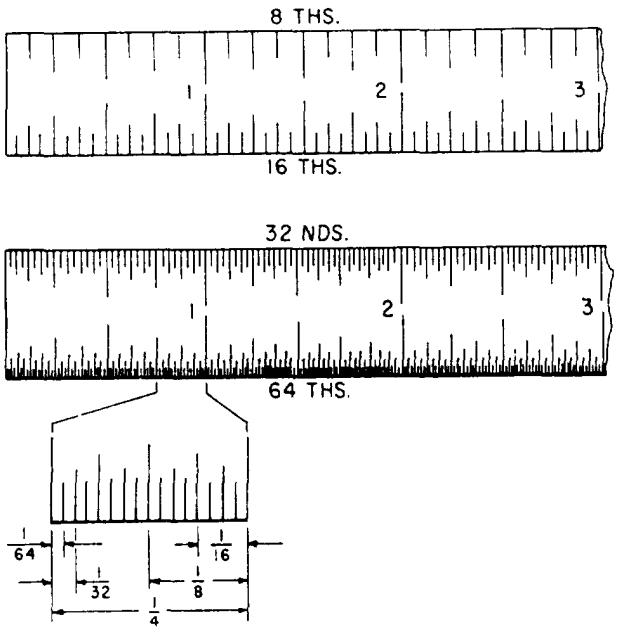


Figure 7-18.-Steel scale.

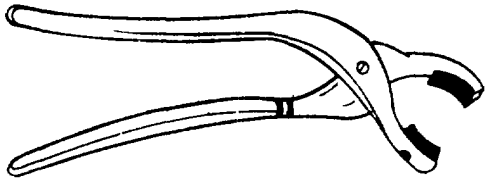


Figure 7-20.-Cannon plug pliers.

Q10. What special tool will hold, twist, and cut?

Q11. Describe the MS 3191-3 crimping tool.

Q12. What is the most common soldering iron used in avionics maintenance?

Q13. Where can you find the special tools for fiber optic repair?

AIRCRAFT HARDWARE AND CONSUMABLE MATERIALS

Learning Objective: *Identify aircraft hardware and consumable materials, and recognize their use in the maintenance of integral aircraft parts and substitution of parts.*

As a technician, you should have knowledge of certain items of hardware and consumable material. Hardware and material are used for installing equipment and repairing installed equipment. You should always use the proper parts and material. The applicable MIMs specify items of hardware and material necessary for aircraft maintenance. If you find you must make substitutions, make sure that the substituted item is satisfactory.

MOUNTING PARTS

The same mounting parts that were removed from an installation should not always be used when you reinstall equipment. Before reinstalling the same items, inspect them to make sure that they are the specified parts and that they are not defective or damaged. You must also determine if instructions forbid their reuse. If not forbidden, then, and only then, reinstall the removed parts.

Information on the use of mounting parts, such as screws. nuts. bolts, and washers, is of a general nature. You should follow established doctrine for their use. A valuable source of detailed information is *Aircraft Structural Hardware for Aircraft Repair,* NAVAIR 01-1A-8.

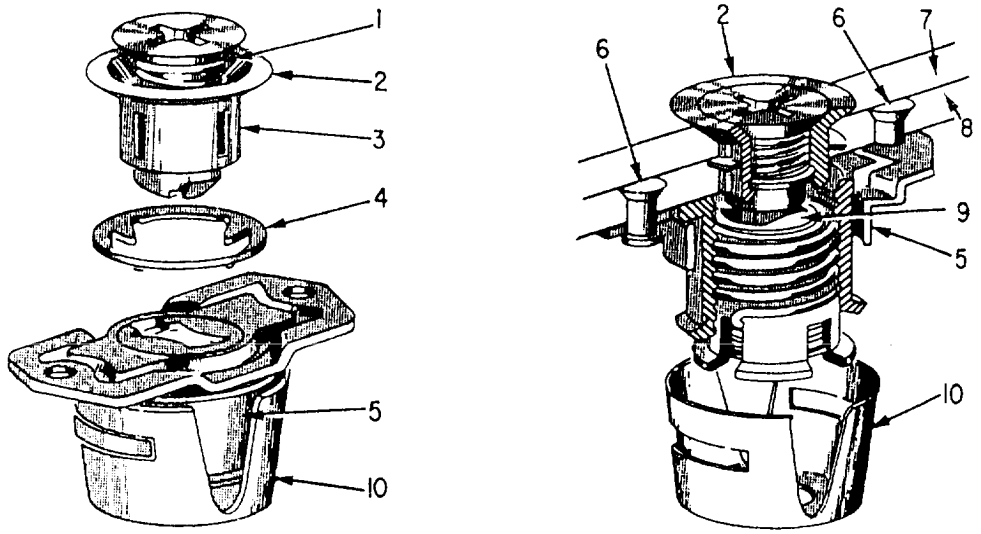
TURNLOCK FASTENERS

Turnlock fasteners secure inspection plates, doors, and other removable panels on aircraft. Turnlock fasteners are also referred to by such terms as *quick-opening, quick-action,* and *stress panel fasteners.* The most desirable feature of these fasteners is that they let you quickly and easily remove access panels for inspection and servicing purposes.

Turnlock fasteners are manufactured and supplied by a number of manufacturers under various trade names. Some of the more commonly used fasteners are the Camloc stress panel fastener and the Airloc fastener. For a discussion of other turnlock fasteners, you should refer to *Airman,* NAVEDTRA 14014.

Camloc Stress Panel Fasteners

The Camloc stress panel fastener (fig. 7-21) is a high-strength, quick-release, rotary-type



1. Tension spring
2. Stud assembly
3. Bushing
4. Retaining ring
5. Receptacle assembly
6. Receptacle attaching rivets
7. Outer skin
8. Inner skin
9. Insert
10. Cover

Figure 7-21.-Camloc stress panel fasteners.

fastener. You may find them on flat or curved inside or outside panels. The fastener may have either a flush or a nonflush stud. The studs are held in the panel with flat or cone-shaped washers, the latter being used with flush fasteners in dimpled holes.

You can tell this fastener from screws by the deep No. 2 Phillips recess in the stud head and by the bushing in which the stud is installed. A threaded insert in the receptacle provides an adjustable locking device. As you insert the stud and turn it counterclockwise one-half turn or more, it screws out the insert enough to permit the stud key to engage the insert cam when you turn it clockwise. Rotating the stud clockwise one-fourth turn engages the insert, and continued rotation screws the insert in, tightening the fastener. Turning the stud one-fourth turn counterclockwise will then release the stud, but it will not screw the insert out far enough to permit reengagement in installation. It is necessary to turn the stud at least one-half turn counterclockwise to reset the insert.

To unlock the stress panel fastener and reset it in the same operation, you should use a No. 2 Phillips screwdriver to turn the stud counterclockwise one-half turn or more. Do not turn the stud past the stop.

CAUTION

Do not use a power screwdriver on this fastener.

To lock the stress panel fastener, you should use a No. 2 Phillips screwdriver. Push the stud in, and turn clockwise until you feel increased torque; then continue turning until the fastener is tight.

When installing a large panel, it may be necessary to engage all the fasteners before tightening them. This is done by pushing each stud in and turning it clockwise one-fourth turn. The stud should engage the receptacle, but it should remain loose. If the stud does not engage, it will pop out, indicating that the insert must be reset by turning the stud counterclockwise one-half turn or more.

Airloc Fastener

The Airloc fastener consists of a stud, a stud cross pin, and a receptacle (fig. 7-22). The stud is attached to the access cover and is held in place by the cross pin. The receptacle is riveted to the access cover frame. A quarter turn of the stud (clockwise) locks the fastener in place. Turning the stud counterclockwise unlocks the fastener.

THREADED FASTENERS

For a discussion of threaded fasteners, refer to *Airman,* NAVEDTRA 14014. However, a brief discussion of Torq-set screws is included in this text.

ANSWERS FOR REVIEW QUESTIONS Q8. THROUGH Q13.

A8. Many RF circuits are using slug tuning.

A9. Micrometer-setting, dial-indicating, and deflecting-beam.

A10. Safety wiring pliers.

A11. The MS 3191-3 is the latest standard crimping tool designed specifically for use with MS 3191 connectors. It features interchangeable heads to accommodate various size terminals.

A12. The pencil soldering iron.

A13. NEETS, module 21, and Installation Practices, Aircraft Electric and Electronic Wiring, NA 01-1A-505.

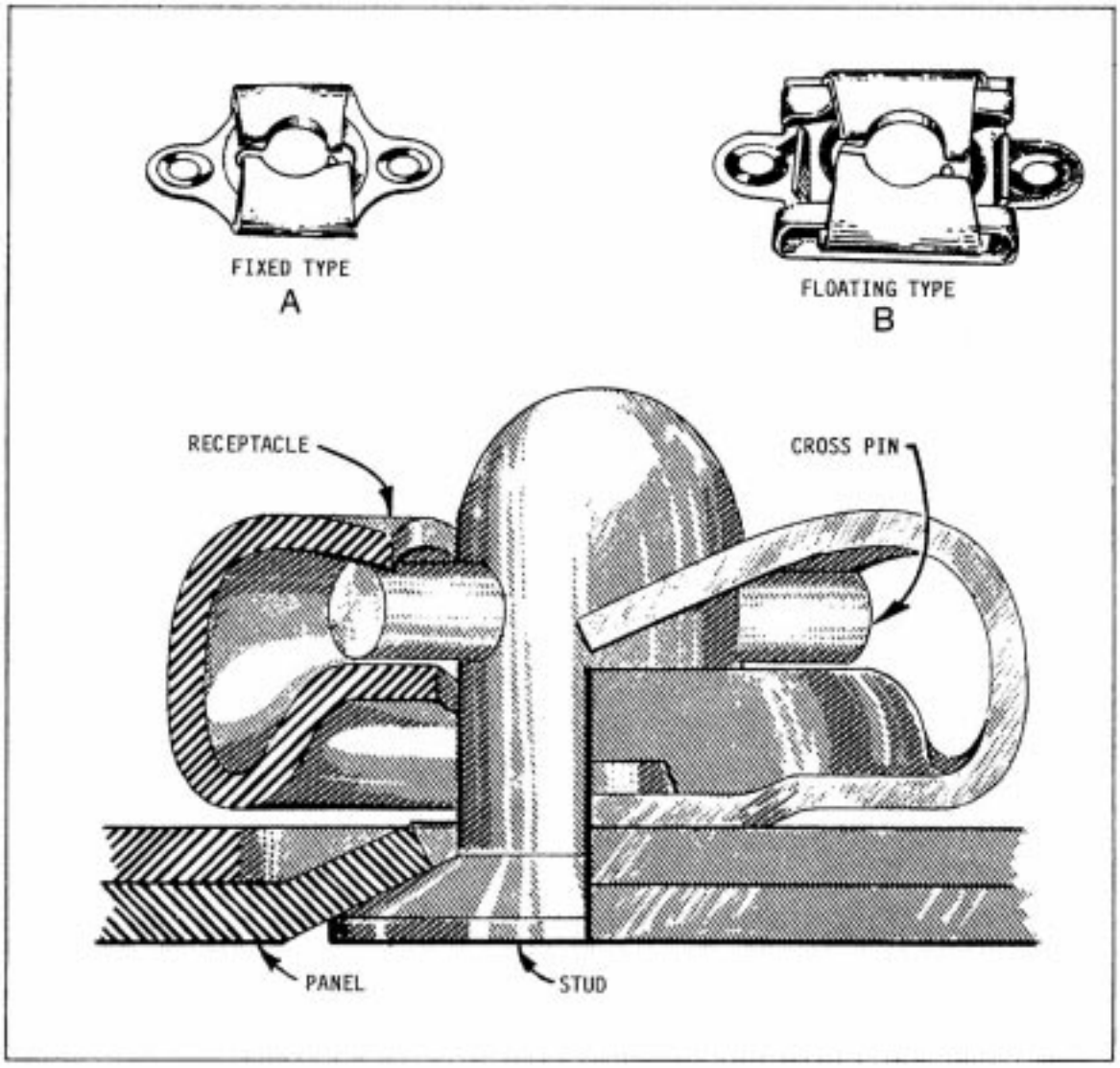


Figure 7-22.-Airloc fastener.

Torq-Set Screws

Torq-set machine screws (offset cross-slot drive) have begun to appear in new equipment. Their main advantage is that you can apply more torque to its head while tightening or loosening. You can apply more torque than any other screw of comparable size and material without damaging the head of the screw. Torq-set machine screws are similar in appearance to the more familiar Phillips machine screws. Look at figure 7-23. Here, you can see the difference between the Phillips machine screw and the Torq-set machine screw. Using a Phillips screwdriver could easily damage a Torq-set screwhead, making it difficult, if not impossible, to remove the screw, even if the proper tool is later used.

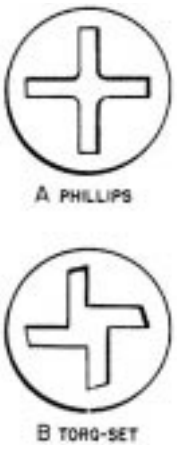


Figure 7-23.-Comparison of Phillips and Torq-set screwheads.

Torque Information

You should use torque tables, such as shown in table 7-2, as a guide in tightening nuts, bolts, and screws whenever specific torque values are not called out in maintenance procedures. Using the proper torque allows the structure to develop its designed strength and greatly reduces the chance of failure due to fatigue.

Threads must be free from grease or oil. Lubrication changes the torque value and results in overtorquing.

When using castellated nuts, you should tighten them to the lower torque limit; then continue tightening until the cotter pin hole aligns with slots in the nut. Do not back off the nut to align the hole.

When you need to tighten from the bolt head, use the high side of the torque range. If necessary, the maximum allowable tightening torque may be used.

When using corrosion-resistant steel bolts, lubricate them with an antiseize compound.

Table 7-2.-Torque Values in Inch-Pounds

Wrench size (in.)	Standard nuts, bolts, and screws		
	Bolt, stud, or screw size	Tension-type nuts AN310 and AN365	Shear-type nuts AN320 and AN364
1/4	4-48	4-5.5	2.5-3.5
5/16	6-40	7.5-11	4.5-6.5
11/32	8-36	12-15	7-9
3/8	10-32	20-25	12-15
7/16	1/4-28	50-70	30-40
1/2	5/16-24	100-140	60-85
9/16	3/8-24	160-190	95-110
5/8	7/16-20	450-500	270-300
3/4	1/2-20	480-690	290-410
7/8	9/16-18	800-1,000	480-600
15/16	5/8-18	1,100-1,300	660-780
1 1/16	3/4-16	2,300-2,500	1,300-1,500
1 1/4	7/8-14	2,500-3,000	1,500-1,800
1 7/16	1-14	3,700-5,500	2,200-3,300

NOTE: To convert to foot-pounds, divide inch-pounds by 12.

Corrosion-resistant steel bolts and nuts must be used together. Use shear nut torque values when tightening these bolts.

CONNECTORS

In the discussion that follows, the word *connector* is used in a general sense. It applies equally well to connectors designated by AN numbers and those designated by MS numbers.

Electrical connectors are designed to provide a detachable means of coupling between major components of electrical and electronic equipment. These connectors can withstand the extreme operating conditions imposed by airborne service. They must make and hold electrical contact without excessive voltage drop despite extreme vibration, rapid shifts in temperature, and great changes in altitude.

These connectors vary widely in design and application. Each connector consists of a plug assembly and a receptacle assembly. The two assemblies connect by a coupling nut, and each consists of an aluminum shell containing an insulating insert that holds the current-carrying contacts. The plug usually attaches to a cable end and is the part of the connector on which the coupling nut mounts. The receptacle is the half of the connector to which the plug is connected, and is usually mounted on a part of the equipment.

There are wide variations in shell type, design, size, layout of contacts, and style of insert. Figure 7-24 shows six types of connector shells.

The shells of MS connectors come in eight types, each for a particular kind of application. A letter designation in the MS number will indicate the shell design, as in MS 3106E, where E is the shell indicator. The shell indicators are as follows:

A	Solid shell
B	Split shell
C	Pressurized
D	Sealed construction
E	Environment resistant
F	Vibration resistant
H	Flame barrier shell
K	Fireproof construction

Solid-shell connectors are used where no special requirements, such as fireproofing or moistureproofing, must be met. The rear shells are made from a single piece of aluminum.

Split-shell connectors allow maximum accessibility to soldered connections. The rear shell has two halves, either of which you may

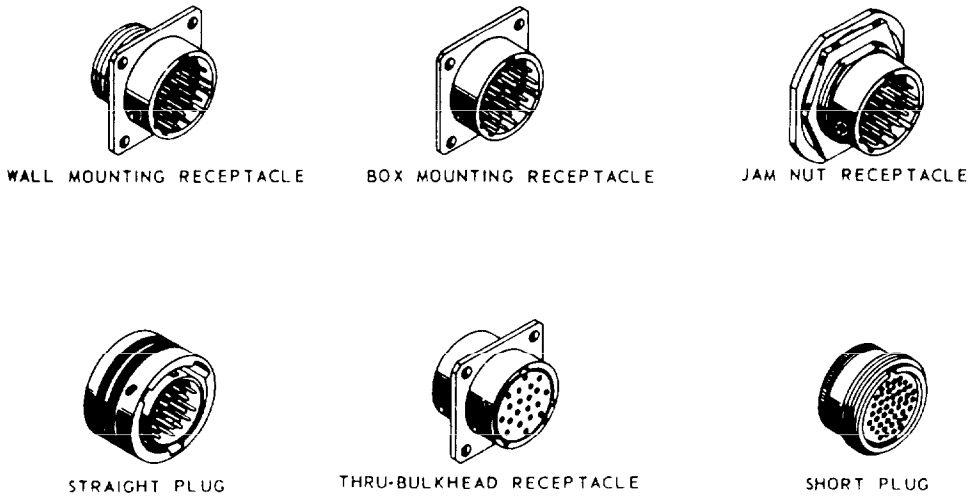


Figure 7-24.-Connector shells.

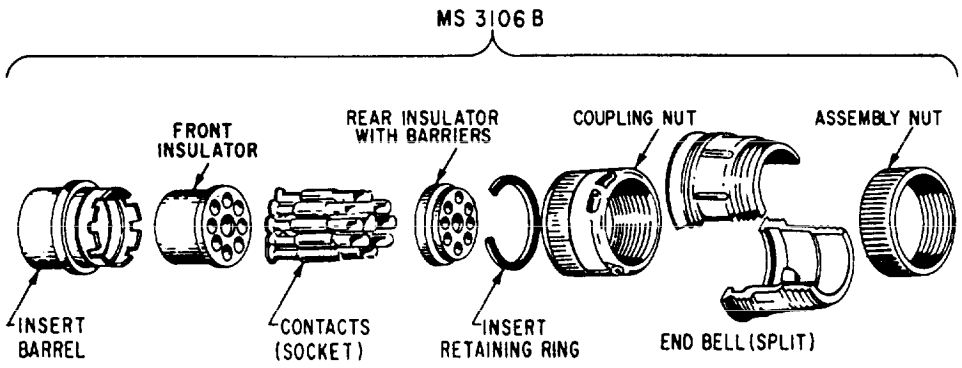
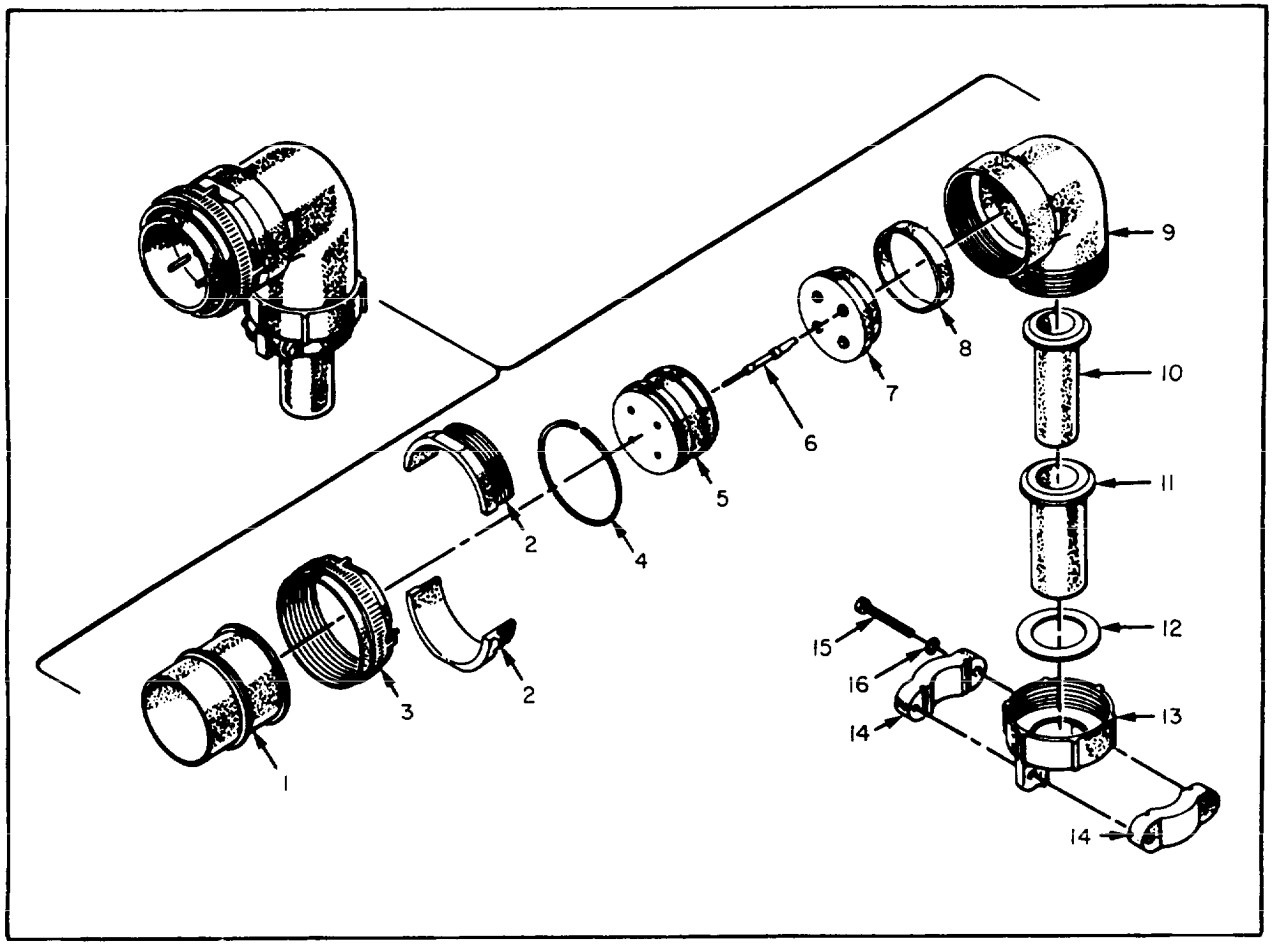


Figure 7-25.-Exploded view of a split-shell connector.



1. Insert barrel
2. Split nut (half)
3. Coupling nut
4. Split-nut retaining ring
5. Insulator
6. Contact (pin)
7. Grommet
8. Ferrule
9. Angle—90° end bell
10. Telescoping gland bushings
11. Telescoping gland bushings
12. Bushing washers
13. Gland-clamp fittings
14. Clamp saddles
15. Clamp-saddle screws
16. Lock washers

Figure 7-26.-Exploded view of a 90-degree angle connector.

remove. Figure 7-25 shows an exploded view of one type of split-shell connector.

Pressurized connectors provide a pressure-tight feed-through for wires that pass through walls or bulkheads of pressurized compartments in high-altitude aircraft. The contacts are usually molded into the insulator, and the shell is spun over the assembly to seal the bond.

Sealed connectors are used in equipment that is sealed and operated under gas pressure. These connectors include a glass-to-metal seal and have either special rubber inserts or a cementing compound applied to the insert.

Vibration-resistant connectors are used in equipment that is subject to intense vibrations in installations on or near reciprocating engines.

Fireproof connectors are made under specifications that require the connector to maintain effective electrical service for a limited time even when exposed to fire. The inserts are made of a ceramic material, and special crimp-type contacts are used.

Moisture-resistant connectors consist of a combination of the features of the solid-shell, the pressurized, and the vibration-resistant types. Figure 7-26 shows the component parts of this kind of connector.

Each connector has an identification symbol called the MS part number. This symbol indicates the shell type, the shell design, the size, the insert type, the insert style, and the insert position. An example is the designator MS 3100-A-16-11 PX.

The letters **MS** form the prefix. The number 3100 indicates the shell type and identifies the connector as one of the types shown in figure 7-24,

The letter **A** indicates a solid-shell connector. The number **16** is the shell size.

The number **11** is a designation of the insert pin arrangement used in the connector. A chart showing various pin arrangements is available in *Installation Practices, Aircraft Electric and Electronic Wiring,* NA 01-1A-505.

The letter **P** means the insert is a pin, or male, insert. (The letter **S** indicates it is a socket, or female, insert.)

The concluding letter, **X,** is a designation of the insert position. Connectors specially designed for a particular application sometimes have nonstandard contact, or insert, positions. Four positions of the inserts are employed, and these are lettered **W, X, Y,** and **Z.** Each letter refers to an angle by which the insert is rotated from the standard position. When the standard position is employed, there is no letter at the end of the MS designation.

Figure 7-27 shows three common types of subminiature connectors. Since these connectors are the wire-connected type, they have no flanges for mounting. However, the receptacle shown in view C can be mounted with nuts and lock washers. They are used on miniature instruments, switches, transformers, amplifiers, and relays.

The subminiature connectors described and shown in figure 7-27 have not proven sufficiently satisfactory and are not being used in new aircraft designs. Their use is limited to those aircraft in which they were initially installed.

The miniature connectors (MS 311X and 313X series) are intended to supersede these subminiature connectors. The miniature connectors differ from the types just described in their method of coupling and contact sizes. They will have two types of quick-disconnect couplings—axial and bayonet.

A reduction in size of contacts, from 0.062- to 0.040-inch diameter, allows a greater number of contacts per unit area, The miniature connectors with smaller contacts rated at 7.5 amperes have found increased use in aircraft ac power, where the majority of the circuits are low power and low current. All these connectors are environment-resisting class E. Hermetic

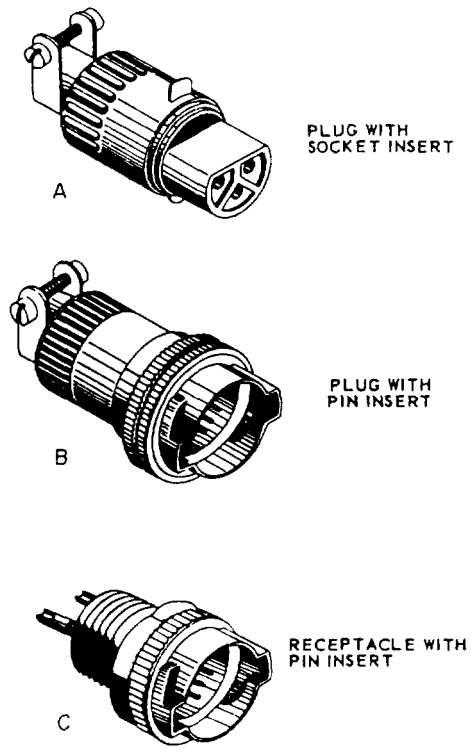


Figure 7-27.-Subminiature connectors.

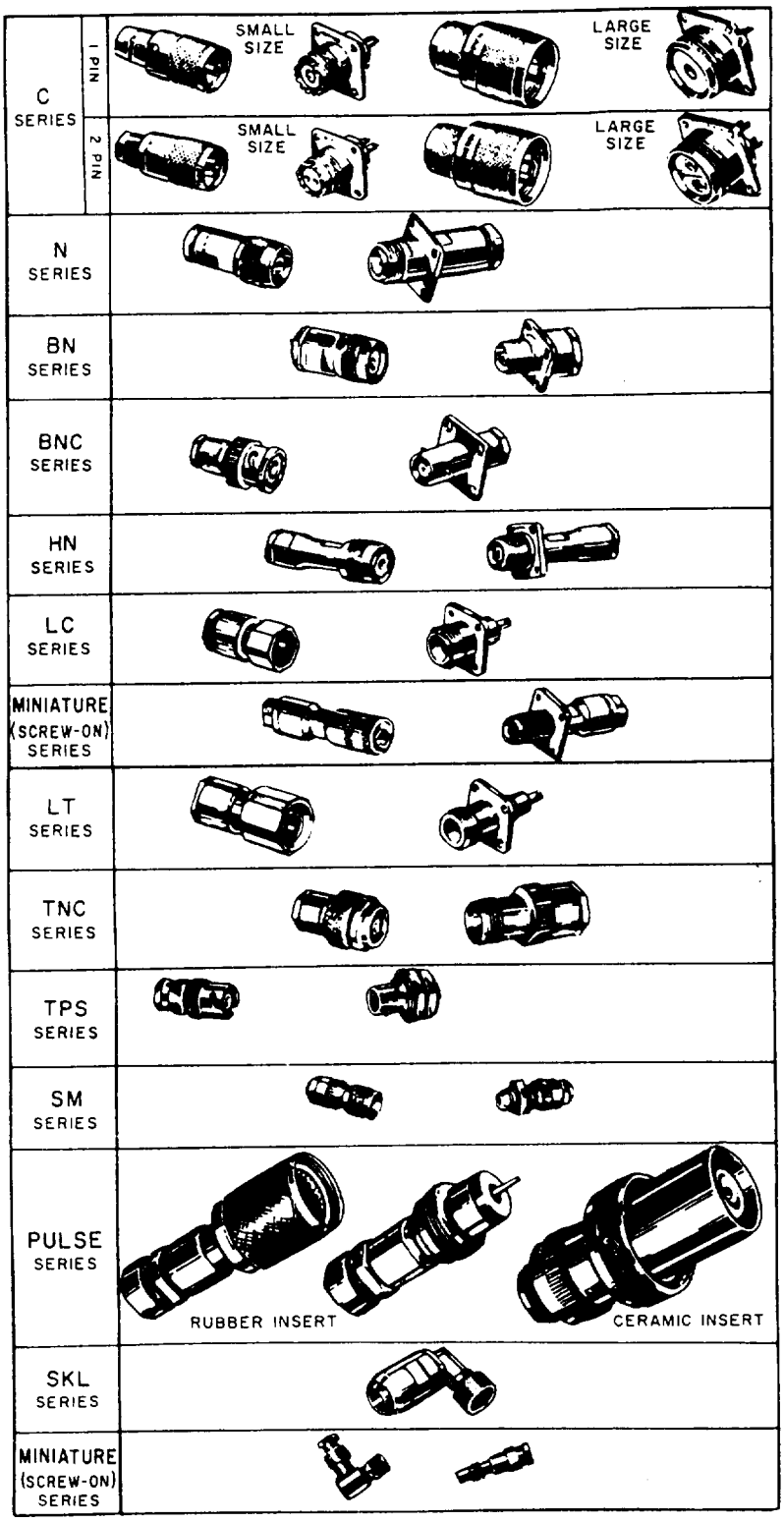


Figure 7-28.-Several typical coaxial connectors.

receptacles and connectors suitable for potting are also provided in this series.

Figure 7-28 shows how coaxial connectors are divided into series. Each series consists of plugs, panel jacks, receptacles, and straight and right-angle adapters.

Series UHF connectors are low-cost, general-purpose connectors of nonconstant impedance. The small and large coaxial types are for use with small and medium size coaxial cables in applications where line imbalance or increased standing wave ratio is not important. Where impedance matching is necessary, you should use C, N, or BNC series connectors. Both small and large series UHF connectors can be weather-proofed for outdoor use, but most are non-weatherproof.

Series N connectors are the most popular constant impedance connectors for medium size coaxial cables. They can be used up through microwave frequencies with minimum line imbalance or increase in standing-wave ratio. Although series N 50-ohm and 70-ohm connectors do not mate, 70-ohm cables may be used with 50-ohm series N connectors where impedance matching is not critical. Series N connectors are completely weatherproof.

Series C connectors are similar to 50-ohm series N connectors. They are used with the same cables, are weatherproof, and are for frequencies up through microwave. Series C connectors are mechanically and electrically superior to series N connectors. Series C connectors feature quick-connect and quick-disconnect bayonet-lock couplings and an improved cable-clamping mechanism for better cable grip with minimum cable indentation. These connectors are intended for use up to 1,500 volts,

Series BNC connectors (fig. 7-29) are commonly used on small coaxial cables. They incorporate quick-connect and quick-disconnect bayonet-lock couplings and are weatherproof. Besides regular and modified low-voltage types of nonconstant impedance, improved series BNC connectors are available that have a constant 50-ohm impedance and yield excellent electrical performance up to 10,000 megahertz.

Series HN connectors are weatherproof, high-voltage connectors of constant impedance for use with 50-ohm RF cables.

Series LC connectors are high-voltage (5 ,000 volts peak), 50-ohm, weatherproof connectors designed for applications involving the transmission of large amounts of RF power.

Series BN connectors are small, lightweight connectors (of nonconstant impedance) designed for use with the same coaxial cables that use BNC connectors. BN connectors are not recommended for applications at frequencies over 200 megahertz unless electrical requirements of the circuit are not critical. You may use them at peak voltages up to 250 volts.

Series LT connectors are very similar in appearance to series LC; however, series LT connectors differ not only in cable accommodation but also in weight—they are lighter than series LC connectors. Series LT connectors are large, 50-ohm, 5,000-volt connectors for use with RG-117/U cable.

Series TNC connectors are basically identical with series BNC connectors. The major difference is that TNC connectors have a threaded type of coupling instead of the bayonet-lock coupling.

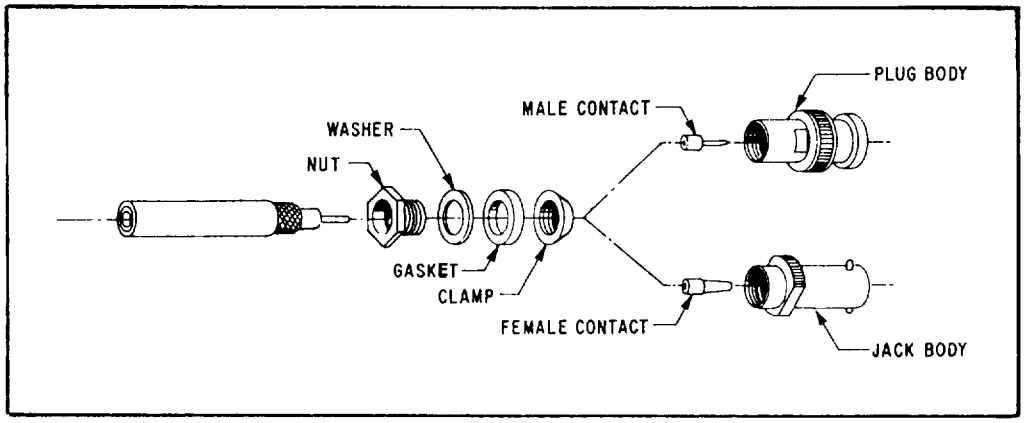


Figure 7-29.-Exploded view of a standard BNC connector.

Consequently, TNC connectors are usually preferred in applications that are subject to extreme vibration.

Series TPS connectors are weatherproof and designed to produce minimum electrical discontinuities in small size 50-ohm coaxial cable up to a frequency of 10,000 megahertz. The connectors are rated at 1,500 volts RMS at sea level. Their use is governed by the temperature limitations of their associated cables.

Series SM connectors are nonweatherproof fittings for coaxial cables of one-fourth-inch overall diameter and smaller. You may use them where electrical matching is not a concern. The SM connectors are smaller and contain fewer parts than the BNC series. The SM series uses a female center-conductor contact on plugs and a male center-conductor contact on jacks and receptacles. However, for consistency in cataloging and usage, a plug is still regarded as having a male mating end and a receptacle or jack as female. The SM series is not meant to replace the BNC series except for internal equipment connections where weatherproofing is not a concern.

The pulse connectors are designed for high-voltage pulse or dc applications. They are nearly all weatherproof and available in three types—rubber insert, ceramic insert, and triaxial. The rubber-insert pulse connectors have a peak voltage rating of 5,000 volts at an altitude of 50,000 feet. They are designed principally for use with cables having an insulated neoprene layer under the braid, such as RG-77/U and RG-78/U.

You may use pulse connectors with cables having a conducting rubber under the braids (such as RG-25/U, RG-26/U, and RG-64/U). However, you must take special care in assembling the connectors. The ceramic-insert pulse connectors are available in small (type A) and large (type B) sizes. Type A connectors are designed for use with the 8,000-volt RG-25/U and RG-26/U cables, and type B with the 15,000-volt RG-27/U and RG-28/U cables. (Use special care when assembling connectors.) Pulse connectors tend to leak noise that may interfere with communications equipment. Triaxial connectors are for transmission line applications where requirements dictate maximum RF shielding and minimum noise radiation. They are commercially available in sizes of the same diameter as the BNC series and C series (and possibly others). Some military equipment use these connectors and some within-series adapters are commercially available.

SKL connectors were originally designed to provide a connection to a klystron tube. However, newer klystrons are coming with BNC connectors. Various design modifications now provide general-purpose cable-to-cable connectors and adapters.

Miniature connectors have a gold finish, have screw-type coupling, and contain a high-voltage dielectric. They have a nominal impedance of 50 ohms, a sea-level breakdown voltage of 1,500 volts RMS, a practical frequency limit of 10,000 megahertz, and will operate up to 200°C.

WIRE

Although printed circuits and microelectronic components are widlely used in today's electronic equipment, wire is still important as a signal or current-carrying device. Since most naval equipment is of conventional construction, and complete conversion to the new forms of conducting components has not occurred, traditional wire conductors are used and will continue to be used for some time to come. This means that when wire is requisitioned, either for installation or repair, you should select it carefully. The three major factors involved in this selection, in descending order of importance, are—

1. size,
2. insulation, and
3. the characteristics required to satisfy specific environments in which the wire must function.

COAXIAL CABLES

Flexible coaxial cables (sometimes called RD cables) are a special type of cable used for carrying video and RF signals, cathode-ray tube sweep currents and voltages, trigger range marks, blanking pulses, and other signals for radar receivers, transmitters, and indicators. These cables are constructed with special considerations for shielding, impedance, capacitance, and attenuation. All of these factors are important in many circuits. Coaxial cables have neither induction nor radiation losses. These lines have low attenuation even at very high frequencies, and are used as high as 3,000 MHz.

The name *coaxial* is derived from the construction. The inner and outer conductors have a common axis or coaxis. These cables consist of an inner conductor, a dielectric insulator, an outer conductor, and an outer covering. The inner conductor is usually made of copper—plain, tinned, or silver coated. The

dielectric insulation is usually polyethylene, although other materials are used. The outer conductor is made of a single or double braid of plain, tinned, or silver-coated copper. The outer conductor is covered by a protective jacket. This jacket serves both to weatherproof the outer conductor and to protect it from mechanical abuse.

Flexible coaxial cables are classified in four groups—general purpose, high temperature, pulse, and special characteristics. The general-purpose cables consist of various sizes of cables as just described. The high-temperature cable is basically the same but usually has a dielectric and outer covering designed to withstand increased temperatures. Pulse cables have the ability to withstand high voltages because of conductor spacing and the type of dielectric used in their construction. The special characteristics cables are made of various materials and sizes of inner conductor, outer conductor, dielectic, and outer covering. By varying these parts, the capacitance, impedance, shielding, attenuation, voltage rating, and ability to withstand weather and abuse are varied to fit the required qualities.

With the exception of the special characteristics type, coaxial cables have an impedance of 50 to 75 ohms. The impedance of the special characteristics type is often much higher; for example, the RG-65A/U, which has an approximate impedance of 950 ohms and is used as a high impedance video cable. When replacing a coaxial cable, you should use the correct replacement, otherwise most of the advantages of coaxial cables are lost.

At frequencies near 3,000 MHz, flexible coaxial cables have appreciable losses. At these frequencies, rigid coaxial cables are used with air as the dielectric. The inner conductor is supported by ceramic or polystyrene beads.

FIBER OPTIC CABLES

You can repair fiber optic cables using the special tools for fiber optic cable repair and the procedures in *Installation Practices, Aircraft Electric and Electronic Wiring,* NA 01-1A-505.

SUBSTITUTION OF PARTS

If the specified parts cannot be obtained, a temporary installation may be made using suitable substitute parts, and these parts should be replaced with the proper items as soon as they can be obtained. When making parts substitutions, give special attention to the following considerations:

1. Corrosion. The chemical or metallic composition of the part must be such that its use does not contribute appreciably to the danger of corrosion,

2. Strength. The strength of the substitute part must be the same as or greater than the prescribed strength. When determining the strength, give consideration to the tensile, compression, and/or shear strength, as applicable to the specific use.

3. Size. Substitute bolts and screws should be the same size as the prescribed item. If a detachable nut is to be used, a different thread may be tolerated; if a threaded hole or an anchor nut is involved, the thread must be the same as the one prescribed. In all cases, washers must have the same inner diameter as the prescribed item, but a different outer diameter or thickness may sometimes be permitted.

4. Length. Substitute screws or bolts must have a length that is sufficient for the particular installation, but they must not be so long that they are in the path of any moving part. They must not be in contact with other aircraft items such as electrical wiring, hydraulic lines, and so forth.

5. Magnetic properties. Specific areas of the aircraft (for example, vicinity of such items as the magnetic compass, magnetic anomaly detection equipment, radio direction finder, or gyros) should not be changed in a manner that may cause the magnetic fields of the area to become distorted. In these areas, any substitute part must possess the same magnetic properties and characteristics as the one prescribed.

6. Style. Most items of mounting hardware are available in various styles. It is usually easy to find screws and bolts that are identical in all respects except for the type of head. These parts are preferred as substitutes, provided they possess all the required special features.

7. Special features. If a bolt is to be torqued to a given value, a torque wrench that is usable with that type of part and has the proper torque range must be available. If lockwiring is required, the part must have suitable provisions.

8. Lubrication or coating. If specific instructions call for lubrication or coating of the parts, they must be followed for the substitute part as well as for the prescribed part. If no lubrication is permitted, the substitute part is not to be lubricated.

SOLDER

Two types of solder are available, the tin-lead alloy known as soft solder and the so-called hard or silver solder. Soft solder alloys permit the use of lower soldering temperatures; therefore, they are recommended for electronic applications. Where a joint of greater strength is required, silver solder is used.

Most solder alloys do not liquify immediately as the temperature is increased. Ordinarily, they change from the solid state to a plastic or semiliquid, and finally become completely liquid. Most tin-lead solders enter the plastic state at 358°F, and become totally liquid at various temperatures, depending upon the individual solder composition. A combination of 63 percent tin and 37 percent lead has the best melting point (361°F) for the tin-lead group. However, since it changes from solid to liquid without an intervening plastic state, it is susceptible to fracture from slight vibration while cooling. (Solder is commonly referred to as 70/30, 60/40, and so on. This is the tin-lead content.)

FLUXES

All common metals are covered with a nonmetallic film, usually an oxide of the material, that prevents them from making the intimate contact so necessary for a good electrical connection. The purpose of a flux is to remove the oxide from the surfaces to be soldered, not to clean them. Flux cannot replace good cleaning methods in preparing surfaces for soldering. Without a clean, intimate contact, poor soldering techniques may result in a mechanically weak, high-resistance joint, a so-called rosin joint in the case of rosin-base flux. Solder fluxes may be divided into three general groups—rosin, organic, and chloride (sometimes called acid).

The residue from the rosin-base fluxes is noncorrosive and electrically nonconductive, making them highly acceptable for use in military electronic equipment. The organic and chloride types are seldom used (sometimes even prohibited) because of their corrosiveness. Only rosin-base flux is recommended for electronic applications.

Activated or intensified rosin-alcohol fluxes are permitted if they are noncorrosive. For details, you should consult applicable military specifications.

Organic fluxes consist of mild organic acids and bases. These fluxes are almost as active as the organic salts, but their period of activity is brief due to their susceptibility to thermal decomposition. This limits corrosion; therefore, they may be used in applications where the soldered assembly lends itself to residue removal.

Chloride fluxes are not recommended for electronic applications.

POTTING COMPOUND

Most electrical connectors and some relays used in aircraft are potted to prevent corrosion, contamination, or arc-over between pins and terminals. Because of temperature variations throughout the aircraft, two different potting compounds are used. You can tell which one was used by its color. The tan compound is used where the temperature under operating conditions does not exceed 87.8°C (190°F). The red compound is used where the temperature is higher. If it becomes necessary to replace or repot a relay or connector, the potting compound that is used should have the same temperature range (color) as the original material. Care should also be taken to duplicate the shape of the original potting so that no installation problems will occur.

Q14. When can you reinstall removed mounting parts?

Q15. What is the main advantage of Torq-set screws?

Q16. If maintenance procedures do not call out specific torque requirement, how can you determine the proper torque for tightening?

Q17. Each electrical connector has an identification symbol called the MS part number. What information can you obtain from this number?

Q18. Describe the difference between a BNC and TNC connector.

Q19. List the three major factors in wire selection.

Q20. What considerations should you pay special attention to when making part substitutions?

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ANSWERS FOR REVIEW QUESTIONS Q14. THROUGH Q20.

A14. Before reinstalling, inspect them to make sure the parts are of the type specified and that they are not defective. You must also determine if instructions forbid reusing them. If they are not forbidden, then, and only then, should you reinstall the removed parts.

A15. The main advantage is that you can apply more torque to its head.

A16. You should use torque tables as a guide for tightening nuts, bolts, and screws whenever specific torque values are not called out.

A17. The shell type, design, size, insert type, insert style, and the insert position.

A18. The TNC connector has a threaded coupling instead of the bayonet-lock coupling.

A19. Size, insulation, and the characteristics required to satisfy specific environments in which the wire must function.

A20. Corrosion, strength, size, length, magnetic properties, style, special features, lubrication or coating.

CHAPTER 8

TEST EQUIPMENT

The operational theory of equipment is only one part of the knowledges you need to maintain avionics equipment. You also need a knowledge of avionics drawings, schematics, and test equipment.

You use many publications to properly maintain a weapons system in modern-day aircraft because they are so complex. Just the list of the electronics equipment installed in modern-day aircraft is lengthy. It is impossible for each individual to know all the various types of electronics equipment presently in use. However, with a good general background on electronic principles and circuit theory and a little study, you, the Aviation Electronics Technician, can rapidly become familiar with any specific system or test equipment.

In this chapter, you will learn about some common test equipment used by Aviation Electronic Technicians (ATs). This information is in addition to modules 3 and 16 of the Navy Electronic and Electricity Training Series (NEETS) on test equipments. Review and refer to the NEETS modules as necessary for additional information about the test equipment described in this chapter. No in-depth theory beyond that necessary to describe the operation of the test set under discussion is included here. When you use a piece of test equipment with which you are not familiar, **always** use the appropriate instruction manual. These publications contain detailed and specific information about the particular equipment.

CARE AND USE OF AVIONICS SUPPORT EQUIPMENT

Learning Objective: *Identify the proper care and use of avionics support equipment to include calibration, repair, and handling requirements.*

All electronic maintenance shops have and require many pieces of test equipment to maintain different types of electronic units. However, there are very few spare test sets. When a test set becomes inoperative, shop maintenance suffers. Therefore, each person should use the test equipment properly and **only** for its designed purpose. Protect the equipment from physical harm that may result from dropping, falling, or any other careless misuse, and always observe proper operating techniques.

One of the chief causes of test set failure is carelessness. The user can be careless in an operating procedure or in handling the set. Improper range selection for the measured quantity is the most common mistake in an operating procedure. Such an error might be to try to measure 250 volts on the 50-volt scale of a meter. If you aren't sure about proper use of a test set, refer to the manual issued with the set.

Improper handling causes damage to test equipment. Often, technicians place test sets near the edge of the bench where they can be easily knocked or pulled off. Read the instructions for proper handling and operating procedures, and **think** when you use a piece of equipment. Refer to NEETS, modules 3 and 16, for further information on test equipment operation and theory.

CALIBRATION

Test sets require checks to determine if they are within operating tolerances. Some test sets are used as frequency standards and require periodic calibration. You should always follow the recommendations of the manual or pamphlet issued with the set, unless current instructions change those recommendations.

Normally, personnel in an intermediate-level maintenance shop perform calibration using special-purpose calibration equipment. Personnel at the organizational level of maintenance seldom calibrate test equipment.

REPAIR

The using activity normally makes any minor repair of test sets not requiring calibration. Repairs are usually limited to the replacement of test leads and fuses. Before you make any repair, consult current instructions on repair of test equipment.

Personnel assigned to an intermediate-level maintenance activity repair test equipment on a wider scale. Repair can vary from the replacement of circuit components to modules, depending on the authorized level of repair. However, most test equipment work at this level consists of calibrating equipment.

HANDLING PRECAUTIONS

Some equipments require special handling; however, several precautions apply to test equipments in general. Rough handling, moisture, and dust all affect the useful life of test equipment. For example, bumping or dropping a test instrument can destroy the calibration of a meter or short circuit the elements of an electronic tube within the instrument. Creasing or denting coaxial test cables alter their attenuating effect, affecting the accuracy of any RF measurements made with these cables. To reduce the danger of corrosion to untreated parts, always store test equipment in a dry place when not in use. Excessive dust and grime inside a test equipment affect its accuracy. Be sure all assembly screws that hold the case of the test equipment in place are tight and secure. As an added precaution, place all dust covers on test equipments when they are not in use.

Meters are the most delicate part of test equipments. To make sure the meter maintains its accuracy, you should follow these additional precautions:

1. Make certain the amplitude of the input signal under test is within the range of the meter.
2. Keep meters as far away as possible from strong magnets.
3. When servicing an item of electronic equipment that contains a meter, disconnect the meter from the circuit before making resistance or continuity tests. This precaution should prevent the possibility of burning out the meter.

The instruction manuals that come with a piece of equipment contain the procedures for properly stowing test equipment cables and other accessories. Read these manuals carefully and follow the equipment instructions. Improper stowage of accessories could change cable characteristics and cause intermittent shorts in cables and leads. Improper stowage causes unreliable test equipment indications.

Q1. Name one of the chief causes of test set failure.

Q2. Although test equipment is repaired at the intermediate-level maintenance activity, most work performed at this level on test equipment consists of _____.

Q3. What is the most delicate part of a piece of test equipment?

Q4. List the basic measuring parameters of electronic equipment.

MEASURING INSTRUMENTS

Learning Objective: *Recognize types and uses of measuring equipment to include electronic meters, frequency measurement, and power measurement.*

In this chapter, the term *measuring instruments* includes only the class of test equipments that measure the basic parameters of an electronic equipment. The basic parameters are voltage, current, resistance, power, and frequency.

METER OPERATION

There must be some source of power available to operate a meter. Some meters use batteries installed in the meter case as a power source; others may use an electrical power cord plugged into a power receptacle. A vacuum tube voltmeter (VTVM) is an example of the second type. The power to operate some meters (such as meggers) is self-produced by manual operation of a handcrank.

Most meters provide the means to measure more than one electrical quantity; these are multimeter. Before discussing any one particular type of meter, a brief review of each of the basic meters is necessary. For more details refer to NEETS, modules 3 and 16.

Ammeter

The amplitude of current flow through the basic meter mechanism limits it to measuring a fixed range of only a fraction of an ampere. A current shunt overcomes this limitation and protects the mechanism. The current shunt is actually a resistance of low value, permitting the instrument to serve as a dc ammeter that can measure relatively large direct currents.

The current distribution between meter movement and shunt is inversely proportional to their individual resistances. Thus, the shunt, which has less resistance, carries most of the current. Since the meter coil carries only a small portion of the circuit current, it can indicate relatively large values of circuit current. The instrument provides a variety of current ranges by the use of shunts of different values. Figure 8-1 shows a simplified schematic diagram of an ammeter section taken from a typical volt-ohm-milliammeter (VOM).

Ohmmeter

The midscale deflection of an ohmmeter occurs when the current drawn by the meter is one-half the value of the current at full-scale (zero ohms) deflection. This condition exists when the measured resistance is equal to the total meter circuit resistance. Analysis of the circuit in figure 8-2 shows that full-scale deflection occurs when shorting the meter probes together. Less than full-scale deflection occurs when the resistance to be measured, Rx, is connected into the circuit. If the meter now reads one-half of its former current, the total circuit resistance has doubled. This indicates that RX is equal to the total meter circuit resistance.

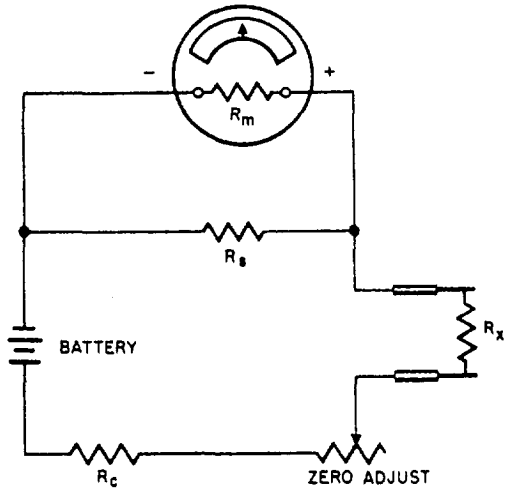


Figure 8-2.-Series-type ohmmeter basic circuit.

Since the ohms-calibrated scale is nonlinear, the midscale portion represents the most accurate portion of the scale. The usable range extends with reasonable accuracy on the high end to 10 times the midscale reading. However, on the low end it decreases to one-tenth of the midscale reading.

To extend the range of an ohmmeter, the proper values of shunt and series resistors and battery voltages are connected into the circuit. The proper values let you read the meter full scale with the test leads shorted. Figure 8-3 shows a

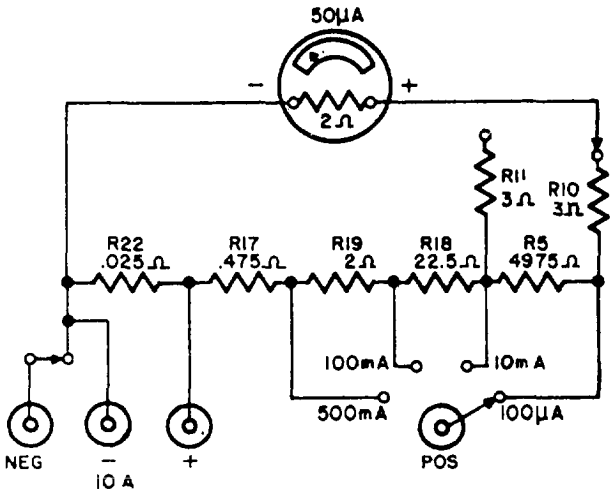


Figure 8-1.-Simplified schematic diagram of an ammeter.

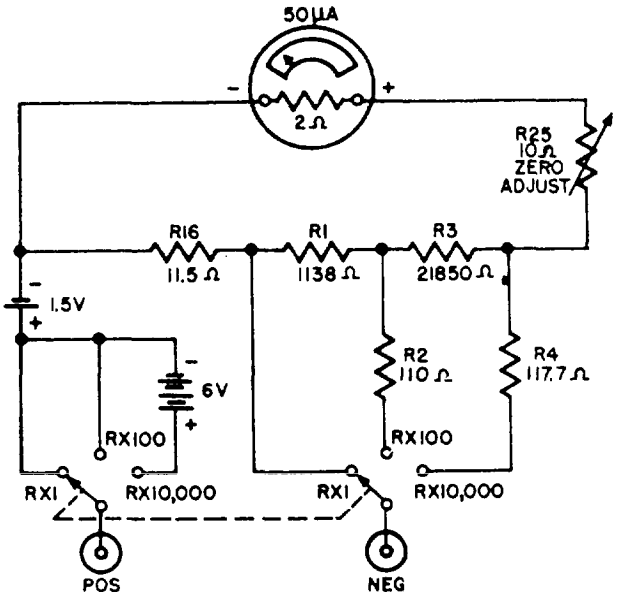


Figure 8-3.-Simplified schematic diagram of an ohmmeter.

simplified schematic diagram of an ohmmeter section taken from a typical VOM.

Voltmeter

Adding a voltage-multiplying resistor makes the basic meter mechanism suitable for use when measuring dc voltages. The voltage-multiplying resistor is placed in series with the coil (fig. 8-4) and limits the flow of current to a safe value.

Since the value of the resistor is constant for any given application, the flow of current through the coil is proportional to the voltage under measurement. By properly calibrating the dial, the instrument indicates voltage. However, it is actually the current that activates the meter. The use of different values of multiplying resistors establishes the voltage ranges of the instrument.

MULTIMETER

Much of the work that you do using a VOM can be done with a multimeter. The name *multimeter* comes from **multiple meter,** which is exactly what a multimeter is. It is an ohmmeter, a dc and an ac milliammeter, and a voltmeter. A typical multimeter is shown in figure 8-5.

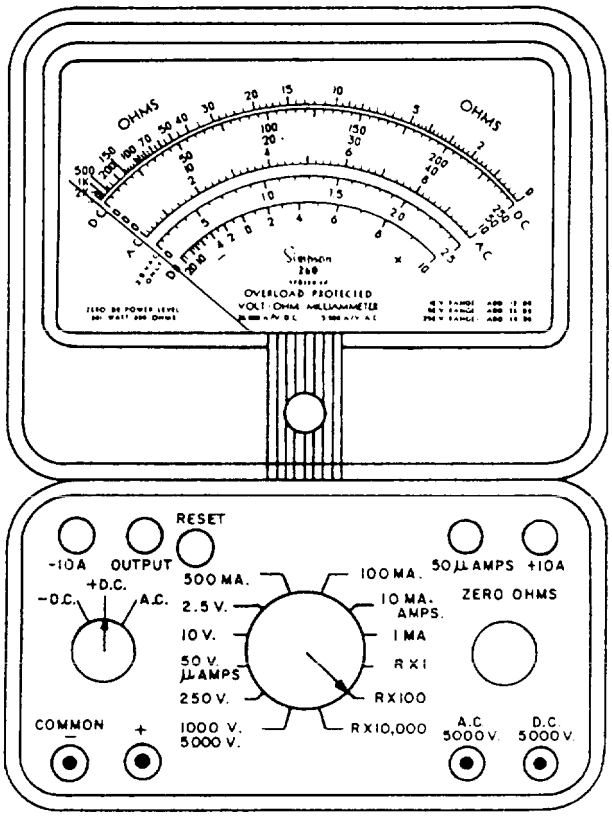


Figure 8-5.-Typical multimeter.

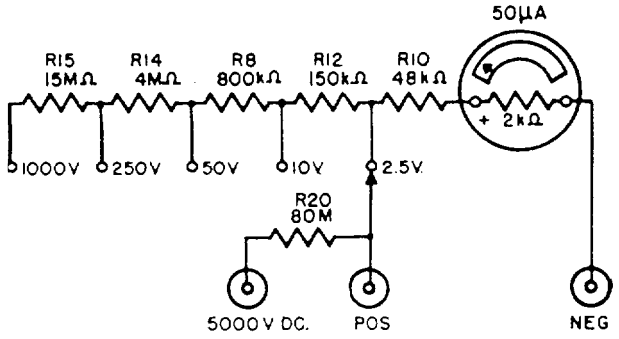


Figure 8-4.-Simplified schematic diagram of a dc voltmeter.

In many shops, you might use a portable, battery-operated multimeter such as a TS-352, USM-311, Simpson 260, or Simpson 160 for field use (troubleshooting in the aircraft, for instance). As an AT, however, you will often need a more sensitive meter—one that gives more accurate readings and has wider ranges.

Often, equipment schematics and wiring diagrams specify that voltages indicated at test points were obtained with a meter of a certain sensitivity, such as a 20,000-ohms-per-volt meter. You should use a meter with the same sensitivity

ANSWERS FOR REVIEW QUESTIONS Q1. THROUGH Q4.

A1. Carelessness.

A2. Calibration.

A3. Meters.

A4. Voltage, current, resistance, power, and frequency.

in repairing that equipment to obtain accurate readings because of circuit loading.

NOTE: For a review of the basic theory and operation of the multimeter, refer to NEETS, module 3.

MILLIOHMMETER

One of the most common and troublesome problems is finding the exact location of a short circuit in a power distribution circuit involving many parallel paths. This and several trouble-shooting problems are easier to solve with a milliohmmeter.

A milliohmmeter is a low-range ohmmeter that can measure resistances in the milliohm range or less. The AN/USM-21A is a typical milliohmmeter used in the fleet. It can measure resistances in the range of 10 milliohms or less. Most ohmmeters read zero at such a low value.

When using a milliohmmeter, you may encounter several problems. These problems include stray circuit resistances, such as contact resistance, test lead resistance, and switching resistance. In the conventional low-range ohmmeters, the primary problem is in the contact resistance at the test probes. The design of the AN/USM-21A overcomes the contact resistance problem.

MEGOHMMETER (MEGGER)

The megohmmeter, commonly called the *megger,* is an instrument that applies a high voltage to the component under test and measures the current leakage of the insulation. This lets you check a capacitor or an insulated cable for leakage under much higher voltages than an ohmmeter can supply. The megger consists of a hand-driven dc generator and an indicating meter. It measures resistances of many megohms.

There are various resistance ratings of meggers with full-scale values as low as 5 megohms and as high as 10,000 megohms. Figure 8-6 shows the scale of a 100-megohm, 500-volt megger. Notice that the upper limit is infinity and that the upper end of the scale is also crowded. The first scale marking below infinity represents the highest accurate value the instrument can provide. Thus, if the pointer goes to infinity while you are making a test, it means that the resistance is higher than the range of the set.

There are also various voltage ratings of meggers, such as 100, 500, 750, 1,000, and 2,500. The most common type is the one with a 500-volt rating. This voltage rating refers to the maximum output voltage of the megger. The output voltage depends on the turning speed of the crank and armature. When the megger's armature rotation reaches a predetermined speed, a slip clutch maintains the armature at a constant speed. The voltage rating is important. If too high a voltage is applied, it will cause even a good component to break down. Therefore, do not use a 500-volt megger to test a capacitor rated at 100 volts.

You can use meggers to test the insulation resistance of conductors that may be shorting or breaking down under high voltage. In some situations, you can use meggers in the prevention of unnecessary breakdowns. You could maintain a record of insulation resistance of power and high-voltage cables, motor and generator windings, and transmission lines. These records reflect fluctuations in resistance and help

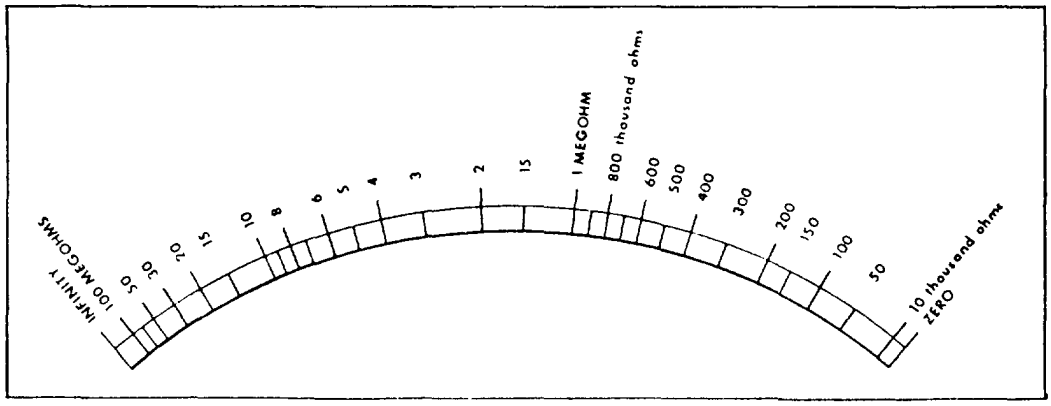


Figure 8-6.-Scale of a 100-megohm, 500-volt megger.

determine when to replace the components to prevent a breakdown.

Meggers are used for testing capacitors whose peak voltages are not below the output of the megger. They are also used for testing for high-resistance grounds or leakage on devices such as antennas and insulators.

The following are precautions you should take when using meggers:

1. When you are making a megger test, do not energize the equipment. Disconnect it entirely from the system before testing.

2. Observe all safety rules in preparing equipment for test and in testing, especially when testing installed high-voltage apparatus.

3. Use well-insulated test leads, especially when using high-range meggers. Check the leads after connecting them to the megger and before connecting them to the component under test. Operate the megger and make sure there is no leak between the leads. The reading should be infinity. Check the leads by touching the test ends of the leads together while turning the crank slowly. The reading should be about zero. If the indication reads differently, you may have a faulty lead or a loose connection.

4. When using high-range meggers, take proper precautions against electric shock. There is enough capacitance in most electrical equipment to *store up* energy from the megger generator to give a very disagreeable and even dangerous electric shock. Because there is a high protective resistance in the megger, its open circuit voltage is not as dangerous as it would otherwise be; still, be careful.

5. Discharge equipment having considerable capacitance before and after megger tests. This should help you avoid receiving a dangerous shock. You can do this by grounding or short circuiting the terminals of the equipment under test.

The AN/PSM-25, shown in figure 8-7, is a common megger used through the fleet. For more information on meggers, refer to NEETS, module 16.

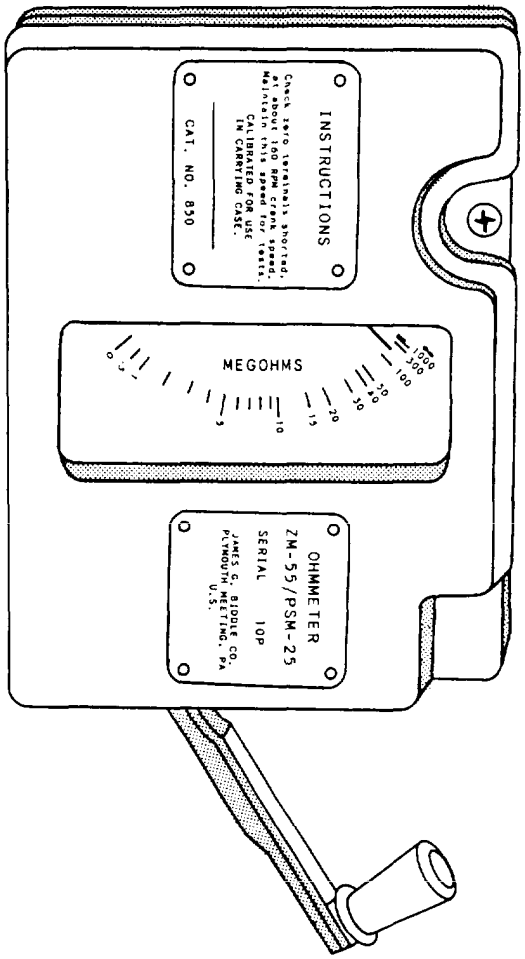


Figure 8-7.-AN/PMS-25 megger.

ELECTRONIC METERS

Electronic meters and nonelectronic meters are used for the same purposes; however, they do have some differences. In the electronic multimeter and corresponding nonelectric measuring devices, the current- and resistance-measuring circuits function in the same way. However, when an electronic multimeter is used to measure voltage, an amplifier is involved. Therefore, the electronic meter requires calibration before it is used. The proper calibration and use of the instruments vary slightly, according to model. You should refer to the operation instruction manual for the specific details of each model.

The ordinary voltmeter cannot be accurately used to make voltage measurements in high-impedance circuits. For example, you need to measure the plate voltage of a pentode amplifier. (See fig. 8-8.) When you connect the meter between the plate and cathode of the electron tube, the meter resistance (R_m) is in parallel with the effective plate resistance (R_{eff}). Thus, the plate resistance is lowered. The effective plate resistance is in series with the plate load resistor (R_L), and this series circuit appears across the supply voltage (E_{bb}) as a voltage divider. Since the overall

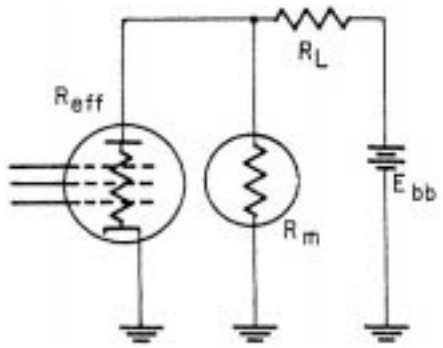


Figure 8-8.—Loading effect created by meter resistance.

resistance is now lower, the current through R_L will increase. This causes the voltage drop across R_L to also increase, and the voltage drop across R_{eff} will decrease. The result is an incorrect indication of plate voltage and is called the *loading effect.* The lower the sensitivity of the meter, the greater the loading effect and the higher the incorrect indication (error) will be.

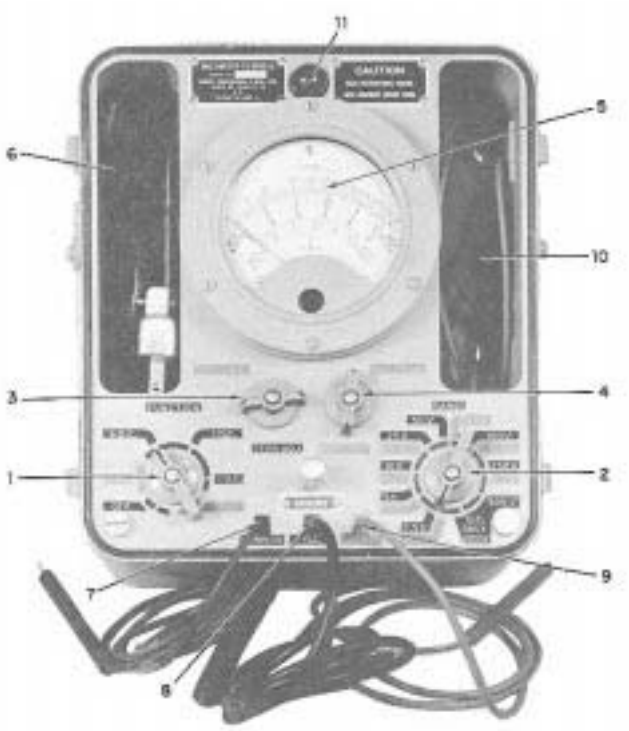
A meter having a sensitivity of 20,000 ohms per volt and a 250-volt maximum scale reading would introduce an error of about 1 percent. However, in circuits with very high impedances, even a meter with a 20,000-ohm-per-volt sensitivity would impose too much of a load on the circuit.

VACUUM TUBE VOLTMETER

Another limitation of the ac, rectifier-type voltmeter is the shunting effect at high frequencies of the relatively large capacitance of the meter's rectifier. This shunting effect may be greatly reduced by replacing the usual metallic oxide rectifier with a diode electron tube. The output of the diode goes to the grid of an amplifier, in which the plate circuit contains the dc meter. Such a device is an electron tube voltmeter or a vacuum tube voltmeter (VTVM). Voltage measurements are extremely accurate with this type of meter, even at frequencies up to 500 megahertz and sometimes higher. The VTVM model that is used determines its frequency limitation.

The input impedance of a VTVM is large; therefore, the current drawn from the circuit voltage being measured is small and in most cases negligible. The main purpose of a VTVM is to reduce the loading effect by taking advantage of the VTVM's extremely high input impedance. The TS-505 multimeter contains a VTVM, and it is used extensively in electronics maintenance.

You should refer to figure 8-9 as you read this section. The VTVM measures dc voltages from 0.05 volt to 1,000 volts (in nine ranges) and ac voltages from 0.05 volt to 250 volts rms (in seven ranges) at frequencies from 30 Hz to 1 MHz. Using the RF adapter with the dc voltage measurement circuit lets you measure RF voltages from 0.05 volt to 40 volts rms at frequencies from 500 kHz to 500 MHz. You may measure resistances from 1 ohm to 1,000 megohms.



1. Function switch
2. Range switch
3. Zero adjust
4. Ohms adjust
5. Meter
6. AC line cord (power cord)
7. Common probe (black)
8. DC probe (black, special tip)
9. Ohms probe (green)
10. AC probe (red)
11. Indicator lamp (glows red with power on)

Figure 8-9.—TS-505 multimeter front panel.

The accuracy of this meter is ±5 percent for dc voltages and ±6 percent for ac and RF voltages. The meter movement requires 1 mA for full-scale deflection. The input impedance to the meter is 6 megohms at audio frequencies, 40 megohms on the 1,000-volt dc range, and 20 megohms on all other ranges. The power requirement is 98 to 132 volts, single phase, 50 to 1,000 Hz, at about 21 volt-amperes.

The removable cover of the TS-505 contains accessories such as alligator clips, an RF adapter, and miniature probe tips. The miniature tips slip over the regular tips for work in confined areas.

Operating Controls

The following are the controls you use when operating the meter (fig. 8-9):

- FUNCTION switch—Selects the type of multimeter operation desired and turns the multimeter on or off.
- RANGE switch—Selects the various voltage or resistance measurement ranges.
- ZERO ADJ. control—Controls the pointer of the indicating meter. Use it to set the meter pointer at zero on the +DC, –DC, AC, or OHM scale, or at midscale on the ±DC scale.
- OHMS ADJ. control—Controls the pointer of the indicating meter. Use it to set the meter pointer at ∞ on the OHMS scale when the FUNCTION switch is set on OHMS position.
- Meter—Indicates the value of voltage or resistance measured.
- AC LINE cord—Connects the multimeter to the ac power source.
- COMMON probe—Connects the ground or common circuit of the multimeter to the equipment under test.
- DC probe—Connects the equipment under test to the dc measuring circuit of the multimeter
- OHMS probe—Connects the equipment under test to the ohmmeter circuit of the multimeter
- AC probe—Connects the equipment under test to the ac measuring circuits of the multimeter.
- Pilot light indicator—Lights when power is applied to the multi meter.

Techniques for Use

The TS-505 multimeter is not difficult to operate. However, do not try to use this instrument unless you have studied the technical manual that contains the operating procedures, or unless you have received instruction in its proper use from your shop supervisor. There are two peculiarities of this meter that you need to know about.

1. It must warm up before it gives accurate readings. This usually takes about 10 minutes. During this period, the meter pointer may drift rapidly. This is normal.
2. You cannot read voltage measurements directly off the meter scale when the function switch is in the ±DC position. The purpose of the ±DC position (zero center scale) is to determine the polarity of an unknown dc voltage. It also indicates a zero dc voltage input to the multimeter

CAUTION

The maximum input dc voltage to the multimeter when in the ±DC position is one-half of the range switch voltage setting.

The major difference between any VTVM and a conventional multimeter is that the VTVM uses a vacuum tube in its input. For a detailed explanation of the circuitry of the TS-505 VTVM, consult the manufacturer's manual or the operation and service instruction manual.

PHASE ANGLE VOLTMETER

The overall accuracy of many electronic equipments is determined by measuring phase angles. In the past, the phase shift or phase angles between signals were measured by observing patterns on an oscilloscope. It was hard to determine small angles and difficult to translate various points into angles and sines of angles using this method. Also, using oscilloscope patterns is

a limiting factor if one of the signals contains harmonic distortion or noise.

In any complex waveform containing a fundamental frequency and harmonics, measuring phase shifts presents problems. In most applications, the primary interest is the phase relationship of the fundamental frequency, regardless of the phase relationship of any harmonics that are present. Therefore, one requirement of a phase-measuring device is its ability to measure the phase difference between two discrete frequencies, regardless of the phase and amplitude of other components of the waveform.

Figure 8-10 shows the basic block diagram of a phase angle voltmeter. There are two inputs—the signal and the reference. Each channel contains a filter that passes only the fundamental frequency and highly attenuates all other frequencies. Each channel has a variable amplitude control and amplifiers to increase the variety of signals that you can check.

A calibrated phase shifter is inserted into one channel. That channel signal can then be phase shifted to correspond to the other channel. The phase detector detects this and indicates it on the meter.

The calibrated phase shifter is a switch (whose position corresponds to the 0-degree, 90-degree, 180-degree, and 270-degree phase shift) and a potentiometer (whose dial is calibrated from 0 to 90 degrees). The total phase shift is the sum of the two readings.

The phase detector is a balanced diode, bridge-type demodular. Its output is proportional to the signal frequency amplitude times the cosine of the angle of phase difference between the signal input and the reference input.

If the shifted reference input is in phase or 180 degrees out of phase with the signal input, the output from the phase detector is proportional to the signal input amplitude. The cosine of the angle is unity. If the shifted reference input is 90 degrees or 270 degrees from the signal input, the phase detector output will be zero (the cosine of the angle is zero).

The point at which the two signals are in phase or 180 degrees out of phase is the point of

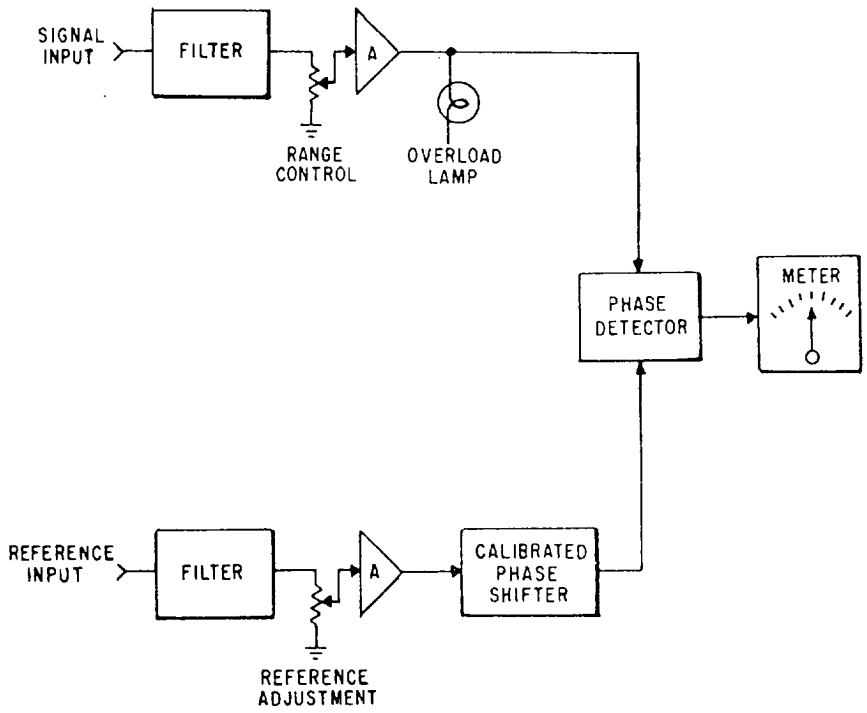


Figure 8-10.-Phase angle voltmeter block diagram.

maximum deflection on the meter. The difference between the in-phase and the 180-degree out-of-phase points is in the direction in which the needle swings—not the distance it swings. Upon approaching the point of maximum deflection, the rate of change of the meter reading decreases because the cosine has a small rate of change near 0 degrees. This makes it difficult to read the exact point of maximum deflection.

The cosine's maximum rate of change occurs as it approaches 90 degrees (and thus gives a better indication on the meter). Therefore, most commercial voltmeters are set to determine the point at which the signals are 90 degrees out of phase, known as *quadrature.* However, this requires converting the phase shifter reading so it shows the correct amount of phase shift rather than 90 degrees more or less than the actual amount.

Different manufacturers use different methods to determine the signal quadrant, which leads to some confusion. Also, manufacturers differ on whether the final reading is a leading or a lagging phase shift. This means that you, the technician, must know the phase angle voltmeter you are using.

The Navy has several phase angle voltmeters and each operates differently. You cannot assume that the method you use to determine the phase angle on one type of meter is the method you should use to determine it on another. Also, you cannot assume that because one meter gives a leading angle between signal and reference waveforms, another meter will also give a leading phase shift.

Q5. What is the most accurate portion of the ohmmeter scale, and why?

Q6. When repairing equipment, you should use a meter with the same sensitivity as specified in schematics and wiring diagrams. What is the reason for doing this?

Q7. Name the piece of test equipment that consists of a hand-driven dc generator, applies a high voltage to the component under test, and measures current leakage.

Q8. Loading effect is the result of a meter's sensitivity, and it causes incorrect voltage indications. What relationship exists between a meter's sensitivity and its loading effect?

Q9. What is the major difference between a VTVM and a conventional multimeter?

Q10. A phase angle voltmeter is used to determine the overall accuracy of electronic equipment by measuring phase angles. What is actually measured by the phase angle voltmeter?

DIFFERENTIAL VOLTMETER

The differential voltmeter is a reliable precision piece of test equipment. Its general function is to compare an unknown voltage with an internal reference voltage and to indicate the difference in their values. A common differential voltmeter is the 883A (fig. 8-11), manufactured by the John Fluke Co. The Fluke 883A has many capabilities and uses. You may use it as

1. a conventional transistor voltmeter for measuring voltages from 0 volt to 1,100 volts dc,

2. a differential voltmeter for precision (0.01 percent of input voltage) measurement of dc voltages in this range, or as

3. an accurate ac voltmeter and a megohmmeter for measuring resistance from 10 megohms to 11,000 megohms.

The Fluke Model 883A is accurate enough for precision work in calibration laboratories yet rugged enough for general shop use. For more information on the Fluke Model 883A, you should refer to NEETS, module 16.

FREQUENCY MEASUREMENT

Often, frequency measurements are an essential part of preventive and corrective maintenance for electronic equipment. You may have to determine rotation frequencies of some mechanical devices. For example, you have to

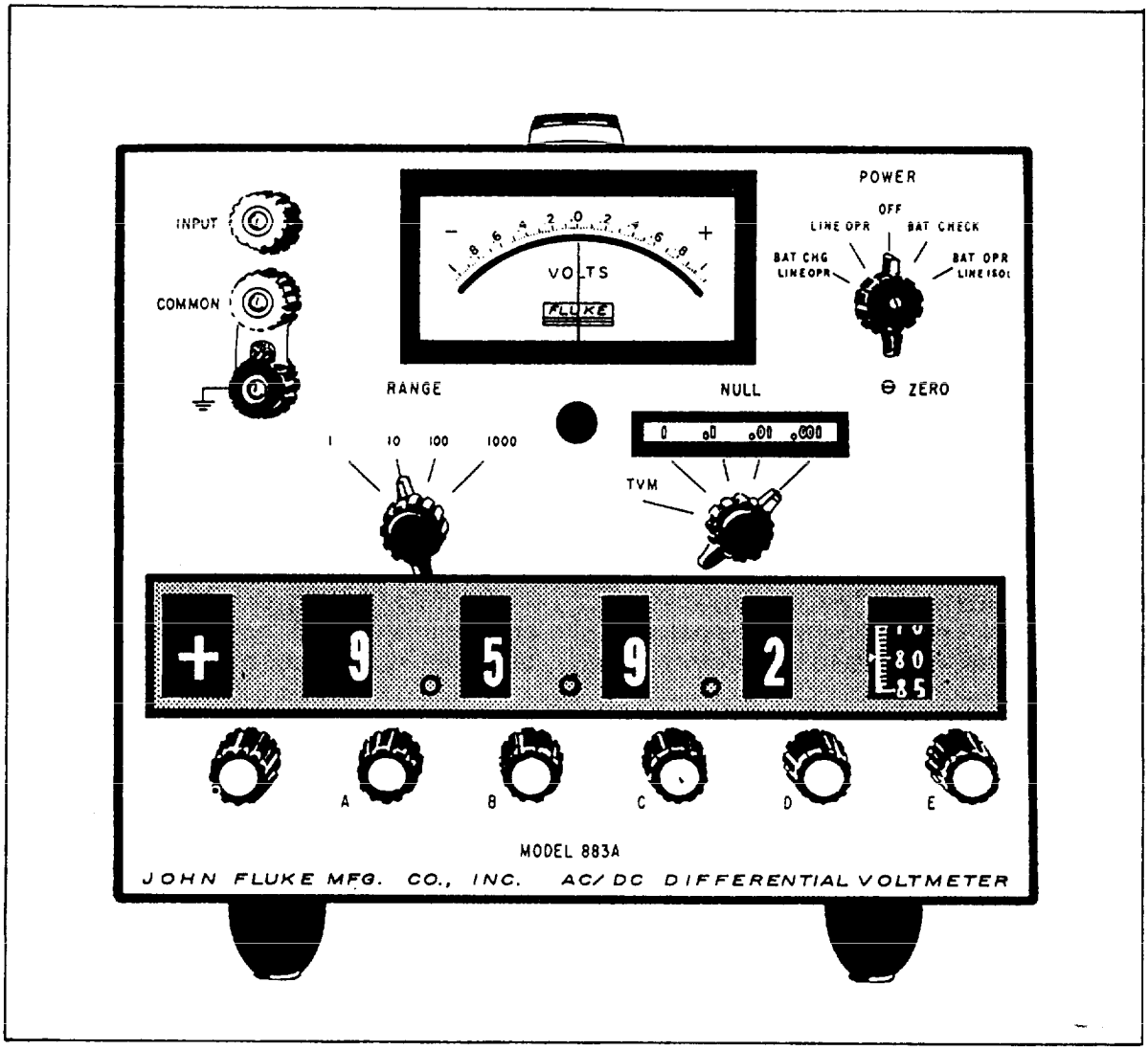


Figure 8-11.-Fluke Model 883A differential voltmeter.

check the output frequency of electric power generators when starting the engine and during preventive maintenance routines. Equipment that operates in the audio-frequency range requires adjusting to operate at the correct frequencies. Accurate tuning of radio transmitters to their assigned frequencies provides reliable communications. Tuning also avoids interfering with radio circuits operating on other frequencies. Radar sets also require proper tuning to get satisfactory performance.

A stroboscope can measure the rotation frequency of rotating machinery such as radar antennas, servomotors, and other types of electric motors. Stroboscopic methods compare the rate of one mechanical rotation or vibration with another or with the frequency of a varying source of illumination. Tachometers can also measure the rotation frequency of armatures in electric motors, dynamotors, and engine-driven generators.

Vibrating-reed, tuned-circuit, or moving-disk meters directly measure the electrical output frequency of ac power generators. The vibrating-reed device is the simplest frequency meter, and it is rugged enough to mount directly on generator control panels. You may also use it to check the line voltage in the shop to be sure the proper

frequency is available to the equipment and/or test sets.

Frequency Meters

The term *frequency meter* refers to an item of test equipment used to indicate the frequency of an external signal. Although some frequency meters generate signals having a basic frequency, you should not confuse them with test equipment known as *signal generators.* The frequency meter measures the frequency of a signal developed in an external circuit.

Some frequency meters generate a signal frequency; others do not. Those that don't generate an internal frequency are known as *wavemeters.* There are two basic types of wavemeters—reaction and absorption. Frequency meters that do generate an internal frequency may use either electronic or mechanical oscillation as the frequency generator.

Measurement Methods

You may make frequency measurements in the audio-frequency range by the comparison method or by using a direct-reading frequency meter. You may make frequency comparisons by use of a calibrated audio-frequency signal generator with either an oscilloscope or a modulator and a zero-beat indicator device. Instruments using series frequency-selective electrical networks, bridge test sets having null indicators, or counting-type frequency meters can make direct-reading frequency measurements.

Since the wavemeter is relatively insensitive, it is very useful in determining the fundamental frequency in a circuit generating multiple harmonics. You may check the calibration of test equipment that measures signals in this frequency range by comparing them with standard frequency signals broadcast by the National Bureau of Standards.

The signal frequencies of radar equipment that operate in the UHF and SHF ranges can be measured by resonant cavity-type wavemeters, resonant coaxial line-type wavemeters, or Lecher-wire devices. When properly calibrated, resonant cavity and resonant coaxial line wavemeters are more accurate. They also have better stability than wavemeters used for measurements in the LF to VHF range. These frequency-measuring instruments often come as part of communication and electronic equipment, but they are also available as general-purpose test sets.

ANSWERS FOR REVIEW QUESTIONS Q5. THROUGH Q10.

A5. The midscale portion of the scale represents the most accurate area because the ohms-calibrated scale is nonlinear.

A6. Because of circuit loading, you should use a meter with the same sensitivity to obtain accurate readings.

A7. Megohmmeter or megger.

A8. The lower the sensitivity of the meter, the greater the loading effect.

A9. The VTVM uses a vacuum tube in its input.

A10. A phase measuring device must measure the phase difference between two discrete frequencies, regardless of the phase and amplitude of other components of the waveform.

Heterodyne Meters

Heterodyne frequency meters are available in several varieties. Although they all function in the same general manner, some differences exist in how they accomplish their purpose.

Test instruments of this class generate a signal within the test set. This signal mixes with a signal from the equipment under test to obtain a beat frequency. The frequency of one signal is then changed to obtain a zero beat. The beat frequency is the difference frequency that results from heterodyning two signals. A zero beat results when heterodyning two signals of the same frequency. You may determine the frequency of the unit under test by reading the frequency indicator of the test set.

A heterodyne frequency meter (fig. 8-12) usually consists of the following parts:

- A heterodyne oscillator
- An RF harmonic amplifier
- A crystal-controlled oscillator
- A mixer or detector
- A modulator
- An AF output amplifier
- A means for indicating frequency

Most models come with a set of calibration charts giving the dial readings for the frequencies listed and a table of the crystal harmonics. The table and charts give complete and accurate frequency coverage over the set's range. Some models indicate the frequency directly on dials.

The crystal-controlled oscillator operates at a fixed frequency. However, it is also capable of emitting various harmonic frequencies of the crystal for use as check frequencies. These checkpoints provide a measure for adjusting the heterodyne oscillator, thus ensuring more accurate operation. Provisions are usually made within the crystal-controlled oscillator for precise adjustment to its assigned fundamental frequency.

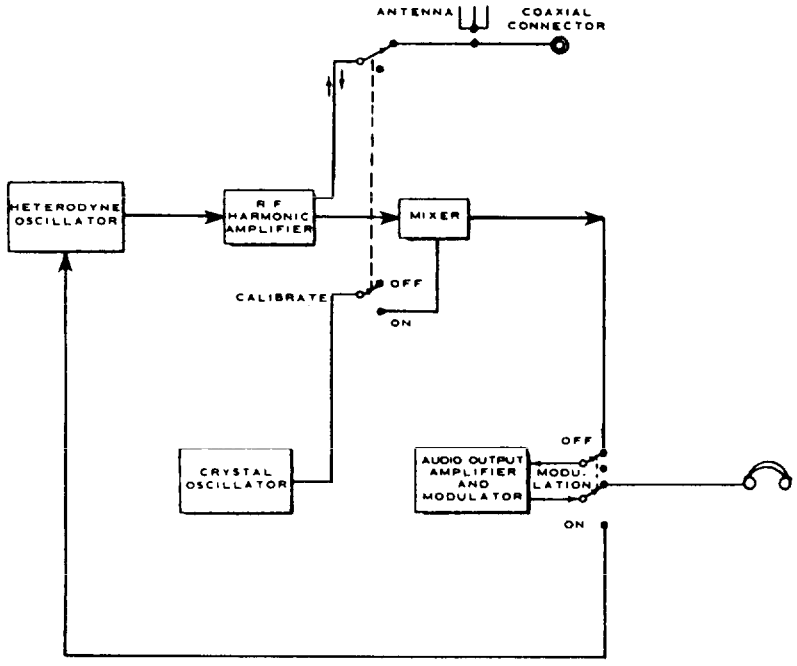


Figure 8-12.-Crystal-calibrated heterodyne frequency meter block diagram.

Wavemeters

Wavemeters are calibrated, resonant circuits used to measure frequency. Although not as accurate as heterodyne frequency meters, wavemeters are comparatively simple and easy to carry.

You may see any type of resonant circuit in wavemeter applications. The exact kind of circuit depends on the frequency range for which the meter is intended. Resonant circuits consisting of coils and capacitors are used with low-frequency wavemeters. VHF and microwave instruments have butterfly circuits, adjustable transmission line sections, and resonant cavities.

There are three basic kinds of wavemeters—the absorption, the reaction, and the transmission types.

The absorption wavemeter consists of the basic resonant circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type of wavemeter loosely couples to the measured circuit. Then, you adjust the resonant circuit of the wavemeter until the current meter shows a maximum deflection. You determine the frequency of the circuit under test from the calibrated dial of the wavemeter.

The reaction wavemeter gets its name from having to be adjusted until a marked reaction occurs in the circuit being measured. For example, the wavemeter is loosely coupled to the grid circuit of an oscillator, and the tuning circuit of the wavemeter is adjusted until it is in resonance with the oscillator frequency. The setting of the wavemeter dial is made by observing the grid-current meter in the oscillator. At resonance, the wavemeter circuit takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the calibrated dial of the wavemeter. This type is commonly referred to as a *grid-dip* meter.

The transmission wavemeter is an adjustable coupling link. When inserted between a source of radio-frequency energy and an indicator, energy is transmitted. However, energy to the indicator only occurs when the wavemeter is tuned to the frequency of the source. Transmission wavemeters are commonly used to measure microwave frequencies. Units of this type are also found in echo boxes. The additional provisions for echo boxes permit additional testing functions.

Many types of wavemeters are used for various functions. The cavity-type wavemeter (fig. 8-13) is the type most commonly used for measuring microwave frequencies; therefore, it is the one covered in this chapter. The device employs a resonant cavity that effectively acts as

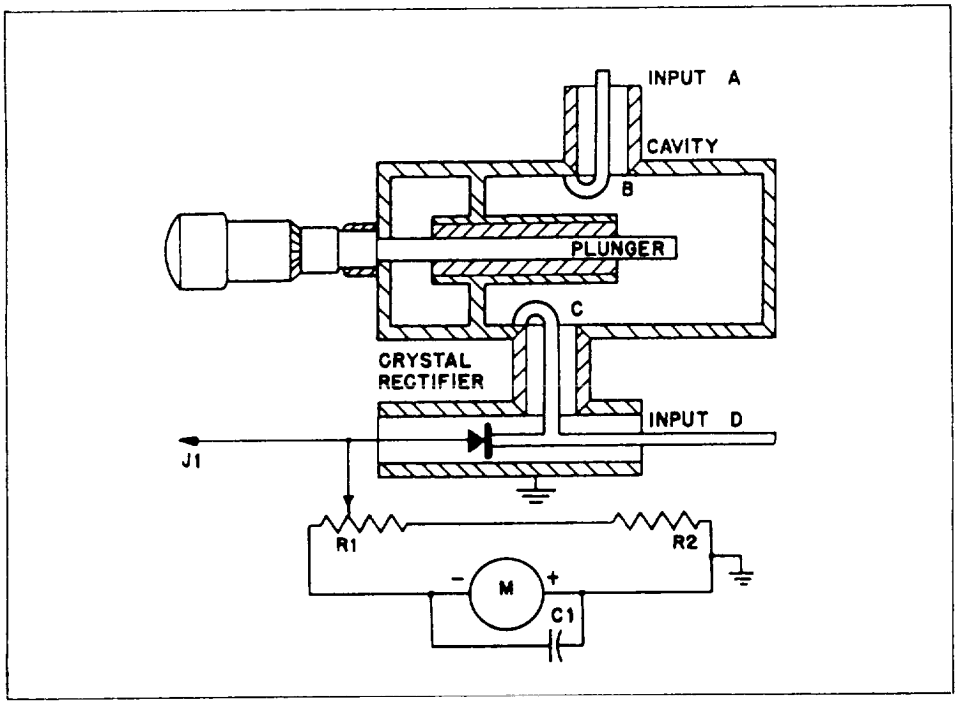


Figure 8-13.-Typical cavity wavemeter.

a high-Q, LC tank circuit. The resonant frequency of the cavity varies by means of a plunger, which mechanically connects to a micrometer mechanism. Movement of the plunger into the cavity reduces the cavity size and increases the resonant frequency. Conversely, an increase in the size of the cavity (made by withdrawing the plunger) lowers the resonant frequency. The microwave energy from the equipment under test goes into the wavemeter through one of two inputs—A or D. The crystal rectifier then detects (rectifies) the signal, and the current meter (M) indicates the rectified current. You can use the cavity wavemeter as either a transmission-type or an absorption-type wavemeter.

When used as a transmission wavemeter, the unknown signal couples into the circuit through the A input. When the cavity is tuned to the resonant frequency of the signal, energy is coupled through coupling loop B into the cavity and out through loop C to the crystal rectifier. It is rectified, and current flow resulting from this rectification is indicated on the meter. At frequencies off resonance, little or no current flows in the detector, and the meter reading is small. Vary the micrometer and attached plunger until you get a maximum meter reading. Compare the resulting micrometer setting with a calibration chart supplied with the wavemeter to determine the unknown frequency.

When the unknown signal is relatively weak, such as the signal from a klystron oscillator, the wavemeter functions as an absorption wavemeter. Connect the instrument at the D input. The RF loop C then acts as an injection loop to the cavity. When the cavity is tuned to the resonant frequency of the klystron, the cavity absorbs maximum energy and the meter will dip. This indicates a reduction of current. When the cavity is not at the resonant frequency of the klystron, the current meter will indicate high current. Therefore, tune the cavity for a minimum reading, or dip, in the meter, and determine the resonant frequency from the micrometer setting and the calibration chart.

Potentiometer R1 adjusts the sensitivity of the meter from the front panel of the instrument. J1 is a video jack for observing video waveforms with a test oscilloscope.

A directional antenna is used with the instrument for making relative field strength measurements of radiated signals for use in measuring the frequency of radar transmitters. This setup is also used for constructing radiation patterns of transmitting antennas.

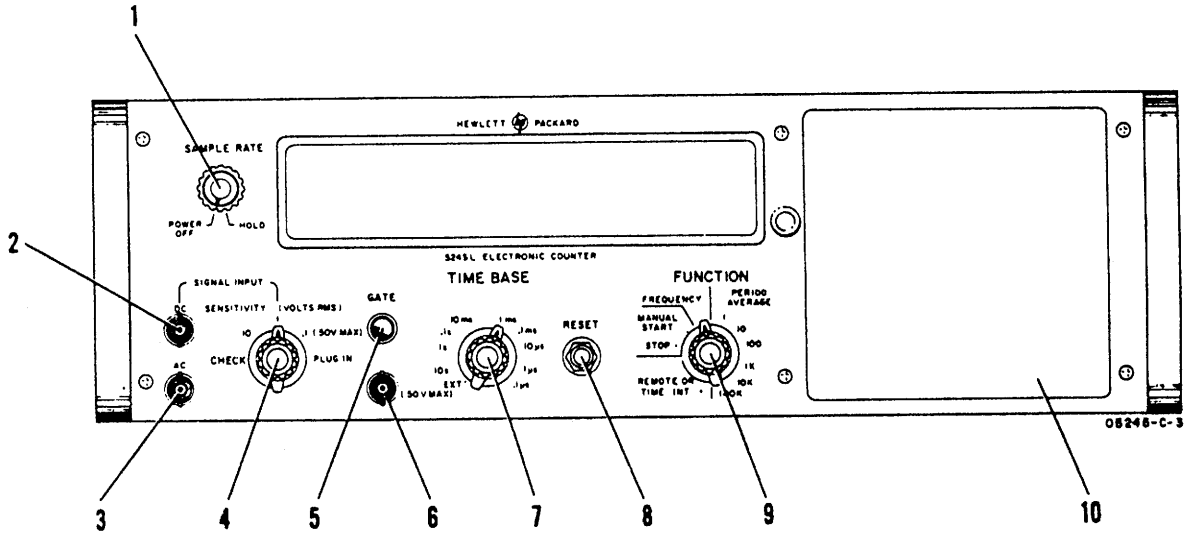
In radiation pattern measurements connect the directional antenna to the wavemeter input and tune the instrument to the frequency of the system under test. The cavity will then lock on this frequency by an automatic frequency control (AFC) system. For reliable results, the output signal must be continuous and constant. This is necessary for any variation in the meter reading caused directly by a change in the actual field strength. That is the signal field strength when the position of the wavemeter changes with respect to the transmitting antenna. After establishing a reference level on the meter, change the position of the wavemeter by moving it around the radiating antenna, maintaining a fixed distance from it. To determine the field pattern, record the wavemeter readings at various positions around the transmitting equipment on polar graph paper.

COUNTER-TYPE FREQUENCY METER

The counter type of frequency meter is a high-speed electronic counter, with an accurate, crystal-controlled time base. This type of combination provides a frequency meter that automatically counts and displays the number of events (hertz) occurring in a precise interval, The frequency meter itself does not generate any signal, it merely counts the recurring pulses fed to it.

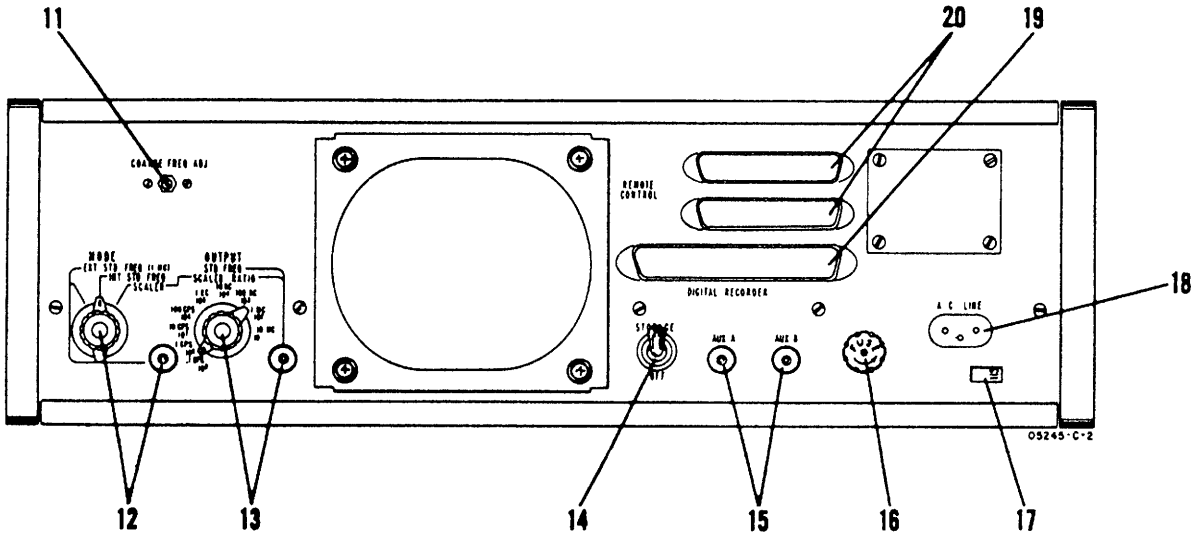
The Hewlett-Packard Model 5245L electronic counter (figs. 8-14 and 8-15) is a high-frequency general-purpose electronic counter. The Model 5245L measures frequencies from 0 to 50 MHz, periods from 1 μsec to 10 seconds, and period averages from 10 to 100,000 periods. Also, it can measure the ratio of two frequencies and the multiplied ratio of two frequencies. The Model 5245L provides the following additional features:

- Decade scaling to 10^9 for any frequency to 50 MHz
- Standard output frequencies from 0.1 Hz to 10 MHz, in decade steps
- Four-line, binary-coded-decimal (BCD) output to drive digital recorder (Hewlett-Packard Model 562A), digital-to-analog converter (Hewlett-Packard Model 580A/581A), remote readout, or data processing equipment
- Remote control by external contact closure



1. SAMPLE RATE
   a. Controls power to all circuits except crystal oven heater; max CCW turns POWER OFF.
   b. Controls time between measurements from 0.1 sec to 5 sec.
   c. Causes display to HOLD indefinitely when maximum CW.
2. DC SIGNAL INPUT provides direct coupling to internal amplifier for most measurements.
3. AC SIGNAL INPUT provides coupling to internal amplifier through 1 μf (600 Vdc maximum).
4. SIGNAL INPUT SENSITIVITY
   a. Controls input attenuator; set to highest position that includes signal amplitude (max overload; 50 V in position 0.1; 150 V in position 1; 500 V in position 10).
   b. Maximum CCW (CHECK position) gives internal self-check; counts 10 Mc with selected TIME-BASE gate for FREQUENCY; 100 kc for number of periods averaged (10 μsec to 1 sec) for PERIOD AVERAGE, or continuously at selected TIME BASE frequency (0.1 cps to 10 Mc) for MANUAL START.
   c. Maximum CW (PLUG-IN position) connects output of plug-in unit directly to input amplifier.
5. GATE lamp glows during counting (main gate open).
6. EXT connector
   a. Provides input for higher of two frequencies for ratio measurement (lower frequency to SIGNAL INPUT) when TIME BASE set to EXT.
   b. Provides output frequency 0.1 cps to 1 Mc as selected by TIME-BASE switch.
7. TIME BASE selects either time that main gate is on for frequency or time unit per count for period measurement.
8. RESET push button returns both displayed and internal count to zero when pressed.
9. FUNCTION
   a. Permits totalizing of pulses applied to SIGNAL INPUT when set to MANUAL START; holds accumulated count when switched to MANUAL STOP.
   b. Permits measurement of frequency applied to SIGNAL INPUT during interval selected by TIME-BASE switch when in FREQUENCY.
   c. Permits period measurement of waveforms applied to SIGNAL INPUT averaged over 1 to 100,000 periods when set to PERIOD AVERAGE.
   d. Removes control of TIME-BASE and FUNCTION switches when set to REMOTE or TIME INT; remote control is provided through rear connector or plug-in unit.

Figure 8-14.-Model 5245L electronic counter front panel.



10. Plug-in compartment
    a. Receives plug-in unit to extend basic counter capabilities. To install plug-in (1) turn power off, (2) loosen knurled screw at side of compartment, (3) remove blank panel or plug-in unit, (4) slide desired plug-in unit into place and tighten knurled screw.
    b. Permits access to fine and medium frequency controls through panel at rear of compartment; FINE FREQ ADJ has range of about 5×10^{-8}; MED FREQ ADJ has range of about 1×10^{-6}.
11. COARSE FREQ ADJ permits adjustment of oscillator over a range of about 1×10^{-5}.
12. MODE
    a. Permits use of external 1-Mc frequency standard for time-base control when set to EXT STD FREQ (1 MC).
    b. Permits normal operation of counter using internal oscillator when set to INT STD FREQ.
    c. Permits scaling of input signal by factors of 10 when set to SCALER.
13. OUTPUT
    a. Supplies selected frequency when MODE is set to INT STD FREQ.
    b. Supplies scaled input frequency when MODE is set to SCALER.
14. STORAGE switch provides display storage when up; continuous display of internal count when OFF (down).
15. AUX A/AUX B (TIME INTERVAL TRIGGER OUT - START/STOP). Auxiliary plug-in outputs.
16. Fuse provides overload protection; should be 2 ampere slow-blow for 115-volt operation; 1 ampere slow-blow for 230-volt operation.
17. Line-voltage switch permits selection of either 115- or 230-vac line; insert narrow blade and slide to left for 115 V, slide to right for 230 V.
18. AC LINE connector connects to flat plug on power cable.
19. DIGITAL RECORDER connector supplies BCD information to recorder, analog converter, or data processing equipment.
20. REMOTE CONTROL connectors permit connection to remote location for control of all front-panel switch functions except SENSITIVITY and SAMPLE RATE.

Figure 8-15.—Model 5245L electronic counter rear panel.

- Display storage that permits reading display while making a new count
- Eight-digit display using rectangular (narrow) digital display tubes, with decimal point position and measurement units displayed automatically
- Operation with plug-in units that extend the basic range and performance of the counter

The Model 5245L features solid-state design, low-power consumption, small size (5 1/4-inch panel height), light weight (32 pounds), easy conversion for rack mounting, and modular plug-in circuit boards for simplified maintenance. To increase the range of measurement, five plug-in units (not shown) are available.

The Model 5245L measures frequency, period average, ratio of two frequencies, and total events. A FUNCTION selector switch selects measurement function, and a TIME BASE selector switch selects time base or multiplier. A SAMPLE RATE control selects the sampling rate, and a SENSITIVITY control adjusts instrument sensitivity.

Direct readout is available in both PERIOD and FREQUENCY functions with measurement units displayed and with decimal point automatically positioned. In the MANUAL function the display is a direct read. The decimal point will not light. Note that the only difference between ratio and period measurements is the use of an external frequency instead of the internal 1-MHz oscillator.

Two factors determine the basic counter accuracy, One factor is the aging rate of the 1-MHz crystal standard in the time base, which is less than 2 parts in 10^9 per week. A second factor is the inherent error of ±1 count present in all counters of this type. This error is due to phasing between the timing pulse that operates the electronic gate and the pulses that pass through the gate to the counters. The chart in figure 8-16 shows the errors possible for frequency or period measurements,

The three factors contributing to the accuracy of period measurements are as follows:

1. The aging rate of the l-MHz standard, which is less than 2 parts in 10^8 per week
2. The ambiguity of the ±1 count
3. The ± trigger error (for one period, and a signal-to-noise ratio of 40 dB, this trigger error is 0.3 percent at rated sensitivity)

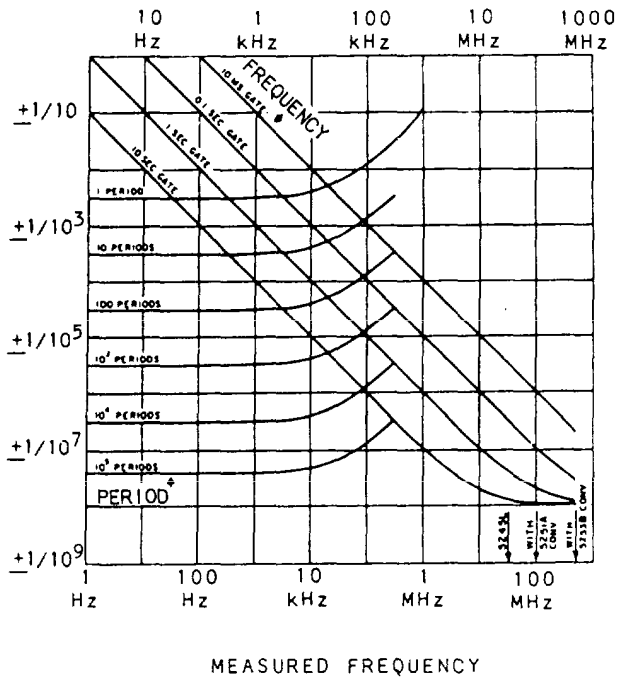


Figure 8-16.-Model 5245L electronic counter measurement accuracy.

Frequencies of 0.1 Hz to 1 MHz are available in decade steps at the TIME BASE EXT connector as selected by the TIME BASE switch. This output is subject to the following restrictions,

Frequencies of 0.1 Hz through 10 MHz are available in decade steps at the rear-panel OUTPUT connector as selected by the rear-panel OUTPUT switch. This output is subject to the following restrictions.

All frequencies are available one at a time in the MANUAL function without interruption. 1 kHz is continuously available for all functions except 100K PERIOD AVERAGE. The 10 kHz to 10 MHz is continuously available in all functions.

NOTE: The accuracy and stability of these outputs are the same as those of the time base oscillator.

The Hewlett-Packard Model 525 1A frequency converter extends the frequency range of the Model 5245L to 100 MHz. The Model 5251A mixes a selected 10-MHz harmonic (between 20 and 90 MHz) with the input signal. The resulting difference-frequency signal receives amplification and goes to the basic counter for counting and display. Because the selected 10-MHz harmonic

is from a harmonic generator driven by a 10-MHz output from the basic counter, the stability and accuracy of the basic counter remains.

The Hewlett-Packard Model 5253B frequency converter extends the frequency range of the Model 5245L to 512 MHz. To retain the stability and basic accuracy, multiply a 10-MHz signal, from the counter's internal time base, to a known harmonic frequency. When this harmonic frequency mixes with the input signal frequency, the difference frequency that results is within the range of the basic counter, and the counter displays the difference frequency.

The Hewlett-Packard Model 5254A frequency converter provides the Model 5254L with a frequency range from 300 to 3,000 MHz. To retain the stability and accuracy of the basic counter, use a 50-MHz multiple of the crystal-oscillator signal from the counter to beat with the measured signal. The difference frequency produced is within the display range of the basic counter. The converter has an indicator that aids in frequency selection and indicates the output level to the counter. The required input signal level is 50 mV rms to 1 V rms. The input connector is a type N female.

The Hewlett-Packard Model 5261A video amplifier unit extends the sensitivity of the Model 5245L to 1.0 millivolt over the frequency range of 10 Hz to 50 MHz. Input impedance increases to 1 megohm and can increase to 10 megohms by using an accessory 10:1 divider probe (Hewlett-Packard 10003A) for signals greater than 10 mV. A 50-ohm output is used for oscilloscope monitoring of the amplified signal.

The Hewlett-Packard Model 5262A time interval unit provides start and stop pulses. These pulses start by electrical inputs to the main count gate in the Model 5245L, enabling it to make time measurements. Time intervals from 1 microsecond to 10^8 seconds are measured with a resolution of 0.1 microsecond. Basic counter accuracy remains when the signal counted is from the internal oscillator.

Q11. Describe the general function of a differential voltmeter.

Q12. What item of test equipment is used to indicate the frequency of an external signal?

Q13. List the parts of most heterodyne frequency meters.

Q14. Wavemeters are calibrated resonant circuits used to measure frequency. List the three basic kinds of wavemeters.

Q15. Of the three basic wavemeters, which one is commonly used to measure microwave frequencies?

Q16. The counter frequency meter is a high-speed electronic counter, with an accurate, crystal-controlled time base. What does this combination provide?

Q17. What does the Model 5245L counter frequency meter measure?

POWER MEASUREMENTS

You must check the power consumption and the input and output signal power levels of electronic equipment. It is easy to determine dc power; the unit of power (the watt, P) is the product of the potential in volts (E) and the current (I) in amperes, or, P = IE. You can take a few basic circuit measurements and compute the power using Ohm's law.

It is not as easy to determine ac power. To make ac power measurements, you must consider the phase angle of the voltage and current. Measurement is further complicated by the frequency limitations of various power meters. If there is no phase difference, compute ac power in the same manner as dc power—by determining the average value of the product of the voltage and current.

Electric power at a line frequency of approximately 60 Hz is directly measured by a dynamometer type of wattmeter. This type of meter indicates the actual power. Therefore, the phase angle of the voltage and current does not have to be determined. Normally, the exact power consumption of equipment is not necessary for maintenance, and a current measurement is enough to decide whether the power consumption is within reasonable limits.

Many ac voltmeters have scales calibrated in decibels (dB) or volume units. Such meters are used to make measurements where direct indication in decibels is desired. Remember, these are voltmeters and that power measurements are not meaningful unless the circuit impedance is known. The topic of decibels is discussed in chapter 1 of *Aviation Electronics Technician 3,* NAVEDTRA 14028, NEETS, modules 11 and 16, and in the *Electronics Installation & Maintenance*

Book Test Methods and Practices, NAVSHIPS 0967-LP-000-0130. For more information on decibels, refer to these publications.

At radio frequencies below the UHF range, power is usually determined by voltage, current, and impedance measurements. One common method used to determine the output power of RF oscillators and radio transmitters consists of connecting a known resistance to the equipment output terminals. After measuring the current flow through the resistance, you then calculate the power as the product of I^2R. Since the power is proportional to the current squared, the meter scale can indicate power units directly. A thermocouple ammeter is used to measure RF current. The resistor used to replace the normal load is of special design. It has to have low reactance and the ability to dissipate the required amount of power. Some common names for such resistors are *dummy loads* or *dummy antennas*.

In the UHF and SHF portions of the RF spectrum, it is more difficult to accurately measure voltage, current, and impedance. These basic measurements may change greatly at slightly different points in a circuit. Also, small changes in the placement of parts near the tuned circuits may affect their measurements. Test instruments that convert RF power to another form of energy, such as light or heat, can measure the power output of microwave radio or radar transmitters indirectly. One method measures the heating effect of a resistor load on a stream of passing air. To achieve accurate measurement of large magnitude power, you can measure the temperature change of a water load. The most common type of power meter for use in this frequency range uses a bolometer. The bolometer is a loading device that undergoes changes of resistance as changes in the power dissipation occur. Measure the resistance before and after applying RF power; the change in resistance determines the power.

The Model 432A power meter operates with Hewlett Packard (HP) temperature-compensated thermistor mounts, such as the 8478B and 478A coaxial and 486A waveguide series. The frequency range of the 432A with these mounts in 50-ohm coaxial systems is 10 MHz to 18 GHz. Its frequency range in waveguide systems is 2.6 GHz to 40 GHz. Full-scale power ranges are 10 microwatts to 10 milliwatts (-20 dBm to +10 dBm). The total measurement capacity of the instrument is divided into seven ranges, selected by a front-panel RANGE switch (fig. 8-17).

The COARSE ZERO and FINE ZERO controls zero the meter. Zero carry-over from the most sensitive range to the other six ranges is within ±0.5 percent. When setting the RANGE

A11. Its general function is to compare an unknown voltage with an internal reference voltage and to indicate the difference in their values.

A12. Frequency meter.

A13. A heterodyne oscillator, RF harmonic amplifier, crystal-controlled oscillator, a mixer or detector, a modulator, an AF output amplifier, and a means for indicating frequency.

A14. Absorption, reaction, and transmission.

A15. Transmission.

A16. A frequency meter that automatically counts and displays the number of events (hertz) occurring in a precise interval.

A17. Frequency, period average, ratio of two frequencies, and total events.

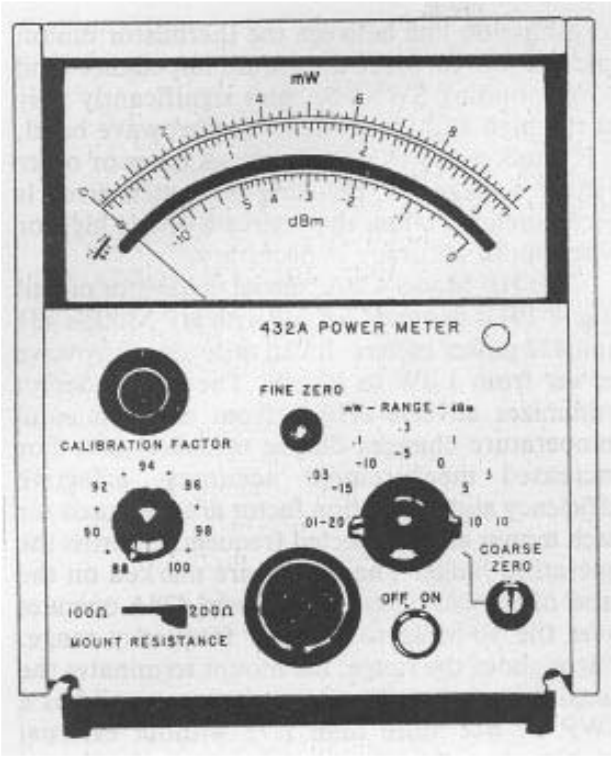


Figure 8-17.—Model 432A power meter front panel.

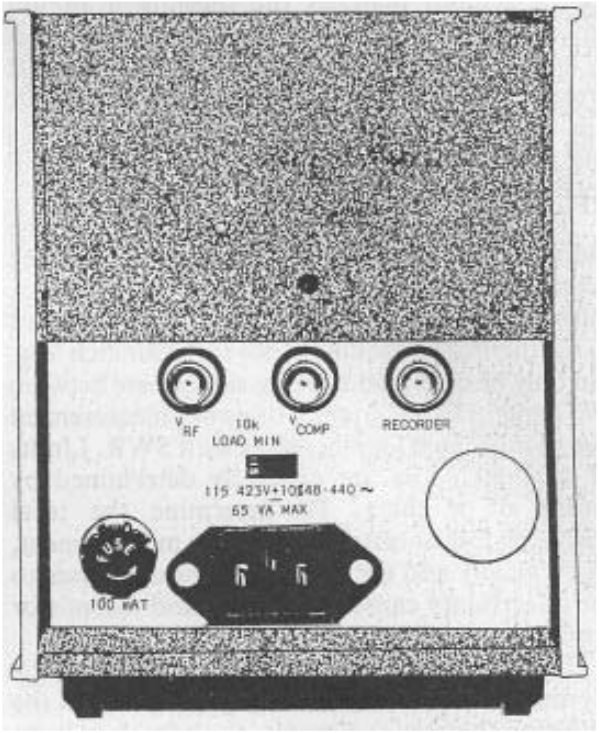


Figure 8-18.-Model 432A power meter rear panel.

switch to COARSE ZERO, the meter indicates thermistor bridge unbalance. Adjust the front panel COARSE ZERO adjust for initial bridge balance. For best results, FINE ZERO the 432A on the particular meter range in use.

The CALIBRATION FACTOR switch provides discrete amounts of compensation for measurement uncertainties related to standing wave ratio (SWR) and thermistor mount efficiency. The calibration factor value permits direct meter reading of the RF power delivered to an impedance equal to the characteristic impedance (Z_o) of the transmission line between the thermistor mount and the RF source. The label of each 8478B, 478A or 486A thermistor mount contains calibration factor values.

The MOUNT RESISTANCE switch on the front panel compensates for three types of thermistor mounts. You can use Model 486A waveguide mounts by setting the MOUNT RESISTANCE switch to 100 or 200Ω, depending on the thermistor mount. The 200Ω position is for use with Models 478A and 8478B thermistor mounts.

The rear panel *baby N* connector (BNC) labeled RECORDER (fig. 8-18) provides an output voltage that is linearly proportional to the meter current. One volt fed into an open circuit equals full-scale meter deflection. This voltage develops across a 1-kilohm resistor. Therefore, when a recorder with a 1-kilohm input impedance is connected to the RECORDER output, about 0.5 volt will equal full-scale deflection. This loading of the RECORDER output has no effect on the accuracy of the 432A panel meter.

You may connect a digital voltmeter to the rear panel RECORDER output for more resolution of power meter readings. When connecting a voltmeter with an input impedance greater than 1 megohm to the RECORDER output, 1 volt equals full-scale deflection.

The 432A has two calibration jacks (V_{RF} and V_{COMP}) on the rear panel. You can use them for precision power measurements. Instrument error can be reduced from ±1 percent to ±0.2 percent of reading +5 µW. This depends on the care taken when measuring and on the accuracy of auxiliary equipment.

Some factors affect the overall accuracy of power measurement. The major sources of error are mismatch error, RF losses, and instrumentation error.

In a practical measurement situation, both the source and thermistor mount have SWR, and the

source seldom matches the thermistor mount unless using a tuner. The amount of mismatch loss in any measurement depends on the total SWR present. The actual thermistor mount impedance, the electrical length of the line, and the characteristic impedance of the line (Z_o) will determine the impedance that the source sees.

In general, neither the source nor the thermistor mount has Z_o impedance, and the actual impedances are only reflection coefficients, mismatch losses, or SWR. The power delivered to the thermistor mount, hence the mismatch loss, can only be described as being somewhere between two limits. The uncertainty of power measurement due to mismatch loss increases with SWR. Limits of mismatch loss are generally determined by means of a chart. To determine the total mismatch loss uncertainty in power measurement, algebraically add the thermistor mount losses to the uncertainty caused by source and thermistor mount Z_o match.

RF losses account for the power entering the thermistor mount but not being dissipated in the detection thermistor element. Such losses may be in the walls of a waveguide mount or in the center conductor of a coaxial mount. Losses may also be from the capacitor dielectric, poor connections within the mount, or be due to radiation.

The degree of inability of the instrument to measure the substitution power supplied to the thermistor mount is called *power meter accuracy* or *instrumentation error*. Instrumentation error of the Model 432A is ±1 percent of full scale, 0°C to +55°C.

Calibration factor and effective efficiency are correction factors for improving power measurement accuracy. Both factors are marked on every HP thermistor mount. The calibration factor compensates for thermistor mount VSWR and RF losses whenever connecting the thermistor mount to an RF source without a tuner. Effective efficiency compensates for thermistor mount RF losses when using a tuner in the measurement system.

Set the 432A CALIBRATION FACTOR selector to the appropriate factor indication on the thermistor mount. This resulting power indicates the power that would go from the source to a load impedance equal to Z_o. The calibration factor does not compensate for source VSWR or for multiple reflections between the source and the thermistor mount.

You can minimize mismatch between the source and the thermistor mount without a tuner. Insert a low SWR precision attenuator in the transmission line between the thermistor mount and the source. Since the mount impedance (and corresponding SWR) deviates significantly only at the high and low ends of a microwave band, it is unnecessary to use a tuner. A tuner or other effective means of reducing mismatch error is recommended when the source SWR is high or when more accuracy is necessary.

The HP Model 478A coaxial thermistor mount (fig. 8-19) is designed for use with HP Models 431 and 432 power meters. It can measure microwave power from 1 µW to 10 µW. The mount design minimizes adverse effects from environmental temperature changes during measurement. For increased measurement accuracy, effective efficiency and calibration factor are measured for each mount and at selected frequencies across the operating range. The results are marked on the label of the instrument. The Model 478A operates over the 10-MHz to 10-GHz frequency range. Throughout the range, the mount terminates the coaxial input in a 50-ohm impedance and has a SWR of not more than 1.75 without external tuning.

Each mount contains two matched series pairs of thermistors, which cancel the effects of drift with ambient temperature change. Thermal stability is accomplished by mounting the leads of all four thermistors on a common thermal conductor to ensure a common thermal environment. This conductor is thermally insulated from the main body of the mount. The thermal insulation makes sure thermal noise or shocks applied externally to the mount, such as those



Figure 8-19.-Model 478A thermistor mount.

from handling the mount manually, cannot significantly disturb the thermistor. The thermal immunity lets the thermistors be used to measure microwave power down to the microwatt region.

Q18. By what method is dc power determined?

Q19. You use a resistor that is specially designed to dissipate the required amount of power and replace normal loads. List the two types of resistors used for this purpose.

Q20. List the major sources of error that affect the overall accuracy of power measurements.

SEMICONDUCTOR TESTERS

Since semiconductors have replaced vacuum tubes, the testing of semiconductors is vital. In this section, three basic types of equipment are discussed—the Huntron Tracker 1000, Huntron Tracker 2000, and the Automatic Transistor Analyzer Model 900 in-circuit transistor tester.

Huntron Tracker 1000

You will test components with Huntron Tracker 1000 using a two-terminal system, where two test leads attach to the leads of the component under test. The 1000 tests components in-circuit, even when there are several components in parallel. The following types of devices are tested using the Huntron Tracker 1000:

- Semiconductor diodes
- Bipolar and field effect transistors
- Bipolar and MOS integrated circuits (both analog and digital)
- Resistors, capacitors, and inductors

The 1000 is used on boards and systems with **ALL** voltage sources in a power-off condition. A 0.25 ampere signal fuse (F1) connects in series with the channel A and B test terminals. Accidentally contacting test leads to active voltage sources (for example, line voltage, powered-up boards or systems, charged high-voltage capacitors, etc.) may cause this fuse to open, making replacement necessary. When the signal fuse blows, the display shows open circuit signatures, even with the test leads shorted together.

CAUTION

The device to be tested must have all power turned off and have all high-voltage capacitors discharged before connecting the 1000 to the device.

The line fuse (F2) should only open when there is an internal failure inside the instrument. Therefore, you should always locate and correct the problem before replacing F2.

The front panel of the 1000 makes function selection easy. The 1000 uses interlocking push-button switches for range selection. A toggle switch is used for channel selection, and integral LED indicators show the active functions.

The CRT displays the signatures of the parts under test. The display has a graticule consisting of a horizontal axis that represents voltage, and a vertical axis that represents current. The horizontal axis is divided into eight divisions, which lets you estimate the voltage at which signature changes occur. This is mainly useful in determining semiconductor junction voltages under either forward or reverse bias.

Push in the power on/off switch. The 1000 should come on line with the power LED illuminated.

Before you can analyze signatures on the CRT, you must focus the 1000. To do this, turn the intensity control to a comfortable level. Now, adjust the focus control (back panel) for the narrowest possible trace. Aligning the trace is important in determining the voltages at which changes in the signature occur. With a short circuit on channel A, adjust the horizontal control until the vertical trace is even with the vertical axis. Open channel A and adjust the vertical control until the horizontal trace is even with the horizontal axis. Once set, you should not have to adjust these controls during normal operation.

Turn the power off by pushing the power switch in. When you turn the power on again, the same intensity setting will be present.

The 1000 has three impedance ranges—low, medium, and high. To select these ranges, press the appropriate button on the front panel. Always start with the medium range; then you can adjust for other ranges. If the signature on the CRT is close to an open (horizontal trace), try the next higher range for a more descriptive signature. If the signature is close to a short (vertical trace), try the next lower range.

There are two channels (channel A and channel B) that you can select by moving the

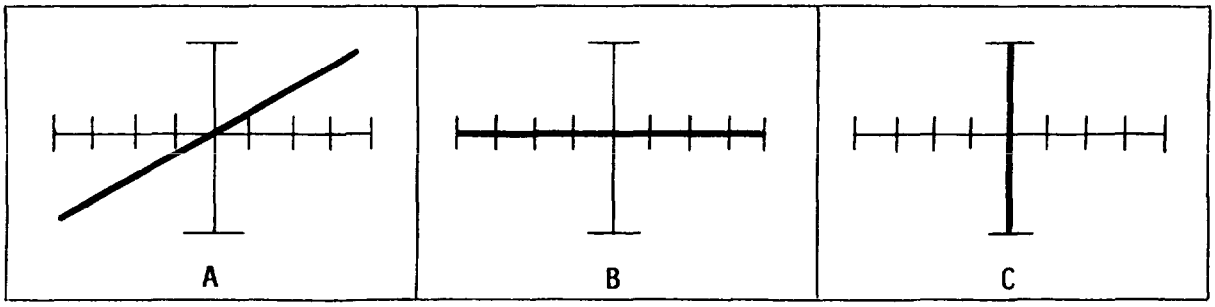
toggle switch to the desired position. When using a single channel, plug the red probe into the corresponding channel test terminal. Then plug the black probe into the common test terminal. When testing, connect the red probe to the positive terminal of the device (that is, anode, +V, etc.). Connect the black probe to the negative terminal of the device (that is, cathode, ground, and so forth.). By following this procedure, the signature will appear in the correct position on the CRT display.

The alternate mode of the 1000 provide-s automatic switching back and forth between channel A and channel B. This allows easy comparison between two devices or the same point on two circuit boards. You select the alternate mode by moving the toggle switch to the ALT position. The alternate mode is useful when comparing a known good device with the same device whose quality is unknown.

The signal section applies the test signal across two terminals of the device under test. The test signal causes current to flow through the device and a voltage drop across its terminals. The current flow causes a vertical deflection of the signature on the CRT display. The voltage across the device causes a horizontal deflection of the signature on the CRT display. The combined effect produces the current-voltage signature of the device on the CRT display.

An open circuit has zero current flowing through the terminals and a maximum voltage across the terminals. In the LOW range, a diagonal signature from the upper right to the lower left of the CRT (fig. 8-20, view A) represents an open circuit. In the HIGH and MEDIUM ranges, an open circuit shows as a horizontal trace from the left to the right (fig. 8-20, view B). When you short the terminals together, the maximum current flows through the terminals, and the voltage at the terminals is zero. A vertical trace from the top to the bottom of the CRT graticule in all ranges shows this short (fig. 8-20, view C).

The CRT deflection drivers boost the low-level outputs from the signal section to the higher voltage levels needed by the deflection plates in the CRT. The HORIZONTAL and VERTICAL controls on the front panel adjust the position of the trace on the CRT display.



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Figure 8-20.-Circuit signatures: View A—Low-range open circuit; view B—medium- and high-range open circuit; and view C—all ranges short circuit.

ANSWERS FOR REVIEW QUESTIONS Q18. THROUGH Q20.

A18. The unit of power (the watt, P) is the product of the potential in volts (E) and the current (I) in amperes, written in equation form P = IE.

A19. Dummy loads or dummy antennas.

A20. The major sources of error are mismatch error, RF losses, and instrumentation error.

You use three other CRT controls to adjust the brightness and clarity of the trace—INTENSITY, FOCUS, and ASTIGMATISM. The front panel intensity control is the primary means of adjusting the visual characteristics of the trace. The focus control is on the back panel and is operator adjustable. The astigmatism trim pot is inside the 1000 on the main printed circuit board. The pot is factory adjusted to the correct setting.

Huntron Tracker 2000

The Huntron Tracker 2000 (fig. 8-21) is a versatile troubleshooting tool having the following features:

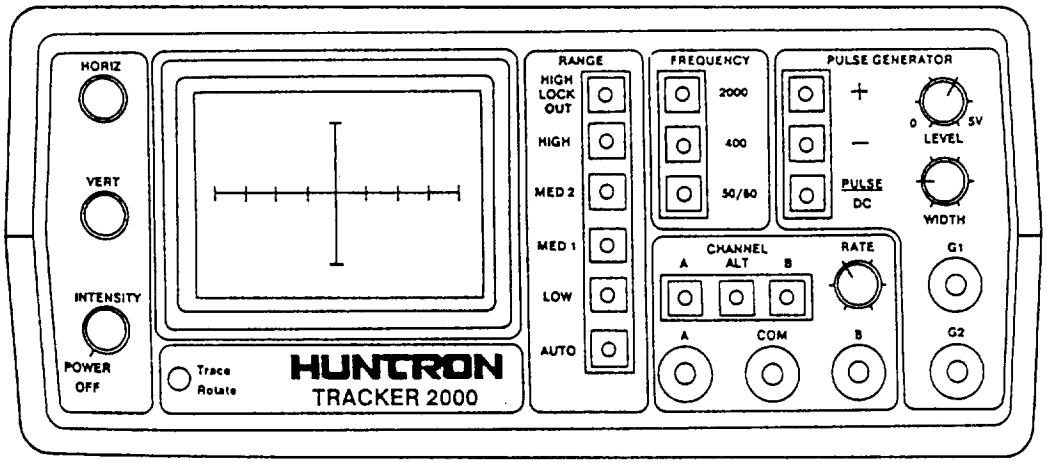
- Multiple test signal frequencies (50/60 Hz, 400 Hz, 2000 Hz)
- Four impedance ranges (low, medium 1, medium 2, high)
- Automatic range scanning
- Range control: high lockout
- Adjustable rate of channel alteration and/or range scanning
- Dual polarity pulse generator for dynamic testing of three terminal devices
- LED indicators for all functions
- Dual channel capability for easy comparison
- Large CRT display with easy to operate controls

GENERAL OPERATION.— You will test components using the 2000 t wo-terminal system. It also has a three-terminal system when using the built-in pulse generator. When using this system, you place two test leads on the leads of the component under test. The 2000 tests components in-circuit, even when there are several parts in parallel.

Use the 2000 only on boards and systems with all voltage sources in a power-off condition. A 0.25 ampere signal fuse connects in series with the channels A and B test terminals. Accidental contact of the test leads to active voltage sources, such as line voltage, powered-up boards or systems, and charged high-voltage capacitors may cause this fuse to open, making replacement necessary. When the signal fuse blows, the 2000 displays short circuit signatures even with the test leads open.

CAUTION

The device under test must have all power turned off and all high-voltage capacitors discharged before connecting the 2000 to the device.

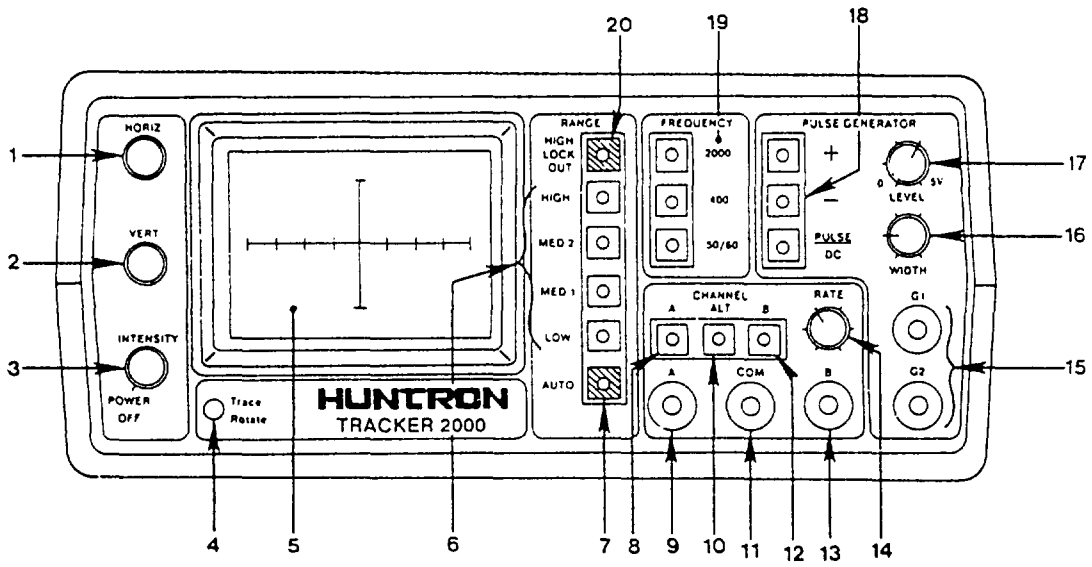


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Figure 8-21.-Huntron Tracker 2000.

Table 8-1.-Front Panel Controls and Connectors

Item No.	Name	Function
1	HORIZ Control	Controls the horizontal position of the CRT display.
2	VERT Control	Controls the vertical position of the CRT display.
3	INTENSITY Control Power On/Off Switch	Controls the intensity of the CRT display. Power Switch: Rotate clockwise to turn on.
4	TRACE ROTATE Control	Controls the trace rotation of the CRT display.
5	CRT Display	Displays the component signatures produced by the 2000.
6	Range Selectors	Push buttons that select one of four impedance ranges: low, medium 1, medium 2, high.
7	AUTO Switch	Push button that initiates automatic scanning of the four ranges from low to high. The scanning speed is determined by the RATE control (see item #14).
8	Channel A Switch	Push button that causes channel A to be displayed.
9	Channel A Test Terminal	Fused test lead connector that is active when channel A is selected. All test lead connectors accept standard banana plugs.
10	ALT Switch	Push button that causes the 2000 to alternate between channel A and channel B at a speed determined by the RATE control (see item #14).
11	COM Test Terminal	Test lead connector that is instrument common and the common reference point for both channel A and channel B.
12	Channel B Switch	Push button that causes channel B to be displayed.
13	Channel B Test Terminal	Fused test lead connector that is active when channel B is selected.
14	RATE Control	Controls the rate of channel alternation and/or range scanning.
15	G1 & G2 Terminals	Pulse generator output test lead connectors.
16	WIDTH Control	Controls the duty cycle of the internal pulse generator.
17	LEVEL Control	Controls the amplitude of the internal pulse generator.
18	Pulse Generator Selectors	Push buttons that select various output modes of the pulse generator: Positive (+), Negative (−), PULSE/DC.
19	Frequency Selectors	Push Buttons that select one of the three test signal frequencies: 50/60 Hz, 400 Hz, 2000 Hz.
20	HIGH LOCKOUT Switch	Push button that activates a mode where it is not possible to enter the high range either by manual or automatic range selection.



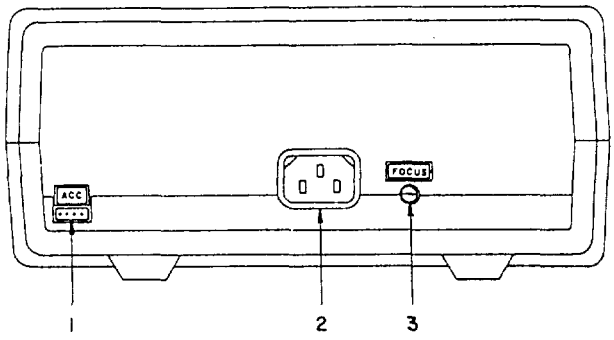
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Figure 8-22.-Front panel.

The line fuse should only open when there is an internal failure inside the instrument. Always locate the problem and correct it before replacing this fuse.

Front Panel.—The front panel of the 2000 makes function selection easy. All push buttons are the momentary action type. Integral LED indicators show which functions are active. Look at figure 8-22 and table 8-1 for details about each item on the front panel.

Back Panel.— Secondary controls and connectors are located on the back panel (fig. 8-23 and table 8-2).



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Figure 8-23.-Back panel.

Table 8-2.-Back Panel Controls and Connectors

Item No.	Name	Function
1	Accessory Output Connector	Connector which provides power and clock to the Huntron Switcher Model HSR410.
2	Power Cord Connector	IEC standard connector that mates with any CEEE-22 power cord.
3	FOCUS Control	Controls the focus on the CRT display.

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CRT Display.— The signature of the part under test is displayed on the CRT. The display has a graticule consisting of a horizontal axis that represents voltage, and a vertical axis that represents current. The axes divide the display into four quadrants. Each quadrant displays different portions of the signatures.

- Quadrant 1 displays positive voltage (+V) and positive current (+I).
- Quadrant 2 displays negative voltage (-V) and positive current (+I).
- Quadrant 3 displays negative voltage (-V) and negative current (–I).
- Quadrant 4 displays positive voltage (+V) and negative current (–I).

The horizontal axis divides into eight divisions, which allows the operator to estimate the voltage at which changes in the signature occur. This is useful in determining semiconductor junction voltages under either forward or reverse bias.

OPERATION OF PANEL FEATURES.— The following section explains how to use the front and back panel features.

Turn the power/intensity knob clockwise. The 2000 comes on with the LEDs for power, channel A, 50/60 Hz, low range, and pulse/DC illuminated.

Focusing the 2000 display is an important part of analyzing the test signatures. First you adjust the intensity control to a comfortable level. Then, adjust the focus control (back panel) for the narrowest possible trace.

Aligning the trace is important in determining which quadrants the portions of a signature are in. With a short circuit on channel A adjust the trace rotation control until the trace is parallel to the vertical axis. Adjust the horizontal control until the vertical trace is even with the vertical axis. Open channel A and adjust the vertical control until the horizontal trace is even with the horizontal axis. Once set, you should not have to readjust these settings during normal operation.

Range Selection.— The 2000 has four impedance ranges—low, medium 1, medium 2, and high. You select these ranges by pressing the appropriate button on the front panel. Start with one of the medium ranges; that is, medium 1 or medium 2. If the signature on the CRT display is close to an open (horizontal trace), select the next higher range for a more descriptive signature, If the signature is close to a short (vertical trace), select the next lower range.

The high lockout feature, when activated, prevents the instrument from entering the high range. This feature works in either the manual or auto mode.

The auto feature scans through the four ranges—three with the HIGH LOCKOUT activated at a speed set by the RATE control. This feature allows you to see the signature of a part in different ranges while freeing your hands to hold the test leads.

Channel Selection.— There are two channels on the 2000-channel A and channel B. You select a channel by pressing the appropriate front panel button. When using a single channel, plug the red probe into the corresponding channel test terminal. Plug the black probe into the common test terminal. When testing, connect the red probe to the positive terminal of the device; that is, anode, +V, etc. Connect the black probe to the negative terminal of the device; that is, cathode, ground, and so forth. Following this procedure should assure that the signature appears in the correct quadrants of the CRT display.

The ALT mode is a useful feature of the 2000. It lets you compare a known good device with a device of unknown quality. In this test mode, you use common test leads to connect two equivalent points on the boards to the common test terminal. The ALT mode of the 2000 allows you to automatically switch back and forth between channel A and channel B so you can easily compare two devices. You may also compare the same points on two circuit boards. Select the ALT mode by pressing the ALT button on the front panel. You may vary the alternation frequency by using the RATE control.

NOTE: The black probe plugs into the channel B test terminal.

When using the alternate and auto features simultaneously, each channel is displayed before the range changes. Figure 8-24 shows the sequence of these changes.

Frequency Selection.— The 2000 has three test signal frequencies—50/60 Hz, 400 Hz and 2000 Hz. You can select these by pressing the appropriate button on the front panel. In most cases, you should start with the 50/60 Hz test

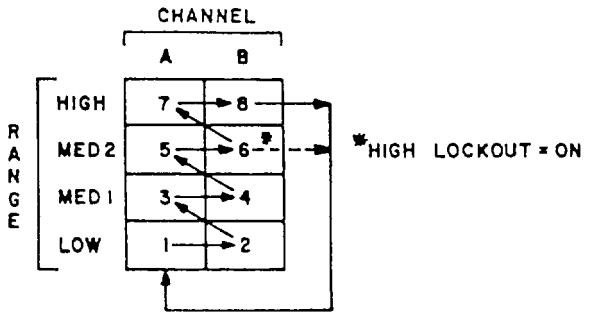


Figure 8-24.-Auto/alternate sequence.

signal. Use the other two frequencies to view small amounts of capacitance or large amounts of inductance.

Pulse Generator.— The built-in pulse generator of the 2000 allows dynamic, in-circuit testing of certain devices in their active mode. In addition to using the red and black probes, you use the pulse generator. The output of the pulse generator connects to the control input of the device under test with one of the blue micro clips provided. The pulse generator has two outputs, G1 and G2, so you can test three terminal devices in the alternate mode.

A variety of output waveforms is available using the pulse generator selector buttons. First select the pulse mode or the dc mode using the PULSE/DC button.

- In the pulse mode, the LED flashes at a slow rate.
- In dc mode, the LED is continuously on.

Then select the polarity of output desired using the positive (+) and negative (–) buttons. All three buttons function in a *push-on/push-off* mode, and only interact with each other to avoid the NOT ALLOWED state.

After selecting the specific output type, set the exact output using the LEVEL and WIDTH controls. The LEVEL control varies the magnitude of output amplitude from zero to 5 volts (peak or dc). During pulse mode, the WIDTH control adjusts the duty cycle of the pulse output from a low duty cycle to 50 percent maximum (square wave). The start of a pulse is triggered by the appropriate zero crossing of the test signal. This results in the pulse frequency being equal to the selected test signal frequency. The WIDTH control setting that selects the duty cycle determines the end of a pulse. The WIDTH control has no effect when in the dc mode.

Troubleshooting Tips

You will use the Huntron Tracker 1000 and the Huntron Tracker 2000 to test various types of devices and circuits. Some troubleshooting tips are given in this section.

- Perform most tests using the medium or low range.
- Use the high range only for testing at a high impedance point, or if higher test voltages are required (that is, to test the Zener region of a 40-volt device).
- Sometimes, component defects are more obvious in one range than another. If a suspect device appears normal for one range, try the other ranges.
- Use the low range when testing a single bipolar junction, such as a diode, a base-emitter junction, or a base-collector junction. It offers the best signature.
- Use a higher range to check for reverse bias leakage.
- When performing in-circuit testing, do a direct comparison to a known good circuit.
- The 1000 test leads are not insulated at the tips, Be sure to make good contact to the device(s) under test. **(NOTE:** This tip pertains to the 1000 only.)

When you troubleshoot, try relating the failure mode of the circuit under test to the type of defect the 1000 shows. For example, expect a catastrophic printed circuit board failure to have a dramatic signature difference from that of a normal device of the same type. A marginally operating or intermittent board may have a failed part that shows only a small pattern difference from normal.

If you cannot relate a system failure to a specific area of the printed circuit board, begin by examining the signatures at the connector pins. This method of troubleshooting shows all the inputs and outputs. It will often lead directly to the failing area of the board.

Devices made by different manufacturers, especially digital integrated circuits, are likely to produce slightly different signatures. This is normal and may not show a failed device.

Remember, leakage current doubles with every 10-degree Celsius rise in temperature. Leakage current shows up as a rounded transition (where the signatures show the change from zero current flow to current flow) or by causing curvature at other points in the signatures. Leakage current causes curvatures due to its nonlinearity.

Never begin the testing of an integrated circuit using the low range. If you initially use the low range, confusion can result from the inability of this range to display the various junctions. Always begin testing using the medium range. If the signature is a vertical line, switch to the low range. Here you can check for a short or low impedance (less than 500 ohms). Switch to the low range if the device is suspect and appears normal in the medium range. This will reveal a defective input protection diode not evident when using the medium range.

NOTE: The 2000 test leads are conductive only at the tips. Be sure to make good contact with the device(s) under test.

When testing analog devices or circuits, use the low range. Analog circuits contain many more single junctions. Defects in these junctions show more easily when using the low range. Also, the 54-ohm internal impedance in the low range makes it less likely that parts in parallel with the device under test will sufficiently load the tester to alter the signature.

When testing an op amp in-circuit, compare it directly to a known good circuit. This is because the many different feedback paths associated with op amps can cause an almost infinite number of signatures.

Often when checking a Zener diode in-circuit, it will not be possible to examine the Zener region due to circuit leakage. If you must see the Zener region under this condition, unsolder one side of the diode to eliminate the loading effects of the circuit.

HUNTRON TRACKER 1000.— Bipolar integrated circuits containing internal shorts produce a resistive signature (a straight line). This line begins in the 10 o'clock to 11 o'clock position. It ends in the 4 o'clock to 5 o'clock position on the display when using the low range. This type of signature is always characteristic of a shorted integrated circuit. It results from a resistive value of 4 to 10 ohms, typical of a shorted integrated circuit. A shorted diode, capacitor, or transistor junction always produces a vertical (12 o'clock) straight line using the low range.

HUNTRON TRACKER 2000.— Bipolar integrated circuits containing internal shorts produce a resistive signature (a straight line) beginning in the 1 o'clock to 2 o'clock position. This signature ends in the 7 o'clock to 8 o'clock position when using the low range. This type of signature is characteristic of a shorted integrated circuit. This results from a resistive value of 4 to 10 ohms. A shorted diode, capacitor, transistor junction, etc., always produces a vertical (12 o'clock) straight line when using the low range.

Automatic Transistor Analyzer Model 900

You can use this instrument to test bipolar transistors and diodes in any one of three different modes. Two modes, the VIS and SND, can be used either in-circuit or out-of-circuit.

- In the VIS mode, red and green lights flashing in or out of phase with the amber light show the condition of the device under test.

- In the SND mode, the Sonalert™ also indicates good devices by beeping out of phase with the amber light. The intent of the SND mode is to permit the operator to perform in-circuit tests on transistors or diodes without having to look at the light display.

- The third mode is the METER mode. You can only use this for out-of-circuit testing. In the METER mode, you may measure Beta, I_{ceo}, I_{cbo}, and material identity. Also, you can measure emitter base voltage, base current (Ib), and collector current (Ic). There are four ranges for the Beta mode—one for small signal transistors, two ranges for medium-power transistors, and one for large-power transistors.

In the VIS mode and the SND mode, the maximum voltage, current and signal levels applied to the device under test are within safe limits. Therefore, the device under test will receive no damage nor will any adjacent circuitry.

This instrument will test transistors and diodes in-circuit in the VIS or SND mode if the total dynamic shunt impedances across the junctions are not less than 270 ohms. Also, the total

dynamic shunt for the emitter to collector must not be less than 25 ohms. If such should occur, the test set will give the indication for a SHORT.

The 8-inch meter, which reads from left to right, has two scales marked 0-10 and 0-50. The 0-10 range is used in the leakage collector current and Vbe (IDENT) modes. The 0-50 range is used in the BETA modes. Notice a mark on the meter just short of half-scale with the nomenclature GERMANIUM and SILICON. This mark is the reference in the IDENT mode. As the meter markings show, those readings below the mark show the device material is germanium. The readings above the mark show the device is silicon. On the slanting horizontal panel immediately in front of the meter face are the appropriate test sockets and two push-button switches. One switch is ZERO and the other BETA. On the vertical front panel immediately below the push-button switches are knobs marked ADJ and CAL. At the top center is the POLARITY switch marked PNP and NPN. In the center of the vertical front panel is the RANGE switch, the FUNCTION switch, and the Sonalert™. Near the bottom of the vertical front panel are the probe jacks. The slide switch for turning the instrument on and off is also in this location.

VIS MODE: TRANSISTOR.— To test transistors with the visual indication only, turn the FUNCTION switch to the XSTR-VIS mode. The amber light should flash at about a 1-second rate. Insert the transistor under test in the proper socket.

In this mode, you perform two tests on the transistor. The amber light shows the performance of each test. When the amber light is out, this is the EB-BC test mode. When the amber light is on, this is the emitter-collector test mode. The test shows good transistors by one pair of similarly colored lights (green for NPN and red for PNP) when the amber light is off. When the amber light is on, no lights show good transistors. The left-hand lights show the condition of the base-collector. The absence of one or all lights in the EB-BC test mode shows an open or opens. The occurrence of both a red and a green light on either side in the EB-BC test mode shows a short.

For more information about the Model 900 tracker, refer to the *Maintenance Manual, All Levels for Automatic Transistor Analyzer Model 900, ST810-AD-0PI-010,* for patterns other than those just discussed. There are 96 possible patterns listed,

VIS MODE: DIODE.— You cannot properly test diodes in the XSTER mode. To test a diode, insert the diode in the proper socket and turn the FUNCTION switch to the DIODE/VIS mode. If the diode is good, a pair of green lights will flash out of phase with the amber. If a pair of red lights flash out of phase with the amber light, the diode is either installed improperly or marked improperly. If the diode has a short, additional lights will flash out of phase with the amber. No lights will flash in phase with the amber.

You cannot properly test transistors in the DIODE mode. When testing transistors, only one transistor should be in the test socket at one time. Do not leave any diodes in the diode socket while testing transistors. When testing diodes, do not leave transistors in the transistors sockets. If you do not observe these precautions and the devices left in the socket are defective, incorrect light indications will occur. These indications may mislead the operator into believing the device under test is defective.

WARNING

Unit being tested must be disconnected from ac outlet, and all capacitors capable of storing electricity should be discharged.

IN-CIRCUIT TESTING.— When testing diodes in-circuit, attach the emitter lead to the anode of the diode. Attach the collector lead to the cathode. When testing transistors, attach the leads to the right terminals as shown by the schematic. If the operator happens to fasten the leads to the transistor in the wrong order, an erroneous display will result. However, if the transistor is good, the instrument will give a good indication. The indication will be for the transistor of the opposite type. A good NPN improperly connected will give good PNP indications and vice versa. If the device is bad, the instrument will give a bad indication. You cannot make a qualitative analysis of the kind of failure unless you attach the proper leads to the correct terminals.

To ensure the instrument will show the correct type of transistor (PNP or NPN), you must identify the base lead. Use the following procedure to identify the base lead:

1. Disconnect the lead to the emitter terminal on the instrument. Only the light representing the emitter junction should go out.
2. Reconnect the emitter lead.

3. Disconnect the lead to the collector terminal of the instrument. Only the light representing the collector junction should go out.
4. Should both lights go out during the tests, the connections are incorrect.
5. Rearrange the leads on the transistor and perform-the tests again. You should now see the proper results.

There are six possible combinations for the connection of these leads. Four of these combinations are incorrect. These will cause the instrument to give an incorrect indication as to transistor type (PNP or NPN). The other two combinations will give proper indications, but you still may not know which leads are the emitter and collector terminals. You will know whether the transistor is good and whether it is an NPN or a PNP transistor. If you must know which leads are the emitter and collector terminals, it is possible to find out after identifying the base lead using the meter mode for Beta.

SND Mode.— In either the XSTR/SND mode or DIODE/SND mode, light patterns showing good devices will have an accompanying beeping sound from the Sonalert™. The beeping will be out of phase with the amber light.

METER Mode.— Before testing a transistor in any of the METER modes, you should test the transistor in one of the visual modes. This will tell you whether the transistor is an NPN or a PNP. After determining this, put the POLARITY switch in the proper position to agree with the indication in the visual mode.

Beta.— To test the Beta of the transistor, set the FUNCTION switch to the BETA position. Next, set the RANGE switch to the appropriate position according to the power capability of the transistor under test. After the RANGE switch is in the proper position, operate the push-button switch marked ZERO. Now adjust the ADJ knob for a zero reading on the meter. Next, actuate the push-button switch marked BETA and adjust the CAL knob for full-scale deflection, Release the BETA push-button switch; now the Beta of the device will show on the meter. Take care in selecting the Beta range to test the transistor. It is possible to damage small signal transistors should you try to test them in the 2 mA Ib (LG. PWR. XSTR) mode.

Leakage: I_{ceo} or I_{cbo}.—To To test a transistor for I_{ceo} or I_{cbo}, set the FUNCTION switch on the proper position. Next, set the RANGE switch to the 100 mA position. Then push the switch marked ZERO and adjust the ADJ knob for a zero reading on the meter. Now release the ZERO button. Set the RANGE switch on the lowest leakage range, which will still permit less than full-scale deflection on the meter. You may now read the leakage directly off the meter. Read the I_{ceo} first and then I_{cbo}. Use this order because the meter will read down scale when switching from I_{ceo} to I_{cbo}. Also, you can increase the meter sensitivity. However, if you read I_{cbo} first and then switch to I_{ceo}, the meter will read up scale. It is now possible to peg the meter. Although the meter has protection, avoid undue abuse.

Material Identity: Transistor.— To use this instrument in the IDENTITY mode, set the FUNCTION switch to IDENT. Check the ZERO ADJUST on the meter as mentioned before. After setting the ZERO, release the ZERO push button. Now note whether the needle reads above or below the mark on the meter face just short of half scale, If the meter reads below the mark, the device is a germanium transistor. If it reads above the mark, it is a silicon transistor. This information can be extremely useful when trying to substitute transistors.

Leakage: Diode. — To test the reverse leakage of diodes, install the diode in the diode socket. You now determine whether the diode is good by testing the device in the visual mode. Once you determine that the diode is good, place the POLARITY switch to NPN. Turn the FUNCTION switch to the I_{ceo} mode, and set the RANGE switch to 100 mA. Now check to see that the meter is at zero, as mentioned before. After zeroing the meter, set the RANGE switch on the lowest range possible that still permits less than full-scale deflection on the meter. Read the leakage on this range.

Material Identity: Diode.— To test the material identity of a diode with the diode properly installed in the socket, place the POLARITY switch in the PNP position (zero the meter) and the FUNCTION switch in the IDENT position. Using the leads, short the base and collector terminals together. The meter will show either germanium or silicon as described before in the IDENT mode for transistors.

CAUTION

Do not identity test transistor material with the base and collector leads shorted together. This may create an erroneous reading.

Model 109 Probe

The Model 109 probe, used with the Model 900 tester, is easy to use, having one-hand operation. It automatically adjusts to any spacing between one-thirty second inch to five-eighths inch. You can rotate each probe point in a full 360-degree circle. The points are individually spring loaded for proper contact. You can connect the probe to three printed circuit board terminations. The probe has the extremely low contact resistance of less than .005 ohm. The use of the probe eliminates unsoldering while making in-circuit tests of transistors, diodes, ICs, and other components. Finally, the retractable cord stretches to a full 12 feet.

DESCRIPTION.— The Model 109 three-point probe speeds servicing of printed circuit assemblies that have transistors, diodes, and most other board-mounted components. You can make instant connections to three points on a printed circuit board. You will make rapid evaluation of transistors using the Model 109 probe with the Model 900 automatic transistor analyzer in-circuit. You can accomplish a complete test of all stages in a piece of electronic equipment in a matter of minutes. You can also use the Model 109 to make temporary component substitutions on the printed circuit board.

OPERATION.— Connect the leads of the Model 109 probe to an appropriate piece of test equipment. Determine the connection points on the printed circuit board to connect to the test equipment. Apply the Model 109 probe points to the circuit board. Press the probe toward the board to ensure a good connection. The Model 109 probe green point is slightly shorter than the yellow and blue probe points. This allows connection of the collector and emitter before the base to provide maximum ease of use.

The Model 109 probe is a valuable aid when making resistance and voltage measurements using a conventional VOM or VTVM. Use the yellow and blue probe points as the negative and positive meter feeds. You can make rapid evaluations of entire circuits faster than with any other method because each point pierces through conventional resist coatings and solder residues.

Q21. The Huntron Trackers 1000 and 2000 are for use on circuit boards and systems with all voltage sources in what condition?

Q22. What mode on the automatic transistor analyzer Model 900 has the Sonalert™?

Q23. What type signal display does the Huntron Trackers 1000 and 2000 show when the signal fuse is open and the test leads shorted together?

Q24. When using the Huntron Tracker 2000, why must you make good contact with the test leads?

Q25. What is the minimum total shunt impedance across the junction of the diode or transistor under test using the automatic transistor analyzer Model 900 to ensure a good test reading?

SIGNAL GENERATORS

Learning Objective: *Recognize characteristics and identify the uses of signal generators to include frequency-modulated and pulse-modulated signal generators.*

Standard sources of RF energy are used to maintain airborne electronic equipment. These energy sources are called *signal generators.* The principal function of the signal generator is to produce an alternating voltage of the desired frequency and amplitude. The generated signal may be modulated or unmodulated, depending on the test or measurement in question. When using the signal generator, the output signal couples into the circuit under test. You trace its progress through the equipment by using a high-impedance device such as a VTVM or an oscilloscope.

RF SIGNAL GENERATORS

Radio-frequency signal generators comprise a rather large and very useful class of test equipment. Because of the extremely wide frequency range in the RF region of the spectrum, many signal generators, with different RF ranges

as well as other instrument refinements, are available.

FREQUENCY-MODULATED RF SIGNAL GENERATORS

Many types of frequency-modulated (FM) signal generators are available for your use; however, some are used for special applications. The following discussion of FM generators provides basic information that applies to most FM generators.

An FM signal is one in which the output frequency varies above and below a center frequency. The overall frequency variation is known as the *frequency swing* (or *deviation).* The rate at which this swing recurs is controllable at any audio- or video-frequency rate for which the generator is capable. The frequency change of the output is accomplished by the mechanical variation of either the capacitance or inductance of the oscillator circuit or by the use of a reactance tube connected to the oscillator circuit. In the latter case, changes of the voltage impressed on the grid of the reactance tube change the amount of reactance introduced into the oscillator-tuned circuit. As a result, it causes the output frequency to change. The frequency of the signal on the grid of the reactance tube thereby controls the rate of frequency deviation. The amplitude of the signal voltage controls the amount of the deviation.

A sweep generator is a form of an FM signal generator. Its carrier deviation is adjustable by a sweep-width control. The sweep generator differs from the ordinary FM signal generator because it maintains the rate of carrier deviation at a fixed frequency. The voltage used to effect the deviation is either a sine wave or a sawtooth waveform. You use an oscilloscope to observe the patterns formed when the passband of interest is swept by this type of generator. The oscilloscope time base must use (or be synchronized with) the same waveform used to produce the deviation. The horizontal (or time) axis of the pattern represents the instantaneous frequency of the generator output. The vertical axis shows the response characteristic of the circuit under test for each frequency. Sweep generators are widely used for observing the response characteristics and the visual alignment of tuned circuits. The sweep generator is used to check the bandwidth of IF amplifiers used in radar receivers.

Deviation of the carrier may occur either electromechanically or electronically. The electromechanical method consists of mechanically varying the capacitance or the inductance of the oscillator tank circuit, causing the frequency to vary accordingly. The electronic method makes use of a reactance-tube modulator.

A sweep generator produces patterns containing a considerable number of instantaneous frequencies. Marker signals, which are superimposed on the trace, are introduced. These signals orient passband characteristics (or center frequency) of the circuit under test with respect to frequency. The circuit that produces the marker signals may be an integral part of the instrument, or the marker signals may come from an external source.

Most modern frequency-swept signal generators use a reactance-tube method of modulation. Modulation of this type results in greater flexibility. Also, the equipment is lighter and more compact than rotating capacitor equipment.

The reactance tube and its associated components are connected across the tank circuit of the oscillator in the signal generator. Often, the ac power line, which provides an excellent oscilloscope-synchronizing medium, couples to the grid of the reactance tube to control the rate

ANSWERS FOR REVIEW QUESTIONS Q21. THROUGH Q25.

A21. In the power-off condition.

A22. The SND mode.

A23. Displays short circuit signatures, even with the test leads open.

A24. Because the test leads are conductive only at the tips.

A25. Not less than 270 ohms.

of the sweep. The reactance-tube modulator has an advantage over electromechanical modulators because it can be excited by an external variable AF signal generator. The electromechanical modulator is usually limited to single-frequency operations.

PULSE-MODULATED RF SIGNAL GENERATORS

A pulse-modulated (PM) RF signal generator is similar to the conventional RF signal generator. It differs in its output, which consists of RF energy in the form of pulses that occur at an audio rate. The generator controls can vary the pulsewidth (duration of each pulse) and the repetition rate (number of pulses per second). The PM generator is commonly used to check receiver performance of many radar systems that have a pulse-type emission.

A conventional oscillator circuit generates a constant RF carrier to produce pulse-modulated RF signals. This energy goes to the grid of a mixer stage, which has at the same time impressed on its suppressor grid a square wave generated in a separate circuit. The positive half-cycles of the square wave allow the mixer tube to conduct, and the negative half-cycles cut the tube off. During the conducting intervals, the RF signal on the control grid varies the plate current. Therefore, pulses of RF current, corresponding to the positive half-cycles of the square wave, appear in the mixer plate circuit. The pulses normally go to one or more amplifier stages. Controls in the square wave circuit vary pulse time and repetition rate.

The Model 628A SHF signal generator (fig. 8-25) is a general-purpose broadband signal generator that produces RF output voltages from 15 GHz to 21 GHz. A single control determines the output frequency, which is directly read on a dial calibrated to an accuracy of ±1 percent or better.

The 628A signal generator has some versatile modulation characteristics. It is possible to frequency modulate, square-wave modulate, or pulse modulate the output by internally or externally generated signals. The 628A also provides synchronizing pulses for use with external equipment.

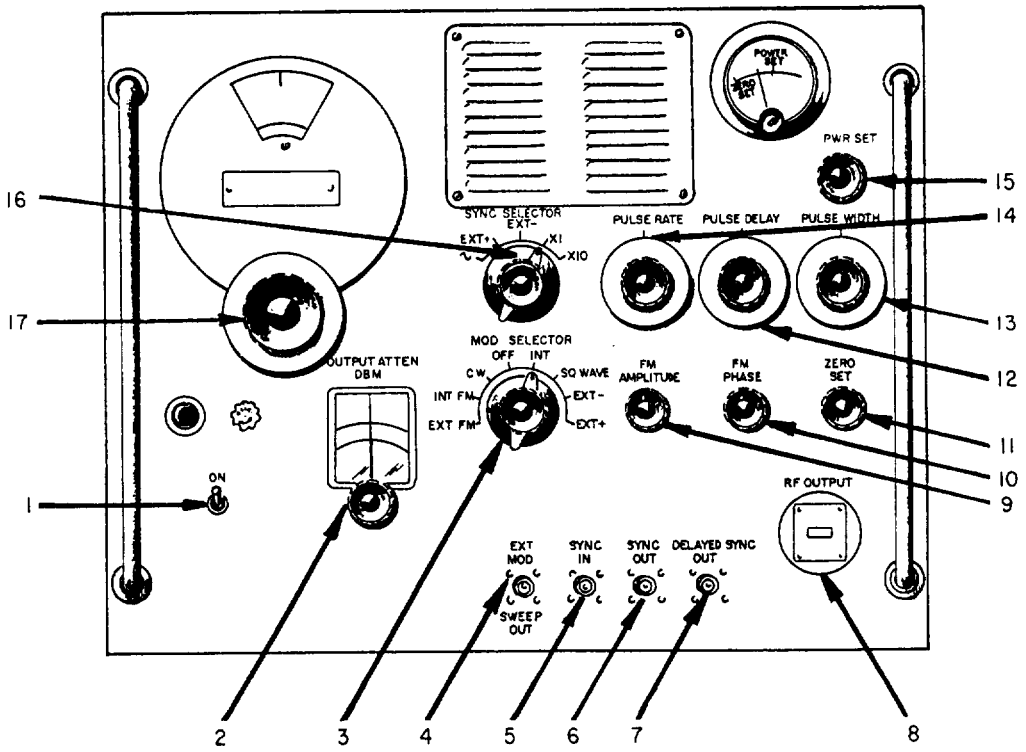


Figure 8-25.-Model 628A SHF signal generator front panel.

In addition to producing an accurate and controllable RF signal, you can use the 628A signal generator to

- test pulse systems,
- measure sensitivity and selectivity of amplifiers, receivers, and other tuned systems,
- measure signal-to-noise ratio of RF signals,
- make slotted line measurements,
- investigate microwave impedances and other transmission line characteristics,
- measure frequency response of microwave systems, and
- determine resonant frequency and Q of waveguide cavities.

Q26. What is the principal function of the signal generator?

Q27. While various types of FM signal generators are available, many are restricted to special applications. What type is used for general applications?

Q28. Most frequency-swept signal generators use a reactance-tube method of modulation. What is the reason for this?

Q29. What is a common application for pulse-modulated generators?

SIGNAL ANALYZERS

Learning Objective: *Identify signal analyzers to include signal analysis and waveform measurements including* O *scope, synchroscope, spectrum analyzers, and distortion analyzers.*

Signal analyzers, while used in many different situations, are normally used for one purpose—to check the response of an equipment under simulated conditions of specific operations.

WAVEFORM MEASUREMENT

Waveform measurements are made by observing displays of voltage and current variations with respect to time or by harmonic analysis of complex signals. Waveform displays are particularly valuable for adjusting and testing pulse-generator, pulse-former, and pulse-amplifier circuits. The waveform visual display is also useful for determining signal distortion, phase shift, modulation factor, frequency, and peak-to-peak voltage.

You can use harmonic analysis test sets to determine the energy distribution in electrical signals. Frequency-selective circuits separate the signals into narrow frequency bands. The energy in each band is indicated by a meter or displayed on a CRT. By connecting a group of frequency-selective circuits in parallel, you can manually or automatically tune a single frequency-selective circuit. You can also use a heterodyne method (using a sweep generator and fixed-tuned circuit) to select electrical power present in a narrow frequency band.

OSCILLOSCOPE

An oscilloscope or *O scope is* an electronic test set that displays information on the face of its CRT. There are many ways you can use an oscilloscope; however, its primary use is in troubleshooting and aligning electronic equipment. You do this by observing and analyzing waveform shape, amplitude, and duration. The maintenance instruction manual (MIM) for the particular equipment specifies the waveforms that you should see at the various test points throughout the equipment. Waveforms at any one selected test point may differ, depending on whether the operation of the equipment is normal or abnormal.

Figure 8-26 is a typical display you may see on a cathode-ray oscilloscope. This illustration shows the instantaneous voltage of the wave plotted against time. The elapsed time equates to the horizontal distance (view A), from left to right, across the etched grid (graph) placed over the face of the tube. The amplitude of the wave is the vertical measure (view B) on the graph.

The oscilloscope also provides picture changes in quantities other than voltages in electric circuits. If an electric current waveform is of interest, you can usually send the current through a small series resistor and look at the voltage wave across the resistor with the oscilloscope. There are also suitable transducers that change other quantities such as temperature, pressure, speed, and acceleration into voltage for display on the oscilloscope.

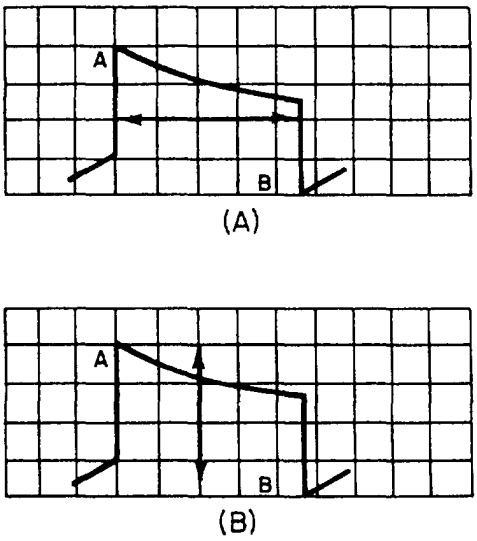


Figure 8-26.-Typical waveform display: (A) measurement of elapsed time; (B) measurement of voltage difference.

Interpreting the Display

As you read this paragraph, look at figure 8-26. Find the elapsed time between two points on the graph (view A, points A and B). Multiply the horizontal distance between these points in major graduated divisions by the setting of the TIME/DIV (time per division) control. This control sets the horizontal sweep rate of the oscilloscope. The distance between points A and B is 4.5 major divisions. If the TIME/DIV control is set at 100 microseconds per division, then the elapsed time between points A and B is 4.5 x 100 = 450 microseconds. In general, elapsed time = horizontal distance (in divisions) x TIME/DIV setting.

If you are using the MULTIPLIER control with the TIME/DIV control, multiply the above result by the setting of the MULTIPLIER. If a MAGNIFIER is in operation, divide the result by the amount of magnification.

Again, look at figure 8-26. To find the voltage difference (view B, points A and B) between any two points on the graph, multiply the vertical distance between these points (in major graduated divisions) by the setting of the VOLTS/DIV control. This control sets the vertical deflection factor, or sensitivity, of the oscilloscope. The vertical distance between points A and B is 4.0 divisions. If using the VOLTS/DIV control at 0.5 volt per division, then the voltage difference between points A and B must be 4.0 x 0.5 = 2.0 volts.

You can express the quantity called *pulse repetition rate* (or *pulse repetition frequency)* for periodic pulses as the number of pulses per unit of time. For example, 10 pulses per second and 50 pulses per microsecond. In using the oscilloscope to measure the frequency or repetition rate of periodic waveforms, you read the horizontal distance in major divisions between corresponding points on two succeeding waves first. This is the horizontal distance occupied by one cycle of the wave. Multiply this by the setting of the TIME/DIV control in seconds, milliseconds, or microseconds. Determine the reciprocal of this product; that is, divide 1 by the product. The result is the desired frequency or repetition rate.

Square waves, rather than other forms of waves, are usually used to test equipment. By using square waves, you can see more than just a defect's presence; you can see the nature of the defect. The nature of the defect is suggested by the kind of distortion that occurs on a square wave. By observing the square wave response, you, the technician, can easily tell whether the transmission of low or high frequencies is affected. However, this observation is not so clear with regard to frequency with waves other than square waves.

Linear devices that give identical responses to square wave inputs generally give responses similar to each other when other waveforms are input to them.

Information Contained in a Square Wave

A periodic wave contains the following components:

1. A fundamental wave, which is a sine wave having a frequency equal to the repetition frequency of the square wave.
2. An infinite series of odd harmonics—sine waves having frequencies that are equal to whole numbers multiplied by the fundamental frequency. The harmonics must be in phase and in amplitude to the fundamental.

Waveform D of figure 8-27 depicts a periodic rectangular wave (square wave). With the square wave, the only harmonics present are the odd harmonics (those whose frequencies are equal to the fundamental frequency multiplied by odd whole numbers). The strengths of the harmonics vary in inverse proportion to the frequencies of the harmonics, the fifth harmonic being one-fifth as strong as the fundamental, for example. Figure 8-27 suggests a way in which these waves combine to make up a square wave.

By looking at the four curves shown in figure 8-27, you can see that

1. curve A is the fundamental sine wave,
2. curve B is the sum of the fundamental and third harmonic,
3. curve C is the sum of the fundamental plus third and fifth harmonics, and
4. waveform D is the ultimate square wave.

You can see by looking at figure 8-27 that the first few harmonics combine with the fundamental to provide an approach to an actual square wave.

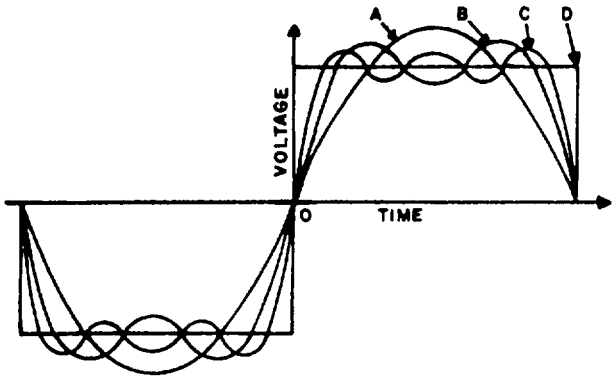


Figure 8-27-Addition of harmonics to a fundamental waveform.

Additional harmonics, of higher frequencies, would cause the leading edge of the wave to rise more rapidly. This will produce a sharper corner between the leading edge and the top of the wave. It would require an infinite range of harmonics to produce a truly vertical leading edge and an actual sharp corner. Although this situation is physically impossible to produce, waves can be generated that are very close to this ideal. (The same considerations apply to the falling edge of the waveform and to the following corner.)

You can find information about the amplitude and phase relationships of the higher harmonics within the leading-edge steepness and in the sharpness of the corner.

If low-frequency components (fundamental and the first few harmonics) are not present in the proper amounts and in the correct phase relationships, the flat top of the square wave is affected. Refer to figure 8-28. View A shows the

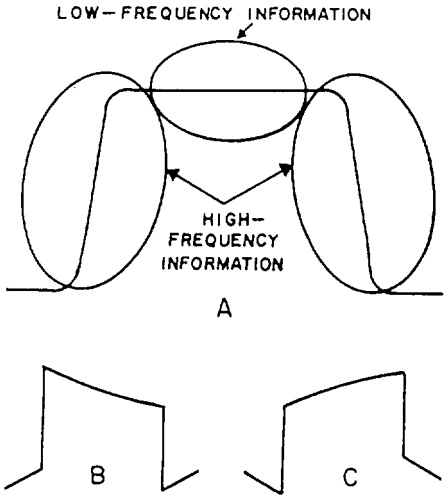


Figure 8-28.-Information found in a square wave.

ANSWERS FOR REVIEW QUESTIONS Q26. THROUGH Q29.

A26. The production of an alternating voltage of the desired frequency and amplitude.

A27. The sweep generator.

A28. It results in greater flexibility, and the equipment is lighter and more compact.

A29. Checking receiver performance in radar systems that have a pulse-type emission.

location of the low- and high-frequency information in a square wave. Low-frequency defects appear in the form of slope or general curvature in the top (views B and C). In view B, the low-frequency components have leading phase angles and are attenuated. In view C, the low-frequency components have lagging phase angles and are accentuated.

Oscilloscope Block Diagram

Figure 8-29 is a block diagram of a typical oscilloscope, omitting power supplies. The

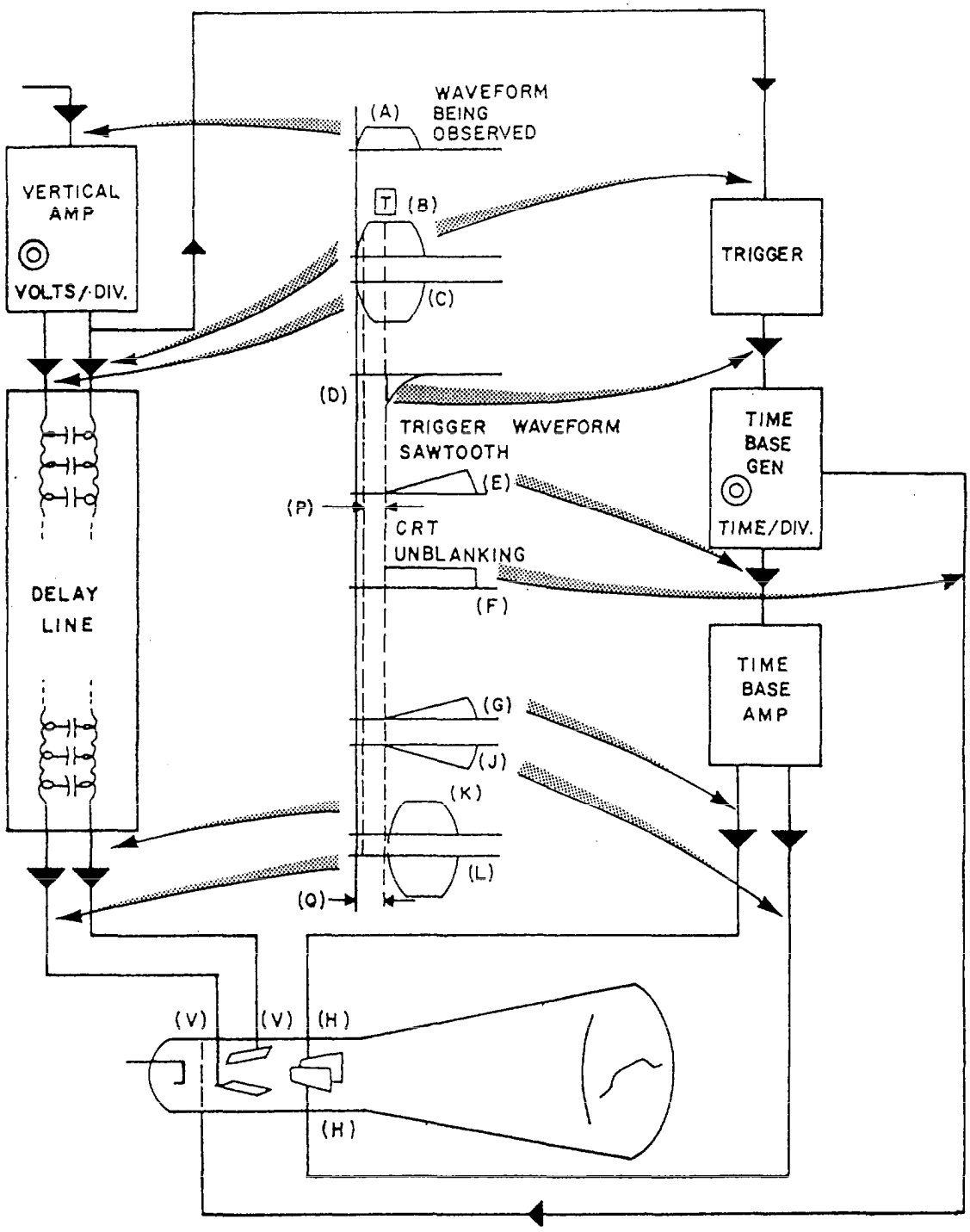


Figure 8-29.-Typical oscilloscope block diagram.

waveform (A) is input into the vertical amplifier input. The calibrated VOLTS/DIV control sets the gain of this amplifier. The push-pull outputs (B and C) of the vertical amplifier go through a delay line to the vertical deflection plates of the cat bode-ray tube.

The time base generator or *sweep generator* develops a sawtooth wave (E) that is a horizontal deflection voltage. The rising or positive-going part of this sawtooth, called the *runup* portion of the wave, is linear. It rises through a given number of volts during each unit of time. This rate of rise is set by the calibrated TIME/DIV control. The sawtooth voltage goes to the time base amplifier. This amplifier supplies two output sawtooth waveforms (G and J) simultaneously—one of them positive-going, like the input, and the other negative-going. The positive-going sawtooth goes to the right horizontal deflection plate of the CRT, and the negative-going sawtooth goes to the left deflection plate. As a result, the cathode-ray beam sweeps horizontally to the right through a given number of graduated divisions during each unit of time. The TIME/DIV CONTROL establishes the sweep rate.

To maintain a stable display on the CRT screen, each horizontal sweep must start at the same point on the waveform. To accomplish this, a sample of the displayed waveform goes to a *trigger* circuit, which gives a negative output voltage spike (D) at some selected point on the displayed waveform. This triggering spike starts the rising portion of the time base sawtooth. As far as the display is concerned, then, *triggering* is synonymous with the starting of the horizontal sweep of the trace at the left side of the grid.

The rectangular *unblanking* wave (F) is derived from the time base generator goes to the grid of the CRT. The duration of the positive part of this rectangular wave corresponds with the duration of the positive-going or rising part of the time base output. The beam is switched on during its left-to-right travel and switched off during its right-to-left retrace.

Often, the leading edge of the displayed waveform actuates the trigger circuit. However, it may be desirable to observe this leading edge on the screen—and the triggering and unblanking operations require a measurable time (P), often about 0.15 microsecond. To see the leading edge, a delay (Q) of about 0.25 microsecond is introduced by the delay line in the vertical deflection channel. The delay occurs after the point where the sample of the vertical signal is tapped off and fed to the trigger circuit.

The purpose of the delay line is to retard the application of the observed waveform to the vertical deflection plates. This occurs until the trigger and time base circuits have had an opportunity to begin the unblanking and horizontal sweep operations. This permits viewing the entire desired waveform—even though the leading edge of that waveform was used to trigger the horizontal sweep. If the delay line were not used, only that portion of the waveform following the instant (T) in waveform (B) could be seen.

Oscilloscope Probe

The input circuit to the vertical amplifier (fig. 8-30) of an oscilloscope can be simulated by a high resistance (R) shunted by a small shunt capacitance (C).

In some applications, even this high resistance and small capacitance can produce undesirable loading on the circuit whose waveforms are being examined by means oft he oscilloscope. Loading can cause the oscilloscope presentations to be different from the waveforms that would be present with the oscilloscope disconnected. Use of a passive probe reduces this resistive-capacitive loading on the circuit under investigation.

The probe (fig. 8-31) includes a resistor (R_p) shunted by a capacitor C_p. This combination is connected in series with the inner conductor of the cable to the oscilloscope input. The result is that when connecting the probe to the circuit under investigation, a new effective loading capacitance smaller than the original capacitance (C) and a new effective loading resistance larger than the original resistance (R) occurs. Thus, the probe reduces the loading effect of the oscilloscope input circuit on the circuit under investigation.

A second effect of the probe is to reduce the amount of signal voltage applied directly to the

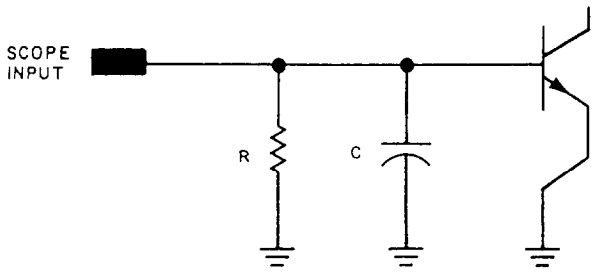


Figure 8-30.-Oscilloscope vertical amplifier input circuit.

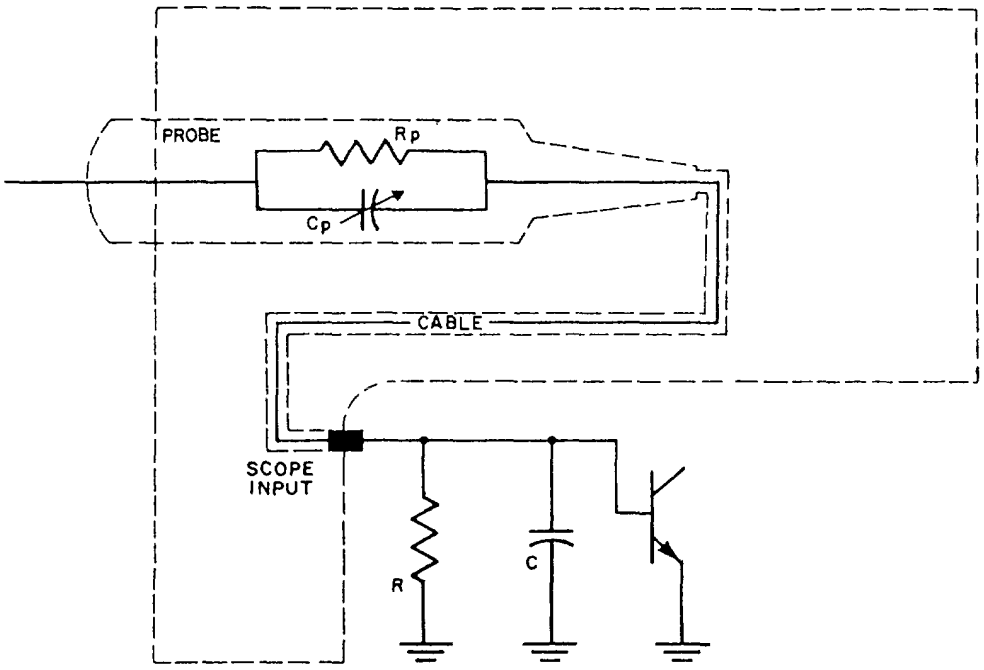


Figure 8-31.-Oscilloscope vertical amplifier using a passive probe input.

oscilloscope input connection for a given amount of original signal voltage. This occurs because of the voltage-divider action of R_p and R. This effect is taken into account in the attenuation ratio marked on the probe. Thus, if the probe is a 10 x ATTEN, all oscilloscope voltage indications must be multiplied by 10.

If an oscilloscope equipped with a probe is used to look at a square wave, and the probe capacitor (C_p) is too small, some of the high-frequency components of the square wave are bypassed around the oscilloscope input terminals by the input capacitance (C). Thus, the steepness of the leading edge of the displayed square wave (fig. 8-32, view A) is reduced.

If the probe capacitor is adjusted to the correct value, a compensating amount of high-frequency information is bypassed around the probe resistor (R_p) (fig. 8-31). To makeup for the loss through C (fig. 8-31), the leading edge of the displayed square wave is restored to its original steepness (fig. 8-32, view B). If C_p (fig. 8-31) is made too large, the high-frequency response of the circuit is overcompensated and applies too much high-frequency information to the oscilloscope input connection. This results in an overshoot in the displayed waveform (fig. 8-32, view C) that was not present in the original waveform. C_p (fig. 8-31) is adjusted to its correct value by using the probe to display the square wave generated by the voltage calibrator, which is a part of the oscilloscope. Adjustment is made to display a square wave with as flat a top as possible.

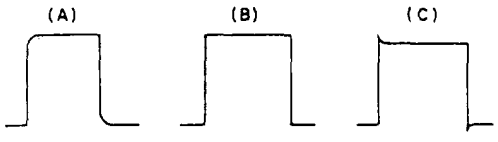


Figure 8-32.-Effects of probe adjustment.

You must check the probe adjustment whenever you use a probe with an oscilloscope or a plug-in preamplifier. This is especially important if the previous use was with an input capacitance different from that of the instrument to which you are now connecting the probe.

NOTE: As indicated in figure 8-31, the attenuation achieved is a result of R as well as R_p. Though you may swap probes with other types of oscilloscopes, the calibration may be in error even though the waveform distortion may adjust out.

SYNCHROSCOPE

The synchroscope is an adaptation of the oscilloscope. Its normal use is for radar applications. A trace occurs only with an input trigger, as contrasted with the continuous sawtooth sweep provided by the oscilloscope. Synchroscope circuits are similar to oscilloscope circuits, with the exception of the signal and the sweep channels. Figure 8-33 shows these circuits in block diagram form.

The signal channel of a typical synchroscope includes an input circuit that is usually in the form of a 72-ohm adjustable-step attenuator. Various degrees of attenuation are available, and the calibrated dial indicates how much attenuation is present. The attenuator makes sure all signals, regardless of amplitude, produce about the same input level to the amplifier section.

Following the attenuator is an artificial delay line. This low-pass filter has a cutoff frequency higher than the highest passed frequency and an impedance of 72 ohms. The delay line terminates into a 72-ohm gain control. One purpose of the delay line is to delay presentation of the observed signal. The delay lasts until an undelayed portion of the input signal initiates the sweep trace. Without the delay line, the initial portion of the waveform would not appear on the trace. This would occur because a certain amount of time is necessary for the input signal voltage to rise to the level needed to trigger the sweep circuit. With the delay line in use, the signal does not reach the amplifier until one-half microsecond after the trace starts. As a result, you can see the entire pulse. A secondary purpose of the delay line is to provide, by reflection, a series of accurately spaced pulses suitable for calibration of short time intervals.

A switch causes a mismatch in the termination of the delay line, causing the secondary purpose. When a sharp pulse is input into the line, a series of reflections occurs similar to those shown in figure 8-34. Since the time required for a pulse to travel down the line and back is 1 microsecond, a series of pulses occurring 1 microsecond apart occur. Each successive pulse is smaller because of the losses in the delay line, but enough pulses are visible for most high-speed calibration purposes.

The gain control feeds a wideband or video amplifier, which connects to the vertical deflection plates. In addition, an external connection is provided to the vertical plates.

The horizontal circuit consists of a sync switch for either internal or external sync, a sync amplifier with a gain control, and a start-stop sweep generator. The sweep generator will not develop a sweep voltage until it receives a pulse of enough amplitude. The duration of the sweep, or sweep speed, is adjustable from a very few microseconds to about 250 microseconds. The sweep generator connects to a conventional horizontal amplifier. Since the trace is triggered by the input signal, the synchroscope may be used to observe nonperiodic pulses; for example, the

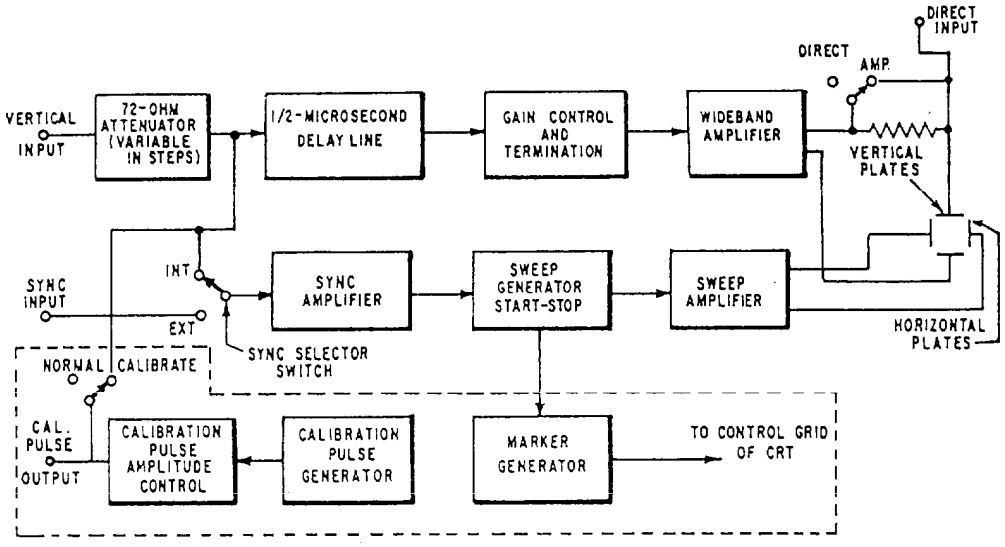


Figure 8-33.-Typical synchroscope block diagram.

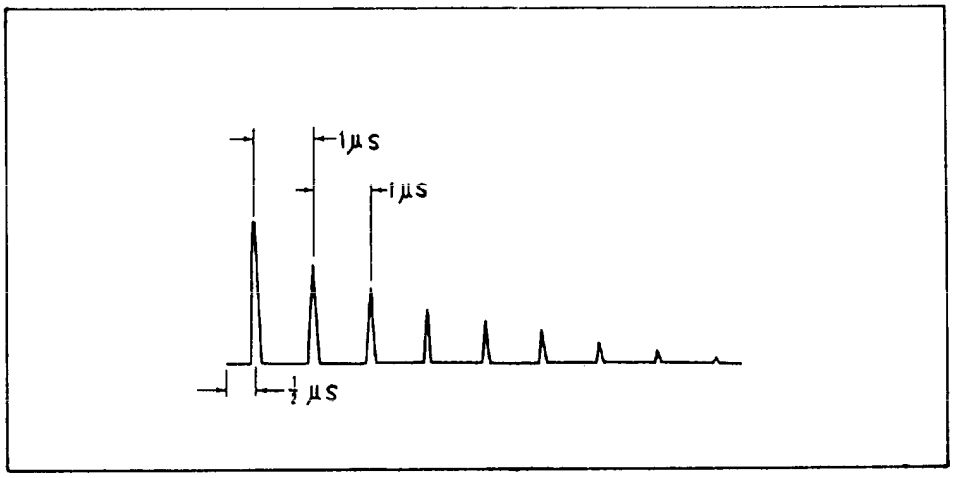


Figure 8-34.-Pulse reflection on a mismatched line.

nonperiodic pulses occurring in a radar system with an unstable PRF generator.

In later designs, provisions are commonly made for calibration of input voltages and sweep time. Voltage calibration is made by comparing the unknown voltage with a variable-voltage pulse of known value, generated internally. The calibrating pulse is adjusted so it is equal in amplitude to the unknown voltage. You can then read the value from the dial that controls the calibrating pulse. Sweep time calibration occurs with the help of marker pulses produced by accurately adjusted tuned circuits. The marker pulses appear on the trace as a series of bright dots spaced at intervals chosen by the operator. In a typical synchroscope, you may select marker intervals of 0.2, 1, 10, 100, and 500 microseconds, depending on the time duration of the pulse under test.

Q30. Signal analyzers can be used in many applications. It is used for what function?

Q31. What determination can you make by observing the square wave response?

Q32. Look at figure 8-28. At what point on a square wave does low- and high-frequency information appear?

Q33. An oscilloscope probe reduces the loading effect of the O-scope input circuit on the circuit under test. What is the second purpose of the probe?

Q34. The synchroscope is an adaption of the oscilloscope. What is the difference of the trace on the synchroscope and oscilloscope?

SPECTRUM ANALYZER

When a radio-frequency carrier wave is modulated by keying, speech or music, or pulses, the resulting wave contains many frequencies. The original carrier is present, together with two groups of new frequencies *(sideband components).* One group of sidebands is displaced in frequency below the carrier. The other group is displaced above the carrier. The distribution of these frequencies, when shown on a graph of voltage or power against frequency, is called the *spectrum* of the wave.

A spectrum analyzer is a device used to exhibit the spectrum of modulated waves in the radio-frequency range and the microwave region. In principle, the spectrum analyzer operates by tuning through the frequency region in question, using a narrow band receiver. A cathode-ray oscilloscope usually measures the output of the receiver, and the plot on the screen is a graph of voltage versus frequency. The device is essentially a superheterodyne receiver with a very narrow-band intermediate frequency amplifier section. The local oscillator frequency varies between two values at a linear rate. The frequency-control generator governs the frequency of the local oscillator. It also produces the horizontal sweep voltage for the CRT deflection plates. (See

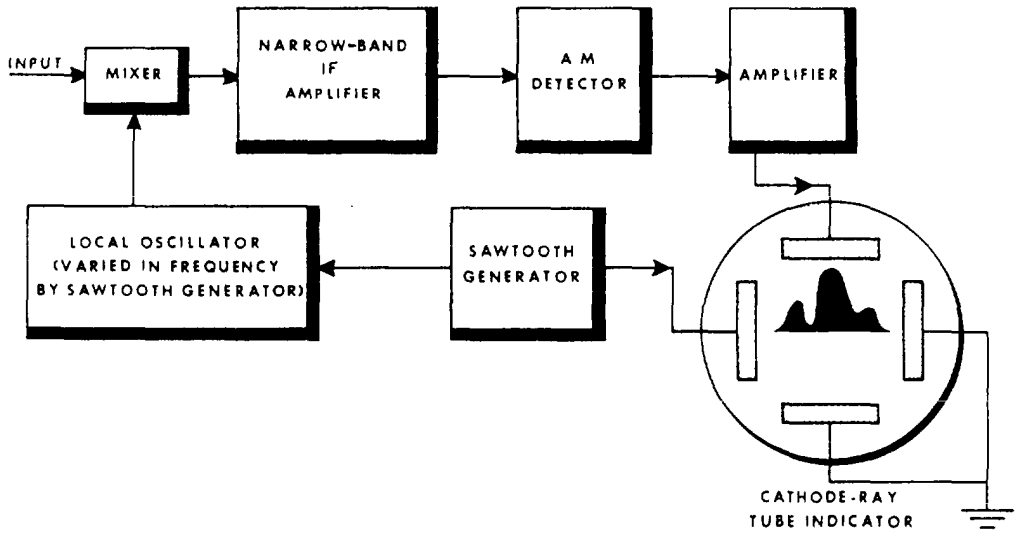


Figure 8-35.-Typical spectrum analyzer block diagram.

fig. 8-35.) As a result, each position of the beam corresponds to a definite frequency value, and the display is a graph in which the X-axis is interpreted in terms of frequency.

The output of the receiver detector is amplified and goes to the vertical deflection plates. The beam deflects vertically by an amount proportional to the voltage developed in the detector (and amplifier).

The signal for analysis goes into the mixer stage of the receiver. The local oscillator changes in frequency at a linear rate, beating with each of the signal frequency components in succession to form the intermediate frequency of the narrowband amplifier. The output of the IF amplifier is detected, amplified, and applied to the vertical deflection plates.

Spectrum analyzers designed for analysis of microwave signals have klystron tubes in the local oscillator stage. Analyzers adapted for lower frequency RF signals use triode oscillators that vary through reactance-tube modulators.

Spectrum analyzers are the main tool for studying the output of pulse-radar transmitter tubes, such as magnetrons. In this kind of analysis, unwanted effects, such as frequency

ANSWERS FOR REVIEW QUESTIONS Q30. THROUGH Q34.

A30. To check the response of an equipment under simulated conditions or specific operations.

A31. Whether the transmission of low or high frequencies is affected.

A32. Low-frequency information is contained on the top portion of the square wave, and high-frequency information is contained on the sides of the square wave.

A33. To reduce the amount of signal voltage applied directly to the O scope input connection.

A34. A trace on the synchroscope is produced only when it is initiated by an input trigger; the O scope has a continuous sawtooth sweep.



Figure 8-36.-Frequency spectra.

modulation of the carrier, are easy to detect. In pure amplitude modulation of a carrier wave by a square pulse, the spectrum is symmetrical about the carrier frequency. Lack of symmetry indicates the presence of frequency modulation. Look at view A of figure 8-36. It shows a spectrum representing the ideal condition. Views B and C show examples of undesirable magnetron spectra. These forms indicate trouble in the modulator, the tuning system, or in the magnetron tube itself.

The best definition of carrier frequency is the center frequency in a symmetrical spectrum (fig. 8-36, view A). Some analyzers use this principle as a means of carrier frequency measurement. A sharply resonant circuit in the receiver acts as a trap to prevent an extremely narrow range of frequencies from appearing in the output of the IF amplifier. The result of its use is a gap that appears in the display, and the gap corresponds to the resonant frequency of the trap. The adjustment of the trap is calibrated in frequency, and the circuit can be adjusted to make the gap occur in the center of the spectrum. You can then read the frequency of the carrier from the calibration of the trap.

For more information about spectrum analyzers, refer to NEETS, module 16. In addition, the EIMB *Test Methods and Practices,* NAVSHIPS 0967-LP-000-0130, contains detailed discussions of spectrum analysis techniques.

Echo Box

The echo box is for use in field testing, troubleshooting, and adjusting pulsed-type radar systems. Although simple in construction and operation, it has many applications. If properly used within its design limitations, the echo box can frequently eliminate the need for a complex test setup and an elaborate step-by-step testing procedure. The echo box uses passive circuitry, which does not require any external power other than the radar set whose signal is under analysis. External power requirement is a critical factor with most other test sets.

The echo box is similar in operation to a tuned cavity frequency meter; however, it has different capabilities. The tuned cavity frequency meter can measure the frequency of CW or pulsed RF signals in the microwave range. The echo box, however, has no practical application in the testing or analysis of CW equipment signals. Figure 8-37 indicates the basic functional elements of a typical echo box.

Energy from the radar transmitter goes through the directional couplers to the resonant

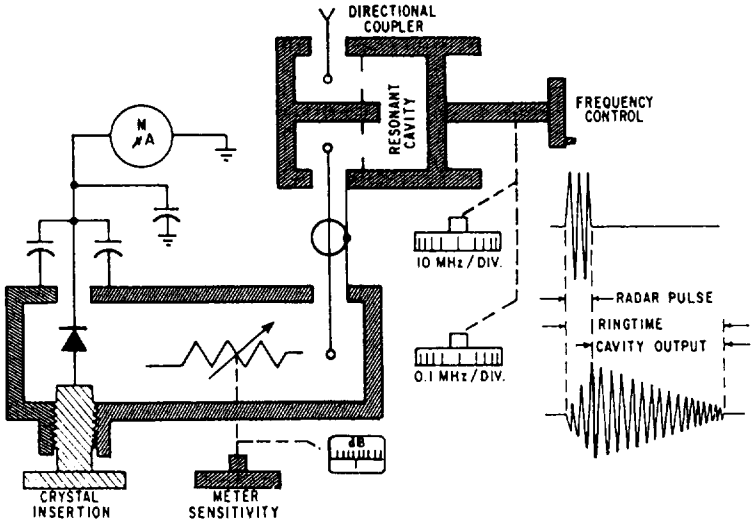


Figure 8-37.-Typical echo box functional circuit.

cavity. When the cavity length is properly adjusted, resonant oscillations are set up by each successive pulse of microwave energy. Maximum amplitude of oscillation occurs when the cavity is tuned precisely to the signal frequency. The crystal diode detects these cavity oscillations and indicates them on the meter as an average dc current. The amplitude of oscillation and the average current reading are proportional to the transmitter power output. Oscillations in the tuned cavity also couple back to the radar set under test, where they are processed as an echo signal. This signal, when viewed on the indicator CRT, permits analysis of the radar pulse and presents an indication of the general operating condition of the radar set.

Since energy builds up in the cavity, saturation of the cavity is possible. If saturation does occur, distortion of the waveform and erroneous values of the measurements result. If the directional couplers do not prevent cavity saturation, there must be some additional attenuation.

Analysis of the displayed waveform can provide a fairly complete functional analysis of the operational condition of a radar set. Among the most important factors it can determine are frequency and bandwidth, power and frequency spectra, sensitivity, pulsewidth and condition, and recovery time. Analysis of the waveform can also prove helpful in locating the cause of malfunctions within the radar set.

You need to remember, however, that the echo box presents only relative (rather than absolute) values of power and sensitivity and only rough values of frequency. These quantities are not as accurate as the corresponding values obtained by using a spectrum analyzer. The primary value of the echo box lies in its regular usage. For maximum benefit, you must compare the values from a given test to corresponding values from a test on a radar set you know is operating properly.

In general, however, the echo box is an extremely valuable instrument. When used in a continuing maintenance program, it lets the operator maintain the equipment in peak operating condition. Also, it gives indications of deterioration before actual malfunctions occur.

Distortion Analyzer

The Hewlett-Packard Model 332A distortion analyzer (fig. 8-38) is a solid-state instrument for measuring distortion and ac voltages. The Model 332A includes a high-impedance AM detector that operates from 500 kHz to greater than 65 MHz.

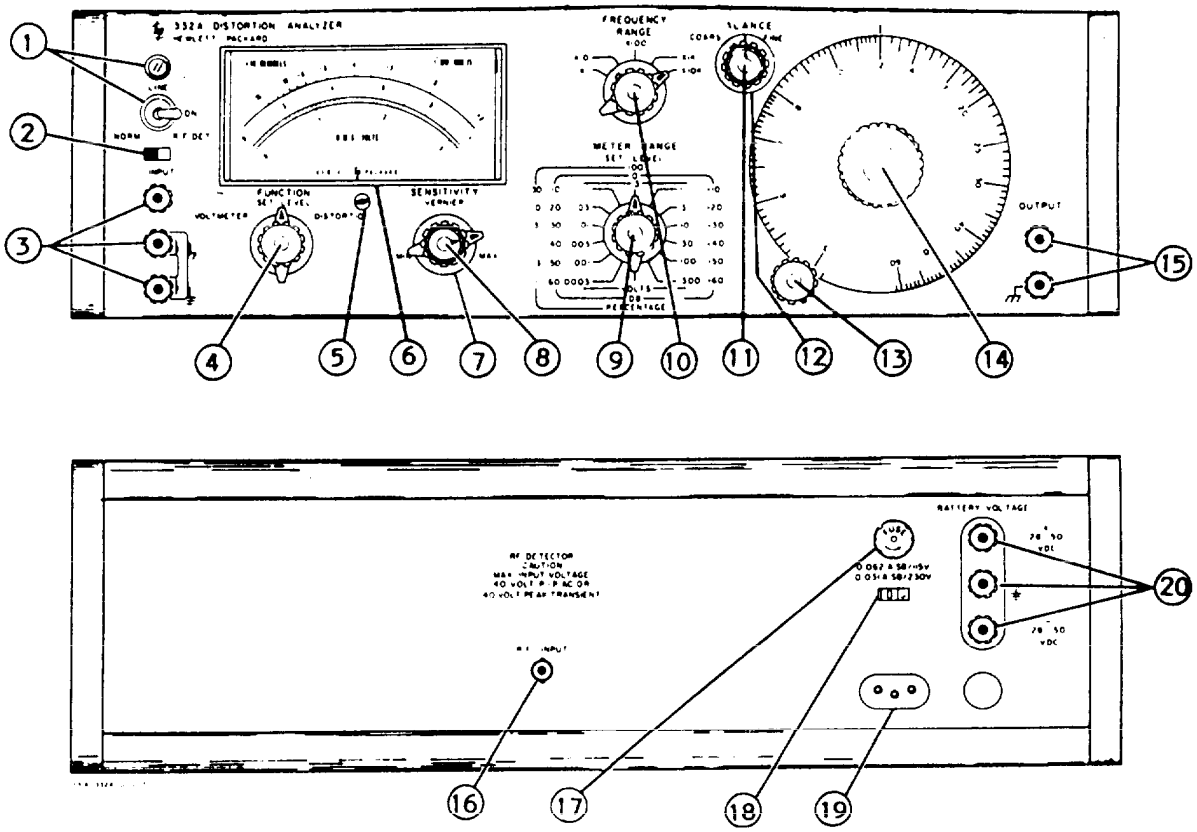
Distortion levels of 0.1 percent to 100 percent full scale are measured in seven ranges for any fundamental frequency of 5 Hz to 600 kHz. Harmonics are indicated up to 3 MHz. The high sensitivity of these instruments requires only 0.3 V rms for the 100 percent set level reference. The OUTPUT connectors provide a low distortion output for monitoring with an oscilloscope, a true rms voltmeter, or a wave analyzer. The instruments are capable of an isolation voltage of 400 volts above chassis ground.

You can also use the transistorized voltmeter contained in the Model 332A separately for general-purpose voltage and gain measurements. The voltmeter has a frequency range of 5 Hz to 3 MHz (20 Hz to 500 kHz for the 300 µV range), and a voltage range of 300 µV to 300 V rms full scale.

The AM detector is a broadband dc restoring peak detector consisting of a semiconductor diode and filter circuit. AM distortion levels as low as 0.3 percent can be measured on a 3 V to 8 V rms carrier modulated 30 percent in the standard broadcast band. Also, lower than 1 percent distortion can be measured at the same level of the carrier up to 65 MHz.

The Model 332A distortion analyzer has two modes of operation—the distortion mode and the voltmeter mode. Total harmonic distortion measurements from 5 Hz to 600 kHz are possible. The distortion mode can indicate harmonics up to 3 MHz. Distortion measurement accuracy is determined by the overall effect of harmonic frequency measurement accuracy, elimination characteristics, distortion introduced by the instrument, and meter accuracy. In the voltmeter mode, the transistorized voltmeter provides a full-scale sensitivity of 300 µV rms (residual noise <25 µV). The voltmeter frequency range is 5 Hz to 3 MHz (20 Hz to 500 kHz on the 300 µV range).

The distortion measurement accuracy of the 332A is a result of the sharp elimination characteristic of the rejection amplifier circuit and the low level of distortion introduced by the instrument. The fundamental reject ion is at least 80 dB, which is small compared to the distortion introduced by the instrument. Thus, low-level harmonic content in the input signal can be measured accurately. You can use the 332A with a wave analyzer for extremely sensitive (>80 dB down in the audio-frequency range) measurements of odd harmonics.



1 ON switch turns instrument ac power on. Pilot lamp glows when instrument is turned ON.
2 NORM-RF DET switch selects front panel INPUT connectors or rear panel RF INPUT connector.
3 INPUT terminals provide connections for input signals.
4 FUNCTION selector selects mode of operation of the instrument.
5 MECHANICAL ZERO ADJUST mechanically zero-sets meter before turning instrument on.
6 DISTORTION/VOLTMETER indicates distortion level and voltage levels of input signals.
7 SENSITIVITY selector provides 0 to 50 dB attenuation of input signal in 10 dB steps in SET LEVEL and DISTORTION positions of FUNCTION selector.
8 SENSITIVITY VERNIER control provides fine adjustment of attenuation level selected by SENSITIVITY selector.
9 METER RANGE selector selects full-scale range of meter in percentage, dB, and rms volts.
10 FREQUENCY RANGE selector selects frequency range to correspond to fundamental frequency of input signal.
11 COARSE BALANCE control provides coarse adjustment for balancing the Wien bridge circuit.
12 FINE BALANCE control provides a vernier adjustment for balancing the Wien bridge circuit.
13 Frequency vernier control provides fine adjustment of FREQUENCY dial.
14 FREQUENCY dial selects fundamental frequency of input signal.
15 OUTPUT connectors provide means of monitoring the output of the meter circuit with an oscilloscope, a true rms voltmeter, or a wave analyzer.
16 RF INPUT connector provides input connection for AM RF carrier input signal.
17 FUSE provides protection for instrument circuits.
18 LINE VOLTAGE (115 V/230 V) switch sets instrument to operate from 115 V or 230 V ac.
19 AC power connector provides input connections for ac power.
20 BATTERY VOLTAGE (+28 to +50 VDC and –28 to –50 VDC) terminals provide connections for external batteries.

Figure 8-38.-Model 332A distortion analyzer front and rear panels.

Q35. Describe what factors a spectrum analyzer exhibits.

Q36. Describe the purpose of the echo box.

Q37. What limitation should you consider when you use the echo box?

REFLECTOMETRY TEST SETS

Learning Objectives: *Recognize the basic theories of time- and frequency-domain reflectometry. Recognize the characteristics of resistive and reactive loads. Recognize TDR displays and identify range and resolution and the uses of analyzing terminations. Identify the advantages and disadvantages of FDR as compared to TDR testers. Recognize the purpose and use of FDR testers.*

Reflectometry test sets have many uses. They are primarily used to help the organizational maintenance technician verify and troubleshoot aircraft wiring, transmission lines, waveguides, and antenna systems. However, the intermediate maintenance technician can use reflectometry test sets to verify cable connectors, determine test cable impedances, and troubleshoot test equipment. There are two types of reflectometry test sets currently used by the Navy—time-domain reflectometer (TDR) and frequency-domain reflectometer (FDR) testers.

TIME-DOMAIN REFLECTOMETRY (TDR) TEST SETS

You will use time-domain reflectometer (TDR) test sets to check and troubleshoot aircraft wiring, transmission lines, and antenna systems for shorts, opens, crimps, bad couplings, etc. To do this, you will monitor TDR reflected waveforms. TDRs operate on the same principle as radar; that is, they send pulses of energy into a system to see what, if anything, is reflected. Like standing waves on an antenna line, if nothing is reflected, the impedance of the transmission line is uniform and properly terminated. However, if crimps, opens, bad couplings, and so forth, are present, a discontinuity exists, and in-phase or out-of-phase pulses return to the TDR test set. These reflections occur on its CRT as positive, negative, or simply fast-rising voltages, which show the known causes usually at fault. Impedances greater than 50 ohms appear to the TDR as in phase, while those less than 50 ohms appear out of phase. These are respectively classified (traditionally) as inductive and capacitive faults, which are explained by the basic equation: $Z_o = \sqrt{L/C}$, where L = inductance, C = capacitance, and Z = impedance.

TDR Basics

The TDR analysis begins with the insertion of a step or pulse of energy (referred to as the *incident signal* into a system or cable. Then, at the point of insertion, you see the energy reflected by the system or cable under test. Figure 8-39 shows the typical TDR analysis. The output of the pulse generator is, a step signal with a rise time of about 110 picosecond. This signal (incident signal) goes through a sampling tee to the CRT of the sampling oscilloscope and to the system under test via a 50Ω termination connector. The equivalent bandwidth of the CRT deflection circuits provides a system rise time of about 140 picosecond. This allows the TDR to give resolution (detect faults) as close as one-half inch apart. The reflected signal from the system under test reenters the TDR test set and returns via the sampling tee to the sampling oscilloscope CRT along with the incident signal. By comparing the magnitude, duration, and shape of the reflected signal, you can determine the nature of the impedance variation in the system under test.

RESISTIVE LOADS.— With a pure resistive load on the output of the TDR, and a step signal applied, a signal whose amplitude is a function of the resistance (fig. 8-40) appears on the CRT. If the line terminates in its characteristic impedance (Z_o) (fig. 8-40), there is no reflected signal. The signal on the CRT will remain flat. However, if the impedance (R_L) at the termination is greater or less than Z_o, then reflections (standing-wave ratio [SWR]) exist. The amplitude of the reflected signal is proportional to the value of R_L. If R_L is greater than Z_o (50 Ω), the reflected signal is in phase with the incident signal, and, when applied to the CRT, the reflected signal adds to the incident signal. If R_L is less than Z_o, the reflected signal is out of phase with the incident signal. When applied to the CRT, the reflected signal subtracts from the incident signal. The dotted lines in figure 8-40 represent various composite signals (incident ± reflected) that you would observe for various values of R_L. The time from the start of the incident (step) signal to the

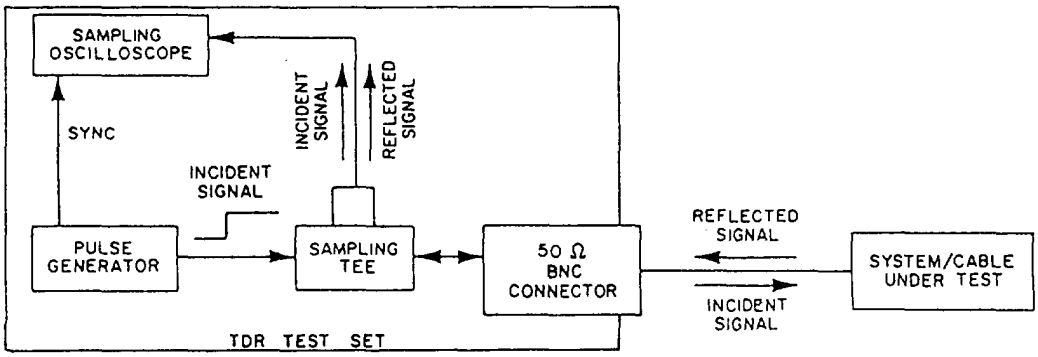


Figure 8-39.-Typical TDR analysis.

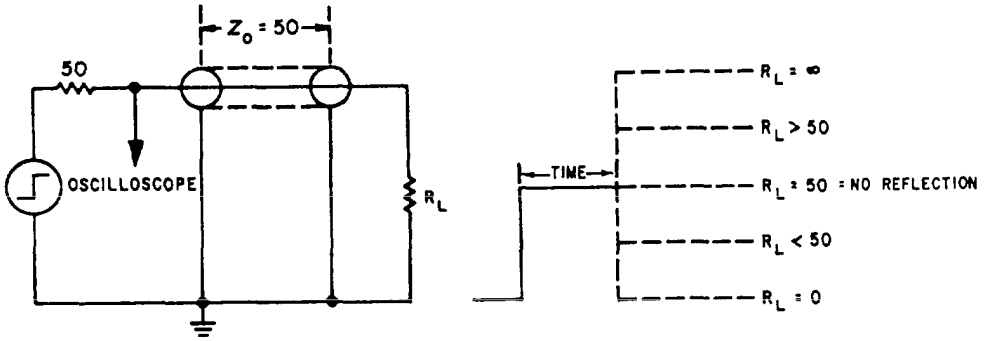


Figure 8-40.-Step signal-height variations resulting from different resistive loads.

step created by the reflected signal represents twice the distance to the discontinuity; that is, the time it took the incident step to reach the discontinuity and return. Most TDRs are calibrated to read this time in feet or inches to the discontinuity.

You should separate the system under test from the TDR test set by 8 inches of 50-ohm cable. This moves the reflections away from the leading edge of the step (start of the incident signal) and prevents overshoot and ringing from appearing on the CRT signal.

REACTIVE LOADS.— The waveform of reactive loads (fig. 8-41) depends on the time

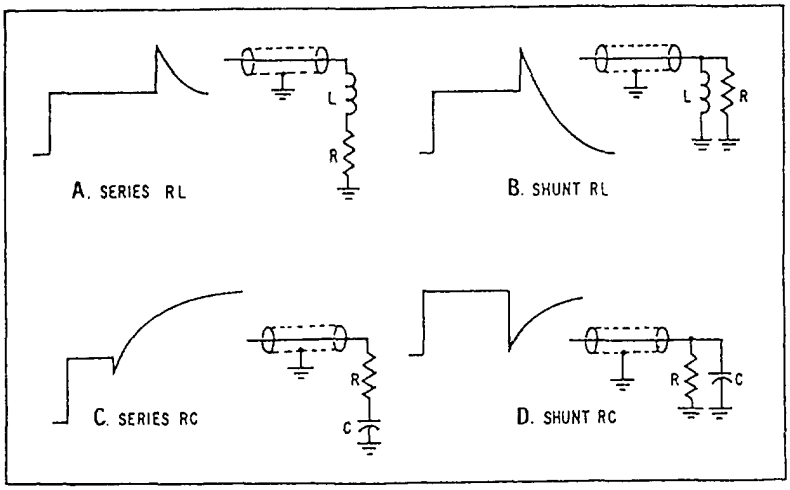


Figure 8-41.-TDR reactive load characteristics (time constant = 1).

constant formed by the load and the 50-ohm source. The series RL network (fig. 8-41, view A) appears as an open the instant the step voltage reaches it. This is because the inductor L offers maximum impedance to the change in current caused by the step voltage. Therefore, the reflected signal is in phase with the step voltage and is additive. This explains the sharp rise in voltage. However, as soon as the inductor saturates, the only opposition to current is resistor R. Since L saturates at a nonlinear rate, the voltage drops at a nonlinear rate from the peak of the spike to the same level as the flat portion of the step voltage. At this time, the only load seen by the line is the 50-ohm resistor, which equals the characteristic impedance of the line. The reflections cease until the next step appears at the termination. Then, the cycle repeats itself.

To understand the wave shape shown in figure 8-41, view B, you need to remember that L appears as an open to the fast-rising step voltage the instant it is felt at the termination. However, as the inductor saturates, it offers less and less opposition to current until it completely saturates (0 ohm). Since the inductor is parallel to R, the termination is a short, and the reflected wave is 180 degrees out of phase with the incident wave. Since L saturates at a nonlinear rate, the voltage declines at a nonlinear rate. Views C and D of figure 8-41 show a similar analysis of the transmission lines with the RC terminations.

The analysis of these different types of discontinuities explains the usefulness of the TDR. Through proper analysis of the discontinuities, you can determine whether they are resistive, inductive, or capacitive and whether it is in series or parallel with the load.

TDR in Practice

TDR discontinuities have clear separations in time on the CRT. You can easily see the mismatch caused by a connector even if another bad discontinuity is present elsewhere in the system. By using the analysis explained before, you can establish which connector is troublesome and in what way. Once you determine that a discontinuity appears in a waveform, it is simple to locate it in the system. You can save time by calibrating the system so 1 centimeter on the horizontal axis equals a certain number of feet for the transmission system under test. The limiting factor is the system rise time, and any closely spaced discontinuities will appear as a single discontinuity.

The finite rise time also limits the size of the distinguishable reactive impedance response. For example, a small shunt capacity in a 50-ohm system causes the waveform to depart from the ideal response (fig. 8-42).

The maximum observable line length is a function of the repetition rate chosen. This rate determines the duration of the pulse after its rise. For example, a 200-kHz repetition rate permits the use of TDR devices with up to 1,000 feet of air dielectric cable or 670 feet of polyethylene dielectric coaxial cable. A system's velocity constant determines the speed at which a wave travels through a transmission system. A wave travels faster through air than through polyethylene. This explains the difference in maximum checkable lengths of coaxial cable using a particular repetition rate on the TDR. The longer the cable, the lower the repetition rate must be.

ANSWERS FOR REVIEW QUESTIONS Q35. THROUGH Q37.

A35. A spectrum analyzer is a device for exhibiting the spectrum of modulated waves in the radio-frequency range and microwave region.

A36. The echo box is used in field testing, troubleshooting, and adjusting pulsed-type radar systems.

A37. You need to remember that the echo box presents only relative rather than absolute values of power and sensitivity and only rough values of frequency.

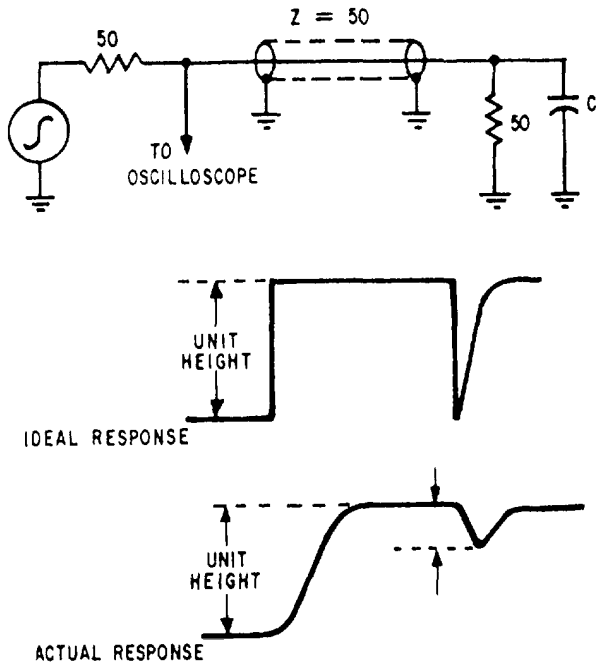


Figure 8-42.-Small shunt capacity in system degrades ideal response.

Range and Resolution

Assuming that the total impedance (Z_o) equals 50 ohms, you may measure a resistance between 0.025 ohm and 100 kilohms. Because the height of the reflection is directly proportional to the resistance, you may determine the resistance by using a precalculated transparent overlay.

One common use of the TDR is in analyzing a coaxial cable. The amount of impedance variation that is detectable in a long section of cable is a function of the flatness of the top of the incident step. If this step is flat within ±0.5 percent, it can detect an impedance variation of 0.5 ohm along the cable, corresponding to a 1 percent check on cable impedance. Thus, irregularities in cable makeup resulting from variations in the braiding process or tightness of the insulating jacket show up clearly.

Analyzing Terminations

A departure from 50 ohms in a termination or cable connector can cause some problems. For example, large reflections in a pulse system or a large voltage standing-wave ratio (VSWR) can occur in a system that carries primarily sinusoidal signals. Because of human errors in the assembly process, even the best connectors will cause reflections or a varying VSWR. Therefore, expensive connectors do not ensure freedom from unwanted reflections. However, the TDR helps you locate unacceptable connectors by rapidly showing where the mismatches are and how bad they are. The TDR also indicates if these connectors are resistive, capacitive, or inductive and whether series or shunt. Figure 8-43 shows a step being propagated from a section of RG9A/U into a load. The connector on the load and the cable are the general radio type 874. It shows four different cases with varying loads. These cases show how you can analyze the connection and the load by using the TDR. With different connectors and loads, the small mismatches (discontinuities) take on different

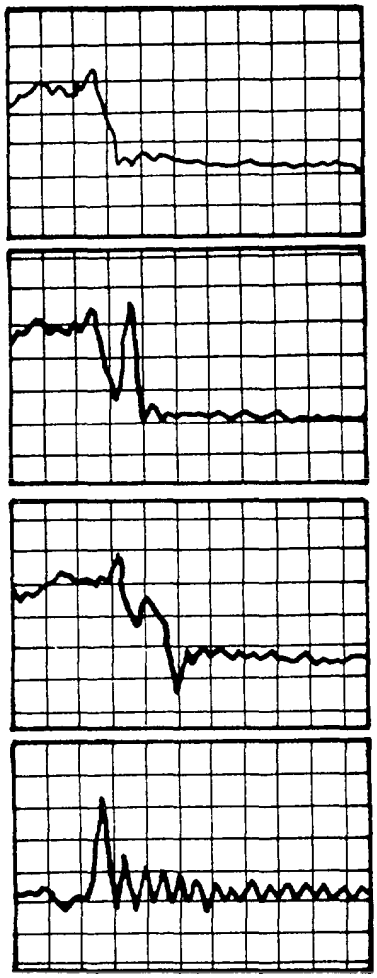


Figure 8-43.-Waveforms resulting from the use of different loads. Horizontal scale 0.4 µsec/cm; vertical scale 0.5 percent/cm.

impedance characteristics and the reflected signals change. This change also appears in the wave shape viewed on the oscilloscope. You can compare these signals with those of a normal system by using an overlay showing the pattern of a normal system.

The most convenient method to make precise measurements of cable impedance is to connect a section of air dielectric line (with precisely determined impedance) between the cable and the TDR. The step height through the air dielectric line section sets the 50-ohm level. You note any variations from this level in the test cable and calculate the impedance of the cable (fig. 8-44).

In this test, the impedance level of the test line is

$$Z_o = 50 \frac{1 \times \varrho}{1 - \varrho}$$

where ϱ (Greek letter rho) is the reflection coefficient of the reflected mismatch, If the change in amplitude shows ϱ to be +0.03, then

$$Z_o = 50 \frac{1.03}{0.97}$$

The impedance of a long section of coaxial cable would be exactly Z_o if there were no line losses. However, most cables have a small series loss and a negligible shunt loss. This series resistance adds to Z_o, causing the impedance level (as observed at one end of a cable) to increase when adding longer sections of cable. The slope on the step height that results from the increasing impedance is evident in figure 8-45.

There are other applications in which the TDR method of analysis is effective, including component characteristic analysis, antenna analysis, and aircraft wiring checks. You can place the components in an appropriate jig and use the TDR method to determine their shunt capacity and series inductance (fig. 8-46).

Investigation of antennas reveals that the TDR pattern is not simple, but instead presents a

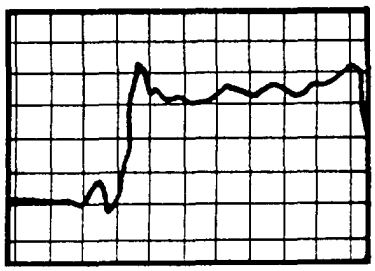


Figure 8-44.-Oscillograph of step from air dielectric line into test cable.

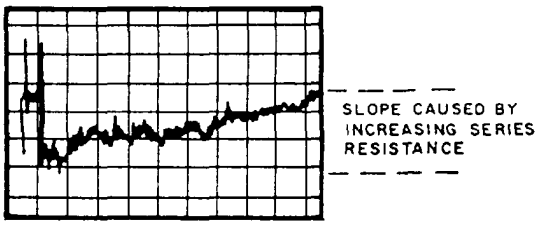


Figure 8-45.-Trace of cable shows construction irregularities and increasing series resistance.

complex reactive profile (fig. 8-47). Once you determine the proper profile for a particular antenna, you can detect any improper construction details and determine the proper corrective action.

FREQUENCY-DOMAIN REFLECTOMETRY (FDR) TEST SETS

Frequency-domain reflectometry (FDR) is a fast, simple, and reliable technique developed to

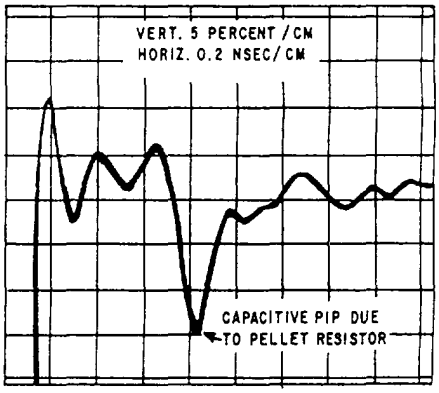


Figure 8-46.-Resistor checked for shunt capacity with special jig.

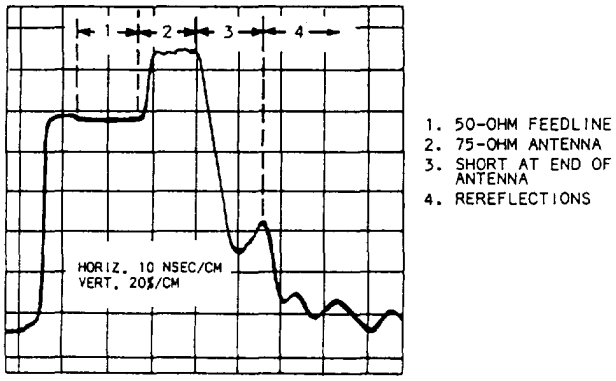


Figure 8-47.-Scope trace of antenna reactive profile.

locate defects in microwave cables and waveguide systems connecting receivers, transmitters, and antennas. Like the TDR, the FDR tester permits direct readout of cable distance, in feet, to the discontinuity (impedance fault). This system has an impressive record of reliability, reduced service time, and improved service standards. Because the FDR checks cables at their actual operating frequencies, discontinuities outside those frequencies do not affect the test. When measurements indicate a fault, you can precisely determine its location (in terms of distance in feet from the point of test). Therefore, you can make repairs quickly and efficiently.

FDR vice TDR

Until FDR testers, TDR was used as the primary test of cables; a system that has several limitations. For example, TDR measurements cover a spectrum determined by its pulse characteristics; therefore, it detects all discontinuities, including those outside the operating frequency range, which do not affect a system's operation. With the FDR, however, the analysis is within the actual operating frequency band of the microwave system, which assures proper system performance at the operating frequencies.

While the FDR works in waveguides and band-limited systems (including transmission networks that contain filters), the TDR cannot work in such systems. The TDR requires a transmission line that passes the whole spectrum from the fundamental frequency (2 MHz to 5 MHz) to the highest harmonic (15 GHz). Waveguides that act as high-pass filters cannot transmit TDR pulses. Similarly, the TDR cannot see through low-pass or bandpass filters because they eliminate the low-frequency harmonics and appear to display a discontinuity on the TDR's CRT.

FDR Testing

The FDR identifies defective systems by injecting an RF signal into a system and using insertion-loss (attenuation in the line) and return-loss (VSWR) measurements. These measurements help to classify the system under test as good or in need of repair. There are various test setup configurations to measure these losses, based on the particular FDR equipment. Figure 8-48

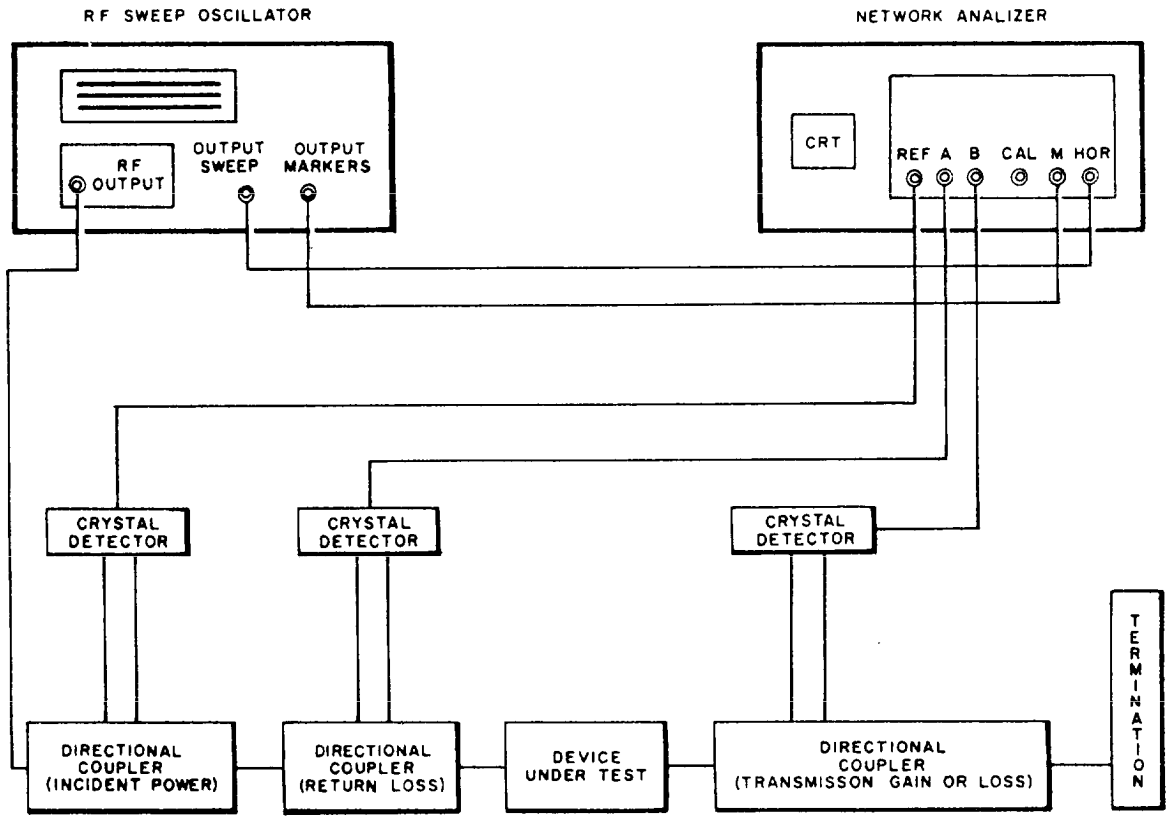


Figure 8-48.-Typical setup for VSWR and insertion performance.

represents a typical test setup for VSWR and insertion-loss monitoring. Such a test configuration provides simultaneous measurement of the losses.

If the input and output connectors of the device under test are accessible, an insertion-loss check verifies input to output performance across the band. For insertion-loss measurement, the network analyzer (fig. 8-48) (using its B and REF channels) indicates the ratio of output signal to input signal directly in dB. For tests of long cables whose ends are accessible, the FDR allows measurements from a connector end as far as 2,000 feet from the tester. In some tested systems, however, either the input or output connector may be inaccessible. For such systems, a return-loss measurement made on the accessible connector provides a total system check. For return-loss measurements, the network analyzer (using the A and REF channels) indicates (measures) the ratio of reflected power to incident power directly in dB. Incident power is the output of the RF sweep oscillator unit. Figure 8-48 shows how the signals in each case are sampled via directional couplers.

Comparison of each measured signal with the incident power of the RF oscillator supplies automatic compensation for any swept-source power variations across the band. This gives a true graph of performance in dB versus frequency on the network analyzer CRT. Figure 8-49 shows an example of insertion-loss measurement on the network analyzer CRT. In this example, a loss of less than 10 dB is acceptable (as determined from previous tests of a good system). The cable, however, needs repair because a fault (discontinuity) is present, which produces an insertion loss greater than 35 dB at a frequency of 3.56 GHz.

Figure 8-50 shows a return-loss measurement for the same cable. Here, a loss of 11 dB (as determined from a good system), which corresponds to a VSWR of 1.8, is acceptable. At 3.56 GHz, however, the return loss on the CRT indicates 5 dB, which corresponds to a VSWR of 3.6, and it is unacceptable.

The dual-channel network analyzer in figure 8-48 permits the display of both measurements simultaneously, and both verify the discontinuity in the system cable under test. Single-channel FDR testers require individual test setups for measuring insertion and return losses and comparison of the individual graphs.

DETERMINING CABLE LENGTHS OR DISTANCE TO FAULTS.— To determine cable length or fault (discontinuity) location measurements (fig. 8-51), a waveguide or a coaxial tee is added in the test setup. You then calibrate the FDR test setup with a calibration cable (provided with FDR set) to establish a known 0-foot reference on the CRT display, Then connect the system cable to the tee. The resulting CRT display of the network analyzer consists of a stationary pattern containing a series of *half-dome ripples.* A count of the total number of these ripples indicates the number of feet from the cable end to the fault, as shown in figure 8-52. The FDR display is from the cable that needs repairs (figs. 8-50 and 8-51). Multiply the 5 2/3 ripples by the

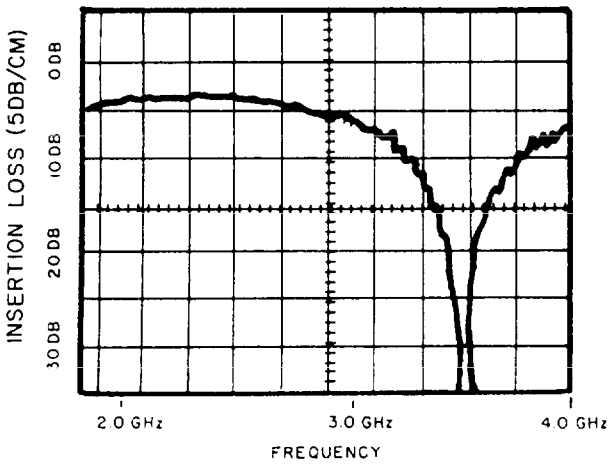


Figure 8-49.-Insertion-loss display.

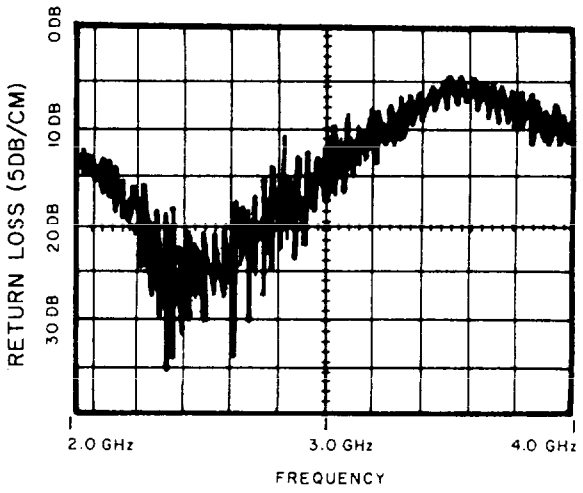


Figure 8-50.-Return-loss display.

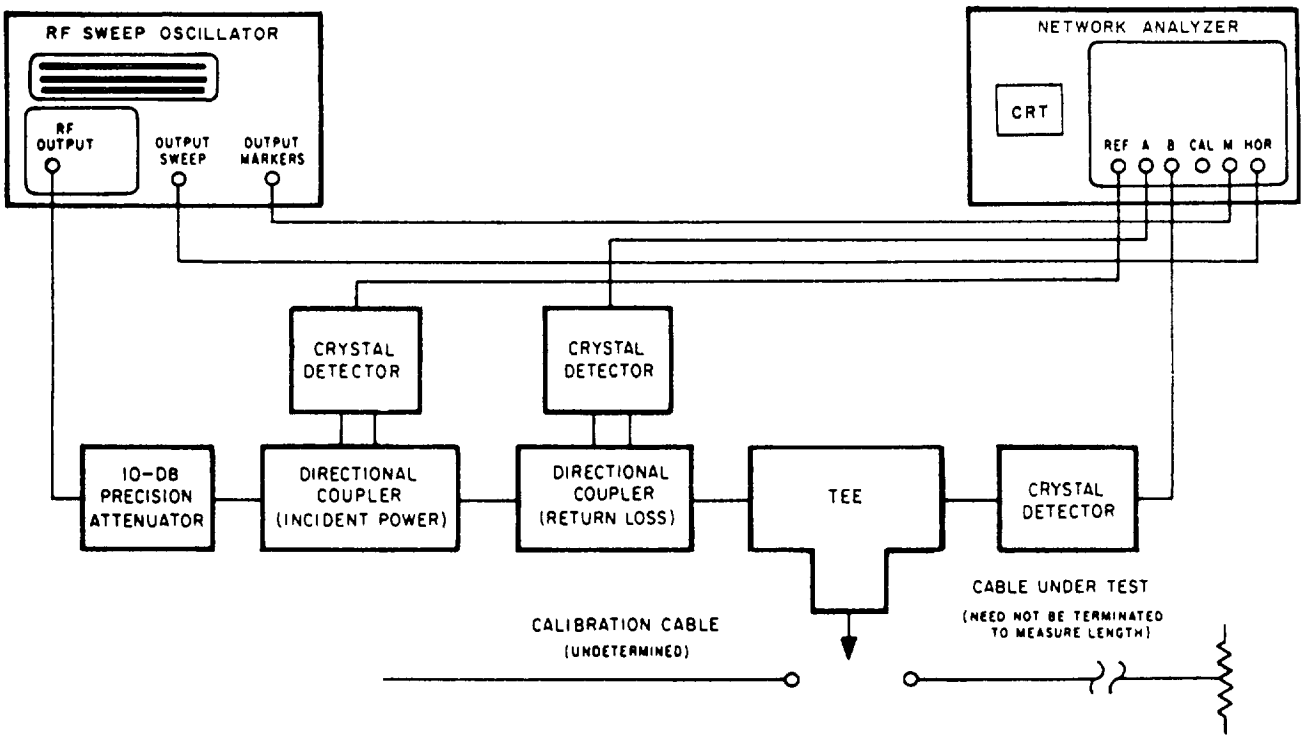


Figure 8-51.-Test setup for fault location measurement.

calibration factor of 2 feet per ripple (CRT calibrated that way). You can see that the location of the fault is 11 1/3 feet from the cable end connector (5 2/3 **x** 2 = 11 1/3 ft). Figure 8-53 shows a dual-channel display of the cable after completing the repairs. The insertion loss is less than 10 dB and the return loss is greater than 11 dB, indicating proper performance of the system cable.

DETAILED FDR ANALYSIS.— With the sweep oscillator output, the transmission system under test, and the crystal detector all connected to the same tee junction, discontinuities and/or termination mismatches in the system reflect some of the incident power. The reflected power combines with the incident signal at the crystal detector, resulting in a changing phase relationship that depends on both distance to the discontinuity and signal frequency. As the frequency is swept, it changes the number of wavelengths that occupy the fixed path from the tee to the point of reflection and back. The display

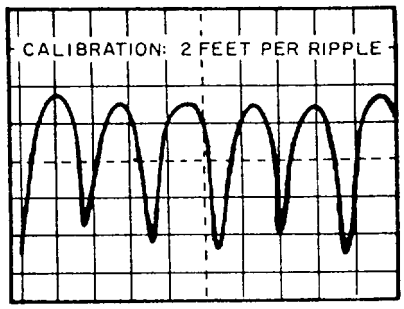


Figure 8-52.-Measuring a cable fault.

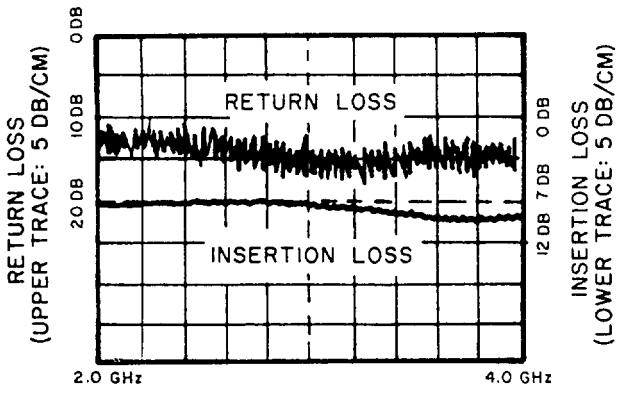


Figure 8-53.-Dual-channel display of a repaired cable.

shows amplitude *ripples* that result from the summing of the incident and reflected signals. This relationship changes with frequency. Figure 8-54 shows how the magnitude of the vector sum of these signals, which is the signal level detected for display, varies with frequency.

The resulting display of the varying-magnitude detected signal is actually a logarithmic SWR presentation. The ripple peaks are adjacent VSWR maxima that occur during the sweep. They occur at each frequency in which the *round-trip* length of the reflected wave path from the source to the defect has changed by one wavelength. The number of ripples appearing across the full width of the display is a measure of the distance from the discontinuity to the crystal detector. Therefore, a direct readout of fault distance is available when the swept source operates over a sweep width (AF). The sweep width is chosen to provide a display calibration (in terms of ripples per foot) compatible with the length of the transmission system under test.

In a coaxial system, the distance to a discontinuity, which may be a fault or the cable end, is represented by the equation

$$D = \frac{492\ K\ N}{\Delta F}$$

Where D is the distance to the fault or cable end in feet,

492 is the half wavelength in feet of a 1-MHz wave in free space transmission,

K is the propagation constant that relates the propagation velocity in the coaxial system to the velocity in free space,

N is the number of ripples observed in the display, and

AF is the swept-frequency excursion (sweep width) of the signal source in MHz.

You should note that for any type of cable, AF can be selected to equal 492K. The distance in feet is equal to the number of ripples (including the fractional ripples) shown in the display.

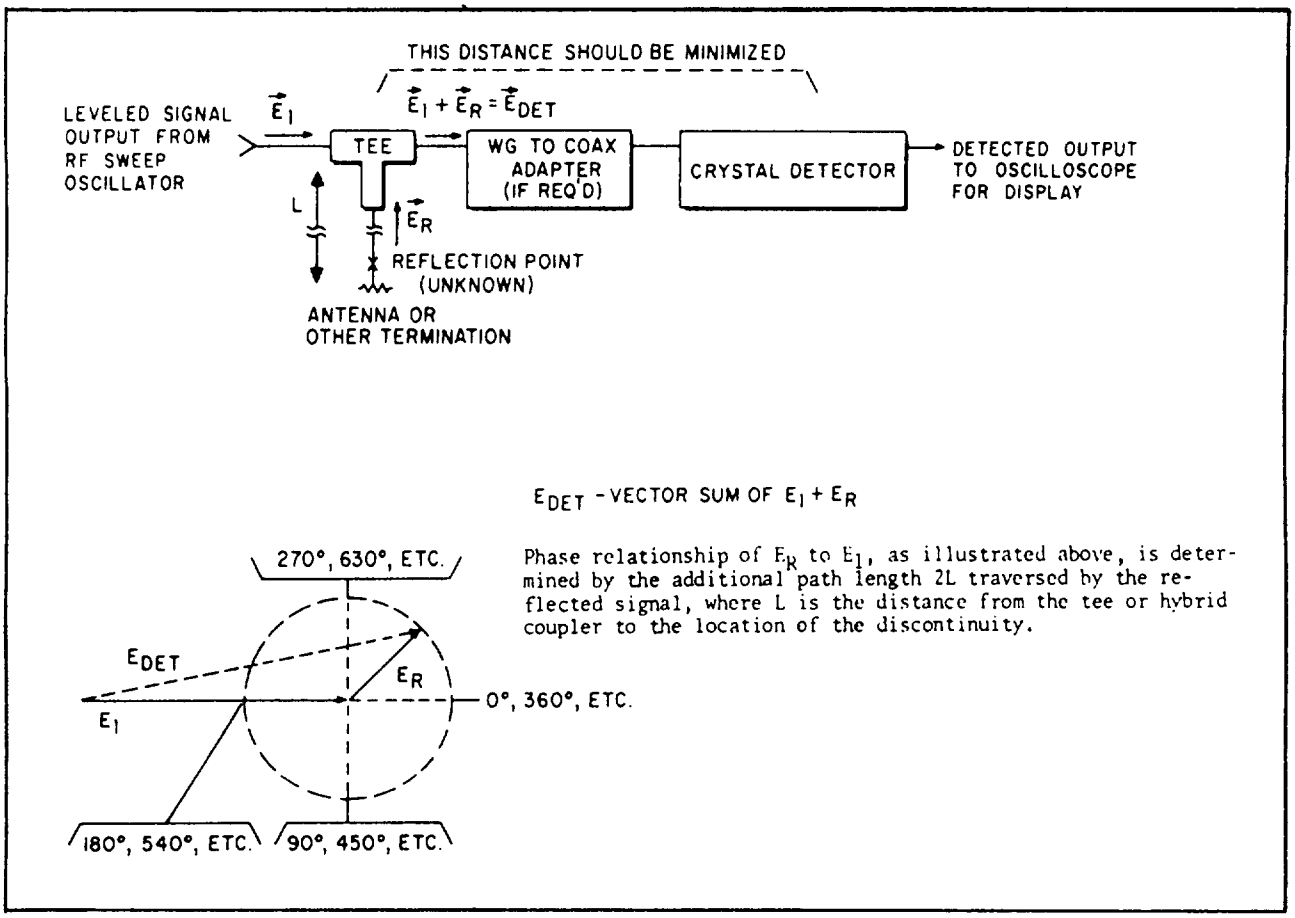


Figure 8-54.-Magnitude of the vector sum.

In waveguide systems, the distance down the waveguide to the fault is represented by the same equation, with K as the

relation $\frac{\lambda}{g}$ (λ is the wavelength in free space

and g is the wavelength in the waveguide) at the frequency of measurement.

Q38. Describe some of the main uses for the TDR.

Q39. Describe the basics of TDR.

Q40. While you can determine different types of discontinuities with the TDR, what else can you determine through proper analysis?

Q41. What factor determines the speed at which a wave travels through a transmission system?

Q42. By what method does using a TDR help you locate an unacceptable connector?

Q43. While TDR and FDR provide similar measurements, the FDR eliminates what limitation of the TDR?

Q44. Describe the means by which the FDR identifies defective systems.

Q45. When determining cable lengths or distance to faults, what means do you use to determine the number of feet from the cable end to the fault?

VAST STATION

Learning Objective: *Identify features, components, and operating procedures of a typical ATE VAST station.*

U.S. Navy aircraft carriers and shore installations are equipped with automatic test equipments (ATEs), such as the Versatile Avionics Shop Test (VAST) station, AN/USM-247(V), and the Hybrid Automatic Test System (HATS), AN/USM-403. The VAST and HATS deal with the continually changing field of avionics testing. The use of these computerized ATEs has significantly reduced the space requirements of special- and manual-support test equipments, The discussion contained in this chapter deals with the VAST station.

TYPICAL VAST STATION

In its basic form, a VAST station is assembled from an inventory of functional building blocks. These building blocks furnish all the necessary stimuli and have the measurement capability to check current naval avionics equipment. As new equipment is developed and introduced, the test station configuration may be modified. As it becomes necessary, new building blocks furnish new parameters or greater precision to existing capabilities.

A typical VAST station (fig. 8-55) consists of a computer subsystem, a data transfer unit

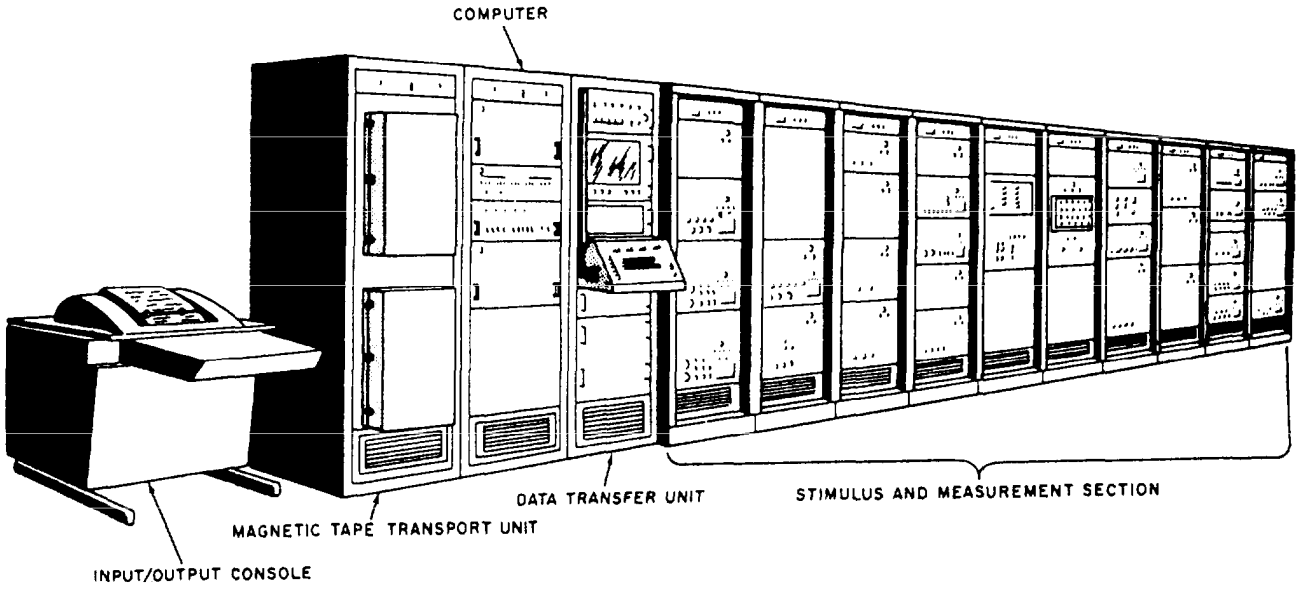


Figure 8-55.-Typical carrier-based VAST station.

(DTU), and a stimulus and measurement section containing functional building blocks configured to meet the intended test application.

A computer subsystem controls the test station, which executes test programs to assure accurate and satisfactory testing. The computer subsystem includes a general-purpose digital computer that executes test routines and has diagnostic and computational capabilities. Also, this subsystem processes data and furnishes a permanent record of test results. Two magnetic tape transports provide rapid access to avionics test programs and immediate availability of VAST self-check programs.

The data transfer unit (DTU) (fig. 8-56) serves as the operator-machine interface. It synchronizes instructions and data flow between the computer and the functional building blocks. Also, it contains the display and control panels.

The operator communicates with the computer and the stimulus and measurement section of the VAST system by using the DTU control panel, which has the keyboard and mode select key. The test station may be operated in three modes—manual, semiautomatic, or fully automatic.

The DTU contains a maintenance panel that monitors station auto-check results and indicates building block faults. Transmission of instructions from the control computer is on a request/acknowledge basis. Essentially, the stimulus and measurement section controls the response rate. This allows instructions to be transmitted at an asynchronous rate, corresponding to the

ANSWERS FOR REVIEW QUESTIONS Q38. THROUGH Q45.

A38. TDR test sets are used to check and troubleshoot aircraft wiring, transmission lines, and antenna systems for shorts, opens, crimps, or bad couplings.

A39. The TDR analysis begins with the insertion of a step or pulse of energy (incident signal) into a system or cable. Then, at the point of insertion, the energy reflected is observed.

A40. You can determine if the discontinuity is resistive, inductive, or capacitive, and whether it is in series or parallel with the load.

A41. The system's velocity constant; a wave travels through air faster than it does through polyethylene.

A42. TDR rapidly shows where mismatches are located; how bad they are; if they are resistive, capacitive, or inductive; and whether in series or shunt.

A43. FDR checks cables at their actual operating frequencies, eliminating the limitation of TDR discontinuities outside the operating frequencies.

A44. The FDR identifies defective systems by injecting an RF signal into a system and using insertion loss (attenuation in the line) and return loss (VSWR) measurements to classify the system under test as good or in need of repair.

A45. The resulting CRT display consists of a series of half-dome ripples. A count of the total number of these ripples multiplied by the calibration factor identifies the location of the fault.

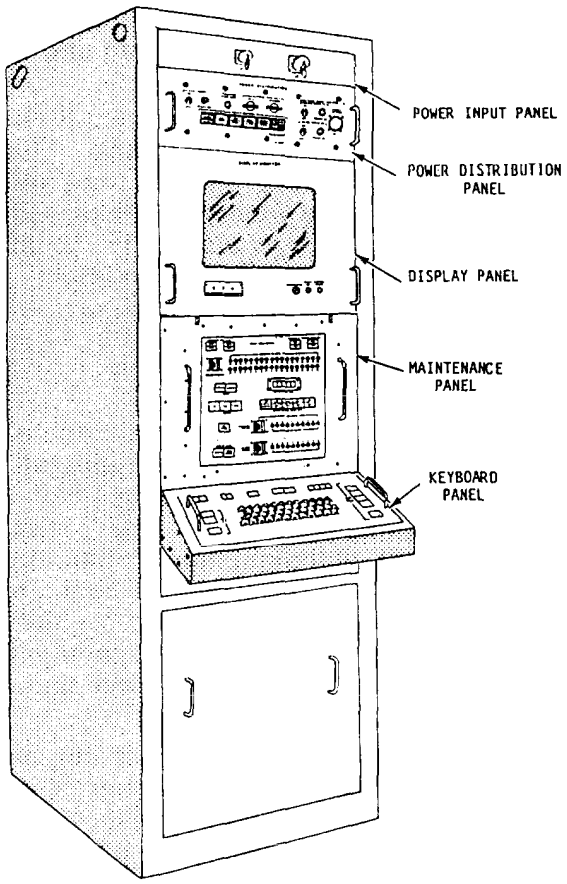


Figure 8-56.-Data transfer unit (DTU).

maximum frequency at which a given building block or avionics unit can respond. Therefore, there is no requirement for immediate program storage in the DTU.

FEATURES OF A VAST STATION

A VAST station may have as many as 14 racks of stimulus and measurement building blocks (fig. 8-57). Large station configurations may contain as many as 17 core building blocks. Core building blocks are designated as a result of high-use factors or because they are needed for self-test requirements. Building blocks not in the core category are usually selected to meet the specific test requirements of shop operations or avionics equipment on board ship. In general, the location of such peripheral building blocks is flexible. To maintain standardization between VAST stations, the effects of building block interconnection cable losses and switches have to remain within predictable limits; this is the purpose of the core concept.

Ease of maintenance is the main objective of the VAST station designed. In addition to the modularized design of VAST building blocks, there are three levels of fault detection, which ensure rapid confidence tests and easy fault location. The three levels of detection are auto-check. self-check, and self-test.

Fault detection may be initially made through auto-check. The auto-check is inherent in the logic and control design of the test station and includes

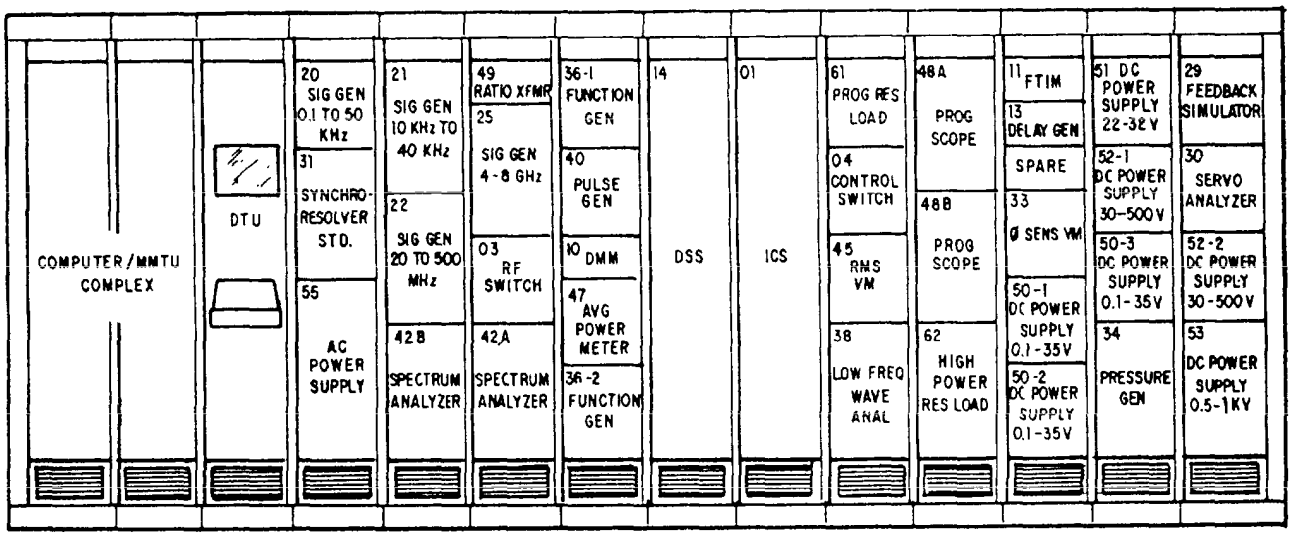


Figure 8-57.-VAST station with building blocks.

verification of instructions and fault monitoring. Auto-check is carried out on a continuous basis during station operation and, when a fault occurs, testing is interrupted.

The second level of VAST fault detection is self-check. Self-check is a programmed sequence that is initiated by the VAST operator through the DTU keyboard. Self-check may be either internal or at the system level. Internal self-check measures the ability of a building block to perform against its own internal standards. System self-check requires the use of two or more building blocks in a test configuration selected to isolate faults within the test setup.

The self-check philosophy used to verify the operation of VAST is based upon confirmation of key system elements first. Then, these elements are used to check the remaining building blocks. Fundamental core building blocks are checked by means of internal standards. Once satisfactory performance is assured, their capabilities are used to check the remaining building blocks, The checkout of noncore building blocks is accomplished by using any combination(s) of core measurement and stimulus building blocks.

The final level of VAST fault detection is self-test. This is a series of test programs used to locate faults within a building block. If a building block has been found to contain a malfunction as a result of a self-check routine, then self-test programs are conducted. This is done by removing the faulty building block from the VAST rack and by connecting it to the test station in the same manner as if it were a unit under test.

Avionics equipment must be designed to be adaptable to automatic testing to assure optimum support by VAST. Moreover, test programs must be prepared that are compatible with VAST performance characteristics.

VAST-TO-UUT INTERCONNECTING DEVICE

Included in the program design is the all-important interconnecting device design. In its simplest form, the interconnecting device consists of an adapter cable, which connects the unit under test (UUT) to the VAST interface. In some cases, however, it is necessary to introduce, as part of the electrical interface in the interconnecting device, passive and active circuits to change impedance levels or to amplify low signals, Ordinarily, this is not required if avionics equipment has been designed within the requirements of VAST. Often, passive circuit functions are obtained through the use of standard plug-in modules.

The last element of the test program is the instruction booklet or microfilm strip. This element details all the steps to follow when you test any given unit, from initial procedures, such as hookup and clearing operations, down to the final stages of disconnect and UUT closeout.

OPERATION OF A VAST STATION

In the typical VAST test procedure, ease of operation in the actual testing becomes apparent, The initial setup of the weapon replaceable assembly, including removal of dust covers, cooling provisions, and connections to interface device, may be made off station to minimize disruptions of station operators. Final connections between the VAST station's interface panel and the UUT are made in a few moments at the station.

The operator begins testing by selecting the code that initiates the test program. Before power or stimulus is applied to the UUT, continuity tests are run to make sure the proper test program has been selected and no condition exists that will damage the VAST station or the UUT once active tests are started. If everything checks out, the testing proceeds automatically, The operator only has to respond to instructions that appear on the CRT display. The program will not stop until a fault is encountered or a program halt is reached.

The purpose of programmed halts is to allow manual intervention during the course of testing to make adjustments and observations. When the identification of faults and the operator's instructions are required (such as interpreting a complex waveform), the operator may be referred to the test program instructions. Upon completion of the test program, the CRT display indicates closeout procedures.

A VAST station is completely autonomous and normally operated under computer control in a fully automatic mode, stopping only as previously mentioned. Of course, the operator can select any one of the semiautomatic modes or a manual mode.

The semiautomatic modes include a one-group, one-test, and one-step mode. These auxiliary modes permit detailed observation of various test sequences, and they are useful

in performing work-around procedures in reconciling differences in equipment and program mode status and in the verification of repairs.

In the manual mode, the test station is completely off-line with respect to the computer. Instructions are introduced by the operator through the keyboard on a one-word-at-a-time basis. (See fig. 8-58.) Although the manual mode is never used for avionics testing, it is useful for debugging new programs, integrating new building blocks into the station, and performing self-check operations on some of the building blocks.

Q46. List the elements of a typical VAST station.

Q47. List the three levels of detection that ensure rapid confidence tests and easy fault detection.

Q48. What is the purpose of programmed halts?

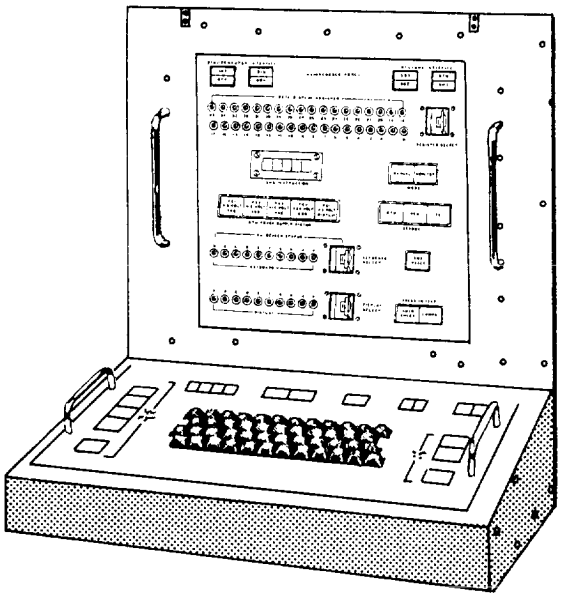


Figure 8-58.-Typical VAST control panel.

ANSWERS FOR REVIEW QUESTIONS Q46. THROUGH Q48.

A46. A computer subsystem, a data transfer unit, and a stimulus and measurement section that contains functional building blocks configured to meet the intended test applications.

A47. Auto-check, self-check, and self-test.

A48. To allow manual intervention during the course of testing to make adjustments and observations.

CHAPTER 9

SAFETY AND SECURITY

As you strive to advance, the responsibilities will increase at each paygrade. As an airman you start developing your character and attitudes. It is at this level, you should start preparing for your future responsibilities for safety and security. This chapter should give you a good start in the right direction for a positive accident-prevention attitude and proper security posture.

MISHAP PREVENTION

Learning Objectives: Identify *mishap prevention responsibilities to include supervisor's role, hazard identification, training, and general mishap prevention. Recognize aviation mishap prevention to include techniques, machinery, electrical equipment, volatile fluids, general hazards, and maintenance hazards.*

The procedures and information within this chapter are for training purposes only. They do not replace local safety procedures and should not be considered as, or take precedence over, established procedures within NAVOSH program manuals. You must use commonsense and become familiar with current NAVOSH safety procedures and information to assist you in your safety awareness and mishap prevention efforts.

Why is mishap prevention necessary? The *product* of the Navy is national defense. Therefore, the quality of our performance must be better than that of any competitor. The Navy's business is deadly serious, is conducted by professionals, and is restricted by limited resources. It allows no room for waste! Mishaps produce waste. Therefore, when mishaps are reduced, waste is reduced, and readiness is improved.

A mishap is an unplanned event that results in injuries to personnel, fatalities, or damage to material. Mishaps can and must be prevented. In the Navy, mishap prevention is everyone's job. *Mishap prevention is the process of eliminating mishap-producing causes before a mishap occurs.*

A near-mishap is an mishap that almost happened. It is an occurrence that, except for location or timely action, would have resulted in property damage and/or injury to personnel. While the near-mishap does not cause damage to equipment, material, or personal injury, it does serve notice that a hazardous condition exists that could result in a future mishap. The near-mishap is significant because it serves as a warning. If you ignore any condition that caused a near-mishap, you are inviting a mishap.

RESPONSIBILITIES

Mishaps are preventable. Each person must become a mishap prevention specialist. Mishap prevention is based on recognizing and eliminating hazards through training, inspections, and an awareness of safety. These actions must become habit. In any environment, personal habits determine the chance of an mishap occurring. For these reasons, you must maintain high standards of cleanliness and neatness. Insist on good housekeeping practices and hold frequent inspections (formal and informal). Mishap prevention is a responsibility of the entire chain of command. Hazardous conditions should be reported, and supervisory personnel should take corrective action. When a mishap occurs, it is investigated, and the cause determined by personnel in the chain of command. Lessons

learned from mishaps are used to prevent their recurrence.

> **NOTE:** OPNAVINST 5100.1 (series) and OPNAVINST 5100.23 (series) contain detailed information about safety programs for afloat and ashore commands. As a supervisor, you need to be familiar with applicable sections of these instructions.

> **NOTE:** One of your responsibilities as a supervisor is to report hazardous situations to the chain of command. For information on the procedures for reporting possible hazardous situations that may affect personnel Navy-wide, you should refer to OPNAVINST 5102.1 (series) and OPNAVINST 3750.6 (series).

The proper use of tools eliminates unsafe acts. All tools and equipment should conform to Navy standards for quality and type. You should use them only in the intended manner, Keep your tools in good repair. Replace all damaged, worn, or nonworking tools. When a job is completed or when work is interrupted, account for all your tools and return them to their toolbox or the tool issue room.

> **NOTE:** Review the *Naval Aviation Maintenance Program,* OPNAVINST 4790.2 (series) for the latest tool control program procedures. Also, information on the use, care, and selection of general tools is contained in the rate training manual, *Tools and Their Uses,* NAVEDTRA 14256.

A Navy ship holds a great potential for mishaps. Fuel, ammunition, high temperatures, electrical circuits, steel decks, salt water, ladders, voids, and machinery create conditions that could cause mishaps. Navy personnel must learn to live safely within this hazardous environment by being aware of its elements.

People cause mishaps. Since people cause mishaps, mishap prevention must be directed at people. As an individual, you can prevent mishaps if you recognize factors that cause mishaps and if you are motivated to carry out corrective action.

The Navy Safety Center has found that 88 percent of all mishaps are caused by human error. Unsafe conditions are the direct cause of only 10 percent. Most mishaps are caused by people; they are not the result of *uncontrolled events* or *acts of God.* If the principal cause is the human being, then people can prevent mishaps through proper knowledge, hazard awareness, and corrective action.

The mishap prevention program is the sum of all actions taken to reduce mishap damage to equipment and/or injury to personnel. It includes the establishment, maintenance, and enforcement of mishap prevention standards and practices. It also consists of mishap prevention training and education, supervision of operations, maintenance and repair, and mishap investigation and reporting. You cannot separate or isolate mishap prevention from other activities.

SUPERVISOR'S ROLE

One key to a successful mishap-prevention program is a safety-minded supervisor. As a petty officer, you must know your work area, your people, and the materials with which you work. You can take action to prevent mishaps by making sure personnel develop and use safe working habits. If you understand the principles of mishap prevention, you can prevent mishaps. Insist on safe practices at all times, recognize hazardous methods and procedures, and take corrective (mishap preventive) measures. Experience has shown that a lack of knowledge or skill is the single biggest cause of mishaps—people doing something they do not know how to do. When a person is taught the RIGHT way to do a job, it is impossible not to teach him the SAFE way. This is why your increasing responsibilities for conducting on-the-job training and supervising subordinates is important.

MISHAP-PREVENTION TRAINING

Mishap-prevention training begins when you first join the Navy. It begins during indoctrination and continues with orientation and on-the-job training. Doing a job **properly** requires knowledge, and you need to pass this knowledge to the less experienced worker. You must motivate this worker.

One way to prevent mishaps is to use the written operating procedures. You can use these to train your subordinates **and** to prevent mishaps. Another important way to prevent mishaps is to use the proper protective device and equipment. This element of mishap prevention is important in any procedure related to a piece of equipment or system. Following correct procedures prevents mishaps.

As a petty officer, you must be aware of hazards. Hazard awareness is important when you consider the shipboard environment. As a supervisor or worker, you must apply your personal experience and improve your awareness of hazards to promote mishap prevention. Supervisors must also correct any hazardous situation they discover. Further, they are challenged with teaching these abilities to subordinates.

The commanding officer establishes the mishap prevention program, according to OPNAVINST 5100.23 (series) and OPNAVINST 5100.19 (series), and gives it direction; but the supervisors make it work. They make it work through supervision and personnel management. Supervisors assess individual qualifications, provide guidance, and develop proper attitudes (pride in a job well done). Supervisors are responsible for identifying and correcting discrepancies; they are the most qualified to train others to recognize unsafe work practices.

GENERAL MISHAP PREVENTION

Some general rules for mishap prevention are listed in the following paragraphs. These rules apply to personnel in all types of activities, and you should strictly observe them because they are directly related to your work or duty.

- Report any condition, equipment, or material that is considered to be unsafe.
- Warn personnel of known hazards or their failure to observe mishap prevention techniques.
- Wear or use the required, approved protective clothing or equipment.
- Report any injury or evidence of impaired health occurring in the course of work or duty.
- Exercise reasonable, appropriate caution if any unforeseen hazard occurs.

The mishap-prevention techniques in this chapter are not intended to replace information given in instructions or maintenance manuals. If, at any time, you are not sure of the steps and procedures to follow, ask your leading petty officer.

AVIATION MISHAP PREVENTION

In this section, the term *aviation mishap prevention* covers all functions and operations dealing with aircraft. Also, it refers to materials and equipment used with aircraft, hangars, parking areas and ramps, and flight lines and taxiways. (Note: See OPNAVINST 4790.2 [series] and OPNAVINST 3750.6 [series] for detailed maintenance and safety information.)

Hazards

The following are some of the major hazards present in aviation activities:

- Fire or explosion due to applying external or internal power to an aircraft that is in some state of malfunction or disrepair. Also, aircraft undergoing maintenance or modification, or creating explosive vapors, or that contains electrical short circuits.
- Personal injuries sustained by falling from aircraft or workstands, being burned or blown about by jet blast or prop wash. Also, injuries caused by people being struck by objects blown about by jet blast or prop wash, being sucked into jet intakes, or being struck by propeller or rotor blades.
- Personnel being run down or run over because they are not alert when aircraft are taxiing or ground equipment vehicles are moving.
- Explosion of aircraft batteries caused by improper charging methods or to current overloading on ground tests within an aircraft.
- Injuries caused by encounters with tie-down lines, pad eyes, chocks, protruding parts of aircraft or other equipment, or other items about a deck or ramp. These injuries are especially common during the hours of darkness.
- Canopy, ejection seat, ordnance, and other "wrong switch at the wrong time" type of mishaps.
- Misuse of and abuse to flight safety equipment, parachutes, "Mae Wests," life rafts, etc.
- Mishaps caused by careless workers, who leave tools or other materials in aircraft bilges, engine nacelles, intake or exhaust ducts, or movable parts of aircraft structures.

Techniques

Many mishap-prevention techniques are of a general nature and apply to all types of aircraft. However, others vary in specific details between specific models. Because your duties will be around aircraft, you need to know both general and specific mishap-prevention techniques or procedures. The mishap-prevention techniques here are not a complete listing. They are a guide to show the types of mishap-prevention items that must be part of the mishap-prevention education and training programs of all aviation activities.

- Place appropriate warning signs in or around aircraft or work areas whenever and wherever a hazardous condition is known or thought to exist. Enforce strict attention and adherence to the signs.

- Observe and enforce smoking regulations and prohibitions. Since explosive vapors may be ignited from any source of open flame or from electrical arcing, these conditions are subject to the same restrictions as smoking.

- Radio and radar transmitters should not be trained on potentially explosive areas or on personnel. They should not be operated near flammable or explosive materials or vapors.

- Do not disconnect or remove storage batteries or electric cables from their circuits in any enclosed space without first ventilating the space to remove accumulated vapors. Open all switches and disable electric power before disconnecting batteries or electric cables.

- Store combustible waste materials, such as rags, in covered metal containers. Never discard used waste and rags near aircraft; put them into plainly marked metal containers. Dispose of waste properly, according to local regulations.

- Aircraft should be parked with parking brakes set, chocks in place, and tie-downs installed.

- During jet engine run-up, foreign objects may be drawn into the intake ducts, causing damage to the engine compressor section and creating a danger of flying debris from the exhaust section. During maintenance procedures involving engine operation, carefully inspect the intake ducts and surrounding areas to ensure the absence of foreign objects. Ensure all engine air intake safety screens are properly installed. Parking areas, turnup areas, taxiways, and runways must be kept clean and free of stones, hardware, and other foreign objects.

MACHINERY

When working with, on, or around machinery, you need to watch out for moving parts. **Never** reach into the path of moving parts of a machine, either with your hands or with any other item. **Always** follow prescribed procedures in making adjustments on operating machinery. If possible, make the adjustments with the machinery shut down. **Never** wear loose, baggy, or ill-fitting clothes in the immediate vicinity of machinery. Remove rags, papers, and all items from pockets. Remove ties, wristwatches, rings, and all jewelry. Button shirt sleeves and make sure dog tags are inside the undershirt or remove them. **Wear** required eye and ear protection.

ELECTRICAL EQUIPMENT

In addition to the danger of a person's being grabbed or struck by moving parts, electrical equipments also present the danger of fire, explosion, electrical shock, and burns.

Never operate electrical equipment in areas where explosive vapors are present or suspected unless the equipment is explosionproof. When working with, on, or around electrical equipment, you should avoid contact with power circuits. Work on energized circuits or electrical equipment requires the commanding officer's permission and special precautions. Use adequate protective materials and be extremely careful. Adequate protective material includes rubber gloves, insulated tools, and insulated matting etc. Never work on electrical equipment when standing in water, when perspiring heavily, or when in contact with metal decks or other metallic structures or equipment. When preparing to work on de-energized electrical circuits, make sure the power switch is off the unit tagged out or locked out. Then, use a grounding probe to eliminate any residual charge that may exist in the circuit.

These precautions apply to low-voltage equipments and high-voltage equipments. Remember, in connection with electrical shock and burns, that it is the current that does the damage, not the voltage.

HAZARDOUS MATERIALS

Hazardous materials include flammables, compressed gases, aerosols, corrosives, and oxidizers. These materials may be hazardous to workers' health, a safety hazard, and an environmental hazard. For special precautions on handling, storage, and use and disposal of hazardous materials, you should refer to OPNAVINST 5100.23 (series), OPNAVINST 5100,19 (series), and the item material safety data sheet (MSDS),

Explosive Vapors

When stored in a closed space, fuels, alcohol, painting materials and supplies, insulating varnish, certain cleaning supplies, and many industrial gases produce potentially explosive vapors. The hazards relating to these materials are associated with the flash point of the liquids. The flash point of a liquid is the lowest temperature at which the liquid gives off vapors that accumulate near the surface in sufficient quantity to form a combustible mixture with the air. Although liquid oxygen does not have a flash point, it has the same explosive effect.

Different fluids have different flash points. You should know the particular characteristics of any volatile liquids with which you work. You should know the flash point and also the concentration that constitutes (makes up) a combustible mixture. You can find this information on the MSDS.

Adequate ventilation dilutes or disperses accumulated vapors. When working in areas where volatile fluids are being used, make sure the space is ventilated before you operate electrical equipment. The smell of gasoline or other flammable or explosive vapors is not a reliable indicator of flammability.

Toxic Vapors

Some liquids produce vapors that are harmful to personnel. Many materials are either prohibited or their use is rigidly limited. Generally, the precautions are listed on the container and the MSDS, You must adhere to and enforce these precautions at all times.

To prevent mishaps, all personnel should know the hazards involved in the use of all materials. Personnel should properly handle, store and dispose of the hazardous materials they use. These actions are attained by training. Also, personnel should use the MSDS.

CONFINED SPACES

When personnel are working in confined or enclosed spaces, the spaces must be gas free. This includes oxygen for normal breathing, cooling to prevent heat stress, and air movement and exchange to prevent accumulations of hazardous gases or vapors. Personnel also require an additional or alternate source of ventilation or respiratory protection if there is an emergency. Whenever workers are to be sent into a confined space for any reason, make advance provisions for their rescue in case there is a mishap or emergency, according to OSHA regulations. These provisions should include the use of safety lines for locating the workers and for retrieving them from the space. Make sure you can communicate with workers inside the space so the existing conditions (both inside and outside the space) may be made known to the concerned personnel. One person (acting as tender) must keep a constant check on the condition of the space and the workers. This person should be prepared to sound the alarm for additional help or to give assistance to the workers in the confined or enclosed spaces, as required. Personnel who enter a confined space and personnel tending a worker must be trained in confined space hazards and rescue procedures.

Vapors and gases tend to collect in confined and enclosed spaces, so the spaces must be certified as being gas free before entering. Personnel should maintain constant communication with the tender, and inform the tender of any abnormal conditions that exist.

Equipment used by personnel working in confined or enclosed spaces is a matter of considerable importance. Enough light should be provided so the workers can clearly see what they are doing. The light should be insulated so that it does not present a shock or explosive hazard. Protective clothing may be required if vapors or gases exist or are suspected to exist within the space. When the space is tested by the gas-free engineer, restrictions and protective equipment requirements are determined.

Q1. What is the benefit of reducing mishaps in the workplace?

Q2. What type of mishap serves notice that a condition exists that could cause a mishap in the future?

Q3. What is the cause of 88 percent of all mishaps?

Q4. Working with 10 w-voltage equipment is just as dangerous as working with high-voltage equipment because _____.

Q5. List the types of materials considered to be hazardous materials.

GENERAL HAZARDS

In addition to the specific hazards encountered in electronic maintenance, there are obvious dangers involved in falling, tripping, slipping, or collision. However, you are concerned with other general classes of hazards. You have learned about some of the dangers from fire and explosion and the hazards of working with materials that produce vapors. You will also learn about hazards present when working with chemicals or radioactive materials.

Fire and Explosion

Although fire and explosion are frequently associated with one another, they can exist separately. *Basic Military Requirements,* NAVEDTRA 14325, contains detailed coverage on fire and explosion. Other sources of information about fire and explosion danger include *Seaman,* NAVEDTRA 14067, *Airman,* NAVEDTRA 14014, *Military Requirements for Petty Officer Third Class,* NAVEDTRA 14504, and *Military Requirements for Petty Officer Second Class,* NAVEDTRA 14504, *Ship Firefighting,* NSTM 555, OPNAVINST 5100.19 (series), OPNAVINST 5100.23 (series), EIMB SE-000-31M-100, and NA 16-1-529, section 3.

FIRE.— A general discussion of the nature of fire, the classes of fires, fire-fighting systems and equipment, protective clothing and equipment, and fire prevention is contained in *Basic Military Requirements,* NAVEDTRA 14325. General information on aircraft crash rescue and fire fighting is found in *Airman,* NAVEDTRA 14014. Specific details relating to fire-fighting and rescue procedures for a particular model aircraft maybe found in the technical manuals for that model aircraft. Take special precautions if a fire is in an enclosed space, and follow local regulations, which will give the appropriate procedures. The following section contains some actions that should be taken.

In the case of electrical fires, take the following steps:

1. Use carbon dioxide. Do not touch energized circuits with the fire extinguisher discharge horn. When possible, leave the CO_2 bottle in contact with the deck. Discharge it in short, intermittent burst. Direct the carbon dioxide at the base of the flame. Here, it serves two purposes—(1) it cools the area, and (2) it decreases the percentage of oxygen present at the fire. However, for major fires of any type in confined spaces, the excessive use of carbon dioxide may be dangerous because it decreases the oxygen content of the air.
2. If CO_2 is not available, use dry chemical *Purple K* (PKP) extinguisher.
3. De-energize all electrical circuits that may interfere with the proper control or extinguishing of the fire or that may constitute a hazard to the fire fighters.
4. Call the fire department or damage control central. This should be done even if it is a small fire that can be easily controlled or extinguised. This is a precautionary measure that covers unforeseen complications or miscalculations.
5. Try to control or extinguish the fire if possible, using the appropriate fire extinguisher and fire-fighting procedure.
6. Make a full report on the fire to the appropriate authority. The fire marshal has complete information about the proper forms and reports and should be contacted for assistance if needed. However, this does not relieve the person discovering the fire from responsibility in this matter.
7. Overhaul of all fires should be accomplished by a trained fire-fighting team.

The following actions should not be taken when fighting electrical fires:

1. Using water to fight an electrical fire can injure personnel because water conducts electricity. Also, water can damage equipment because of its corrosive properties when used on metals.

2. Do not use foam-type fire extinguishers on electrical fires because foam is a good electrical conductor.

3. Do not inhale smoke from fires. Smoke can contain toxic gases, which, if inhaled, could cause serious injury or death.

EXPLOSION.— Fire may cause an explosion, explosion may cause a fire, or the two may be unrelated. Explosion may result from chemical action, heat, mechanical malfunction, or other causes. An explosion is generally accompanied by a loud noise and a sudden buildup of pressure. Several types of explosions are of interest to you as a technician when you perform your normal duties.

1. The accumulation of combustible gases or vapors from fire or from evaporating liquids represents a potential hazard. A spark, an increase in heat, or certain chemical combinations may trigger an explosion.

2. An explosion in the presence of fire may result in the rapid spread of that fire. An explosion in the presence of combustible materials may cause a fire to start.

3. An explosion may result in flying debris, which will act as shrapnel and may cause severe personnel injuries. In the event of a severe explosion, nearby personnel may suffer from the concussion effect of the blast.

There are many explosion hazards besides fire-caused accumulation of combustible vapors and the accumulation of combustible gases near a fire or electric spark. A few of these are discussed in the following paragraphs.

Pressurized equipment and aerosols are susceptible to explosion in the event of excessive pressurization or a mechanical failure of any part of the pressurized system. If an explosion occurs, the major hazards of the explosion are the creation of shrapnel and the increased danger of arcing in the absence of the pressurization. Implosion, like explosion, results in the creation of shrapnel, frequently with toxic materials coating the splinters. The rapid collapse of glass vacuum tubes is an example of an implosion that is of prime concern to electronics personnel.

Explosive ordnance devices are sometimes installed on aircraft or placed adjacent to the aircraft before loading. Accidental operation of switches may result in the firing of these devices. When operating any equipment in the aircraft, you must be constantly aware of any electrically initiated ordnance devices in the vicinity of the aircraft and must observe all precautions that apply to the situation. When missiles or weapons are aboard, only fully qualified personnel should be permitted to operate any electronic equipment in the aircraft. A definite possibility of detonation of ordnance devices by radiated RF energy is also known to exist. This hazard is discussed later in the chapter under RF radiation hazards.

Air Contaminants

The term *air contaminants* refers to vapors, gases, dust, mist, or fumes, especially those that may be toxic or hazardous, They may result from fire, evaporating liquids or solids, chemical action, or air displacement in confined or poorly ventilated spaces. They may be easily detectable, or almost impossible to detect. They may represent a single hazard, or they may represent a combination of several distinct hazards.

FUELS.— The vapors from nearly all hydrocarbon fuels present hazards of fire and explosion. In addition, they are toxic. If breathed in heavy concentration or for prolonged periods, they may result in permanent damage to the respiratory system, loss of consciousness, paralysis, and/or death. For these reasons, there are numerous mishap-prevention regulations and detailed procedures regarding fuels and fueling operations. In general the most important of these regulations require rigid enforcement of the NO SMOKING rules, adequate ventilation, restrictions on the use of electrical equipment, use of special equipment, and the presence of manned fire-fighting equipment.

PAINT SUPPLIES AND MATERIALS.— Most paints, thinners, and many other paint supplies emit vapors that are both flammable and toxic. Regulations require that these items be stored in closed containers in a noncombustible enclosure isolated from living, working, or ordinary stowage spaces. Aboard ship, they must be stowed in approved flammable storage. Use of the material is restricted to well-ventilated areas, and in many cases, personal protective equipment (PPE) and clothing are required.

BATTERY GASES.— In the standard lead-acid storage battery, explosive gases are generated by chemical action. When charging, the battery releases hydrogen. Hydrogen, a highly combustible gas, is violently explosive when in strong

concentration. The newer nickel-cadmium batteries do not present this hazard, but do present other hazards that are covered in a later discussion. Battery lockers are subject to very strict mishap-prevention regulations with special emphasis on smoking restrictions and ventilation requirements.

MISCELLANEOUS MATERIALS.— Many other general classes of materials contain substances that produce hazardous vapors or gases. You should only use them according to specified procedures, Some of these classes are cleaning materials, insecticides, preservatives, solvents, adhesives, and finishes.

Other air contaminants, such as dust and small particles from grinding operations present similar hazards and require similar precautions. Fumes are condensed metal particles from welding or cutting operations. When working in areas where fumes are present, you should take required special precautions and respiratory protection.

Chemical Warfare Agents

The subject of chemical warfare, its agents, treatments, and preventive measures, is treated in detail in other TRAMANs. Among these manuals are *Basic Military Requirements,* NAVEDTRA 14325, *Military Requirements for Petty Officer Third Class,* NAVEDTRA 14504, and *Military Requirements for Petty Officer Second Class,* NAVEDTRA 14504.

Radioactivity

The use of radioactive materials is common throughout the Navy, particularly in the electronics field. Common radioactive materials familiar to most technicians include luminous dials on watches, various instruments, CRTs, and the luminescent markings on equipment. Radioactive material is intentionally added to many special-purpose electron tubes. The material produces a continuous supply of ionized particles to ensure the tube always ionizes at the same voltage. The principal radioactive materials in these tubes include certain isotopes of carbon, cesium, cobalt, nickel, and radium. These tubes are usually TR and ATR tubes, glow lamps and cold-cathode tubes, and certain spark gap tubes. With proper precautions and procedures, these materials present no serious hazard. However, with careless or improper treatment, the hazard may become very serious.

Radioactive materials emit rays (known as *ionizing radiations)* that can cause changes in living tissue, with subsequent injury to the body. The amount of change, and therefore the seriousness of the injury, increases with the amount of radiation absorbed. The absorption of radiation is cumulative, and the repair of damaged tissue is slow. Therefore, the hazard level is based on the total amount of radiation absorbed and the rate of absorption. For more detailed information, refer to OPNAVINST 5100.23 (series) and OPNAVINST 5100.19 (series).

A primary handling hazard would occur if radioactive substances enter the bloodstream. These substances may enter through a cut or an abrasion or through slivers of glass from broken tubes penetrating the skin. This type of injury may be quite serious, even if only minute quantities of radioactive materials were injected. The materials injected are carried throughout the body by the bloodstream. They tend to accumulate in certain organs or parts of the body. In addition

ANSWERS FOR REVIEW QUESTIONS Q1. THROUGH Q5.

A1. Improved readiness.

A2. A near mishap.

A3. Carelessness.

A4. Current not voltage does the damage.

A5. Flammables, compressed gases, aerosols, corrosives, and oxidizers.

to the radiation effects, they also cause a type of poisoning similar to chemical poisoning.

A wound containing a radioactive particle requires treatment by a medical officer as soon as possible, regardless of the size of the wound. The hazard of allowing radioactive particles to remain in a wound **cannot be ignored.**

There are no known antidotes for radiation poisoning caused by radioactive particles remaining in the body. Treatment of radiation sickness is complicated and lengthy. Even with the best medical attention, the results are often inconclusive. However, progress continues in this field, and close liaison with the medical department ensures you receive the latest first-aid procedures and medical treatment.

Inhalation of minute particles of radioactive dust can cause coating of the mucous membranes, which results in poisoning and increased radiation effects. Once lodged in the nasal passages or throat, these particles are difficult to remove. They are even more difficult to remove from the lungs.

Contamination of the skin by radioactive materials may produce radiation burns resembling the temporary redness of a mild sunburn. In severe cases, a serious burn, which destroys the skin, will occur. All such cases should be reported to the medical authorities immediately. With proper medical care, complete recovery usually occurs, except in extreme cases involving severe burns over an extensive area. This type of injury is rare.

DETECTION.— Radioactive radiation is completely undetectable through the use of the human senses; detection relies upon the use of special equipment. The methods of detection and the types of radioactivity detectors are discussed in *Basic Military Requirements,* NAVEDTRA 14325. The following areas and/or conditions require monitoring:

- Periodically, monitor storage areas containing instruments, equipments, or tubes with radioactive materials to make sure the radiation level does not exceed allowable limits. Specifically, monitor the air intake and exhaust screens or filters before cleaning.

- Monitor all areas that surround broken tubes containing radioactive material or flaking radioactive paint or markings to help locate all the radioactive material. These areas should be monitored again after decontamination to determine the effectiveness of the procedures used.

- Monitor personnel whenever contact with radioactive materials is suspected or after participating in decontamination activities.

PRECAUTIONS.— Observe the following mishap-prevention practices to minimize the hazard presented by radioactive materials.

- Tubes or instruments should not be removed from cartons until immediately before actual installation. This serves two purposes—(1) to prevent mishapal breakage and (2) to avoid the possibility of concentrating several radioactive sources in a small volume (which would increase the effective intensity of radiation).

- When removing a radioactive component from equipment, place it in an appropriate carton to prevent breakage.

- **Never** carry items containing radioactive materials in your pocket or elsewhere in a manner that lets flaking or breakage occur.

- Exercise extreme care whenever handling radioactive items, especially during installation or removal from equipment.

- **Never** break tubes intentionally. However, if they do break, **do not** let contaminated material contact any part of your body at any time. Avoid breathing any dust or vapor (such as radon gas, a highly radioactive substance) released by broken tubes. Locate all broken pieces immediately and isolate the area until the broken pieces have been removed or declared nonradioactive by testing with an adequate radiation-sensitive device.

- Do not bring food or drink into a contaminated area or near any radioactive material.

- Personnel who have handled radioactive material in any way should remove contaminated clothing immediately after leaving a contaminated area. They should wash their hands and arms thoroughly with soap and water, especially before eating, drinking, or smoking.

- If you receive a wound from a sharp radioactive object, report to medical authorities for treatment as soon as possible.

DECONTAMINATION AND DISPOSAL.— When cleaning a contaminated area, you should wear rubber or plastic gloves. Remove large fragments of a broken tube by using tools, such as forceps, if they are available. You can remove the remaining particles by using a vacuum cleaner with a HEPA-filter collecting bag or by using a wet cloth to wipe across the area. (If tubes are broken frequently, select the best type of collecting bags.)

If you use a wet cloth, make one stroke at a time, and fold the cloth in half after each stroke, always using a clean side. When the cloth becomes too small, discard it and continue with a clean piece. Be careful not to rub the radioactive particles into the surface by using a back-and-forth motion. Seal all used cleaning debris, cloths, and bags in a container, such as a plastic bag, heavily waxed paper, or a glass jar, Then, place it in a steel can for disposal, according to local disposal guidelines.

Radioactive waste materials and HEPA-filter bags should not be disposed of individually. Collect them in a designated steel container with a tight-fitting lid, suitably marked, until you have a reasonable quantity for disposal. Mark all radioactive material containers with the radiation symbol (fig. 9-1). The symbol is printed in magenta (a purplish red) on a yellow background.

Dispose of radioactive waste in proper containers according to current regulations and instructions of the Nuclear Regulatory Commission.

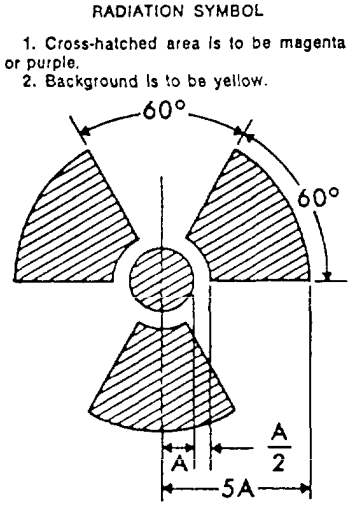


Figure 9-1.-Radiation symbol.

Q6. What training manuals contain information on fire and explosion?

Q7. What is the primary hazard you will meet when handling radioactive materials?

Q8. List some of the general hazards.

Q9. What is an excellent reference for determining flash points and concentration levels of combustible mixtures?

Q10. List the minor hazards associated with an explosion of pressurized equipment.

MAINTENANCE HAZARDS

Everyone who works with electronic equipment must be alert to the hazards of their equipment and be capable of giving first aid. The installation, operation, and maintenance of electronic equipment requires enforcement of a stern mishap-prevention code. Carelessness on the part of the operator or the maintenance technician can result in serious injury or death. Mishap investigations usually show that mishaps are preventable by following simple mishap-prevention techniques and procedures with which the personnel involved should have been familiar.

Because you work with electronic equipment, you should read and follow the mishap-prevention practices and procedures contained in applicable safety directives, manuals, other publications, and in equipment technical manuals. Read the material before you work on electronic equipment. It is your responsibility to identify, report, and eliminate any unsafe condition and unsafe acts that could cause a mishap.

General Precautions

You should take time to consider and use mishap-prevention techniques when working on electronic circuits and equipment. Carefully study the schematics and wiring diagrams of the entire system, noting what circuits must be de-energized and tagged or locked out in addition to the main power supply. Remember that electronic equipments frequently have more than one source of power. Be sure that ALL power sources are de-energized before servicing the equipment. Do

not service any equipment with the power on unless it is necessary.

Remember, de-energizing main supply circuits by opening supply switches will not necessarily *kill* all circuits in a given piece of equipment. An often neglected or ignored source of danger is the inputs to electronic equipment from other sources, such as synchros, remote control circuits, etc. Sometimes neglect and ignorance can be tragic. For example, turning off the antenna safety switch disables the antenna, but it may not turn off or lockout the antenna synchro voltages from other sources. Moreover, the rescue of a victim shocked by a remote power input is often difficult because of the time required to find the power source and turn it off. Therefore, turn off ALL power inputs before working on equipment.

Remember that the 115-volt power supply voltage is not a low, relatively harmless voltage. This voltage source is the cause of more deaths in the Navy than any other.

Do not work with high-voltage circuits by yourself. Another person (safety observer), qualified in first aid for electrical shock, should be present at all times. The person should also know the circuits and switches controlling the equipment. They should de-energize the circuit immediately if anything unforeseen happens.

Always be aware of the nearness to high-voltage lines or circuits. Use rubber gloves, where applicable, and stand on approved matting. Not all so-called rubber mats are good insulators.

Do not use equipment containing metal parts, such as brushes and brooms, in an area within 4 feet of high-voltage circuits or any electric wiring having exposed surfaces.

Inform remote stations as to the circuit on which you are working.

Keep clothing, hands, and feet dry if at all possible. When it is necessary to work in wet or damp locations, use a dry platform or wooden stool to sit or stand on. Place a rubber mat or other nonconductive material on top of the wood. Use insulated tools and insulated flashlights of the molded type when working on exposed parts.

Do not wear loose or flapping clothes. The use of thin-soled shoes with metal plates or hobnails is prohibited. Safety shoes with nonconducting soles should be worn if available. Flammable articles, such as celluloid cap visors, should not be worn.

When working on electronic or electrical apparatus, **remove all** rings, wristwatches, bracelets, ID chains and tags, and similar metal items. Care should be taken that the clothing does not contain exposed zippers, metal buttons, or any other type of metal fastener.

Do not work on energized circuits unless absolutely necessary. Be sure to take time to tagout or lock out (or block out) the switch. Locks for this purpose should be readily available.

Use one hand when turning switches on or off. Keep the doors to the switch and fuse boxes closed except when working inside or replacing fuses. Use a fuse puller to remove cartridge fuses after first making certain that the circuit is dead.

Secure and tag all supply switches or cutout switches from which power could possibly be fed in the OPEN position. The tag should read "THIS CIRCUIT WAS ORDERED OPEN FOR REPAIRS AND SHALL NOT BE CLOSED EXCEPT BY DIRECT ORDER OF. . . ." (the person making, or directly in charge of, repairs). See OPNAVINST 3120.32 (series) and local instructions to ensure proper tagging and securing of electrical and electronic equipment.

Never short out, or tamper with, an interlock switch.

Provide warning signs and suitable guards to prevent personnel from coming into mishapal contact with high voltages.

Avoid reaching into enclosures except when absolutely necessary. If you do have to reach into an enclosure, use rubber gloves or mats to prevent accidental contact with the enclosure.

Do not use bare hands to remove hot tubes from their sockets. Use insulated gloves or a tube puller.

Use only rubber or insulated hose on air lines for blowing out equipment. Use no more than 10 PSI to avoid damage to the insulation and/or components. Use only moisture-free air. Never turn compressed air on yourself or others, since it could cause serious injury.

Use a shorting probe (fig. 9-2) to discharge all high-voltage charges. Before touching a capacitor or any part of a circuit that is known or likely to be connected to a capacitor (whether the circuit is de-energized or disconnected entirely), short-circuit the terminals to make sure that any capacitor is completely discharged.

Degree of Shock

The amount of current that may pass through the body without danger depends on the individual and the current quantity, type, and path. It also depends on the length of time the current passes through the body. Body resistance varies from 1,000 to 500,000 ohms for unbroken, dry skin. Moisture lowers body resistance and dry skin increases it. Breaks, cuts, or burns may lower body resistance to 200 ohms. A current of 1 milliampere can be felt. Five milliamperes is about the highest current safe for the average body. If the palm of your hand makes contact with the conductor, a current of about 12 milliamperes will cause the hand muscles to contract. This current will freeze your hand to the conductor. Such shock may or may not cause serious damage, depending on contact time and personal physical condition, particularly the condition of the heart. A current of 25 milliamperes can be fatal.

Generally, currents between 100 and 200 milliamperes are lethal. Ventricular fibrillation of the heart occurs when the current through the body approaches 100 milliamperes. Ventricular fibrillation is the uncoordinated actions of the ventricles of the walls of the heart. This, in turn, causes the loss of the pumping action of the heart, Fibrillation is usually fatal because people qualified to administer appropriate treatment are not available to administer treatment soon enough.

If currents of 200 milliamperes or higher pass through the body, severe burns and unconsciousness result. Generally, in these cases the heart will not fibrillate, but it will stop. It may be started again by closed-chest heart massage. If breathing has also stopped, the heart may spontaneously restart if cardiopulmonary resuscitation (CPR) brings the blood oxygen supply to a high enough level. In any case, if breathing has stopped, CPR should be started immediately.

When a person receives an electrical shock and is unconscious, it is impossible to tell how much current caused the unconsciousness. CPR must be started immediately if breathing has stopped and continued until the person is breathing normally or until otherwise directed by medical authority.

Special Components

Several components common to aviation electronic maintenance present hazards or potential hazards. The following paragraphs present a brief summary of some of the more important of these components and their hazards.

SELENIUM RECTIFIERS.— When selenium rectifiers burn out, selenium dioxide gas causes

ANSWERS FOR REVIEW QUESTIONS Q6. THROUGH Q10.

A6. Basic Military Requirements, Military Requirements for Petty Officer Third Class, Military Requirements for Petty Officer Second Class, and Airman.

A7. Radioactive substance that enters the bloodstream.

A8. Fire and explosion, fumes, chemicals, and radioactive materials.

A9. MSDS.

A10. The major hazards of the explosion are the creation of shrapnel and the increased danger of arcing in the absence of pressurization.

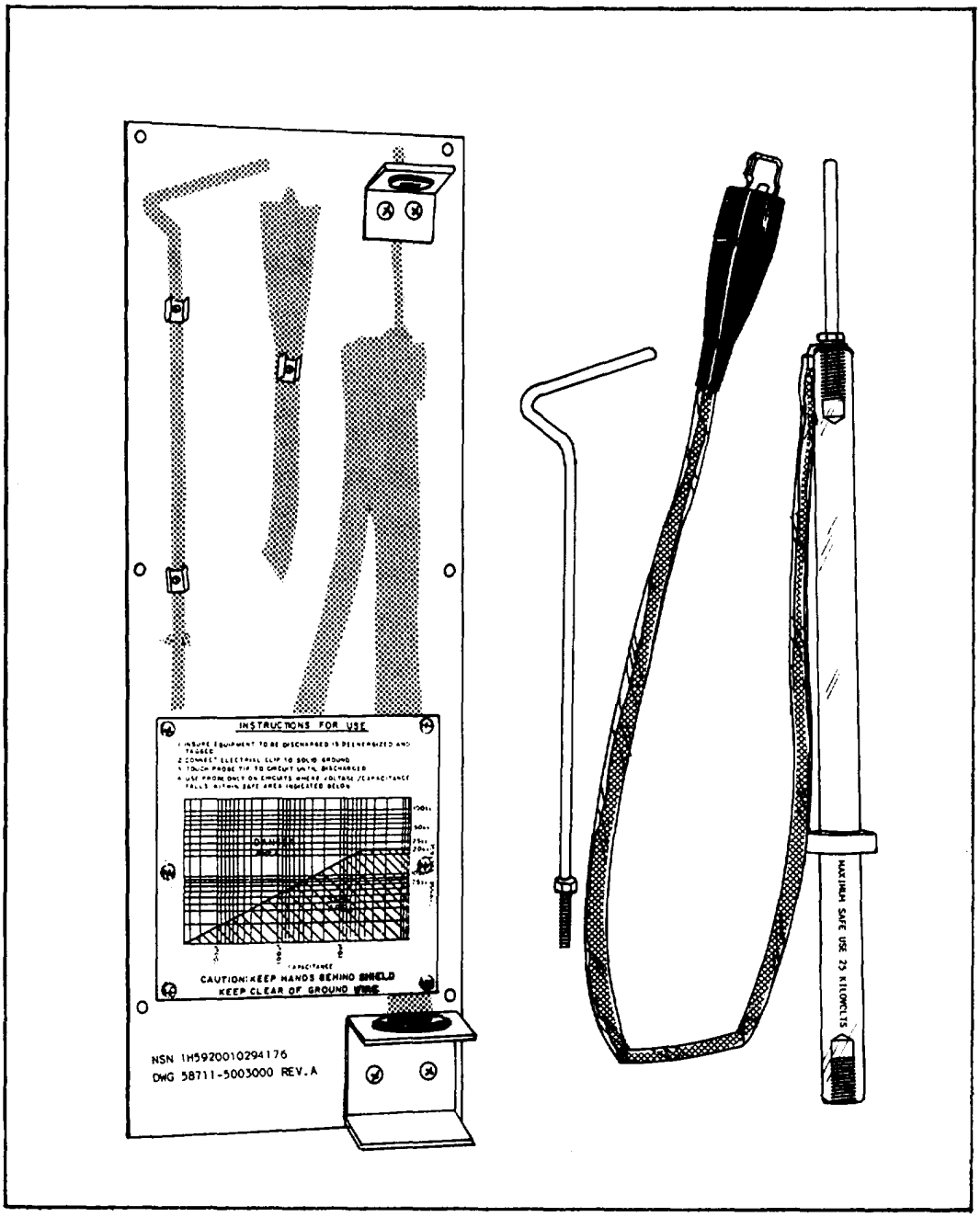


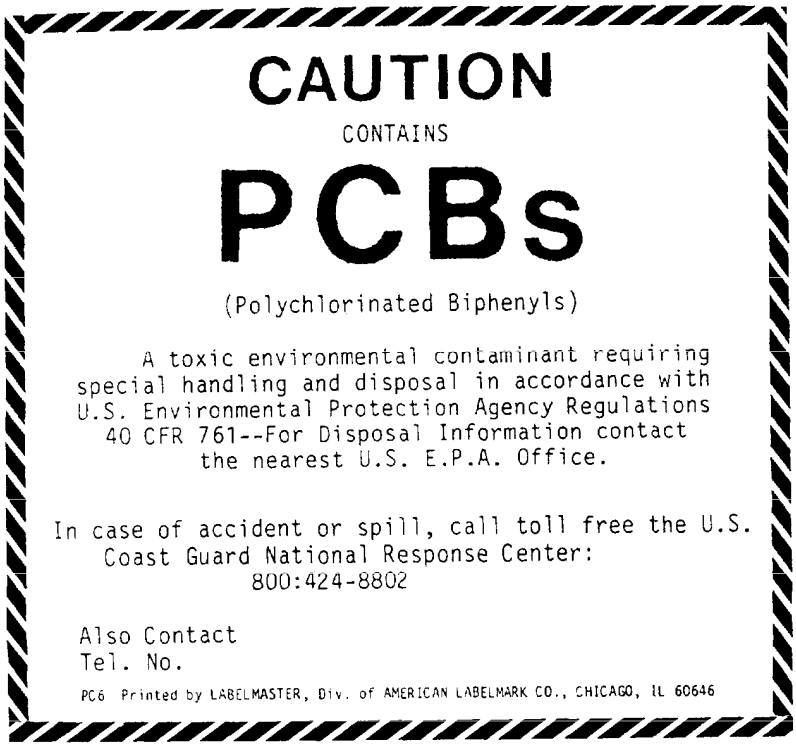
Figure 9-2.-Shorting probe.

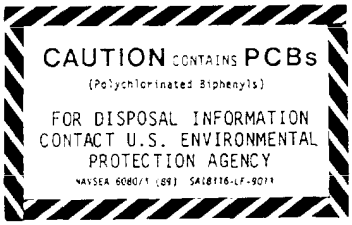
an overpowering stench. Do not breathe these poisonous gases. If a rectifier burns out, you should de-energize the equipment immediately and ventilate the compartment. Allow the damaged rectifier to cool before attempting any repairs. If possible, move the defective equipment outdoors. Do not touch or handle the defective rectifier while it is hot. A skin burn might result, permitting absorption of some of the selenium compound.

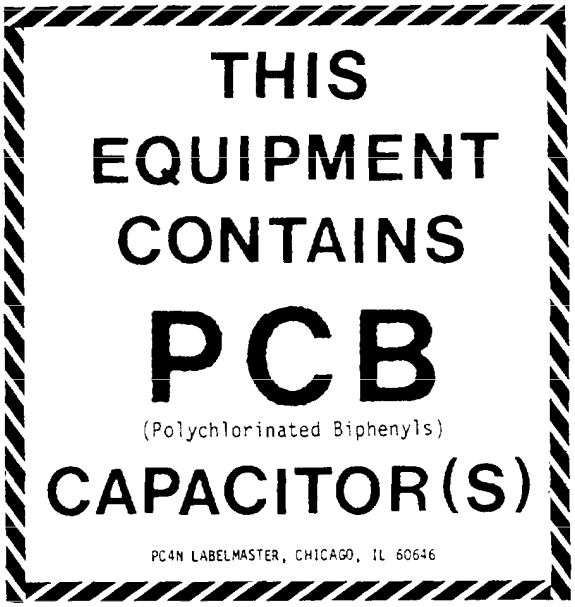
POLYCHLORINATED BIPHENYL (PCB).– PCB is a toxic, environmental contaminant that was commonly used in older transformers. Other material and equipment that contain PCBs should be adequately marked with appropriate warning

labels (fig, 9-3). PCB contaminants require special handling precautions. You should refer to NAVSEA-S9593-A1-MAN-010 and local instructions.

BATTERIES.— Battery hazards are most common during the charging process and during the installation and removal process. The weight and clumsiness of the battery can cause back injury or muscle strain; common sense and routine attention to detail minimize this hazard. All rechargeable storage batteries should be charged in strict accordance with the manufacturer's recommendations.







WARNING LABELS TO BE ATTACHED TO EQUIPMENT CONTAINING PCBs. BACKGROUND IS YELLOW / LETTERING AND BORDER ARE BLACK.

Figure 9-3.-PCB warning labels.

Lead-Acid.— Lead-acid storage batteries present hazards of acid burn, explosion, and back and muscle strain. Prevent burns by the proper use of goggles and a face shield, rubber gloves, rubber aprons, and rubber boots with nonslip soles. Wear protective clothing whenever you are refilling, checking, transporting, or charging batteries. Explosion may result from accumulation of hydrogen gas during the charging operation. Proper ventilation and strict enforcement of the NO SMOKING rules are mandatory.

Nickel-Cadmium.— The electrolyte used in nickel-cadmium (NiCad) batteries is potassium hydroxide (KOH), a highly corrosive alkaline solution, which should be handled with the same degree of caution as sulfuric acid. If KOH is sprayed on any material, wash it immediately with liberal quantities of water and neutralize the affected area with vinegar or a weak solution of acetic acid.

An extremely violent explosion will occur if KOH is added to a lead-acid battery or if sulfuric acid is added to a NiCad battery. Although there is no valid excuse for such an occurrence, it can happen. Clearly mark all battery electrolyte containers and keep them in different stage areas, if possible, when they aren't in use.

Mercury Cell.— Under certain conditions, mercury dry cells or batteries may explode. The most common cause of explosion is overloading the battery (with the subsequent heating and ignition of hydrogen gas within the cell). The loading capacity of the battery decreases as the battery discharges. When a mercury cell (or any cell within a mercury battery) has discharged to 70 percent of its nominal voltage, the cell or battery should be replaced. Discharged mercury batteries should never be stored. Follow disposal instructions contained in OPNAVINST 5190.1 (series).

Lithium Batteries.— Never puncture, incinerate, or recharge lithium batteries. Before lithium batteries are shipped or stored, the terminals should be covered with an insulating material to prevent short circuits. These batteries should be stored in a ventilated and cool fireproof area. Make sure you use eye and skin protection when working with wet lithium batteries. For other precautions on lithium batteries, refer to OPNAVINST 5100.19 (series).

CATHODE-RAY TUBES.— Use extreme caution when handling a cathode-ray tube (CRT). The glass envelope encloses a high vacuum; because of the large surface area, the envelope is subjected to considerable total force due to atmospheric pressure.

The trend toward the use of larger CRTs increases the hazard of implosion. The tubes are not considered hazardous if handled properly. However, if they are struck, scratched, dropped, or handled improperly in any way, they may cause severe injury or death.

When handling, installing, or removing a CRT, be extremely careful to avoid contact between the tube and any sharp or hard object. Wear suitable gloves to protect your hands. Wear goggles, which protect your eyes from flying glass particles if there is an implosion. The goggles should provide both side and front protection and should have clear lenses that can withstand a rigid impact. Insert the tube carefully into the socket, using only moderate pressure. Do not jiggle the tube. Never hold it by the narrow neck. Do not stand directly in front of the face of the tube. Accidental implosion may cause the electron gun or other parts to be propelled directly forward with sufficient velocity to cause severe injury. When the tube must be set down, it is important that the face be placed gently on a thick, clean, soft padding.

In addition to the hazard of implosion, rough handling may also cause displacement of the electrodes within the tube and result in faulty operation or nonoperation of the tube.

The chemical coating material on the face of the tube may be extremely toxic. When disposing of a broken tube, you should use protective devices and procedures to ensure that none of this compound gets on the hands or into the skin. Dispose of the material according to instructions contained in OPNAVINST 5090.1 (series).

Before discarding a CRT, you must eliminate the danger of implosion. While wearing PPE, place the defective tube facedown in an empty CRT carton or special container. Carefully break off the location pin from the tube base. Using a small screwdriver, pliers, or a probe, break off

the tip of the glass vacuum seal. (See fig. 9-4.) With the vacuum seal broken, pressure inside and outside the tube will equalize, and the danger of implosion is removed. However, all other hazards still remain. Before you dispose of a CRT or remove danger of implosion, check local hazardous waste disposal procedures.

DIELECTRIC MATERIALS.— The use of microwave energy causes an increase in power levels, which raises several problems. One problem is the use of certain dielectric materials in new environments without previous application experience. In several cases, personnel were exposed to potentially toxic agents as a direct result of the introduction of new substances, For example, using sulfur hexafluoride as a gas dielectric to increase the power-handling capability of waveguides. In its pure state, this gas is essentially inert and nontoxic. However, when arc-over occurs in a waveguide filled with the gas, decomposition products constitute a toxic gas hazard. These toxic gases, which include fluorine, are colorless and odorless. While they may not irritate the skin, they may cause extreme lung irritation and hemorrhaging.

Arcing may take place periodically in the waveguide until the system fails completely, or at least until system performance drops below an acceptable minimum level. If you open the waveguide while making repairs on the system, you may release these highly toxic gases. When opening a waveguide pressurized with sulfur hexafluoride, use an approved acid gas respirator. Perform this type of work in a well-ventilated area. If toxic hazards exist from a mishap, clear the area of all toxic hazards before allowing other personnel to enter the area.

As toxicological or other information regarding safety matters becomes available, precautionary measures and protective devices are developed, distributed, and issued. If you don't know whether a new material or substance is hazard free, take precautionary measures as if definite hazards were known to exist.

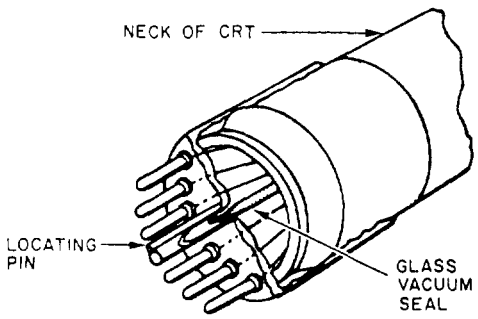


Figure 9-4.-Construction of a CRT base.

RF RADIATION

Electromagnetic radiation (nonionizing radiation) is not visible, Its presence must be detected and measured by instruments or approximated by mathematical calculations. Radiated beams of high-power RF energy present a health hazard and contribute to mishaps. In general, the health-hazard and mishap-contributing factors fall into the ordnance, personnel, fuel, and miscellaneous areas. The Naval Medical Command, Naval Air Systems Command, and Naval Sea Systems Command are responsible for establishing health-hazard and mishap-prevention precautions regarding electromagnetic radiation. For more information on RF hazards, refer to *Radio-Frequency Hazards Manual,* NAVSEA OP 3565/NAVAIR-16-1-529, and *Electronics Installation and Maintenance Book— Test Methods and Practices,* NAVSEA 0976-LP-000-0130, and OPNAVINST 5100.19 (series).

The energy striking an object in an electromagnetic field may be reflected, transmitted, or absorbed; only the absorbed energy constitutes a hazard. The hazard resulting from a focused concentration of such energy, like any hazard, can be controlled if personnel understand the conditions and take precautionary measures.

Ordnance Hazards

The problem of hazards of electromagnetic radiation to ordnance (HERO) is acute. The number and variety of electrically explosive devices are increasing rapidly. For example, some current operational weapons contain more than 76 electro-explosive devices. Continuing development efforts are directed toward reducing weight and space requirements, lowering power requirements, assuring positive response, and increasing mishap-prevention characteristics and reliability. These goals are not always complementary.

At the same time, the power of communications and radar-transmitting equipment is constantly increasing and the frequency spectrum broadened. The airborne Navy uses the radio-frequency spectrum from 10 kHz to about 20 GHz. Transmitter power outputs extend to

10 kilowatts at communications frequencies, and peak power outputs extend to approximately 5 megawatts at radar frequencies. These trends produce situations that are in direct conflict with each other. On the one hand, transmitters and their antennas have only one purpose—to radiate electromagnetic energy. The initiating elements of ordnance devices need only be supplied with the proper amount of electrical energy for an explosion to take place. Therefore, certain precautions are required for mishap prevention and to ensure reliable performance of ordnance items.

To meet the growing need for new procedures to reduce the hazard to ordnance equipment from RF radiation, the Naval Air Systems Command sponsors tests. These tests, coordinated with studies made by other agencies, have provided new guidelines and restrictions for handling electrically initiated ordnance equipment.

The basic problem in determining susceptibility of an ordnance system to RF radiation lies in the evaluation of the antenna-like couplings; specifically, the couplings that exist between illuminating fields and the electro-explosive devices in the system. RF energy may enter a weapon as a wave radiated though a hole or crack in the weapon skin, or it may be conducted into the weapon by the firing leads or other wires leading into the weapon.

The exact chances of such firing of electro-explosive devices are quite unpredictable. The type of occurrence depends upon several variables. These variables may be frequency, field strength, positional and directional orientation, environment, and metallic or personnel contacts with the ordnance or aircraft. The most susceptible time for this type of mishap is during ordnance assembly/disassembly and loading/unloading operations or during testing in electromagnetic fields. The most likely effects of premature actuation are dudding, reduction of the reliability of the device, or propellant ignition. In extreme cases, there is a definite possibility of warhead detonation.

Some specific mishap-prevention techniques that the AT must observe with respect to these weapons and ordnance devices include the following:

- Turn off all RF transmitters during weapons-handling operations in the area.
- Observe all local and general mishap-prevention techniques and HERO restrictions.
- Maintain radio and radar silence during assembly/disassembly, loading/unloading, or testing operations.
- Avoid illumination of ordnance devices by high-power RF transmitters.

The HERO problem is a complex one. The hazard and the solution is a function of the following factors:

1. Frequency and field strength
2. Geometrical configuration
3. Orientation
4. The antenna characteristics of the weapon or weapon-aircraft and weapon-launcher combinations

In general, the path by which energy is introduced to the electro-explosive devices is not readily definable. For more specific information, refer to NAVAIR 16-1-529.

Personnel Hazards

Development of RF systems with high-power transmitting tubes and high-gain antennas has increased the hazard to personnel in the vicinity of these elements. Harmful effects of over-exposure to RF radiation are associated with the average power of the absorbed radiation. The effects are thermal in nature and are observed as an increase in overall body temperature or as a temperature rise in certain sensitive organs of the body. The only known nonthermal effects on personnel are due to power density values considerably greater than the power densities normally associated with present RF transmitting systems.

The Naval Medical Command has established safe limits based on the power density of the radiation beam and the exposure time of the human body in the radiation field. [See OPNAVINST 5100.2 (series) and OPNAVINST 5100.19 (series).] All areas in which the RF levels exceed the safe limits are considered hazardous. The Naval Sea Systems Command is responsible for determining hazardous shipboard areas, posting or marking these areas, and for decreasing the hazard to personnel from RF radiation. Calculations and power density measurements are used to establish the distances from radar antennas within which it is not biologically safe for personnel to enter. This information is then used to determine if and where hazardous areas

exist. All hazardous areas subject to entry by personnel are posted with warning signs, and the ship's intercommunication system is used to warn personnel when the radars are operating.

Personnel must be protected from RF radiation; however, blanket restrictions on antenna radiation are not possible. Maintenance and checkout procedures must take place and can be done by taking the following precautions:

- Do not visually inspect feed horns, open ends of wave guides, and openings emitting RF electromagnetic energy unless the equipment is definitely secured for the purpose of such an inspection.

- Park aircraft having high-power radar or orient their antennas so that the beam is directed away from personnel working areas.

- Observe RF-hazard warning signs and deck markings (fig. 9-5), which point out the existence of RF radiation hazards in a specific location or area.

- Either continuously rotate while radiating antennas that normally rotate or train the beam to a known safe bearing.

- Train and elevate nonrotating antennas away from inhabited areas, hangars, shop spaces, ships, piers, etc., while radiating.

- Where a possibility of mishapal overexposure might still exist, have someone stationed within view of the antenna to warn personnel of the hazard. However, have them stay well out of the beam and in communication with the operator while the antenna is radiating.

- Radiation-hazard warning signs should be available. You must use them not only where they must be permanently posted but also where they may temporarily restrict access to hazardous areas.

- Table 9-1 generalizes the relationship between transmitter power and safe distance for personal exposure of 1 hour or more. It is thus applicable to many types of transmitters. Guidelines and specifics can be found in NAVAIR 16-1-529.

Table 9-1.-Transmission Power Versus Safe Distance

Rated power of transmitter	Distance (feet) from antenna
50 watts or less	15
51 to 200 watts	25
201 to 1,000 watts	50
Over 1,000 watts	75

Fuel Hazards

The increase in radiated RF energy from higher power communications and radar equipments has increased the potential hazard of RF-induced ignition of volatile fuel-air mixtures. This flammable condition is normally present only close to aircraft fuel vents, open fuel inlets, or spilled fuel, or during over-the-wing fueling operations. Ignition of fuel vapors in air has occurred; however, the probability of ignition with normal refueling conditions is remote.

Ignition of gasoline vapors caused by RF-induced arcs is rare because ALL of the following conditions must exist:

1. a flammable fuel-air mixture must be present within the range of the induced arcing,
2. the arc must contain a sufficient amount of energy to cause ignition, and
3. the gap across which the arc occurs must be a certain minimum distance and must contain a sufficient amount of the flammable mixture to ignite.

The possibility that these conditions would occur at the same time is remote; but since the possibility does exist, **radars should not be operated within 100 feet of a fueling operation.** For specific fuel-hazard information, refer to NAVAIR 16-1-529.

Miscellaneous Aspects

Photoflash bulbs, fluorescent lamps, and neon glow lamps can be activated by electromagnetic energy from radar sets. Although this doesn't

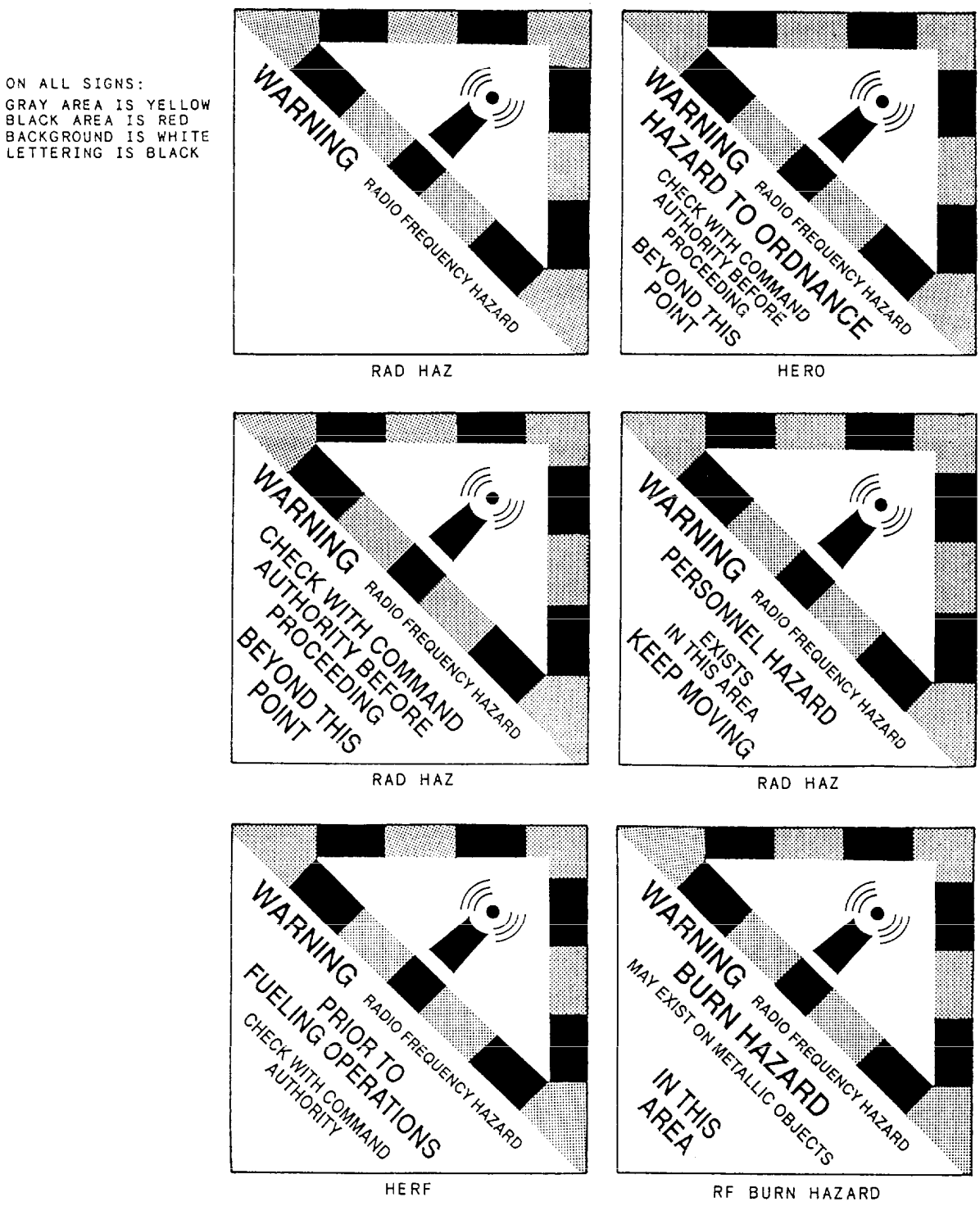


Figure 9-5.-RF hazard warnings.

happen often, personnel should be warned of the presence of any high-power radar operating in the area and of the hazards involved.

In a similar manner, steel wool may be set afire, or metallic chips may produce sparks when exposed to radiation. With some high-power radar sets, steel wool ignites with a violent explosion. The presence of oils and spilled fuels in the vicinity of aircraft constitutes a serious hazard. This makes good housekeeping procedures essential.

Keep in mind that you, the technician, are the key to mishap prevention. Be alert at all times and be safe. No job is so important that you have to be unsafe.

Q11. When a selenium rectifier burns out, selenium dioxide gas is liberated. What steps should be taken when a selenium rectifier does burn out?

Q12. When used as a gas dielectric in a waveguide, what causes sulfur hexafluoride to become toxic?

Q13. List some of the danger sources often neglected when de-energizing electronic equipment.

Q14. Who should you contact if you find a circuit tagged out for repairs?

Q15. When are battery hazards most common?

Q16. Before discarding a CRT, you must eliminate the danger of implosion. What do you do first?

Q17. What times are most susceptible to HERO mishaps?

LASER SAFETY

Learning Objective: *Recognize biological effects of laser radiations, and identify laser safety responsibilities assigned to various commands and personnel.*

The following text discusses the procedures and precautions to follow during laser operation to prevent injury to personnel and damage to material by laser radiation. The biological effects of laser radiation are described, and the descriptions and sources of protective devices are given. Because the Navy uses laser systems, range officers and safety personnel must know laser safety procedures.

BIOLOGICAL EFFECTS OF LASER RADIATION

The electromagnetic spectrum (fig. 9-6) includes radiated energy ranging from gamma rays to dc electricity. The type of emitted energy depends upon the wavelength of the radiation. The optical radiation of the electromagnetic spectrum includes infrared, visible light, and ultraviolet; it is known as light.

The initial physical effects of laser radiation are thermal, photochemical, or thermal acoustic. The initial physical trauma of exposure is followed by a biological reaction of the tissue itself. The lasting effects of this damage range from complete recovery to severe injury with little or no recovery.

The skin can be damaged by exposure to laser radiation. The large surface area makes it susceptible to radiation exposure; therefore,

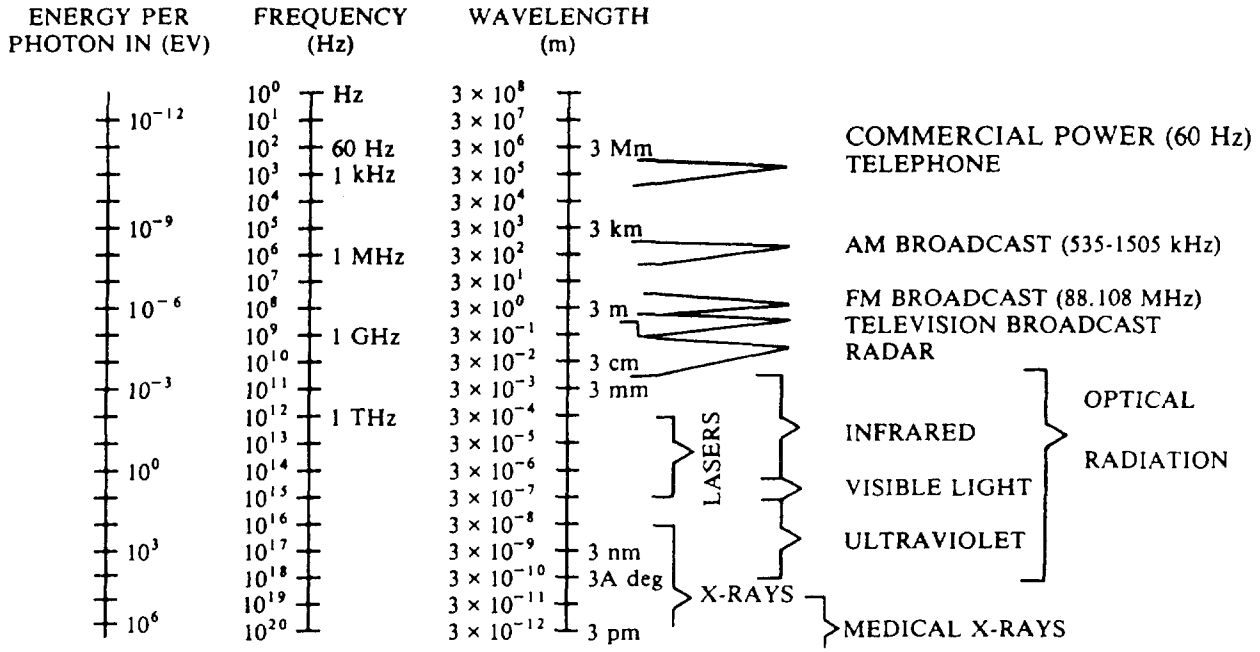


Figure 9-6.-Electromagnetic spectrum.

caution should be taken to protect your skin if you may be exposed to laser radiation. The eye is the one organ of the body that is affected directly by optical radiation because it has no natural protection, and its function is to collect and concentrate light. For information about medical and health considerations, refer to OPNAVINST 5100.23 (series) and OPNAVINST 5100.19 (series).

General Precautions

Most injuries from laser radiation occur in the laboratory or intermediate maintenance activity. These injuries usually happen because personnel do not wear the proper eye protection. Control measures must be taken to make sure that personnel use the correct protection for the highest class of laser in operation.

Eye Protection

In any situation where you may be exposed to laser radiation at levels that can cause eye damage, eye protection must be worn! To determine when eye protection is required and what type should be selected, you must know the following factors:

- The laser wavelengths
- The maximum intensity of the beam at the eye of the observer
- The maximum permissible exposure (MPE) for that wavelength
- The optical density (OD) required of the filter to reduce the intensity-below MPE levels

The characteristic of a protective device that reduces the energy in a laser beam to a safe level is the optical density (OD) of the device.

Laser protective devices are available from many sources. Some devices are available through normal supply channels. Other devices are available from commercial sources only. The recommended protective densities, devices, and their sources for typical laser protective devices currently in the Navy inventory are shown in table 9-2.

Table 9-2.-Protection Densities, Devices, and Sources

Required Optical Densities				Recommended Protection Devices					
	Direct Viewing			Direct Viewing, Air[1]		Direct Viewing, Ground[2]		Optically Aided Viewing[2]	
System	Single Pulse	Multiple Pulse	Optically Aided Viewing	Device	Source	Device	Source	Device	Source
Penguin (Ericson Model UAL 11303)	3.7	4.0	5.0	EEK 3/P Visor or EDU 1/P Spectacles	a a, b	LGS-NDGA Goggles or NDGAK-7448-1 Spectacles	c, d	4 mm Thick KG-3 Filter	e
AN/AAS-33A (A6-E TRAM)	3.8	4.6	5.8	EEK 3/P Visor or EDU 1/P Spectacles	a a, b	LGS-NDGA Goggles or NDGA-7448-1 Spectacles	c, d	4 mm Thick KG-3 Filter	e
AN/AAS-37 (OV-10D NOS)	4.5	5.2	5.6	EEK 3/P Visor or EDU 1/P Spectacles	a a, b	LGS-NDGA Goggles or NDGA-7448-1 Spectacles	c, d	4 mm Thick KG-3 Filter	e
AN/TVQ-2 (GLLD)	3.1	3.9	5.6	EEK 3/P Visor or EDU 1/P Spectacles	a a, b	LGS-NDGA Goggles or NDGA-7448-1 Spectacles	c, d	4 mm Thick KG-3 Filter	e
AN/AVQ-25 (PAVE TACK)	3.7	4.3	5.8	EEK 3/P Visor or EDU 1/P Spectacles	a a, b	LGS-NDGA Goggles or NDGA-7448-1 Spectacles	c, d	4 mm Thick KG-3 Filter	e
AN/ASQ-153 (PAVE SPIKE)	3.7	4.2	5.6	EEK 3/P Visor or EDU 1/P Spectacles	a a, b	LGS-NDGA Goggles or NDGA-7448-1 Spectacles	c, d	4 mm Thick KG-3 Filter	e
AN/PAQ-3 (MULE)	3.3	3.9	5.6	EEK 3/P Visor or EDU 1/P Spectacles	a a, b	LGS-NDGA Goggles or NDGA-7448-1 Spectacles	c, d	4 mm Thick KG-3 Filter	e

NOTES: (1) For protection from single pulse exposure beyond 0.3 km. (2) For protection from multiple pulses at laser output.

a. Aviation Supply Office
Philadelphia, PA 19111

b. Naval Ophthalmological Support and Training Activity
Yorktown, VA 23691
(Contact activity medical officer)

c. Fred Reed Optical Co.
P. O. Box 1336
Albuquerque, NM 87103
Telephone: (505) 265-3531

d. Glendale Optical Co.
130 Crossways Park Drive
Woodbury, NY 11797
Telephone (516) 921-5800

e. Schott Optical Glass, Inc.
400 York Road
Duryea, PA 18642
Telephone: (717) 457-7485

When assigned to a laser system, ensure that you obtain and observe all additional precautions listed in the applicable maintenance instructions manual. To minimize the danger of laser devices, you should always follow these general practices:

1. Use laser equipment properly.
2. Know laser hazards.
3. Ensure research laboratory areas and maintenance shops are closed areas.
4. Wear goggles or filter-type goggles when working with lasers.
5. Do NOT look directly at an operating laser or its reflection in any type of operation.
6. Avoid all contact between the skin and the laser beam.
7. Report any concern or anxiety about possible or existing exposure to laser radiation to appropriate medical personnel.
8. Do NOT look directly at the pump source.
9. Use countdown procedures.
10. Ensure a minimum of two people are present whenever the laser is operating.
11. Identify laser areas properly by posting warning signs (figs. 9-7 and 9-8).

LASER SAFETY RESPONSIBILITIES

The safety responsibilities for the various commands and personnel are discussed in the following paragraphs.

Space and Naval Warfare Systems Command

Space and Naval Warfare Systems Command is the lead agency for laser safety in the Navy. It exercises technical direction over laser safety both afloat and ashore [See SPAWARINST 5100.12 (series)]. The command is responsible for directing and coordinating the following:

- The establishment of Navy laser safety design standards, documentation, and operational guidance
- Surveys, reviews, and measurements and safety certification of laser target areas, laser systems, and installations
- Reviews of laser systems by the Navy Laser Safety Review Board (LSRB)
- The development of laser protective devices

ANSWERS FOR REVIEW QUESTIONS Q11. THROUGH Q17.

A11. De-energize the equipment and ventilate the compartment.

A12. When arc-over occurs, decomposition products constitute a toxic gas hazard.

A13. The inputs from synchros, remote controlled circuits, or other energized sources.

A14. The person that made or is directly in charge of the repair.

A15. Battery hazards are most common during the charging process and during the installation and removal process.

A16. First, check local procedures before trying to dispose of a CRT or removing the danger of implosion.

A17. The most susceptible time for this type of mishap is during ordnance assembly/disassembly and loading/unloading operations or during testing in electromagnetic fields.

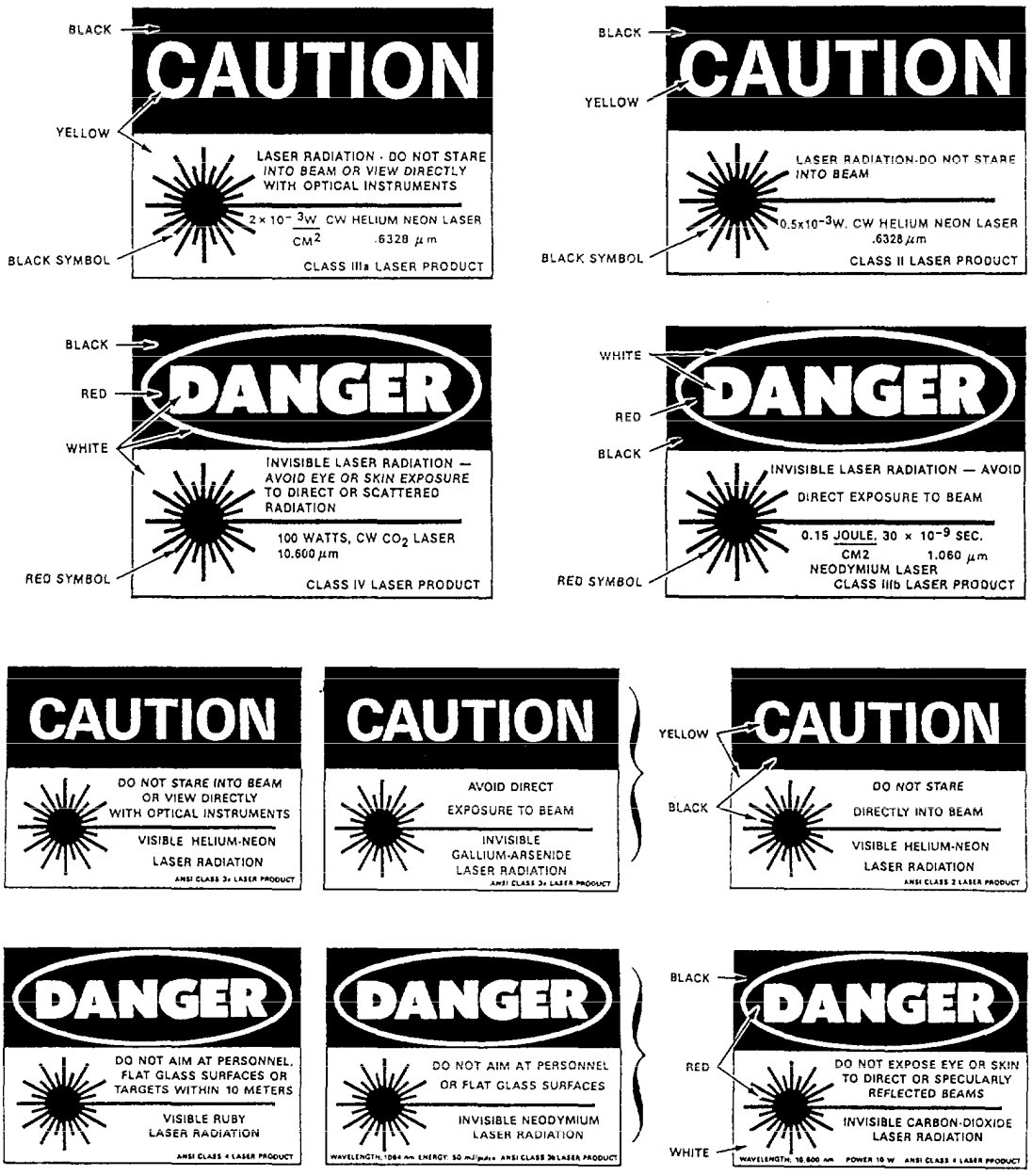


Figure 9-7.-Examples of laser classes 2 through 4 warning labels.

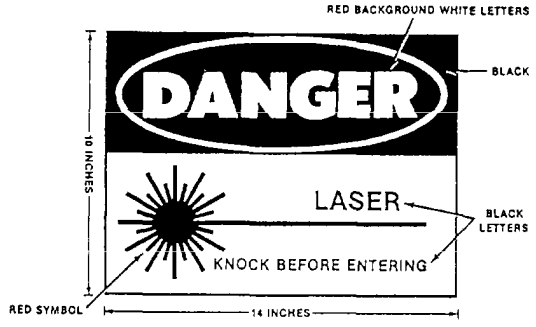


Figure 9-8.-Laser maintenance area warning signs.

- An inventory of all military-exempt lasers and class IIIb and class IV lasers Navy-wide
- The Navy participation in all triservice and interagency laser safety matters and support of the Naval Medical Command (NAVMEDCOM) with regard to laser radiation health medical surveillance
- Support the Chief of Naval Education and Training (CNET) with regard to laser radiation safety training

Naval Medical Command (NAVMEDCOM)

The medical aspects of laser safety are the responsibility of the Naval Medical Command. These responsibilities are as follows:

- Recommend and issue maximum permissible exposure limits.
- Establish medical surveillance programs and evaluate suspected laser overexposure limits.
- Conduct research on the biological effects of laser radiation.
- Conduct laser health surveys ashore and afloat.
- Provide technical assistance and advice concerning laser radiation health hazards.

Commanding Officer

The commanding officer of a ship or naval shore station is responsible for the safety of the personnel under his/her command. The commanding officer should take action to ensure that personnel performing or supervising laser operations are qualified and certified. Also, the commanding officer should require personnel of other agencies, including contract personnel, to conduct their activities according to safety rules when they are on board. Commanding officers also have the authority to impose and enforce more stringent safety rules than those imposed by higher authority. If no safety rule or regulation exists that applies to a given situation, the commanding officer should submit this requirement to the Space and Naval Warfare Systems Command.

Laser System Safety Officer (LSSO)

The LSSO establishes and chairs a local laser safety committee, This committee assists the LSSO in the above responsibilities if warranted by the potential hazards of the local operations.

Supervisory Personnel

Laser and laser system supervisors are responsible for normal installation planning, operational procedures, employee training, and mishap investigation. These supervisors should maintain a log of all laser firings including the date, time, and location (and any abnormal occurrences of the firing[s]).

Operating Personnel

All laser operating personnel should understand the potential hazards of laser operations. Also, personnel who operate lasers should be familiar with normal and emergency procedures and personal protective equipment.

RECOMMENDED READING ON SAFETY AND MISHAP PREVENTION

You have been referred to many publications in this chapter. These publications will give you more detailed information on safety and mishap prevention. For specific information, you should refer to the following publications.

- *Naval Aviation Maintenance Program,* OPNAVINST 4790.2 (series)
- *The Naval Aviation Safety Program,* OPNAVINST 3750.6 (series)
- *Navy Occupational Safety and Health (NAVOSH) Program Manual,* OPNAVINST 5100.23 (series)
- *Navy Occupational Safety and Health (NAVOSH) Program Manual for Forces Afloat,* OPNAVINST 5100.19 (series)
- *DOD Hazardous Materials Information System, Hazardous Item Listing,* DOD 6050: 5-L (series), *Material Safety Data Sheet (MSDS)*

- *Electronics Installation and Maintenance Book–General (EIMB),* SE000-00-EIM-100

- *Navy Laser Hazards Prevention Program,* SPAWARINST 5100.12 (series)

Q18. List the laser factors necessary to determine when eye protection is required and what type of protection.

Q19. What command is the lead agency for laser safety in the Navy?

Q20. What command conducts laser health surveys ashore and afloat?

SECURITY OF CLASSIFIED MATERIAL

Learning Objectives: *Recognize the use and limitations of each category of security classification; identify safekeeping, storage, access to, and control of classified matter policies. Recognize the purpose and scope of each type of security investigation. Identify policies, procedures, and responsibilities pertaining to the handling and disclosure of classified material. Recognize the procedures required for reporting the loss, possible compromise, or mishandling of classified material. Identify means used to transmit each category of classified material. Recognize the methods of destruction of classified material, and identify the records of destruction.*

History indicates that most wars are carefully planned long before the first shot is fired. During so-called peaceful periods, nations collect and evaluate all types of intelligence material from potential enemies. In peacetime, people tend to relax, and security is sometimes ignored. This tendency makes it easier for a potential enemy to gather information concerning our capabilities and intentions.

The term *security* is defined as *a protected condition of classified information that prevents unauthorized persons from obtaining information of director indirect military value.* This condition is the result of establishing and maintaining protective measures that ensures information is safe.

A simple security principle is used within the Department of Defense. Only personnel who have the proper clearance and who have a *need to know* are permitted possession or knowledge of classified information. It is the possessor of the material that has the responsibility of determining whether a person's duties involve a *need to know* or whether that person is authorized to receive classified material.

The regulations and guidance for classifying and safeguarding classified information are found in the *Department of the Navy Information and Personnel Security Program Regulation,* OPNAVINST 5510.1 (series). This instruction is the basic Department of the Navy regulation governing the Information and Personnel Security Program. In OPNAVINST 5510.1 (series), you will also find policy and guidance from the *Department of Defense (DOD) Information Security Program Regulation,* DODINST 5200.1 (series) and *DOD Personnel Security Program Regulation,* DODINST 5200.2 (series). Information from DOD INST 5200.1 (series) pertains to all Department of Defense personnel. Information in this instruction pertains to all military and civilian personnel and to all activities of Department of the Navy.

CLASSIFICATION DESIGNATIONS

Official information that requires protection in the interest of national security must be classified under one of three designations—Top Secret, Secret, and Confidential.

1. Top Secret. Use of the classification Top Secret is limited to defense information or material that requires the highest degree of protection. Top Secret is applied only to information or material the unauthorized disclosure of which could result in **exceptionally grave damage** to the national security and could

- lead to a break in diplomatic relations, armed attack on the United States or its allies, or a war, and

- compromise national defense plans or scientific or technological developments vital to the national security.

2. Secret. Use of the classification Secret is limited to defense information or material whose unauthorized disclosure could result in serious damage to the national security and could

- jeopardize the international relations of the United States,
- endanger the effectiveness of a program or policy vital to the national defense,
- compromise important military or defense plans or scientific or technological developments important to national defense, and
- reveal important intelligence operations.

3. Confidential. Use of the classification Confidential is limited to defense information or material the unauthorized disclosure of which could result in **damage** to the national security. An example is the unauthorized disclosure of technical information used for maintenance and inspection of classified munitions of war.

CUSTODY

The custody of classified material is extremely important. In this section, a brief discussion on classified material storage, custody, and access is presented.

Storage

Commanding officers are directly responsible for safeguarding all classified information within their commands. They are responsible for establishing measures for the inspection of safe storage containers and areas where classified material is kept to ensure compliance with security regulations. The term *commanding officer* is intended to include *competent authority, commander, officer in charge, naval representative, director, inspector,* and any other title assigned to an individual (military or civilian) who, through position or status, is qualified to assume responsibility y and make decisions.

In keeping with the Navy's security principle of *need to know,* combinations to locks of classified containers should only be known to those whose official duties demand access to the container. Also, a record of combinations must be sealed in an envelope and kept on file by a person designated by the commanding officer.

When selecting combinations for locks, you should avoid using personal data, such as birth dates and serial numbers. You should also avoid using multiples of numbers and simple ascending or descending arithmetic series. A combination should never be used for more than one container in any one classified material control center or secondary control point.

When securing dial combination locks, you should rotate the dial at least four complete turns in the same direction. The drawers of safes and cabinets should be checked to assure they are held firmly in the locked position.

The combination to a security container is changed when the container is placed in use after procurement, whenever an individual knowing the combination no longer requires access, and whenever the combination is compromised or the security container is discovered unlocked and unattended. In addition, the combination must be changed at least annually and reset to standard combinations if taken out of service.

Custodians

Custodians of classified material are responsible for providing protection and accountability for that material at all times. They should lock classified material in appropriate security equipment whenever the material is not in use or

ANSWERS FOR REVIEW QUESTIONS Q18. THROUGH Q20.

A18. The laser wavelength, the maximum intensity of the beam at the eye of the observer, the maximum permissible exposure (MPE) for that wavelength, the optical density (OD) required of the filter to reduce the intensity below MPE levels.

A19. The Space and Naval Warfare Systems Command.

A20. NAVMEDCOM.

under direct surveillance of authorized persons. Never remove classified material from working areas for the purpose of working on such material during off-duty hours or for any other purpose that involves personal convenience.

EMERGENCY PLANNING.— Plans must be developed by each command for the protection, removal, or destruction of classified material in case of natural disaster, civil disturbance, or enemy action. Such plans establish detailed procedures and responsibilities for the protection of classified material so that it does not fall into unauthorized hands. Such plans must also indicate what material is to be guarded, removed, or destroyed. An adequate emergency plan provides for guarding the material; removing the classified material from the area; complete destruction of the classified material on a phased, priority basis; or any combination of these actions. However, reducing the amount of classified material on hand and maintaining only current and necessary material can be the most effective step toward planning for an emergency situation. Emergency plans should provide for the protection of classified information in a manner that will minimize the risks of loss of life or injury to personnel.

ACCOUNTABILITY.— Except for publications containing a distribution list by copy number, all copies of Top Secret documents must be serially numbered at the time of origination, in the following manner: Copy No. ___of ___ copies.

Top Secret documents must contain a list of effective pages; this list should include a Record of Page Checks. When this is impractical, as in correspondence or messages, the pages must be numbered as follows: Page___ of ___ pages.

Commanding officers establish administrative procedures for recording all Secret material originated and received. They maintain a receipting system for all Secret material distributed or routed to activities outside their commands. As a general rule, Secret materials are also serially numbered.

Access and Dissemination

Personnel whose work requires access to classified material must have an appropriate clearance. The standards for the various levels of clearances are different, but they all follow a basic format for both civilian and military personnel. Essentially, the standards are that no person is permitted knowledge of, possession of, or access to classified material solely by virtue of rank, position, or security clearance. Clearance serves to indicate that the persons concerned are eligible for access to classified material if required by their official duties. No person is granted a security clearance unless it has been determined that the clearance is in keeping with the interests of national security.

ELIGIBILITY STANDARDS.— Any person authorized access to classified information is considered to be loyal and to possess good character, integrity, trustworthiness, and habits and associations that indicate discretion or good judgment in the handling of classified information. The ultimate determination of whether the granting of a clearance is in keeping with the interests of national security must be an overall determination based on all available information. Some of the significant personal security factors, both past and present, that are investigated and considered before a clearance is granted includes the following:

- Any criminal, infamous, dishonest, or notoriously disgraceful conduct
- Habitual excessive use of intoxicants
- Drug abuse
- Sexual perversion
- Any excessive indebtedness, recurring financial difficulties, unexplained affluence, or repetitive absences without leave that furnish reason to believe that the individual may act contrary to the best interests of national security

SECURITY CLEARANCE.— A personal security clearance requires an administrative investigation by competent authority and certifies that the person is eligible for access to classified material of the same or lower category as the clearance being granted. Security clearances are of two types:

1. Final clearance—one granted upon completion of the required investigation
2. Interim clearance—a temporary eligibility for access to classified information based on a lesser investigative requirement

An interim clearance is issued only when the delay of waiting for the completion of the investigation required for a final clearance would be harmful to the national interest. When interim clearance procedures are used, the investigation required for a final clearance must be initiated. A final clearance is executed upon the satisfactory completion of the investigation, unless such clearance is no longer required.

REQUIREMENTS FOR SECURITY CLEARANCE.— The clearance requirements listed below are solely for military personnel.

Top Secret.— The investigative requirements for access to Top Secret material are as follows:

- Final clearance—a background investigation (BI) or special background investigation (SBI).
- Interim clearance—a satisfactory completion of a national agency check if the BI or SBI has been requested.

Secret.— For access to Secret material, a final clearance requires a specific type of national agency check, depending on the individual's employment status. An interim clearance may be issued to personnel if the necessary national agency check has been requested.

Confidential.— A final clearance requires a national agency check, depending on the individual's employment status. An interim clearance may be granted if the national agency check has been requested.

PERSONNEL SECURITY INVESTIGATIONS

The following are categories of personnel security investigations. The NAC and background investigations are described in this section. Refer to OPNAVINST 5510.1 (series) for specific details.

1. A national agency check (NAC)
2. A national agency check with written inquiries (NACI)
3. A DOD national agency check plus written inquiries (DNACI)
4. A background investigation (BI)
5. A special background investigation (SBI)
6. A periodic reinvestigation (PR)

A National Agency Check (NAC)

A national agency check (NAC) consists of a check with various federal agencies by Defense Investigative Service (DIS) for pertinent facts that have a bearing on the loyalty and trustworthiness of the individual. The initial NAC conducted on inductees and first-term enlistees does not include a detailed technical fingerprint search, and it is referred to as an ENT NAC.

A National Agency Check With Written Inquiries (NACI)

NACI consists of a national agency check (described above) by the Office of Personnel Management (OPM) on civilian employees and written inquiries sent to law enforcement agencies, former employees, references, schools attended, and so forth, for pertinent facts having a bearing on the individual's suitability for federal employment.

A Background Investigation

A background investigation conducted for clearance purposes is designed to develop information on whether the access to classified information by the person being investigated is clearly consistent with the interest of national security. In this investigation, inquiry is made on the loyalty and trustworthiness of the individual. It normally covers the most recent 5 years of the person's life or from the date of that person's 18th birthday, whichever is the shorter period. At least the last 2 years is covered, except that no investigation is conducted before a person's 16th birthday. When derogatory information is developed in the course of any investigation, the investigation is extended to any part of the individual's life necessary to substantiate or disprove the information and to develop adequate information upon which to base a security determination.

SECURITY MANAGEMENT PROCEDURES

Each command develops written security procedures to meet the requirements of security regulations. These procedures specify what is to be done, who is to do it, and who is to supervise it. They are rewritten, as required, when changes in Navy security regulations occur or when changes in the command's assigned functions

occur. These procedures include requirements for any special or extraordinary control measures that need to be observed to provide the required degree of circulation control. This is especially true whenever automatic data-processing equipment is used to process any classified information or when any printing, duplicating, or reproducing of classified material is accomplished at the local command.

Security Manager

The commanding officer is assisted in fulfilling his/her responsibility for the security of classified material by the security manager. The security manager serves as the commanding officer's direct representative in all cases concerning security. The security manager ensures that the proper security clearances are obtained and coordinates a security orientation, education, and training program for the protection of classified information.

Disclosures

Classified material is issued to all agencies of the executive branch of the government. If requests come from Department of Defense activities, the *need to know* maybe judged on the face of the request. When the *need to know* is not discernible from the scope of the requester's activities, classified material is sent via the departmental headquarters of the requesting activity for a determination of the requester's *need to know* and capability to handle classified material.

The authority for disclosure of classified military information to foreign governments has been centralized in the Navy Office of Technology Transfer and Security Assistance. Accordingly, no command, office, agency, or individual in the Department of the Navy may disclose classified information, direct the disclosure of it, or permit the disclosure of it by oral, visual, written communications, or by any other means to foreign governments or international organizations unless such disclosure has been specifically authorized in writing. OPNAVINST R5510.48 (series) contains specifics and guidance for proper authorization authority.

VIOLATIONS AND COMPROMISES

Violations and compromises of classified material occur all too regularly. The following information is a brief outline of procedures necessary for reporting and investigating these occurrences.

Security Violations

Any person who has knowledge of a loss or possible compromise of classified matter must report the fact immediately to the security manager or commanding officer. Any violation of regulations that pertains to the safeguarding of classified material but does not result in compromise (or the material is not subject to compromise) is acted upon by the individual's commanding officer without reference to higher authority. The fact that a security violation has occurred may, at the discretion of the commanding officer, be considered sufficient justification for some form of formal disciplinary action.

If a classified material storage container is found unlocked in the absence of assigned personnel, report such information immediately to the senior duty officer. Guard the container until the duty officer arrives at the location of the unlocked container. The duty officer inspects the classified material involved, locks the container, and makes a security violation report to the commanding officer. If the duty officer believes that classified information has been compromised, the duty officer must require the person responsible for the container to return to the assigned ship or station to make a definite inspection report. Appropriate further action must be taken by the commanding officer or higher authority. In addition, change the combination.

Commanding officers who receive classified material that shows improper handling by the sending activity must promptly notify that activity's commanding officer. For example, security violations involving improper mailing, shipping, wrapping, packaging, or transmission of classified material, or failure to mark or address inner wrappings or envelopes properly should be promptly reported.

If classified information is compromised because it appears in a newspaper, magazine, book, pamphlet, radio or television broadcast, etc., a report is made to the Chief of Naval Operations (CNO). This report fully identifies what information is considered classified, the news media concerned (title, date, issue, volume, page, column, station, program, etc.), and the reporter or author involved. The report cites those portions of the magazine, book, etc., that reveal

the classified information. If known, the level of classification and original classifying authority is established.

If lost classified material is found and the material has definitely been compromised, the compromise must be reported to all personnel notified of the loss.

Preliminary Inquiry

When a command receives a report of a compromise and does not have the custodial responsibility for the material compromised, then the command takes the following actions:

1. Accurately identifies the information or material involved
2. Determines the circumstances of possible compromise
3. Identifies all witnesses to the event
4. Tentatively establishes the degree of probability of compromise

This information is sent to the command having custodial responsibility as quickly as possible. If the command having custodial responsibility cannot be determined, the command initially notified will, to the extent feasible, conduct the preliminary inquiry and any subsequent investigation.

The responsible custodial command conducts a preliminary inquiry if it receives a report of compromise or suspected compromise. If the inquiry finds a suspected compromise but minimal risk and no significant command security weakness, the formal disciplinary action is not required. If the next higher commander in the chain agrees, no further action may be necessary,

If a compromise is confirmed, and probability of damage to national security may exist, significant activity weakness is revealed, or punitive action is appropriate, a JAG manual investigation is started. A report of the preliminary inquiry is sent to the originator. Also, information copies of the preliminary inquiry are sent to the custodial command's chain of command and the Chief of Naval Operations (CNO).

Investigations

In the Department of the Navy, all investigations are in the form of a Judge Advocate General (JAG) manual investigation. The JAG manual investigation includes the following:

1. A complete identification of each item of classified material involved.
2. A complete identification of all the individuals mentioned in the report.
3. Findings of fact in the form of a chronology of the circumstances relating to the event.
4. A finding of fact or opinion, as appropriate, establishing a time frame during which the material was subjected to compromise.
5. A finding of fact or opinion, as appropriate, as to the person or persons responsible, if individual culpability is indicated.
6. A finding of fact or opinion (as appropriate) as to the probability of compromise. If, during the course of investigation, the determination is made that compromise did not occur, the investigation may be terminated. If the investigation is terminated, the recipients of the report of initial inquiry must be so advised, with a brief statement supporting the determination.
7. By reference, enclosure, or finding of fact, affirmation of notification of the originators of the material involved.
8. Recommendation as to remedial action to be taken to prevent recurrence.
9. Recommendation (when required by the appointing order) as to disciplinary action.

This report of investigation is forwarded to the CNO via the chain of command. It includes approval or disapproval of the proceedings, measures taken to prevent a recurrence, and any disciplinary action taken or recommended.

TRANSMISSION OF CLASSIFIED MATERIAL

When material leaves the originator and is sent to the addressees, it is *transmitted.* Whether it goes by courier, by radio, or by mail, if it is classified, it has to be safeguarded.

Top Secret material is transmitted by direct personal contact of officials concerned, Armed Forces Courier Service, or electrical means in encrypted form. Top Secret material is NOT transmitted through the United States postal system or any foreign postal system.

Secret material is transmitted in any of the means approved for transmittal of Top Secret material and by United States registered mail.

Confidential material is transmitted by any means approved for the transmission of Secret material and by U.S. Postal Service certified or first-class mail within U.S. boundaries. U.S. Postal Service registered mail is used for all NATO, SEATO, and CENTO Confidential material; all FPO or APO addressees; and any other addresses when the originator is not sure whether their location is within U.S. boundaries.

DESTRUCTION OF CLASSIFIED MATERIAL

When a command's classified material is no longer required, it is not allowed to accumulate. It is either turned in to the appropriate office or destroyed.

Methods of Destruction

Classified material is destroyed in the presence of appropriate e cleared officials. It is burned, melted, chemically decomposed, pulped, pulverized, shredded, or mutilated so it can't be recognized or reconstructed.

During emergency situations at sea, classified material is jettisoned at depths of 1,000 fathoms or more. If it is not possible to jettison the material in water 1,000 fathoms deep and if time does not permit other means of emergency destruction, the material should be jettisoned to prevent its easy capture. When shipboard emergency destruction plans include jettisoning, document sinking (weighted) bags should be available. If a vessel is to be sunk through intentional scuttling or is sinking due to hostile action, classified material should be locked in security filing cabinets or vaults and allowed to sink with the vessel, rather than being jettisoned.

As a last resort, and when none of the methods previously mentioned can be used, the use of other methods, such as dousing the classified material with a flammable liquid and burning it, is used as an alternate to certain loss.

Records

Records of destruction are not required for Confidential documents. Records of destruction are required for Top Secret and Secret material. They are dated and signed by two officials that witness the actual destruction; however, if the classified material is placed in burn bags, the destruction record is signed by the witnessing officials at the time the material was placed in the burn bags. The record of destruction is retained for 2 years. Persons witnessing the destruction of classified material must

1. have a security clearance at least as high as the category of material being destroyed, and be thoroughly familiar with the regulations and procedures for safeguarding classified information;

2. observe the complete destruction of classified documents;

3. check residue to determine that destruction is complete and reconstruction is impossible; and

4. take precautions to prevent classified material or burning portions of classified material from being carried away by wind or draft.

Q21. What instruction contains regulations, references, and guidance for classifying and safeguarding classified information?

Q22. List the three classification designations of official information that requires protection in the interest of national security.

Q23. When is the combination of a security container changed?

Q24. What are the two types of personnel security clearances?

Q25. List the categories of personnel security investigations.

Q26. Describe the time frame involved in a normal background investigation coverage of an individual's life.

Q27. What Navy office has been established as the centralized authority for disclosure of classified information to foreign governments?

Q28. Which classified material designations would require records of destruction?

Q29. Describe the requirements of personnel witnessing the destruction of classified material.

ANSWERS FOR REVIEW QUESTIONS Q21. THROUGH Q29.

A21. Department of the Navy Information and Personnel Security Program Regulation, OPNAVINST 5510.1 (series).

A22. Top Secret, Secret, and Confidential.

A23. When placed in use, whenever an individual knowing the combination no longer needs access, when compromised, when unlocked and unauthorized, and at least annually.

A24. Final clearance and interim.

A25.
1. *National agency check (NAC).*
2. *National agency check with written inquiries (NACI).*
3. *DOD national check with written inquiries (DNACI).*
4. *Background investigation (BI).*
5. *Special background investigation (SBI).*
6. *Periodic reinvestigation (PR).*

A26. It normally covers the most recent 5 years or from the date of the persons 18th birthday, whichever is shorter. However, at least the last 2 years is covered. No investigation is conducted before a person's 16th birthday.

A27. The Navy Office of Technology and Security Assistance.

A28. Top Secret and Secret.

A29.
1. *Have a security clearance at least as high as the material being destroyed and be thoroughly familiar with the regulations and procedures for safeguarding classified information.*
2. *Observe complete destruction.*
3. *Check residue to determine that destruction is complete and reconstruction is impossible.*
4. *Take precautions to prevent classified material or burning portions from being carried away by wind or draft.*

APPENDIX I

GLOSSARY

ABSORPTION—Loss of energy that is turned into heat.

ABSORPTION FREQUENCY METER (WAVEMETER)—A frequency-measuring device incorporating a variable-tuned circuit that absorbs a small portion of the radiated energy under measurement.

ACCESS TIME—In computers, the time interval between the calling for information from a computer unit and the instant that such information is delivered.

ACCUMULATOR—A computer unit wherein numbers are accumulated. Usually an accumulator holds one number in storage; when a second number is entered, the accumulator adds the two numbers and retains the sum in storage.

ACOUSTIC—Pertaining to sound or the study of sound.

ACTIVE SONAR—An apparatus that radiates and receives information from returning echoes.

ADDER—An electronic circuit capable of providing the sum of two numbers entered therein.

ADDRESS—In computers, an identifying number or numbers or a particular group of symbols that identifies a particular storage location.

ADF—Automatic direction finding. An automatic radio compass that automatically aims a directional antenna to show the direction of the location of a transmitter. The ADF is normally used for homing purposes, but it can be used in conjunction with the magnetic compass to provide line-of-position information.

ADP—Acoustic data processor.

AMBIENT CONDITIONS—Physical conditions of the immediate environment; may pertain to temperature, humidity, pressure, etc.

AMBIENT NOISE—The naturally occurring noise in the sea and the noise resulting from man's activity, but excluding self-noise and reverberation.

ANALOG COMPUTER—A type of computer that provides a continuous solution of a mathematical problem with continuously changing inputs. Inputs and outputs are represented by physical quantities that may be easily generated or controlled.

AND GATE—A logic circuit having multiple inputs and a single output, so designed that the output is energized when (and only when) every input is in the prescribed signal state.

ANTENNA—Also aerial, A conductor or system of conductors that radiates or intercepts energy in the form of electromagnetic waves.

ANTIJAMMING—A function of a radar set to reduce or eliminate enemy jamming of electromagnetic waves, which hinder the usefulness of specific segments of the radio spectrum.

A-SCAN (A-DISPLAY)—In radar, a display in which targets appear as vertical displacements from a line representing the time base. Target distance is represented by the horizontal distance from one end of the time base. Amplitude of the vertical deflection is a function of the signal intensity.

ASW—Antisubmarine warfare. Operations conducted against submarines, their supporting forces, and bases.

ASWOC—ASW operations center.

ASYMMETRIC—Not symmetrical; without symmetry.

AVB—Avionic Bulletin.

AVC—Avionic Change.

AZIMUTH—Angular position or bearing in a horizontal plane, usually measured clockwise from true north. Azimuth and bearing are often used synonymously.

BALLISTICS—The term that refers to the science of the motion of projectiles or bombs.

BAND—The radio frequencies existing between two definite limits and used for a definite purpose; for example, standard broadcast band extending from 550 to 1600 kHz.

BANDWIDTH—The total frequency width of a channel or band of frequencies.

BATHYTHERMOGRAPH—A recording thermometer for obtaining a permanent graphical record of water temperature in degrees Fahrenheit at different water depths, in feet, as it is lowered or dropped into the ocean.

BEACON—Compared to a lighthouse. A radio or radar signal station that provides navigation and interrogation information for ships and aircraft.

BEAMWIDTH—The width of an electromagnetic beam, measured in degrees on an arc that lies in a plane along the axis of propagation, between points of equal field strength. It maybe measured in the horizontal or vertical plane.

BEARING—The angular position of an object with respect to a reference point or line. If the reference point is true north, the bearing is the true bearing; if the reference is NOT true north, then the bearing is a relative bearing. If magnetic north (vice true north) is used as the reference, the bearing then becomes a magnetic bearing. Also, the direction of the line of sight, from a radar antenna to a target, measured in degrees. *See also* AZIMUTH.

BIAS—In vacuum tubes, the difference of potential between the control grid and the cathode; in transistors, the difference of potential between the base and emitter and between the base and collector; in magnetic amplifiers; the level of flux density in the core under no-signal conditions.

BIDIRECTIONAL COUPLER—A waveguide device having two outputs, which sample and present a signal at one output that is largely a function of the wave traveling in one direction, while the signal at the other output is largely a function of the wave traveling in the opposite direction.

BLACKBODY—An ideal body that absorbs all incident light and therefore appears perfectly black at all wavelengths. The radiation emitted from such a body when it is hot is called blackbody radiation. The spectral energy density of blackbody radiation is the theoretical maximum for a body in thermal equilibrium.

BLANKING—The process of applying negative voltage to the control grid of the cathode-ray tube to cut off the electron beam during the retrace or flyback period.

BOLOMETER—A small resistive element used in the measurement of low and medium RF power. It is characterized by a large temperature coefficient of resistance that is capable of being properly matched to a transmission line.

BOTTOM BOUNCE—That form of sonar sound transmission in which sound rays strike the ocean bottom in deep water at steep angles and are reflected back to the surface and returned, which allows the obtaining of target information at long distances.

BRIDGE CIRCUIT—The *electrical bridge circuit* is a term referring to any one of a variety of electric circuit networks, one branch of which, the "bridge" proper, connects two points of equal potential, and hence carries no current when the circuit is properly adjusted or balanced.

B-SCAN (B-DISPLAY)—In radar, a rectangular display in which targets appear as illuminated areas, with bearing indicated by the horizontal coordinate and distance by the vertical coordinate.

CAGING (GYRO)—The act of holding a gyro so that it cannot precess and change its attitude with respect to the body containing it.

CAVITATION—The formation of local cavities (bubbles) in a liquid as a result of the reduction of total pressure. This pressure reduction may result from a negative pressure

produced by rarefaction or from the reduction of pressure by hydrodynamic flow, such as is produced by high-speed movement of an underwater propeller.

CAVITY RESONATOR—A hollow, metallic cavity in which electromagnetic oscillation can exist when the cavity is properly excited.

CCTV—Closed circuit television. The application of television where reception is limited by broadcasting on specific frequencies and/or by connecting the receivers directly to the television camera via coaxial cables.

CHARACTERISTIC (ITERATIVE) IMPEDANCE— The apparent load presented to a source; in electronics, the characteristic impedance at any frequency range is approximately equal to the ratio of the inductance to the capacitance.

CIC—Combat information center. The tactical command center of the ship.

CLEARING PULSE—In computers, a pulse that is employed for clearing or resetting a circuit to its predetermined initial state.

COMPARATOR—A circuit that compares two signals or values, and indicates agreement or variance between them.

COMPOSITE VIDEO—The total video signal, consisting of picture information, blanking pulses, and sync pulses.

COMPRESSION—In wave motion, the forcing together of the medium's molecules. See also RAREFACTION.

COMPUTER—A mechanism or device that performs mathematical operations. See also ANALOG COMPUTER and DIGITAL COMPUTER.

COMPUTER CODE (ALSO CALLED A COMPUTER LANGUAGE)—The code by which data are represented within a computer system; for example, binary coded decimal.

COMPUTER PROGRAM—A series of instructions or statements prepared in a form acceptable to the computer.

CONTROL CIRCUITS—In computers, those circuits involved in the carrying out of the program instructions.

COUNTERMEASURES—Devices and/or techniques intended to impair the operational effectiveness of enemy activity.

COUNTING CIRCUIT—A circuit that receives uniform pulses representing units to be counted and produces a voltage in proportion to their frequency.

CRT—Cathode-ray tube.

DC RESTORER—A circuit used to reinsert the dc component of the video signal lost during amplification.

DEGREES OF FREEDOM (GYRO)—A term applied to gyros to describe the number of variable angles required to specify the position of the rotor spin axis relative to the case.

DETECTORS, INFRARED—Thermal devices for observing and measuring infrared radiation, such as the bolometer, radiomicrometer, thermopile, pneumatic cell, photocell, photographic plate, and photoconductive cell.

DIFAR—Directional frequency analyzing and recording. An ASW technique used in pinpointing submerged contacts.

DIFFERENTIAL—A mechanical computing device used to add or subtract two quantities.

DIFFUSION—The spreading out of energy or particles from a high concentration to a low concentration, due to random velocity and scattering.

DIGITAL COMPUTER—A type of computer in which quantities are represented in numerical form and which is generally made to solve complex mathematical problems by use of the fundamental processes of addition, subtraction, multiplication, and division. Its accuracy is limited only by the number of significant figures provided.

DIPPING SONAR—Used by helicopters. Lowered from the helicopter for searching and retracted for flight.

DIRECTIONAL COUPLER—A device used to extract a portion of the RF energy moving in a given direction in a transmission line or waveguide. Energy moving in the opposite direction is rejected. See also BIDIRECTIONAL COUPLER.

DIRECTION FINDER (DF)—VHF/UHF navigation aid operated by personnel on the ground to furnish azimuth information to aircraft.

DISCRIMINATOR—A dual-input circuit in which the output is dependent on the variation of one input from the other input or from an applied standard.

DISTORTION—The production of an output waveform that is not a true reproduction of the input waveform. Distortion may consist of irregularities in amplitude, frequency, phase, etc.

DIURNAL—Having a recurring daily cycle.

DIVERGENCE—Energy loss caused by spreading in all directions.

DOPPLER EFFECT—An apparent change in the frequency of a sound wave or electromagnetic wave reaching a receiver when there is relative motion between the source and the receiver.

DRIFT—Net change in characteristics of electronic components or parameters, resulting from external or incidental conditions.

DRUM—In computers, a cylinder coated with a material capable of being magnetized so that it can be employed for the retention of information in storage functions.

DUPLEXER—A switch or tube that permits the use of a single antenna for both transmission and reception. The dual function of the duplexer is to prevent absorption of transmitter energy by the receiver system (thereby protecting the receiver) and to prevent absorption of any appreciable portion of the received echo signal by the transmitter.

ECHO—That portion of the energy reflected to the receiver from the target.

ECHO BOX—A high-Q resonant cavity used with microwave radar sets to provide artificial targets for radar testing and for tuning the receiver to the transmitter. The echo box stores RF energy during the transmitted-pulse interval, and reradiates it through the same antenna for a short time following the pulse.

ECM—Electronic countermeasures. The means by which enemy electronic devices are nullified and, at the same time, intelligence is gathered concerning the nature of the enemy radiations. ACTIVE ECM implies jamming/deceptive techniques to degrade enemy equipment or operator functions. PASSIVE ECM entails the use of receiving (only) equipment to detect, locate, analyze, and evaluate enemy radiations and radio emissions.

ELECTRONIC SWITCH—A circuit that causes a start and stop action or a switching action by electronic means.

ELECTROSTRICTION—That property of certain ceramic materials that, after having a permanent operating bias established, causes these materials to vary slightly in length when they are placed in an electric field.

EQUIVALENT CIRCUIT—A diagrammatic arrangement of component parts, representing in simplified form the effects of a more complicated circuit, to permit easier analysis.

ERASING HEAD—A device that removes stored data from the surface of a magnetic storage material.

ESM—Electronic warfare support measures. Concerns electronic emissions and countermeasures.

E-TRANSFORMER—A magnetic device with an E configuration, used as an error detector.

EW—Electronic warfare. Tactical use of electronics to prevent or reduce the enemy's effective use of radiated electromagnetic energy, and the actions taken to assure the effective use of ours. *See also* ECM.

FEEDBACK—The return of a portion of the output of a circuit stage to the input of that stage or a preceding stage, such that there is either an increase (regeneration) or a reduction (degeneration) in amplification, depending on the relative phase of the returned signal with the input.

FERRITE—A hard and brittle crystalline substance made from a mixture of powdered materials, including iron oxides; it has special magnetic properties of particular value in computers and in many other applications.

FIDELITY—The extent to which a system, or a portion of a system, accurately reproduces at its output the essential characteristics of the signal that is impressed upon its input.

FLIR—Foward Looking InfraRed system.

FREE GYRO—A gyro so gimbaled that it can assume and maintain any attitude in space. A free gyro has two degrees of freedom; torque cannot be applied to the rotor of a truly free gyro.

FREQUENCY—The number of hertz (cycles per second) of an alternating current.

FULL ADDER—An adder circuit that can complete the adding procedure involving the carry process, as distinguished from the half adder, which is not capable of accepting a previous carry.

GATING CIRCUIT (GATE)—A circuit used to activate (or deactivate) another circuit by permitting (or prohibiting) operation during selected periods of time.

GIMBAL—A frame in which the gyro wheel spins and that allows the gyro wheel to have certain freedom of movement. It permits the gyro rotor to incline freely and retain that position when the support is tipped or repositioned.

GRADIENT—The nature of the sound-transmission curve (negative, positive, isothermal, etc.) as used in sonar applications. *See also* ISOTHERM and THERMOCLINE.

GRADIENT, NEGATIVE—When the temperature of the water decreases with depth, it has a negative temperature gradient.

GRADIENT, POSITIVE—When the temperature of the water increases with depth, it has a positive temperature gradient.

GYROSCOPES—A wheel or disk so mounted as to spin rapidly about one axis and be free to move about one or both of the two axes mutually perpendicular to the axis of spin.

HALF ADDER—A partial adding circuit that is not capable of accepting a previous carry. It must be combined with another half adder and a circuit capable of performing the carry function to form a full adder.

HERO—Hazardous electromagnetic radiation to ordnance.

HERTZ—A unit of frequency equal to 1 cycle per second.

HETERODYNE—To mix two alternating currents of different frequencies in the same circuit; they are alternately additive and subtractive, thus producing two beat frequencies, which are the sum of, and difference between, the two original frequencies.

HORIZONTAL PLANE—A horizontal plane is tangent to the surface of the earth. Visualize this condition by laying a playing card on an orange. The card represents the horizontal plane; the orange symbolizes the earth; and the point of contact between the two is the point of tangency. Every plane parallel to the horizontal plane is likewise a horizontal plane.

HYDROPHORE—An acoustic device that receives and converts underwater sound energy into electrical energy.

HYSTERESIS—A lagging of the magnetic flux in a magnetic material behind the magnetizing force that is producing it.

INFRARED—Invisible waves in that portion of the electromagnetic spectrum lying between visible light and radio frequencies, and having a penetrating heating effect.

INHIBITORY PULSE—A pulse that acts to inhibit or suppress another signal from going through a logic circuit and appearing at the output.

INPUT-OUTPUT EQUIPMENT—A device that provides the means of communication between the computer and external equipment. The device accepts new data, sends it into the computer for processing, receives the results, and transforms the data into usable form. In many cases it is also referred to as peripheral equipment.

INSTRUCTION—in computer programming, a set of identifying characters or a computer "word" that is designed to cause the computer to perform specific operations.

INTEGRATING CIRCUIT—A circuit whose output voltage is proportional to the product of the instantaneous applied input voltages and their durations.

INTEGRATOR—A computing device used for summing up an infinite number of minute quantities.

INTELLIGENCE—The message or information conveyed, as by a modulated radio wave.

INTERFACE—A concept involving the specification of the interconnection between two equipments or systems. The specifications include the type, quantity, and function of signals to be interchanged via those circuits. A device that converts or translates any type of information from one given medium into signals of another given medium; for example, electrical signals to fluidic signals, fluidic signals to electronic signals, etc.

IR—InfraRed.

ISOTHERM—A line connecting points of equal temperature.

ISOTHERMAL LAYER—A layer of water in which there is no appreciable change of temperature with depth.

ISOVELOCITY LAYER—A layer of water in which there is no appreciable change of sound velocity with depth.

KINEMATIC LEAD—The lead required to score a hit on a specified target due to relative motion between target and gun platform.

KNEE (OF A CURVE)—An abrupt change in direction between two fairly straight segments of a curve.

LAYER DEPTH—The depth from the surface of the seato the top of the first significant negative thermocline.

LAYER EFFECT—Partial protection from echo ranging and listening detection when below layer depth.

LOGIC CIRCUITS—Digital computer circuits used to store information signals and/or to perform logical operations on those signals.

LOOP ANTENNA—One or more complete turns of wire used with a radio receiver. Also used with direction-finding equipment.

LOS—Line of sight. The straight-line distance from ship to horizon. Represents radio and radar VHF and UHF transmission range limits under normal conditions.

MAD—Magnetic anomaly detection. The detection of slight distortions in the earth's magnetic field. In the U.S. Navy, it is used exclusively by aircraft.

MAGNETIC FIELD—The region in space in which a magnetic force exists, caused by a permanent magnet or as a result of current flowing in a conductor.

MAGNETOSTRICTION—That property of certain ferro-type materials that causes them to vary slightly in length when they are in an alternating magnetic field.

MAGNETRON—A microwave oscillator that uses an electron tube (consisting of a cathode and an anode), a strong axial magnetic field, and resonant cavities.

MAGNETRON ARCING—Internal breakdown between cathode and anode of a magnetron, usually resulting from presence of gas. Occurs during the breaking-in or "seasoning" period and again at the end of the useful life. Occasional arcing is common, especially in high-power magnetrons.

MAGNETRON PULLING—The frequency shift of a magnetron resulting from a mismatch at the output. It is caused by such factors as faulty rotating joints, reflections from objects near the antenna, etc.

MAGNETRON PUSHING—The frequency shift of a magnetron resulting from faulty operation of the modulator. It may result from an improperly shaped pulse or from interaction of the pulse with the magnetic field.

MASTER CLOCK—The timed and synchronized generators that comprise the source and time reference for computer signals.

MEMORY UNIT—In computers, a device used for storing data for possible use in computation.

MICROFICHE—A film negative card (fiche) developed for many purposes throughout the Navy wherever microfilming is used to reduce amounts of paper documents.

MICROMETER—A unit of length equal to 10^{-6} meter, Formerly a micron.

MICRON—*See* MICROMETER.

MICROWAVES—A term commonly used to indicate electromagnetic waves in the frequency range between 1,000 and 300,000 megahertz (30 cm to 1 mm).

MILLIAMMETER—An ammeter that measures current in thousandths of an ampere.

MODULATION—The process of varying the amplitude or frequency of a carrier wave in accordance with other signals to convey intelligence. The modulating signal may be an audiofrequency signal, a video signal (as in television), or even electrical pulses or tones to operate relays.

MODULE—In electronic terminology, a group or cluster of circuits/components usually mounted together on a "board" or "potted" together in a lump.

MONOPULSE—A method of antenna lobing that permits information to be obtained on target range, bearing, and elevation from a single pulse (as distinguished from sequential lobing).

NOISE—Any undesired disturbance within the useful frequency band; also, that part of the modulation of a received signal (or an electrical or electronic signal within a circuit) representing an undesirable effect of transient conditions.

NOT CIRCUIT—In computers, a circuit in which the output signal does not have the same polarity as the input signal. A phase inverter.

NULL—A point or position where a variable-strength signal is at its minimum value (or zero).

OFF-LINE EQUIPMENT—Peripheral computer equipment that can operate independently of the main computer for such operations as transcribing punch card information to magnetic tape, or magnetic tape to printed form.

OMNIDIRECTIONAL—Going out in all directions as the radiation pattern of a single dipole antenna.

ON-LINE EQUIPMENT—Computer equipment, due to configuration or design, that requires the use of the central processing unit of the computer.

OR GATE—A logic circuit having multiple inputs and a single output, so designed that the output is energized when any one or more of the inputs are in the prescribed signal state.

PARALLEL MODE—In computer operation, the handling of a group of numbers or other symbols simultaneously.

PARAMETERS—In electronics, the design or operating characteristics of a circuit or device.

PASSIVE SONAR—An apparatus that receives energy generated from another source.

PERIPHERAL EQUIPMENT—Either on-line or off-line auxiliary equipment supporting the operations, but is not a part of the computer itself. These machines may consist of card readers, card punches, magnetic tape feeds, and high-speed printers.

PHOTON—A quantum of electromagnetic energy. The equation hv, where h is Plank's constant and v is the frequency associated with the photon.

PICKOFF—In gyros, a sensing device that measures the angle of the spin axis with respect to its reference, and provides an error signal that indicates the direction and (in most cases) the magnitude of the displacement.

PIEZOELECTRIC EFFECT—Effect of producing a voltage by placing stress, either by compression, expansion, or twisting, on a crystal and, conversely, producing a stress in a crystal by applying a voltage to it.

PIPS—Popular term for bright spots on a CRT display such as a radar or sonar screen.

POLARIZATION—In electronics, a term used in specifying the direction of the electric vector in a linearly polarized electromagnetic wave as radiated from a transmitting antenna, or as picked up by a receiving antenna.

POTENTIOMETER—A variable voltage divider; a resistor that has a variable contact arm so that any portion of the potential applied between its ends may be selected.

PPI SCAN (PPI DISPLAY)—A cathode-ray tube presentation in which the signal appears on a rotating radial line. Distance is indicated radially, and bearing as an angle.

PRECESSION—The reaction of a gyro to an applied torque, which causes the gyro to tilt itself at right angles to the direction of the applied torque in such a manner that the direction of spin of the gyro rotor will be in the same direction as the applied torque.

PROGRAM—A complete plan for the solution of a problem, including the complete sequence of machine instructions and routines necessary to solve the problem by an electronic computer.

PROPAGATION—Extending the action of, transmitting, carrying forward as in space or time or through a medium (as the propagation of sound, light, or radio waves).

PSEUDO—Term meaning false or fake.

PULSE—A momentary sharp surge of electrical voltage or current.

PULSE DURATION—The time interval between the leading and trailing edges of each of a particular group of pulses; the instantaneous values of these are often used in a specific relation to the peak pulse amplitude to determine power output.

PULSE INTERVAL—The time interval between the leading edges of successive pulses in a sequence.

PULSE SEPARATION—The time interval between the trailing edge of one pulse and the leading edge of the next pulse.

PULSE TRAIN—A series of pulses passed through a circuit as control or information signals.

RADIAN—In a circle, the angle included within an arc equal to the radius of the circle. A complete circle contains 2π radians. One radian equals 57.3 degrees and 1 degree equals 0.01745 radian.

RANGE—The distance of an object from an observer.

RAREFACTION—In wave motion, when the vibration is inward, a rrrarefaction or region of reduced pressure is produced.

RASTER—The illuminated rectangular area scanned by the electron beam in a picture tube/CRT.

RATE GYRO—A gyro with 1 degree of freedom, which has an elastic restraint, with or without a damper, and whose output will be proportional to the rate of the applied torque.

REFLECTION, SOUND—Sound rays transmitted in the sea eventually reach either the surface or the bottom. Since these boundaries are abrupt and very different in sound transmitting properties from the water, sound energy along a ray path striking these boundaries will be returned (reflected) to the water.

REFRACTION, SOUND—The bending or curving of a sound ray that results when the ray passes from a region of one sound velocity to a region of a different velocity. The amount of ray bending depends on the amount of difference between sound velocities.

REGISTER—A specific computer unit that stores a single computer word.

RELATIVE BEARING—A bearing taken when the heading of a ship serves as the reference line. *See also* BEARING.

RELATIVE MOTION—The apparent movement of an object in relation to another object.

RESONANT CAVITY—A space, normally enclosed by an electrically conductive surface, in which oscillatory electromagnetic energy is stored, and whose resonant frequency is determined primarily by the geometry of the enclosure.

REVERBERATION—A succession of echoes caused by reflections of sounds. In the ocean it is caused by irregularities in the ocean bottom, surface, and suspended matter (as fish). Under these conditions, an emitted pulse may be received as a muffed echo due to sound interference.

RHEOSTAT—A variable resistor that has one fixed terminal and a moveable contact, Potentiometers may be used as rheostats, but a rheostat cannot be used as a potentiometer because connections cannot be made to both ends of the resistance element.

RIGIDITY—In gyros, the characteristics of a spinning body that causes it to oppose all attempts to tilt it away from the axis in which it is spinning.

RING TIME—In radar, the time during which the output of an echo box remains above a predetermined level; used in measuring the performance of radar equipment.

SAR—Search and rescue.

SCALE FACTOR—A quantity used to introduce a change according to a fixed ratio or scale; a proportionality constant.

SCANNING SONAR—Sonar that transmits sound pulses in all directions simultaneously.

SCATTERING—Reflection losses from particles suspended in the water.

SENSO—Sensor operator (SO). Operates the ASW platforms acoustic and nonacoustic sensor systems.

SENSOR—A component that senses variables and produces a signal therefrom. Temperature, sound, heat, and light sensors are some examples.

SEQUENTIAL LOBING—Successively shifting the radar beam about the scanner centerline through a particular pattern; differs from monopulse.

SERIAL OPERATION-In computers, the sequential handling of a group of numbers or symbols.

SHIFT REGISTER—In computers, a circuit that will shift a digit or a group of digits either to the left or to the right; it is of particular importance in some multiplication and division processes, and in sequential storage of pulse trains.

SHOT EFFECT—Noise voltages developed as a result of the random nature of electron flow in vacuum tubes, or the random flow of either primary or secondary carriers in transistors.

SLEW—To change the position of an indicator mark on a CRT display by varying the time relationship of the mark with respect to the start of the sweep.

SOFTWARE—Pertains to the programs and routines used with computers. The totality of programs and routines used to extend the capabilities of computers. In contrast to HARDWARE, which is the construction parts (mechanical, electrical, and electronic elements) of the computer.

SONAR—Acronym for SOund Navigation And Ranging. Apparatus or technique of obtaining information regarding objects or events underwater.

SONIC—Within the audible range of the human ear.

SONOBUOY—Small floating buoy with an attached hydrophore and a radio transmitter that relays underwater sounds picked up by the hydrophone to ASW units.

SONOBUOY RECEIVER SYSTEM (SRX)– An FM radio receiver system used exclusively for sonobuoy RF signal reception and processing.

SONOBUOY REFERENCE SYSTEM (SRS)– The system used to determine the position of deployed sonobuoys relative to aircraft position.

SOUND CHANNEL—Condition when two layers of water with near equal temperatures produce a sound channel. Sound between the two layers is refracted by the layers, stays between them, and travels for great distances.

SYNC—A short form of the word synchronizing, which means to cause two elements of a system to coincide in speed, frequency, relative position, or time.

TACCO—Tactical coordinator.

THERMAL NOISE—A very low-level noise produced by molecular movement in the sea.

THERMISTOR-A solid-state, semiconducting device whose resistance varies with temperature.

THERMISTOR-A bolometer characterized by a decrease of resistance as the temperature rises. *See also* BOLOMETER.

THERMOCLINE-The layer in the sea where the temperature decreases continuously with depth. Usually the decrease (gradient) is greater than 2.7°F per 165 feet in depth.

TORQUE—A force tending to cause rotational motion; the product of the force applied times the distance from the force to the axis of rotation.

TRANSDUCER—A device that converts signals received in one medium into outputs in some other medium; for example, electrical inputs to fluidic outputs, or mechanical motion into electrical quantities.

TRIGGERING—Starting an action in another circuit, which then operates for a time under its own control.

TRUE BEARING—A bearing given in relation to true geographic north. *See also* BEARING.

TUMBLE (GYRO)—To subject a gyro to a torque so that it presents a precession violent enough to cause the gyro rotor to spin end over end.

VELOCITY—A vector quantity that includes both magnitude (speed) and direction in relation to a given frame of reference.

VERTICAL PLANE—A vertical plane is perpendicular to the horizontal plane, and is the reference from which bearings are measured. Relative bearing, for example, is measured in the horizontal plane clockwise from the vertical plane through own ship's centerline to the vertical plane through the line of sight. The system of planes makes possible the design and construction of mechanical and electronic equipment to solve the fire control problem. These lines and planes are imaginary extensions of some characteristic of the ship or target, or of the relation in space between them.

WAVEGUIDE—Metal tubes or dielectric cylinders capable of propagating electromagnetic waves through their interiors. The dimensions of these devices are determined by the frequency to be propagated. Metal guides are usually rectangular or circular in cross section; they may be evacuated, air filled, or gas filled, and may or may not be pressurized. Dielectric guides consist of solid dielectric cylinders surrounded by air.

WAVELENGTH—The distance traveled by a wave during the time interval of one complete cycle, It is equal to the velocity divided by the frequency.

WAVE PROPAGATION—The radiation, as from an antenna, of RF energy into space, or of sound energy into a conducting medium.

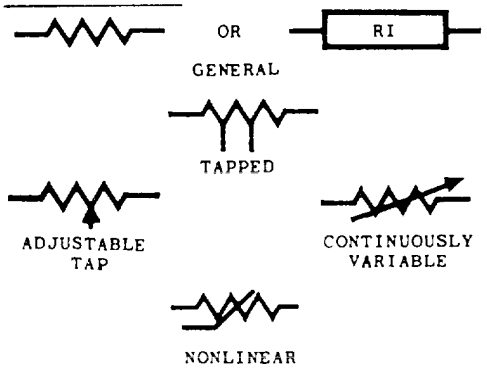
WORD—In computers, a particular number of characters handled as a unit by the computer and having a specific meaning with respect to the computation process.

APPENDIX II

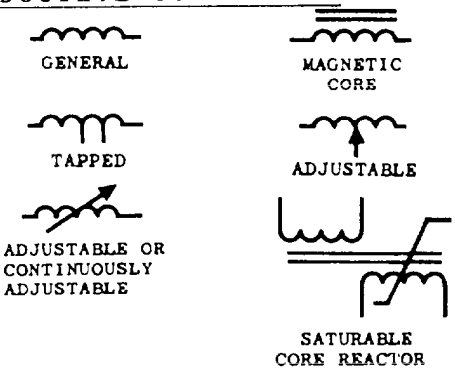
SYMBOLS, FORMULAS, AND MEASUREMENTS

SYMBOLS
(SEE ANSI/IEEE STD Y32.2-1975 AND 315A-1986)

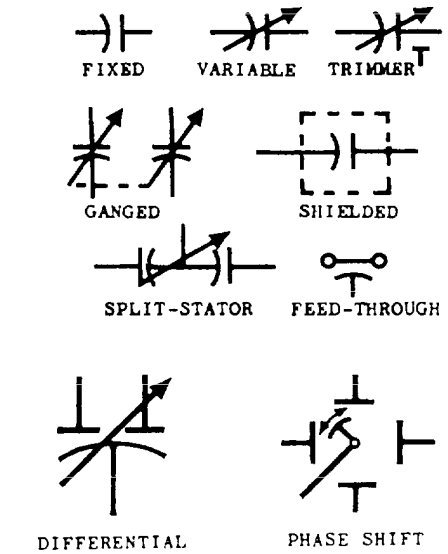
RESISTORS:



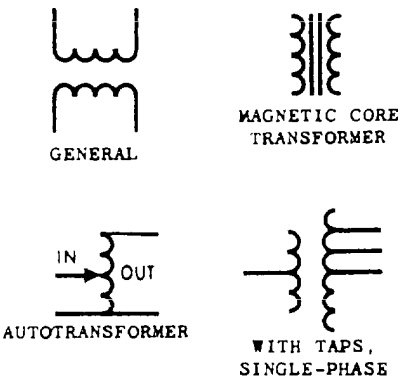
INDUCTIVE COMPONENTS:



CAPACITORS:



TRANSFORMERS



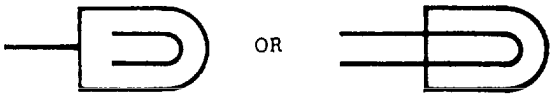
PERMANENT MAGNET

PM

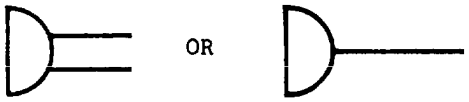
(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

NOTE: FOR FURTHER INFORMATION CONCERNING SYMBOLS REFER TO IEEE STANDARDS AND AMERICAN NATIONAL STANDARD GRAPHIC SYMBOLS FOR ELECTRICAL AND ELECTRONICS DIAGRAMS, ANSI Y32.2/IEEE NO. 315, WHICH HAS BEEN ADOPTED FOR MANDATORY USE BY THE DEPARTMENT OF DEFENSE.

INDICATOR LAMP



MICROPHONE



CRYSTAL

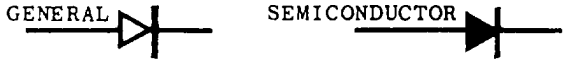


QUARTZ CRYSTAL;
PIEZOELECTRIC CRYSTAL
UNIT.

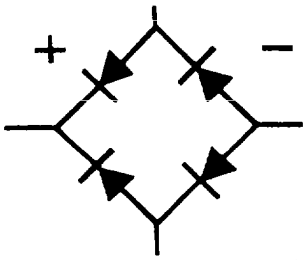
KEY



RECTIFIER

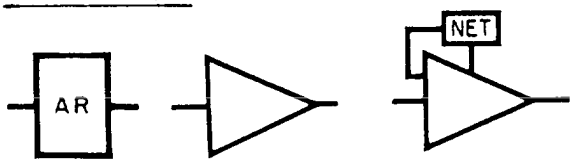


NORMAL CURRENT FLOW IS AGAINST THE ARROW



FULL WAVE BRIDGE TYPE

AMPLIFIER

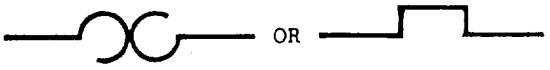


TRIANGLE POINTS IN DIRECTION OF TRANSMISSION (SIGNAL FLOW)

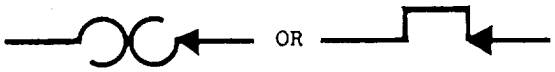
AMPLIFIER WITH EXTERNAL FEEDBACK PATH

BASIC SYMBOL INDICATES ANY METHOD OF AMPLIFICATION EXCEPT THAT OPERATING ON THE PRINCIPLE OF ROTATING MACHINERY.

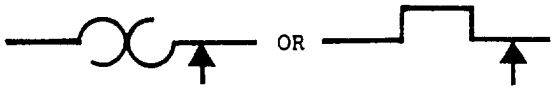
THERMAL ELEMENTS

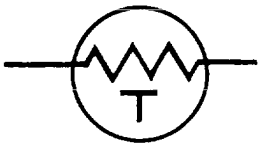


THERMAL RELAY WITH NORMALLY CLOSED CONTACT.

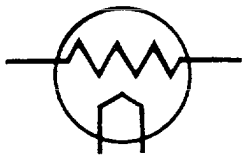


FLASHER; THERMAL CUTOUT





THERMISTOR

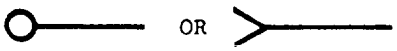


WITH INTEGRAL HEATING ELEMENT



TEMPERATURE-MEASURING THERMOCOUPLE (DISSIMILAR METAL DEVICE)

INPUTS (NONSTANDARD)



PATH, TRANSMISSION



CROSSING NOT CONNECTED



JUNCTION CONNECTED



TWISTED PAIR

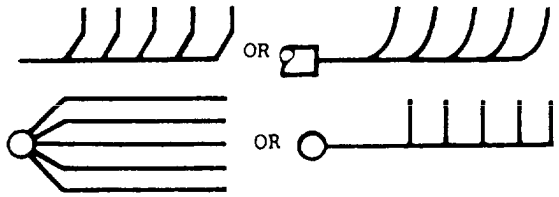


AIR OR SPACE PATH



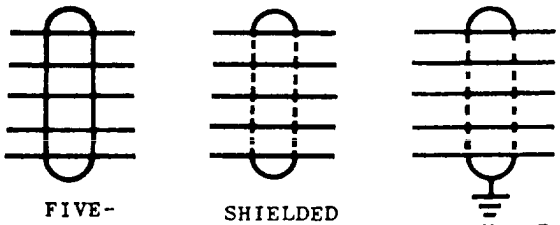
COAXIAL

GROUPING OF WIRES IN BUNDLES



GROUPING OF WIRES IN CABLES

CABLES



FIVE-CONDUCTOR CABLE

SHIELDED FIVE-CONDUCTOR CABLE

GROUNDED SHIELD

NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY

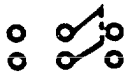
SWITCHES



GENERAL (SINGLE THROW)



GENERAL (DOUBLE THROW)



TWO POLE DOUBLE THROW SWITCH



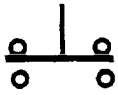
KNIFE SWITCH



PUSHBUTTON (BREAK)

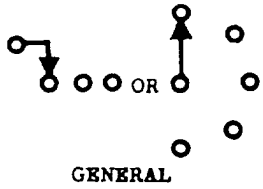


PUSHBUTTON (MAKE)



PUSHBUTTON TWO CIRCUIT

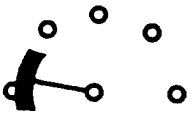
SELECTOR SWITCHES

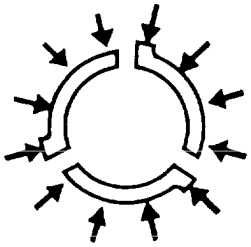


GENERAL

ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK BEFORE MAKE SWITCH.

MAKE BEFORE BREAK





WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

CIRCUIT RETURNS

CHASSIS CONNECTION

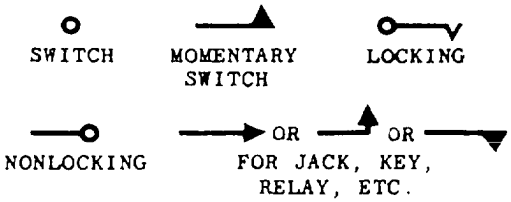


(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)



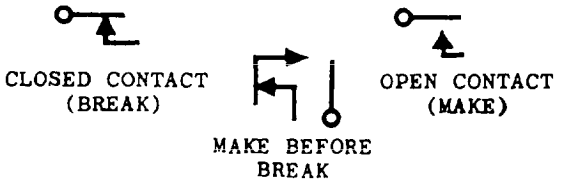
GROUND

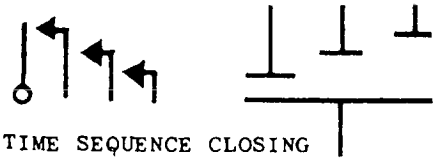
CONTACTS (ELECTRICAL)



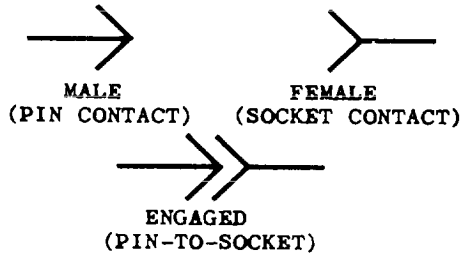
CONTACTS (ELECTRICAL) (CONTINUED)

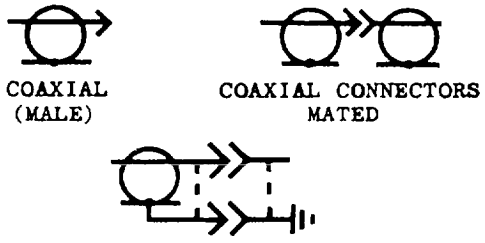
CONTACT ASSEMBLIES



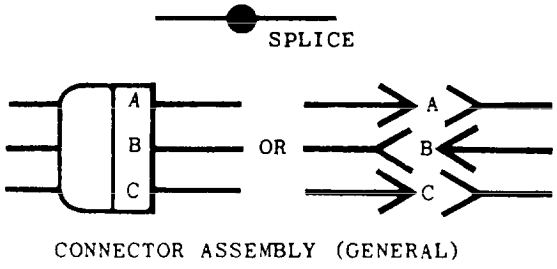


DISCONNECTING DEVICES





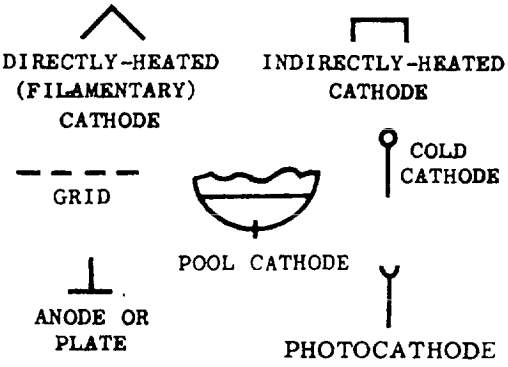
THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.

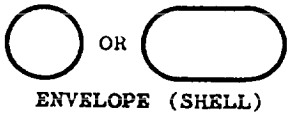


CONNECTOR ASSEMBLY (GENERAL)

ELECTRON TUBES

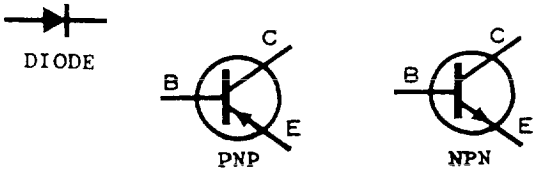
COMPONENT TUBE SYMBOLS



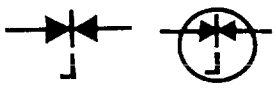




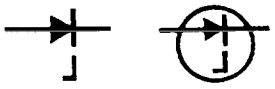
SEMICONDUCTOR DEVICES



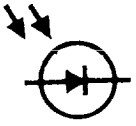
TRANSISTORS



BREAKDOWN DIODE,
BIDIRECTIONAL

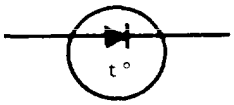


BREAKDOWN DIODE,
UNDIRECTIONAL
(ALSO BACKWARD DIODE)



PHOTODIODE

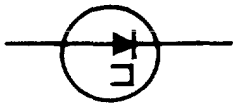
SEMICONDUCTOR DEVICES (CONTINUED)



TEMPERATURE DEPENDENT DIODE



PNPN SWITCH

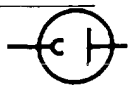


TUNNEL DIODE

TYPICAL ELECTRON TUBES



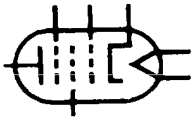
COLD CATHODE GAS TUBE



PHOTOTUBE SINGLE UNIT, VACUUM



DIODE



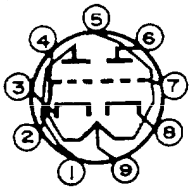
PENTODE



TWIN TRIODE ILLUSTRATING ELONGATED ENVELOPE

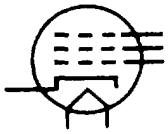


DIODE SHOWING BASE CONNECTIONS



TWIN TRIODE WITH TAPPED HEATER

TYPICAL CATHODE RAY TUBES



MAGNETIC DEFLECTION

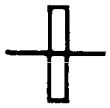


ELECTROSTATIC DEFLECTION

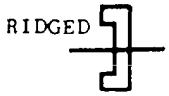
WAVEGUIDES



CIRCULAR



RECTANGULAR



RIDGED

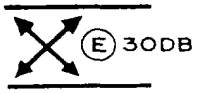


ROTARY JOINT

DIRECTIONAL COUPLERS



GENERAL



E PLANE APERTURE COUPLING, 30 DB TRANSMISSION LOSS

COUPLING METHODS

GENERALLY USED FOR COAXIAL AND WAVEGUIDE TRANSMISSION.



COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).



COUPLING BY LOOP TO SPACE

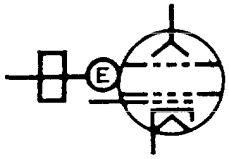


COUPLING BY LOOP TO GUIDED TRANSMISSION PATH



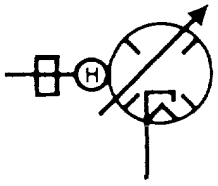
COUPLING BY PROBE FROM COAXIAL TO RECTANGULAR WAVEGUIDE WITH DIRECT-CURRENT GROUNDS CONNECTED

TYPICAL MAGNETRONS AND KLYSTRONS

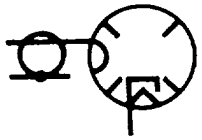


REFLEX KLYSTRON, APERATURE COUPLED

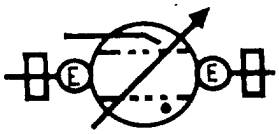
TUNABLE MAGNETRON, APERTURE COUPLED



TYPICAL MAGNETRONS AND KLYSTRONS (CONTINUED)



RESONANT TYPE WITH COAXIAL OUTPUT



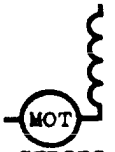
TRANSMIT-RECEIVE (TR) TUBE GAS FILLED, TUNABLE INTEGRAL CAVITY, APERTURE COUPLED, WITH STARTER

ROTATING MACHINES

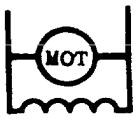


MOTOR GENERATOR

TYPES OF WINDINGS



SERIES



SHUNT



SEPARATELY EXCITED



DYNAMOTOR

WINDING SYMBOLS



SINGLE-PHASE



TWO - PHASE



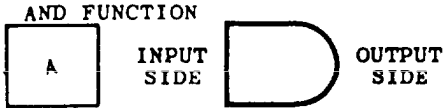
THREE-PHASE (WYE)



THREE-PHASE (DELTA)

LOGIC FUNCTIONS

AND FUNCTION



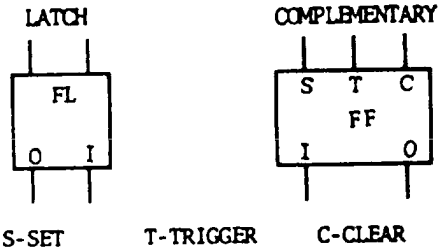
INCLUSIVE OR FUNCTION



EXCLUSIVE OR FUNCTION



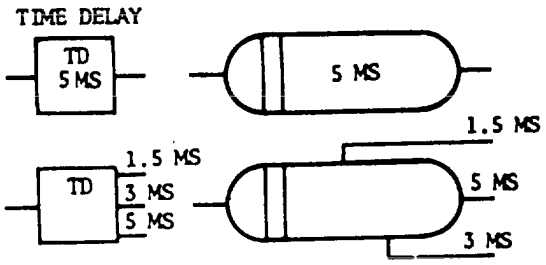
FLIP-FLOPS



NEGATION



TIME DELAY



LOGIC FUNCTIONS (CONTINUED)

SINGLE SHOT



SCHMITT TRIGGER



OSCILLATOR



SYNCHROS

GENERAL



A LETTER COMBINATION FROM THE FOLLOWING LIST MAY BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

- TX - TORQUE TRANSMITTER
- TDX - TORQUE DIFFERENTIAL TRANSMITTER
- CX - CONTROL TRANSMITTER
- CDX - CONTROL DIFFERENTIAL TRANSMITTER
- TR - TORQUE RECEIVER
- CT - CONTROL TRANSFORMER

SYNCHROS (CONTINUED)



TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

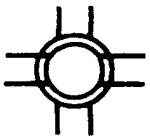


DIFFERENTIAL TRANSMITTER OR RECEIVER

RESOLVER (SYNCHRO)

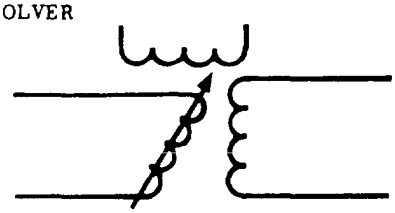


SINGLY-WOUND ROTOR

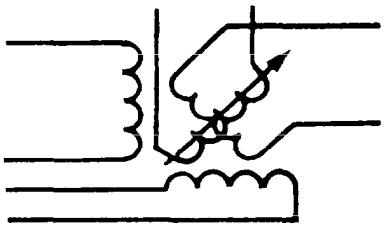


DOUBLY-WOUND ROTOR

RESOLVER



SINGLY-WOUND ROTOR



DOUBLY-WOUND ROTOR

PICKUP HEADS



GENERAL



WRITING; RECORDING; HEAD,
SOUND RECORDER



READING; PLAYBACK; HEAD,
SOUND REPRODUCER

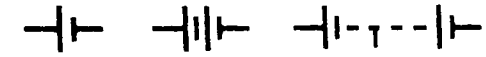


APPLICATION: WRITING, READING,
AND ERASING



ERASING; ERASER, MAGNETIC

BATTERIES



ONE CELL MULTICELL TAPPED MULTICELL

(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT PROTECTORS

FUSE



CIRCUIT BREAKERS



SWITCH

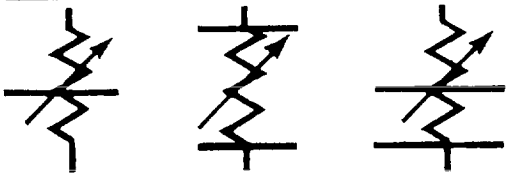


PUSH PULL OR PUSH



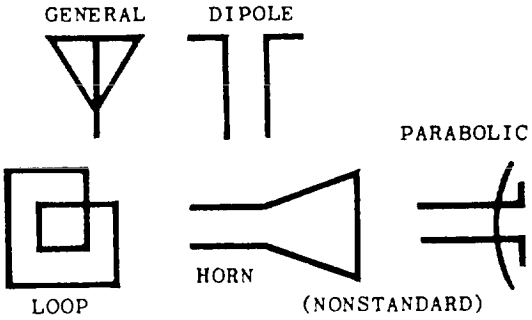
GANGED

ATTENUATORS



GENERAL BALANCED UNBALANCED

ANTENNAS



METERS



A - AMMETER

CRO - OSCILLOSCOPE

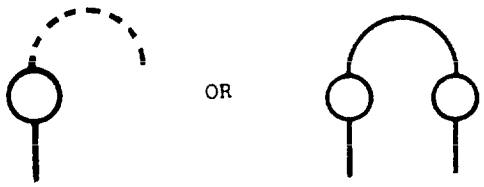
G - GALVANOMETER

MA - MILLIAMMETER

OHM - OHMMETER

V - VOLTMETER

HEADSET



OR

FORMULAS

Ohm's Law for dc Circuits

$$I = \frac{E}{R} = \frac{P}{E} = \sqrt{\frac{P}{R}}$$

$$R = \frac{E}{I} = \frac{P}{I^2} = \frac{E^2}{P}$$

$$E = IR = \frac{P}{I} = \sqrt{PR}$$

$$P = EI = \frac{E^2}{R} = I^2R$$

Resistors in Series

$$R_T = R_1 + R_2 + \ldots$$

Resistors in Parallel

Two resistors

$$R_T = \frac{R_1R_2}{R_1 + R_2}$$

More than two

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

RL Circuit Time Constant

$\frac{\text{L (in henrys)}}{\text{R (in ohms)}}$ = t (in seconds), or

$\frac{\text{L (in microhenrys)}}{\text{R (in ohms)}}$ = t (in microseconds)

RC Circuit Time Constant

R (ohms) × C (farads) = t (seconds)

R (megohms) × C (microfarads) = t (seconds)

R (ohms) × C (microfarads) = t (microseconds)

R (megohms) × C (micromicrofarads) = t (microseconds)

Capacitors in Series

Two capacitors

$$C_T = \frac{C_1C_2}{C_1 + C_2}$$

More than two

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$$

Capacitors in Parallel

$$C_T = C_1 + C_2 + \ldots$$

Capacitive Reactance

$$X_C = \frac{1}{2\pi fC}$$

Impedance in an RC Circuit (Series)

$$Z = \sqrt{R^2 + (X_C)^2}$$

Inductors in Series

$L_T = L_1 + L_2 + \ldots$ (No coupling between coils)

Inductors in Parallel

Two inductors

$L_T = \frac{L_1L_2}{L_1 + L_2}$ (No coupling between coils)

More than two

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots$ (No coupling between coils)

Inductive Reactance

$$X_L = 2\pi fL$$

Q of a Coil

$$Q = \frac{X_L}{R}$$

Impedance of an RL Circuit (Series)

$$Z = \sqrt{R^2 + (X_L)^2}$$

Impedance with R, C, and L in Series

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Parallel Circuit Impedance

$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

Sine-Wave Voltage Relationships

Average value

$$E_{ave} = \frac{2}{\pi} \times E_{max} = 0.637E_{max}$$

Effective or rms value

$$E_{eff} = \frac{E_{max}}{\sqrt{2}} = \frac{E_{max}}{1.414} = 0.707E_{max} = 1.11E_{ave}$$

Maximum value

$$E_{max} = \sqrt{2}\,(E_{eff}) = 1.414E_{eff} = 1.57E_{ave}$$

Voltage in an ac circuit

$$E = IZ = \frac{P}{I \times PF}$$

Current in an ac circuit

$$I = \frac{E}{Z} = \frac{P}{E \times PF}$$

Power in AC Circuit

Apparent power: $P = EI$

True power: $P = EI \cos \theta = EI \times PF$

Power Factor

$$PF = \frac{P}{EI} = \cos \theta$$

$$\cos \theta = \frac{\text{true power}}{\text{apparent power}}$$

Transformers

Voltage relationship

$$\frac{E_p}{E_s} = \frac{N_p}{N_s} \text{ or } E_s = E_p \times \frac{N_s}{N_p}$$

Current relationship

$$\frac{I_p}{I_s} = \frac{N_s}{N_p}$$

Induced voltage

$$E_{eff} = 4.44 \times BAfN \times 10^{-8}$$

Turns ratio

$$\frac{N_p}{N_s} = \sqrt{\frac{Z_p}{Z_s}}$$

Secondary current

$$I_s = I_p \times \frac{N_p}{N_s}$$

Secondary voltage

$$E_s = E_p \times \frac{N_s}{N_p}$$

Three-Phase Voltage and Current Relationships

With wye connected windings

$$E_{line} = \sqrt{3}\,(E_{coil}) = 1.732E_{coil}$$

$$I_{line} = I_{coil}$$

With delta connected windings

$$E_{line} = E_{coil}$$

$$I_{line} = 1.732I_{coil}$$

With wye or delta connected winding

$$P_{coil} = E_{coil}I_{coil}$$

$$P_t = 3P_{coil}$$

$$P_t = 1.732E_{line}I_{line}$$

(To convert to true power multiply by $\cos \theta$)

Resonance

At resonance

$$X_L = X_C$$

Resonant frequency

$$F_o = \frac{1}{2\pi\sqrt{LC}}$$

Series resonance

$$Z \text{ (at any frequency)} = R + j(X_L - X_C)$$

$$Z \text{ (at resonance)} = R$$

Parallel resonance

$$Z_{max} \text{ (at resonance)} = \frac{X_L X_C}{R} = \frac{X_L{}^2}{R} = QX_L = \frac{L}{CR}$$

Bandwidth

$$\Delta = \frac{F_o}{Q} = \frac{R}{2\pi L}$$

Tube Characteristics

Amplification factor

$$\mu = \frac{\Delta e_p}{\Delta e_g} (i_p \text{ constant})$$

$$\mu = g_m r_p$$

AC plate resistance

$$r_p = \frac{\Delta e_p}{\Delta i_p} (e_g \text{ constant})$$

Grid-plate transconductance

$$g_m = \frac{\Delta i_p}{\Delta e_g} (e_p \text{ constant})$$

Decibels

NOTE: Wherever the expression "log" appears without a subscript specifying the base, the logarithmic base is understood to be 10.

Power ratio

$$dB = 10 \log \frac{P_2}{P_1}$$

Current and voltage ratio

$$dB = 20 \log \frac{I_2\sqrt{R_2}}{I_1\sqrt{R_1}}$$

$$dB = 20 \log \frac{E_2\sqrt{R_1}}{E_1\sqrt{R_2}}$$

NOTE: When R_1 and R_2 are equal they may be omitted from the formula. When reference level is one milliwatt

$$dBm = 10 \log \frac{P}{0.001} \text{ (when P is in watts)}$$

Synchronous Speed of Motor

$$rpm = \frac{120 \times \text{frequency}}{\text{number of poles}}$$

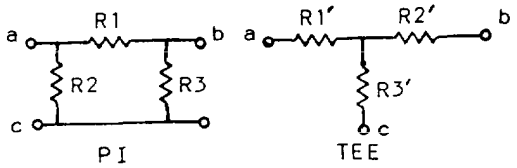
Wavelength

$$\text{wavelength (in meters)} = \frac{300}{\text{frequency (in megahertz)}}$$

$$\lambda = \frac{300}{f \text{ (MHz)}}$$

BRIDGE CIRCUIT CONVERSION FORMULAS

PI to Tee

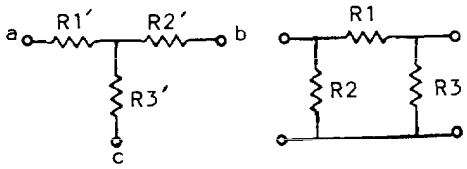


$$R_{1'} = \frac{R_1 R_2}{R_1 + R_2 + R_3}$$

$$R_{2'} = \frac{R_1 R_3}{R_1 + R_2 + R_3}$$

$$R_{3'} = \frac{R_2 R_3}{R_1 + R_2 + R_3}$$

Tee to PI

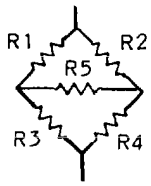


$$R_1 = \frac{R_{1'}R_{2'} + R_{2'}R_{3'} + R_{1'}R_{3'}}{R_{3'}}$$

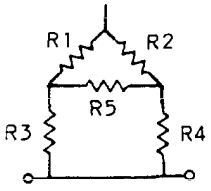
$$R_2 = \frac{R_{1'}R_{2'} + R_{2'}R_{3'} + R_{1'}R_{3'}}{R_{2'}}$$

$$R_3 = \frac{R_{1'}R_{2'} + R_{2'}R_{3'} + R_{1'}R_{3'}}{R_{1'}}$$

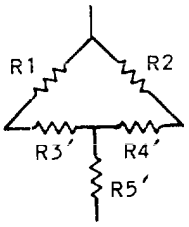
Calculating R_T for Bridge



1. Redraw



2. Convert PI network made up of resistors $R_3R_4R_5$ to Tee network made up of $R_{3'}R_{4'}R_{5'}$

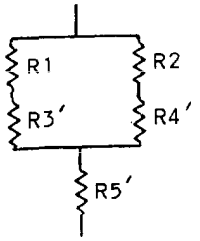


$$R_{3'} = \frac{R_3 R_5}{R_3 + R_4 + R_5}$$

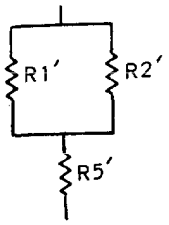
$$R_{4'} = \frac{R_4 R_5}{R_3 + R_4 + R_5}$$

$$R_{5'} = \frac{R_3 R_4}{R_3 + R_4 + R_5}$$

3. Redraw circuit

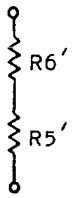


4. Simplify circuit by combining



$$R_{1'} = R_1 + R_{3'} \qquad R_{2'} = R_2 + R_{4'}$$

5. Simplify again



$$R_{6'} = \frac{R_{1'}R_{2'}}{R_{1'} + R_{2'}}$$

6. Solve for R_T

$$R_T = R_{6'} + R_{5'}$$

Comparison of Units in Electric and Magnetic Circuits

	Electric circuit	Magnetic circuit
Force	Volt, E, or emf	Gilberts, F, or mmf
Flow	Ampere, I	Flux, Φ, in maxwells
Opposition	Ohms, R	Reluctance, $\mathcal{R}$
Law	Ohm's law, $I = \frac{E}{R}$	Rowland's law, $\Phi = \frac{F}{\mathcal{R}}$
Intensity of force	Volts per cm of length.	$H = \frac{1.257IN}{L}$, gilberts per centimeter of length.
Density	Current density—for example, amperes per cm^2.	Flux density—for example, lines per cm^2 or gausses.

U.S. CUSTOMARY AND METRIC SYSTEM UNITS OF MEASUREMENTS

Multiples and Submultiples		Prefixes	Symbols
1 000 000 000 000	$= 10^{12}$	tera (ter 'a)	T
1 000 000 000	$= 10^{9}$	giga (ji 'ga)	G
1 000 000	$= 10^{6}$	mega (meg 'a)	M*
1 000	$= 10^{3}$	kilo (kil 'o)	k*
100	$= 10^{2}$	hecto (hek 'to)	h
10	$= 10$	deka (dek 'a)	da
0.1	$= 10^{-1}$	deci (des 'i)	d
0.01	$= 10^{-2}$	centi (sen 'ti)	c*
0.001	$= 10^{-3}$	milli (mil 'i)	m*
0.000 001	$= 10^{-6}$	micro (mi 'kro)	μ*
0.000 000 001	$= 10^{-9}$	nano (nan 'o)	n
0.000 000 000 001	$= 10^{-12}$	pico (pe 'ko)	p
0.000 000 000 000 001	$= 10^{-15}$	femto (fem 'to)	f
0.000 000 000 000 000 001	$= 10^{-18}$	atto (at 'to)	a

*Most commonly used

GREEK ALPHABET

Name	Capital	Lower Case	Designates
Alpha.....	A	α	Angles, coefficient of thermal expansion.
Beta	B	β	Angles, flux density.
Gamma	Γ	γ	Conductivity.
Delta	Δ	δ	Variation of a quantity, increment.
Epsilon	E	ε	Base of natural logarithms (2.71828).
Zeta	Z	ζ	Impedance, coefficients, coordinates.
Eta	H	η	Hysteresis coefficient, efficiency, magnetizing force.
Theta	Θ	θ	Phase angle.
Iota	I	ι	
Kappa	K	$\varkappa$	Dielectric constant, coupling coefficient, susceptibility.
Lambda.....	Λ	λ	Wavelength.
Mu	M	μ	Permeability, micro, amplification factor.
Nu	N	ν	Reluctivity.
Xi.....	Ξ	ξ	
Omicron	O	o	
Pi	Π	π	3.1416
Rho	P	ϱ	Resistivity.
Sigma.....	Σ	ς	Summation symbol (cap).
Tau	T	τ	Time constant, time-phase displacement.
Upsilon	Y	υ	
Phi	Φ	ϕ	Angles, magnetic flux.
Chi.....	X	χ	
Psi	Ψ	ψ	Dielectric flux, phase difference.
Omega.....	Ω	ω	Ohms (capital), angular velocity (2 π f).