Electronics
Radio
Television
Radar

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RADAR PRINCIPLES

ASSIGNMENT 13B

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During the period of the last few years, the field of radar has become one of the truly important branches of the electronics industry. The radar "nets" which have been established across Canada and around the coastline of the continental United States are the key parts of the Defense Department's program to protect the continental USA. Similarly, our radar installations on foreign soil are outposts for this program. Radar is our only possible way of detecting the approach of missiles while they are at a great enough distance to permit countermeasures to be taken.

Civilian electronics technicians are used very widely in the maintenance and repair of this type of electronics equipment, as well as in the design and manufacture of the equipment.

In the non-military missile field radar also plays an important role. Radar tracking of missiles and satellites makes it possible to keep in touch with space probes.

Radar also has many commercial applications, such as airborne radar to map the extent of storms in the vicinity of which an airplane is flying, radar landing systems, Federal Aviation Authority radar tracking systems, and radar used aboard river-, lake-, and ocean-going ships.

The use of radar is so extensive that special assignments are included in the training program at appropriate points dealing with the subject of radar. This is the first of these special assignments on this subject.

Introduction and History of Radar

The best definition of radar is obtained by analyzing the actual meaning of this term. The word **Radar** is an abbreviation of the following: **Ra**dio **D**etection **a**nd **R**anging. The term radar is, then, an abbreviation of the longer phrase, radio detection and ranging, which indicates the actual purpose of radar equipment. In military usage the term **range** means a measure of distance between some object such as a gun, or a radar set in this case, and some objective. Thus radar is used to detect the presence of objects and to determine the distance of the object from the radar set. Not only does radar indicate the distance to an object but it also indicates the direction of that object.

To achieve the desired results, radar sets employ radio waves. Consequently, the history of radar dates back to the beginning of radio experiments. Thus Heinrich Hertz's crude radio experiments in the year 1888 and Marconi's experiments which followed in the year 1896 actually laid the cornerstone for the complex radar installations of today.

The major developments in radar equipment occurred during the years between 1935 and 1945—that is, prior to and during World War II. However, radar was not entirely unknown before that time as Marconi predicted it in the year 1922.

It is interesting to note that nature has been employing a principle quite similar to radar probably since the beginning of time. One thing which mystified biologists for many years was the fact that bats are able to fly in absolute darkness, for example, in a cave far below ground, and still they do not strike the walls or other objects. However, since the darkness is absolute, it is not possible for them to "see" the objects. Thus it remained a mystery for many years just how the bats "achieved the impossible". It has been found that the system employed by these animals to achieve the impossible is quite similar to radar.

The bats produce very high pitched sounds, so high pitched in fact that they are not audible to the human ear. These high pitched sounds are **reflected** from the walls of the caves or other objects and returned to the bat. When these returned "echos" are received by its sensitive ears the bat is able to determine the position of the object producing the echo and make the necessary corrections in the line of flight to prevent collision. This is illustrated in Figure 1.

Before considering the subject of radar in more detail let us consider a little further "nature's radar system" as employed by the bat. Notice that in the first place the bat must produce,or radiate, some sort of sound or signal which can be heard by its ears. As this signal travels away from the bat it strikes the walls of the cave and other obstacles nearby. Part of the energy striking the walls of the cave or other objects, is reflected toward the bat, forming an **echo.** Thus the second requirement in the natural radar system is the **reflection of the energy.** The energy which is reflected to the bat must be picked up, or "received", by the bat's ears. This illustrates the third requirement of the radar system; namely a **receiver.** However, this entire process would be useless if the bat did not possess some means of interpreting the echo and indicating the direction and position of the object causing the echo. This, in the case of the bat, is accomplished through its brain or instinct. We might for simplicity, call this portion of the natural radar system an **indicating device.** To summarize this action it can be stated that the fundamental requirements of the natural radar system are: (1) a means of generating and radiating a signal, (2) an echo from the object to be detected, (3) a means of receiving this signal and (4) a means of interpreting the signal and indicating the position and distance of the object.

As we shall soon see, the same fundamental components are required in a radar system. It should be emphasized that there is one fundamental difference between the radar system of the bat and the radar system which is used to practical advantage in military and civilian applications. This is the fact that the signal radiated in radar systems is a **radio frequency wave,** whereas, the bat employs high frequency sound waves.

Radar Applications

The first radar systems were designed for use in detecting the presence of aircraft while they were still at a sufficiently great distance so they could be intercepted by fighter aircraft. This is still one of the major applications of radar. The developments in the missile field have necessitated the development of radar units with much greater range to detect the presence of enemy missiles thousands of miles away. Other types of radar systems have been developed for use in many other situations. For example, modern radar equipment is available for locating exactly the position of an aircraft, which is nearby, so that this information can be used in directing anti-aircraft fire. This equipment has been developed to the point where the radar device actually controls the position of the anti-aircraft guns thereby greatly increasing their accuracy. These applications of radar are normally referred to as **ground** radar, since the equipment is located on the ground.

Another important application of radar is **airborne** radar. There are a number of different types of radar equipment which are airborne. One type, which is used primarily by fighter planes, enables the pilot to "see" an enemy aircraft at night and thereby enable interception. Another type of radar which is used largely by bombers, enables the crew to "see" the terrain over which the plane is flying at night or in the case of heavy fog or bad weather conditions. This is particularly important in locating a target for high level pin-point bombing.

A third application of radar to aircraft is the radar altimeter. This device is far more accurate than the customary altimeter and is very important in connection with bombing missions as the exact altitude is an important factor in determining the proper time to release the bombs.

Another radar application which is used in conjunction with aircraft is the radar landing system. Strictly speaking, this is a ground radar application since the equipment is located on the ground. During World War II, when targets in Germany were being bombed by aircraft stationed in England, the facts indicated that the number of planes lost during landing operations were nearly as great as those lost by enemy action over the target. Thus it was obvious that a landing method must be devised for use in case of bad weather conditions. Special radar equipment was designed for this purpose which enables an operator on the ground to determine very accurately the position of a plane approaching an airport. Directions can be given to the pilot by radio, telling him the necessary corrections to make in his glide path and direction of flight so that he will be able to make a safe landing. This equipment has also been adapted for use by commercial airlines and is called Ground Controlled Approach (GCA).

Radar is also used widely on naval vessels. This equipment is quite similar to ground radar except it is, of course, adapted for use at sea. The equipment used includes radar units for detecting and indicating the range of other surface vessels, for long range detection of aircraft, for position indication of close-flying aircraft, and for anti-aircraft gun direction. Another marine application of radar is in navigation, particularly in the case of bad weather or darkness when a ship is close to shore. When a ship is approaching port etc., radar may be used to determine the distance to the shoreline, buoys, other ships, etc., to assist in the navigation of the vessel.

While the foregoing does not constitute a complete list of the uses of radar it does outline its major uses. It should be very evident that the types of radar equipment used to perform the various types of operations differ rather widely. For this reason the detailed study of particular units is impossible in the training program. However, since all radar equipment operates on similar principles, the basic radar circuits and principles which will be included in the training program should enable you to intelligently analyze any radar equipment with which you may have association in the future.

A Fundamental Radar System

Figure 2 illustrates the fundamentals of a radar system. A radar transmitter generates very short radio waves which are radiated by the radar antenna. The transmitter is turned on and off automatically in such a manner that the radio waves transmitted are in the form of pulses, somewhat similar to a succession of dots being sent by code (radio telegraph) station, except the radar pulses occur for shorter intervals of time. As the radio waves travel through space they will strike objects which reflect a portion of the radio wave back toward the radar antenna. A receiver is connected to the antenna in such a manner that the reflected waves are picked up and amplified and are then passed on to the visual indicator. The indicator consists of electronic circuits and a cathode-ray tube similar to those used in television receivers. The effect of the returning pulse is to produce an indication on the indicator which can in turn be used to determine the distance from the radar set to the object which caused the reflected radio wave to occur. In addition directional antennas are employed with radar equipment so that the radio waves which are transmitted are sent out in a narrow beam somewhat similar to the beam from a flashlight. Thus the reflection occurs from a particular object only when the antenna is aimed at that object and the direction the antenna is pointing may be used to indicate the direction of the object. Thus an object can be detected and its range and direction can be determined by radar.

The fact that radar employs a radio wave instead of other means of indicating the presence of objects, enables it to offer a decided advantage over other detection methods. For example, the presence of approaching planes can be detected by constantly searching the sky with a pair of powerful binoculars. However, the range of detection in this case is very limited and in case of fog or other adverse weather conditions this method of detection is almost useless. Another method of detection, which was employed previous to radar, was a sensitive listening device, which can be used to detect the sound of the motors of the approaching plane. This method too, is very limited in range and is very inaccurate. The radio waves used by a radar system are, however, unaffected by fog or other similar weather conditions and the useful range of the instrument can be extended in excess of one hundred miles. Also, radar can be used to detect objects which are dark and silent and therefore could not be seen nor heard. An aircraft flying at a very high altitude can determine the location of a target area even though that target area is blanked out and silent. This importance is so obvious that no additional discussion is required.

Almost any object can be detected by means of radar since practically all materials reflect the short radio waves used by radar. For example, ships, aircraft, land, water, trees, buildings, birds, etc., will cause radar reflections to occur. It should be emphasized, however, that different objects reflect the radar waves to a different degree, thereby enabling detection to occur. It was mentioned that a radar wave is reflected from water and also that it was reflected from a ship; consequently, it might appear that a ship in the water could not be detected. This, however, is not the case since the metal of a ship reflects the radar waves and returns them to the radar antenna to a greater degree than does the water. Thus the presence of the ship will be indicated by the fact that its reflection is greater than the reflection of the water.

To state this in a general manner it can be said that the radar reflection which occurs is dependent upon the material of the object which is being struck by the radar beam and upon the size and shape of that object. Metal is one of the best reflectors; consequently, metal ships, airplanes, etc., produce better reflected waves than do wooden ships or plywood aircraft.

The fact that a large object causes a greater echo to occur than a small object, should be readily understood. Thus a radar set is capable of detecting the presence of a large object at a greater distance than it can detect a smaller object. In this respect the radar antenna compares with the eye since a large object can be seen at a greater distance than the small object.

Radio waves travel at the speed of light which is approximately 186,000 miles per second. Not only do radio waves travel with the speed of light but, their reflection characteristics are, in many respects, similar to the reflection characteristics of light. This effect is illustrated in Figures 3 and 4. Everyone is, of course, familiar with the effect produced when a beam of light shines upon a sheet of smooth metal. As illustrated in Figure 3(A), if the metal has a flat smooth surface, the light rays are reflected. In a similar manner radio waves are reflected from the sheet of metal as shown in Figure 3(B). The amount of light reflected **toward the source** from the sheet of metal is determined by the position of the sheet of metal. This condition can be seen by comparing the illustrations in Figures 3(A) and 4(A). When the position of the sheet of metal is such that the surface is turned toward the source of the light, a strong reflection is returned toward the source as illustrated in Figure 4(A). Similarly the reflected radar waves returned to the source is far greater when the surface of the sheet of metal is turned toward the radar antenna as illustrated in Figure 4(B).

In most instances an object which is to be detected by radar does not consist of a single flat surface (for example, the sheet of metal in Figures 3 or 4), but has instead an irregular shape. However, for most any position of an irregular surface there will be some portions of the surface which are turned directly toward the source. This is illustrated in Figure 5. It will be noted that the waves reflected toward the source from the irregular surface, shown in Figure 5, are less than than those returned from the flat surface, as shown in Figure 4, because a great deal of energy is reflected in other directions. However, it should be obvious that a portion of the energy is reflected back toward the source.

This effect can be summarized by stating that although reflection occurs from the irregular surface, only those portions of the surface which are **facing the source** produce reflections which are returned to the source. In other words, only the portions of the surface of an object which are at right angles to the line of approach of the waves produce reflections which are returned to the source. However, any object to be detected by a radar set has portions of its surface at right angles to the radar set and will thereby produce reflections which return to the radar set. Figures 6 and 7 illustrate the manner in which this effect enables a radar set to distinguish between objects. Notice for example in Figure 6 that some of the metal surfaces of the ship face directly toward the radar set and thereby produce strong reflections in the direction of the radar set. It can be seen moreover that the radio waves strike the surface of the water at a glancing angle and the major portion of the reflected waves from the surface of the water go off at various angles and do not return to the radar set. Since the surface of the water is not entirely smooth, a small amount of reflection toward the radar set will occur, but, because this reflection is very small in comparison to the reflections from the ship, the ship is easily identified.

Figure 7 illustrates the similar effect produced when the radar set is carried by a plane. The glancing angle at which the waves strike the flat surface of the earth or the water cause reflections, very few of which return to the radar set, but a strong echo is returned to the radar set from the surfaces of the buildings in the city. It can be seen also that the reflections returned to the radar set from the hillside are greater than those from the flat countryside.

The maximum range at which an object can be detected by radar depends upon two factors; the amount of reflected signal obtained from that object, and the sensitivity of the radar receiver. As long as the reflected energy is sufficiently great to produce the required indication on the indicator screen, the object can be detected. There are, however, a number of factors which determines the amount of reflection obtained from an object. Foremost among these are: (1) the size, shape and composition of the object, (2) the power of the signal radiated from the radar transmitter, (3) the distance of the object from the radar transmitter, (4) the width of the radar beam and (5) the terrain.

Let us now consider how these various factors effect the amount of radar signal which is reflected from an object.

The manner in which the size, shape,and composition of an object affects the reflected wave was dealt with previously and needs no further explanation. The manner in which the power radiated from the radar transmitter affects the reflected signal should also be rather obvious. Compare this effect with a searchlight. If it is desired to see an object at a relatively great distance a powerful searchlight must be used. Similarly the greater the power transmitted from the radar antenna the greater will be the distance at which a particular object can be detected. In connection with this point it should be emphasized that all the power radiated by the transmitter does not strike an object. In fact only a very small portion of the power radiated ever strikes the object. This condition arises because the beam from the radar antenna is a **divergent beam.** In other words this beam becomes gradually wider as the distance from the antenna increases. Thus the strength of the signal striking a given object is much less than the transmitted power.

The diverging or "fanning" of the radar beam also accounts for the fact that the amount of reflection received from an object is dependent upon the distance of the object from the antenna. This effect can be compared to the effect produced by a flashlight with a divergent beam as illustrated in Figure 8(A). Practical experience will tell the Associate that the object held at position No. 1 in Figure 8(A) will be illuminated to a greater degree than it would if held at position No. 2 in the beam of the flashlight. (When reading this assignment material, if at night, you move relatively close to the light because the illumination is greater there. The farther you move away from the light the lesser is the illumination on the page.) Figure 8(B) illustrates the similar effect which occurs in a radar system. If the object, as represented by the plane in Figure 8(B) is at position No. 1 which is close to the radar antenna, the radio energy which strikes the plane will be strong, consequently the reflected signal will be strong. If the plane is in the position illustrated as No. 2 on Figure 8(B) the radio energy striking the plane is less and the reflected signal is reduced a proportional amount.

The fact that the width of the radar beam affects the amount of radio signal reflected from an object at a given distance is illustrated in Figure 9. Once again comparison is made to a similar situation with a flashlight. It was pointed out previously that the energy transmitted from the radar antenna is in the form of a beam. In different types of radar installations which are serving different purposes, the width of the beam varies. If one of the prime objectives is to detect objects at a great distance a narrow beam will be employed. To understand why this is true, examine Figure 9 carefully. Notice in Figure 9(A) and (B) the same flashlight is used. However, in Figure 9(A), the lens is so adjusted that a wide-angle beam is produced and the object is only dimly illuminated. Contrast this with the condition shown in Figure 9(B) where the lens is adjusted to produce a narrow beam. Note particularly that in each case the actual amount of light produced is the same. Due to the narrow beam used in Figure 9(B) a greater amount of illumination is produced at the object, although the object is at the same distance from the flashlight. Similarly in Figure 9(C) the radar antenna produces a wide-angle beam and only a small portion of this energy strikes the ship which represents the object in this case. However in Figure 9(D) the angle of the beam has been reduced and a greater amount of energy strikes the ship. Consequently a greater reflected signal would result in Figure 9(D) than in the case of Figure 9(C). From this explanation it should be apparent that the same object, for example the ship in Figure 9(C) or (D), can be detected at a greater distance if the radar beam has a narrow angle.

The ability to detect an object by a radar system requires that the reflected signal from that object be picked up by an antenna and amplified by the radar receiver before application to the indicating device. For a given amount of echo signal a more pronounced indication will be secured if the radar receiver is sensitive. (Sensitivity is a measure of the ability of a receiver to produce a satisfactory output from a weak input signal.) Thus, increasing the sensitivity of the radar receiver increases the ability of the receiver to handle weak reflected signals. Consequently the more sensitive the receiver is the greater will be the distance at which an object can be identified.

The maximum range at which a particular object can be detected is also affected by the terrain between the radar set and the object, and the terrain close to the object. To illustrate this point consider once more Figure 6. If the ship were close to a shore having, for example, rather steep cliffs there is a possibility that the reflection from the shoreline would mask the reflections from the ship to such an extent that the ship could not be identified.

In the case of long-range radar the curvature of the earth is the factor which limts the maximum range. Since the high frequency radio waves used in radar are reflected by the earth's surface they cannot penetrate through the earth. Also these waves travel in straight paths similar to light rays thus producing an effect referred to as a "radar horizon". This effect is illustrated in Figure 10. The illustration shows the path of the beam from the radar antenna on a ship. Any object of sufficient size located on the surface of the water or, for that matter, in the air above the surface of the water between the radar antenna and the radar horizon could be detected in this case. However, an object located at a point further from the radar antenna than the radar horizon can be detected only if a portion of the object extends above the radar horizon. For example notice that the ship at point A in Figure 10 is entirely below the radar horizon and would not be detected since the radar beam would not strike this ship. The ship at point B of Figure 10 is farther from the radar antenna than the horizon but a portion of the superstructure of this ship extends above the horizon and would be struck by the radar beam producing the reflection necessary to produce detection. The plane at point C in Figure 10 is far beyond the radar horizon but its altitude is sufficient so that the line-of-sight radar beam can strike it, thereby producing reflections.

Careful analysis of Figure 10 should reveal that there are two factors which affect the maximum range of radar installations as far as the curvature of the earth is concerned. These two factors are: (1) the height of the radar transmitting antenna and (2) the height of the object to be detected. Before proceeding with illustrations showing the manner in which the height of the antenna and objects affect the maximum range it should be mentioned that although the radio beam from a radar antenna is normally considered to follow a straight line there is a **slight** downward bending of the beam which occurs. This causes the radar horizon to be slightly farther away than would otherwise be expected. Under certain, very rare, conditions the bending of the beam is quite great and objects at unusually great distances can be detected. However, this phenomenon is so rare it is of little practical value.

The actual line-of-sight distance from an elevated point to the horizon can be determined easily by the application of the formula given in Figure 11(A). It should be emphasized that due to the slight bending that normally occurs the maximum radar range under these conditions will be slightly greater. To illustrate the use of this formula let us consider an example in which the height of the radar antenna is 100 feet. The distance from the antenna to the horizon can be determined as follows:

$$\begin{aligned} D &= 1.23 \times \sqrt{H} \\ D &= 1.23 \times \sqrt{100} \\ D &= 1.23 \times 10 \\ D &= 12.3 \text{ miles.} \end{aligned}$$

The distance, which a radar installation could detect an object on the surface of the earth, in this case, would be slightly in excess of 12.3 miles ranging to perhaps 15 miles.

A similar computation would show that if the radar antenna were located 200 feet above the earth the distance to the horizon would be approximately 17 miles. Thus, an object on the surface of the earth could be detected by a radar set under these conditions at a maximum distance of approximately 20 miles.

Let us apply this same effect to determine the maximum distance at which a radar installation aboard an aircraft flying at 20,000 feet could detect an object on the surface of the earth.

$$\begin{aligned} D &= 1.23 \times \sqrt{H} \\ D &= 1.23 \times \sqrt{20{,}000} \\ D &= 1.23 \times 10^2 \times \sqrt{2} \\ D &= 1.23 \times 100 \times 1.4 \\ D &= 170 \text{ miles (approximately).} \end{aligned}$$

Due to the bending of the radar beam the plane could actually detect an object on the surface of the earth at a distance of approximately 200 miles.

Now let us consider a situation as illustrated in Figure 11(B) where the object is located some distance above the surface of the earth. For example, the object might be an airplane. Let us assume for the sake of illustration that the height of the radar antenna is 50 feet and that the aircraft is flying at an altitude of 5000 feet. The formula which is used in this case is:

$$D = 1.23 \times (\sqrt{H} + \sqrt{A})$$
$$D = 1.23 \times (\sqrt{50} + \sqrt{5000})$$
$$D = 1.23 \times (7.1 + 71)$$
$$D = 1.23 \times 78.1$$
$$D = 97 \text{ miles.}$$

The curvature of the radar beam would permit detection of a plane at the slightly greater distance of approximately 110 miles.

Let us consider one more example to illustrate the use of this formula. Suppose the radar antenna is located at an altitude of 200 feet and the plane is flying at an altitude of 10,000 feet. The formula would then be:

$$D = 1.23 \times (\sqrt{H} + \sqrt{A})$$
$$D = 1.23 \times (\sqrt{200} + \sqrt{10{,}000})$$
$$D = 1.23 \times (14.1 + 100)$$
$$D = 1.23 \times 114.1$$
$$D = 140 \text{ miles (approximately).}$$

The above figure gives the actual maximum line-of-sight distance in this case but the radar distance would be slightly higher ranging to approximately 150 miles.

The foregoing computation should indicate the fact that the higher a radar antenna is located the greater will be the distance which can be covered by the radar set. It should also be evident that the higher the object is above the surface of the earth the greater is the distance at which it can be detected. For this reason planes can be detected at a much greater distance than can ships, for in very few instances does the superstructure of a ship extend more than 50 feet above the level of the ocean. The foregoing discussion has applied directly to the type of radar equipment used for practically all purposes with the exception of the equipment used **to detect missiles at great distances.** The speed at which missiles travel is so great that detecting the presence of a missile, say, 200 miles away, would be of little value as there would not be sufficient time for an antimissile missile to operate. For this particular purpose (detecting missiles at great distances), therefore, it became necessary to extend the range of radar many times. Since the information stated above regarding line-of-sight transmission is based on the laws of nature, it at first appeared impossible to accomplish this task. Radar equipment has, however, been developed which has extremely long range. This is accomplished primarily through the use of brute force. Although practically all of the radar waves follow the straight line of sight path, a **very few** of them follow a curved path around the earth's atmosphere. This occurs because of their striking certain ionized particles in the upper atmosphere—reflection from bits of dust, meteor trails, etc. This effect is sometimes referred to as **scatter.** By using extremely large transmitting powers and extremely sensitive receivers to detect the reflected signals, it is possible to "locate" missiles at extreme ranges.

Determination of Direction and Distance

Now that we have determined the factors which affect the maximum distance at which an object can be detected by a radar set, let us determine the manner in which the direction and distance of the object can be determined. To clearly explain this phenomenon let us consider an example where sound waves can be used to determine distance and direction, as almost everyone is familiar with the echo effect produced by sound waves.

Consider Figure 12. Assume that the man shouts through the megaphone as he turns in various directions. Sound waves travel from the megaphone in the form of a beam and will strike objects in their path. In the example shown in Figure 12, when the sound waves strike the cliff they are reflected back very strongly toward the person who is shouting. Thus the person will hear an echo. The strongest echo will be heard when the megaphone is pointing directly at the cliff. If the person doing the shouting has a compass he can determine the direction of the cliff by noting the compass bearing when the echo is the strongest, or if the spot at which the person is standing has the compass bearings marked on it as illustrated in Figure 13 the direction of the cliff can easily be determined. In a similar manner the direction of the barn shown in Figure 13 could be determined by facing the megaphone in that direction, noting the point at which the maximum echo is returned and observing the calibrated compass readings for that direction. In a similar manner the direction of an object can be determined in a radar system by noticing the direction of the antenna which produces a maximum indication. In most cases the base of the antenna is calibrated in compass direction or in some cases a remote compass is employed. In either case, however, the direction of the object is indicated by **maximum reflection** from the object.

In the case of the situation as illustrated in Figure 12, not only can the direction of the cliff be determined but the **distance** from the person who is shouting to the cliff can be determined fairly accurately. This can be done by measuring the interval of time between the instant when the shout is uttered and the echo is heard. As mentioned in Assignment 1, sound travels at the rate of 1089 feet per second at sea level. However, this speed varies slightly under different altitude conditions and weather conditions and we will use the figure of 1100 feet per second for simplicity. Let us assume that two seconds of time elapse between the instant the shout occurs and the echo is heard. From the figures at hand the distance traveled by the sound waves can be easily determined. This can be done by applying the following very simple formula. Distance = Speed × Time. In this particular example:

$$D = 1100 \times 2$$
$$D = 2200 \text{ feet.}$$

Thus in the two second interval which elapses between the time of the shout and the echo, the sound waves travel a total of 2200 feet. Since the sound waves travel from the person who is shouting to the cliff and return to the "shouter", the actual distance between the person and the cliff is half this value, or 1100 feet.

To further illustrate this point let us assume that an interval of five seconds occurs between the time of the shout and the time the echo is heard. Applying the formula this becomes:

$$D = S \times T$$
$$D = 1100 \times 5$$
$$D = 5500 \text{ feet.}$$

Note that the above figure, 5500 feet, is the actual distance covered by the sound wave (from the shouter to the cliff and back to the shouter). However, our primary concern is the distance from the shouter to the cliff which is only half of the distance traveled by the sound wave. Thus the distance to the cliff in this case is 2750 feet.

In a radar system the radar wave travels from the antenna to the object where it is reflected and returned to the antenna. The speed at which the radio wave travels is known to be **186,000 miles per second** and if the time of travel can be measured the distance to the object can be determined as in the preceding example. It should be obvious, however, that the time of travel from the radar set to an object and back by the radio wave will be very small due to the extremely high speed at which the radio waves travel. For this reason the time of travel of the radio waves is normally measured in millionths of a second, or as millionths of a second are normally called, **microseconds**, abbreviated µsec. (One microsecond equals one millionth of a second.) Since radio waves travel 186,000 miles in one second it should be obvious that in one microsecond they would travel one millionth of 186,000 miles or .186 miles.

A very convenient way of using this information is to determine how many microseconds are required for a radio wave to travel one mile. This may be accomplished by dividing one by the distance traveled by the radio wave per millionth of a second. If this is done it will be found that it requires 5.375 microseconds for a radio wave to travel one mile. Similarly 10.75 microseconds of time elapse as a radio wave travels two miles, three times 5.375 or 16.125 microseconds elapse as a radio wave travels three miles, etc. This is illustrated in Figure 14. Analyze this figure carefully to make sure that you understand the relationship between the time of travel and the distance covered by the radar wave.

The primary concern in a radar system is not, however, how long it takes the radio waves to travel from the radar set to an object. Instead it is the **round-trip time** required for the radio wave to travel from the radar set to the object and for the reflected wave to return from the object to the radar set. This condition is illustrated in Figure 15. The rate of travel of a radio wave is the same regardless of the power present in the radio wave.

The reflected wave from the objective travels back toward the radar transmitter at the same speed as the wave travels when leaving the radar transmitter or 186,000 miles per second. Thus if the object is one mile from the transmitter the round-trip time will be 5.375 microseconds (time traveling to the object) plus 5.375 microseconds (time for echo to return to radar set), or a total of 10.75 microseconds. Similarly if the object is two miles from the radar transmitter the round-trip time will be 2 × 10.75 microseconds or 21.5 microseconds. Notice that the round-trip time is the important time interval to remember in connection with the radar system and the figure of 10.75 **microseconds per mile round-trip time** should be remembered. For example, if the object is a plane ten miles away the round-trip time for the radar wave would be 107.5 microseconds and if the objective were a high-flying plane one hundred miles away, the time between the transmitted pulse and the return echo would be 1075 microseconds.

The "mile" which has been used in this example is the statute mile (land mile) of 5280 feet. Another "mile" which is often used in connection with radar is the **nautical** mile, which is approximately 6080 feet in length. The "round-trip" time for the radar wave to travel the nautical mile is 12.36 microseconds. For sake of simplicity we will use the statute mile of 5280 feet, with its round-trip radar travel time of 10.75 microseconds, in our discussion of radar.

Why the Radar Signal is Transmitted in the Form of Pulses

Past experience with sound should illustrate to you that the best results are obtained when dealing with echos if the brief sound is used rather than a long sound. For example, if the system illustrated in Figure 12 or 13 were being used to determine the direction of a cliff the best results would be obtained if a very brief hello were shouted rather than a long drawn-out hello. The reason for this is the fact that if a long drawn-out hello is called, the echo may return before the shout is completed. Thus the shout would cover up the echo and it could not be distinguished. However, if the call is very brief, it will be finished before the echo returns and the direction can be determined very simply. The same condition is true in a radar system. If energy were transmitted from the radar antenna constantly, the weak reflected signal could not be detected when it returned and the radar system would be useless. Instead, the energy is transmitted for a very brief period and then there is a period of non-transmission. During this period when no energy is being transmitted, the previously transmitted radio wave has sufficient time to travel to an object and be reflected, returning to the radar antenna. Since the transmitter is not operating and the receiver is quite sensitive, this returning pulse can be detected, thus indicating that an object has been struck by the radar wave. For this reason the radar waves are **always** transmitted in the form of pulses. The length of the pulses varies with the different types of radar sets which are designed for different applications and also the number of pulses transmitted per second varies. In the different types of radar installations the length of the pulses ranges from ¼ microsecond to 30 microseconds, and the number of pulses transmitted per second ranges from 200 to approximately 5000.

There are three factors which remain to be explained in this basic explanation of a radar system. These are: (1) The effects of the pulse length on a radar system and the reason why different pulse lengths are used in different types of radar installations. (NOTE: Pulse width is often used in place of the term pulse length.) (2) The importance of the number of pulses per second in a radar system. (3) The manner in which a radar indicator is able to measure the time interval between the transmitted pulse and the echo pulse, considering the fact that this is only in the order of a few millionths of a second. The first two of these items will be dealt with in detail at this time. The third will be explained briefly. Later in the training program after cathode-ray tubes have been considered in detail, this subject can be explained more thoroughly.

In the previous explanation, the various factors which affect the maximum range of a radar set were outlined. The **minimum range** of a radar set is determined by the pulse length. The shorter the pulse the closer will be the minimum range of a radar system. The term minimum range means the minimum distance at which an object can be correctly located. For this reason it should be apparent that in a radar installation designed for use in locating objects at great distances, a relatively long pulse (several microseconds) may be used. However, in radar systems which are used to locate objects which are close, for example, in a radar installation used to aid in the navigation of a ship, a very short pulse length will be used so that objects close to the ship can be accurately located.

Since the radio wave requires 5.375 microseconds to travel one mile, in one microsecond the radar wave will travel 1/5 of a mile, or approximately 1000 feet. Bearing this fact in mind analyze the series of events depicted in Figure 16. Illustration A of this figure shows a radar equipped ship one mile from an object which is shown to be a rock in this particular case. At this instant the radar transmitter is just beginning to send out a pulse of radio frequency energy which travels away from the antenna at the speed of light, approximately 1000 feet per microsecond. Illustration B of this figure shows the conditions which exist if the pulse length is one microsecond. In this case the first energy transmitted during the pulse has traveled 1000 feet and this "bunch" or packet of radio frequency energy occupies a space 1000 feet in length. Since it is assumed that the pulse length in this particular case is one microsecond, the transmitter is turned off at this instant. However, the radio frequency energy which has been transmitted continues to move away from the ship at the speed of light and after an additional one microsecond has elapsed a condition as illustrated in Figure 16(C) is produced. The "packet" of radar energy has now moved approximately 1000 feet from the antenna, but since the transmitter is now turned off no further energy is being transmitted.

Figure 16(D) illustrates the fact that after a total of 5.375 microseconds has elapsed from the time of the start of the pulse the "front edge" of the packet of radio waves just reaches the obstacle. A portion of the energy is reflected back toward the radar antenna and the remaining portion of the radio frequency energy continues on as illustrated in Figure 16(E). The reflected energy is still in the form of a bunch or packet of radio waves and returns toward the ship at the speed of light as illustrated in Figure 16(F). Since the distance to be covered is one mile, 5.375 microseconds of time elapses between the instant the reflection occurs and the instant the returning wave reaches the radar antenna on the ship. Thus a total of 10.75 microseconds of time elapses during the entire process depicted in Figure 16. Since the transmitter was not again turned on after the initial pulse was transmitted, the receiver would be able to detect the echo signal and the time which elapsed between the time of the transmitted pulse and the echo pulse could be measured on the indicating device. This could, in turn, be converted into distance, indicating that the rock was one mile from the ship. This would be a very satisfactory radar system and the presence of the rock would be indicated in sufficient time to permit correct navigation.

Let us now use the same radar installation to illustrate the fact that the one microsecond pulse duration is too great if the radar installation is to indicate the presence of close obstacles, for example, an obstacle 400 feet from the ship such as might be encountered when navigating a narrow channel. This condition is illustrated in Figure 17. As in Figure 16, the illustration labeled A shows the condition at the start of the transmitted pulse. Figure 17(B) illustrates a condition ¼ microsecond after the start of the pulse. Notice that in this case the "front edge" of the wave packet has progressed to a point more than half-way to the obstacle. In Figure 17(C) the condition which occurs ½ microsecond after the start of the pulse is illustrated and it can be seen that reflection is occurring from the rock and that the transmitter is still generating a pulse. Since a pulse length of one microsecond is employed the condition which is illustrated in Figure 17(D) occurs when the time is still slightly less than one microsecond from the start of the pulse. Notice that although the pulse is still being transmitted the echo has arrived at the transmitter. Under these conditions the signal arriving at the receiver from the transmitter is so strong that the pulse will not be detected at this time at all. Even at the time of one microsecond as illustrated in Figure 17(E) a similar condition is still occurring. After this instant the transmitter is cut off and a very small portion of the reflected pulse follows. However, this portion of the energy is quite small and since a small amount of time is required for the receiver to recover from the effect of the strong pulse applied to it during transmission of the radar signal, no indication of the reflected signal will be received on the indicator.

After analyzing Figure 17 the question may arise, how is it possible for a radar system to indicate objects which are close at hand. The answer to this question is: Close objects can be detected through the use of very short radar pulses. For example, if radar pulses of ¼ of a microsecond in length are employed in an instance as shown in Figure 17, the presence of the object can be detected since the transmitter will have been turned off for an appreciable time before the reflected pulse returns to the radar set. Expanding this reasoning it should be apparent that pulse lengths of several microseconds can be employed when objects are to be detected at great distances.

From the foregoing a general conclusion can be drawn. If the radar installation is to indicate objects close at hand short pulses will be employed whereas longer pulses may be employed in indicating objects at great distances.

The use of a short pulse has one other advantage. This is the fact that adjacent objects can be separated to a better degree with a short pulse. If the radar transmitter uses pulses of one microsecond duration, objects must be at least 500 feet apart to give separate indications. Thus if a radar installation is being used to detect the presence of aircraft, and a group of aircraft is approaching, a single indication will be given if a one microsecond pulse is employed and the planes are less than 500 feet apart. However, if the planes are more than 500 feet apart separate indications will be given and the number of planes can be determined. If, however, a shorter length pulse is employed separate indications will be obtained if the planes are closer together. For example if a ¼ microsecond pulse is used, separate indications can be obtained if the objects are more than 125 feet apart. With this arrangement the number of planes or other objects such as ships in a group can be more easily determined by means of radar.

Let us now consider the pulse repetition rate or in other words the number of pulses transmitted per second in a radar installation. If only one radar pulse strikes an object and is reflected back to the radar set, the energy returned will be a very minute value of energy and will not be sufficient to produce an indication on the radar indicator. Consequently the transmitted pulses in a radar installation are repeated at regular intervals, that is, the pulse is transmitted and then a period of non-transmission occurs. (The period of "silence" must be sufficiently long for the echo to return to the transmitter.) Then another pulse is transmitted and followed by a period of non-transmission. A careful analysis of the foregoing explanation concerning the time required for the round-trip travel of the radar signal should indicate that the time interval between pulses, or in other words the number of pulses per second, is determined by the maximum distance to be covered by a radar set. For example let us assume that a radar set is being used to detect planes at the maximum distance of 200 miles. (Of course the planes would have to be flying at altitudes in excess of 20,000 feet to be detected at this distance.) Under these conditions the round-trip time of the radar wave would be 200 × 10.75 or 2150 microseconds. As illustrated previously the next pulse should not be transmitted until this echo has returned, thus an interval of at least 2150 microseconds should occur between pulses. To determine the number of pulses and intervals of the required length which can be produced in a second it is only necessary to divide 1,000,000 by 2150 which gives a figure of 465 pulses per second. Note that this is the maximum number of pulses that could be employed and most radar installations do not use the maximum pulse repetition rate. Instead, in such instance, a pulse repetition rate of approximately 250 pulses per second would probably be employed. In radar installations which are intended primarily for detecting objects at closer ranges, the round-trip time of the signal will be smaller, therefore the interval between pulses can be less, and higher pulse repetition rates may be employed.

It should be emphasized that aside from the fact that one reflected radar pulse produces only a very minute amount of energy as mentioned previously there is another decided advantage to the use of many pulses per second in a radar installation. This is the fact that such an arrangement permits the indication of the radar set to "follow" a moving object. For example, as an object approaches the radar installation the indicator will reveal the fact that the distance to the object is becoming gradually less. There are two advantages gained by this. Not only does this arrangement permit the radar operator to determine at all times the exact position of the object, but it also enables him to identify the object to a certain degree. To illustrate: the indication secured for a low flying aircraft or a ship might be practically identical on the radar indicator. However, by observing the speed at which the object is moving as indicated on the radar indicator, the operator can determine whether the object is a plane or a ship.

The Radar Beam Elevation and Rotation

If a person were sitting in a boat in the middle of a lake at night and wished to determine whether or not there were any islands located nearby, he could do so by shining a powerful searchlight along the surface of the lake and swing the beam of the light around a complete circle or 360 degrees. A similar arrangement may be used in a radar set if it is desired to detect objects on the surface of the earth. Such an arrangement is employed for example in the case of naval vessels with the radar equipment designed to detect other surface vessels. If, however, the person sitting in the boat wished to determine whether or not there were any bats flying around, he would not only have to swing the searchlight beam in a 360 degree arc around the boat but would also have to elevate the beam. That is the air near the surface of the water would have to be searched as would the air at higher angles of elevation. In the case of a radar installation there are two ways in which this can be done. One of these is to use a beam which is very broad in the vertical direction so that altitudes ranging from slightly above the earth to approximately 50,000 feet are covered by this beam at a distance of 100 to 150 miles. If such a wide beam is used, however, the radar set cannot indicate the altitude of the plane. Figure 18 shows a method which can be used to search the desired altitudes with a narrow radar beam. The mechanical mechanism which rotates the radar beam around the 360 degree circle also gradually increases the tilt of the antenna as the antenna is rotated. The result is that the beam at any particular distance from the transmitter is slightly higher on each revolution, or in other words, effectively the tip of the beam is spiraling upward. In this manner the air surrounding the radar set can be scanned completely and any object present can be indicated.

In some installations it is not necessary for the radar equipment to search all of the area around the unit. For example a radar installation along the seashore may be used only for the purpose of searching for planes approaching from the sea. In this case the antenna equipment is modified so that the antenna moves back and forth through the desired angle of rotation to search a required sector. Such an arrangement is often called **sector scanning.**

The width of the beam used by the different types of radar sets varies. In general it can be stated that the wider the radar beam, the greater is the area covered by the beam and therefore the more easy it is to detect an object. However, the more narrow the beam is, the more accurate a particular object can be located. This can be understood very easily by comparing the effect obtained with a flashlight. If there is an object to be located with the light it can be located much more easily if the angle of the flashlight beam is wide, provided of course the beam intensity under these conditions is still sufficient to illuminate the object. However if the flashlight were to be used to "locate" the object, that is, indicate its direction in degrees and its elevation, it should be apparent that a narrow beam would provide a much more accurate indication. The same is true in radar installations.

Figure 19 shows a radar antenna installation on the pilot boat New Jersey which operates out of New York harbor. This antenna can be rotated so that the radar beam covers the required area.

In connection with the rotation of the radar beam and its vertical movement, there are two terms which are used. These are **azimuth** and **elevation.** The term azimuth indicates the angular measurement of the object from North. For example, if an object is located due east of the radar set the azimuth would be 90 degrees. The term elevation indicates the angle at which the radar antenna is "tipped" from its normal position. For example in the case of ground radar installation, if an object is located when the radar beam is at an angle of 30 degrees with the earth surface, the elevation is 30 degrees.

In many radar installations automatic computers are incorporated so that when the distance to an object is known and the elevation is obtained, the altitude at which a plane is flying may be automatically computed.

Measuring the Distance to an Object by Measuring the Time Interval Between the Transmitted Pulse and Returned Echo.

As pointed out, the time between a transmitted radar pulse and echo pulse is a very minute quantity; so minute, in fact, that it would seem impossible to measure this small interval. In any mechanical clock arrangement it is indeed impossible to measure these intervals of a few millionths of a second. However, electronic circuits in conjunction with cathode-ray tubes can be used very conveniently to measure such time intervals. To understand exactly how this is possible will require an understanding of the operation of cathode-ray tubes which will be dealt with at a later point in the training program. However, a very basic explanation will suffice at this point.

The cathode-ray tubes which are used in radar indicators are quite similar to the picture tubes which are used in television receivers. The inside surface of the face of the cathode-ray tube (The face of the tube is the end with the large diameter.) is coated with a fluorescent material and when the electronic circuits associated with the cathode-ray tube cause a beam of electrons to strike this surface, a glowing spot will appear. As other electronic circuits cause the electron beam to move, this spot will trace a visible line across the screen of the cathode-ray tube as illustrated in Figure 20(A). This glowing line, called the trace, is moved across the screen of the cathode-ray tube at a uniform rate by the associated electronic circuits. That is, if ten microseconds are required for the beam to move from the left edge of the screen one inch toward the right, ten more microseconds will be required for the next one inch motion of the beam and so forth. When the cathode-ray tube and its associated circuits are used in conjunction with a radar transmitter the trace obtained on the screen is somewhat as illustrated in Figure 20(B). When the pulse from the transmitter occurs the rectangular pulse is produced on the glowing line. Notice that this is a large pulse as the high powered transmitter is very close to the receiver and the r-f energy which enters the receiver under this condition is quite high. After the transmitter is turned off the glowing line continues across the screen at a uniform rate as illustrated in Figure 20(A). When the echo pulse returns to the radar set another smaller rectangular pulse or "pip", as it is often called, is produced in the trace.

As mentioned previously a time of 10.75 microseconds corresponds to one mile round-trip between the occurrence of the transmitted pulse and echo. Let us assume in the example of Figure 20(B) that it was determined by checking a calibrated dial on the indicator that it took exactly 215 microseconds for the trace of Figure 20(B) to be produced on the indicator cathode-ray tube. It would be possible under these conditions to lay a scale across the face of the tube as shown and thereby measure the position of "pips" on the trace in terms of time. In Figure 20(B), since 215 microseconds are required for the entire trace to be produced, only half of this value (107.5 microseconds) elapses as the spot moves from the left edge of the trace to the center. For sake of convenience the echo pulse is shown at this point. Through this means it can be determined that the echo pulse occurs 107.5 microseconds after the transmitted pulse. Since the round-trip time of a radar pulse is 10.75 microseconds per mile, the 107.5 microseconds delay between the transmitted pulse and the echo in Figure 20 indicates that the object is ten miles from the radar transmitter. It would be simpler therefore to mark the scale in miles, as shown, rather than in time and read the distance directly in miles.

Although a scale could be used to measure this distance, as illustrated in Figure 20(B), in normal cases such a system is not used because variations in voltage in the radar circuits may cause the glowing line or trace to move about on the screen of the cathode-ray tube. Consequently the scale cannot be maintained in a fixed position. Instead of using an external scale, **marker pulses** or **range pulses** are normally used in conjunction with the trace. This condition is illustrated in Figure 21. The electronic circuits associated with the indicator time these range pulses very accurately so that they are spaced at a definite distance or range from each other. For example in Figure 21 the electronic circuits time these pulses at intervals of 107.5 microseconds apart on the trace. This time is equal to the round-trip time for the radar waves if the object is ten miles from the radar set. Thus these pulses are effectively "10 miles apart" on the trace. It is only necessary to observe the relationship of the echo pulses with respect to the range pulses to determine the distance of the object or objects producing the deflection. For example in Figure 21 the first echo shown would indicate an object at about 25 miles (note a range pulse occurs at the start of the transmitted pulse but cannot be seen). Similarly the second echo occurs from an object approximately 42 miles from the radar set whereas the third echo is produced by an object approximately 57 miles from the radar set. Thus it can be seen that the presence of the range pulses enables the radar operator to determine the position of objects to a fairly high degree of accuracy.

Most radar installations incorporate a range selector switch so that the length of time required to produce the line across the face of the cathode-ray tube (this line is often called the time base) can be set at several values. When this switch is changed the marker pulses are usually changed also. For example in the illustration shown in Figure 21 the switch would be in such a position that the time base would represent 70 miles with 10 mile markers or range pulses. If it were desirable to obtain the accurate range on an object less than 10 miles from the transmitter the radar set would probably incorporate a 10 mile range position. When the switch is placed in this position the time required to produce the entire time base would be 107.5 microseconds and 10.75 microsecond range pulses would be inserted as shown in Figure 22. Thus each one of these range pulses would represent a distance of one mile and if the display as indicated in Figure 22 were obtained it would indicate that one object was approximately 3½ miles from the transmitter and another was approximately 7.7 miles from the transmitter. Thus by shortening the time base the accuracy at which close objects can be located is improved.

In radar installations where a large number of echo pulses would be received from objects it is very difficult to identify each of the objects and to keep track of them. In such instances the indicator arrangement is such that a **map** of the surrounding area is plotted. Such an indicator is normally called a **plan-position-indicator** (abbreviated P-P-I). Plan-position-indicators are normally employed in radar installations aboard ship for use when navigating near shore. Figure 23 shows a plan-position-indicator installed aboard a commercial liner. Plan-position-indicators are also employed in airborne radar installations used for bombing as well as in commercial aircraft to enable the observation of the terrain over which the plane is flying.

In a commercial application, a radar set may be installed at a port. In this case a plan-position-indicator is employed and the radar installation may be used as an aid to piloting ships approaching or leaving the harbor when visibility is limited. The position of incoming ships can be determined and the pilot boats can be guided to the incoming ships by means of radio instructions. Figure 24 illustrates such an application of radar. At the left of this figure is shown a chart of the harbor at the port of Long Beach, California. The radar site is indicated and the shoreline, breakwater, etc., can be seen. At the right of this figure is shown the plan-position-indicator view of the same area. Notice that the position of the breakwater is again clearly discernible, as in the shoreline. The small white dots appearing in the harbor are ships or buoys.

Summary

In a radar system pulses of high frequency radio energy are produced by the transmitter and radiated into space by a special, highly directional antenna. These pulses of radio energy travel away from the antenna at the speed of light, in a straight path. As the radio waves strike various objects, part of the energy is reflected, and a portion of this reflected energy travels back to the radar antenna. At this point the reflected signal, or echo, is "picked up" and applied to the radar receiver which amplifies it many times. The signal is then applied to the radar indicator. Since the radio waves travel at a constant rate, it is possible to determine the distance, which the objects causing the echo, is from the radar antenna by measuring the total time between the instant the pulse is transmitted and when the echo returns.

This action is accomplished in the radar indicator. The direction of the object producing the reflection can be determined by the antenna position because the maximum reflected signal results when the antenna is aimed directly at an object.

The foregoing discussion should provide you with an understanding of the underlying principles of radar. This discussion is, of course, in no way complete since the manner in which the various circuits operate has not been considered. As you advance through the training program, however, special assignments will be included at appropriate points explaining the operation of the various radar circuits.

"How To Pronounce . . ."

(Note: the accent falls on the part shown in CAPITAL letters.)

altimeter	(al - TIMM - eh - tur)
azimuth	(AZZ - ih - muth)
fluorescent	(FLEW - or - ESS - sent)

Test Questions

Use the enclosed multiple-choice answer sheet for your answers to this assignment.

The questions on this test are of the multiple-choice type. In each case four answers will be given, one of which is the correct answer, except in cases where two answers are required, as indicated. To indicate your choice of the correct answer, **mark out** the letter opposite the question number on the answer sheet which corresponds to the correct answer. For example, if you feel that answer (A) is correct for question No. 1, indicate your preference on the answer sheet as follows:

1. ~~(A)~~ (B) (C) (D)

Submit your answers to this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. The strongest radar echo would be obtained from:
   (A) An object underground.
   (B) An object near the surface of the sea.
   [✓ (C)] An object near the transmitter.
   (D) An object far away from the transmitter.
2. The maximum range of a radar set is: (CHECK TWO)
   [✓ (A)] Increased by raising the antenna height.
   [✓ (B)] Greater if the object to be detected is at a high altitude.
   (C) Increased by lowering the antenna height.
   (D) Greater if the object to be detected is at a low altitude.
3. What is the line-of-sight distance between a radar antenna 200 feet above the ground and a plane traveling at an altitude of 5000 feet?
   (A) 1,000,000 feet
   [✓ (B)] Approximately 104 miles
   (C) Approximately 25 miles
   (D) Approximately 85 miles
4. One microsecond is:
   (A) 1000 seconds
   ~~(B)~~ 1,000,000 seconds
   (C) one thousandth of a second
   [✓ (D)] one millionth of a second
5. What is the total time in microseconds required for a radar wave to travel from the antenna to an object one mile away, and for the reflected wave to travel back to the radar antenna?
   (A) 1 microsecond
   [✓ (B)] 10.75 microseconds
   (C) 53.75 microseconds
   (D) 2 microseconds

6. If a radar installation is to identify objects close to the radar set:
   - (A) The pulse length makes no difference.
   - (B) The pulse length should be long.
   - [✓ (C)] The pulse length should be short.
   - (D) The pulse should be on the order of 10 microseconds in length.

7. The term azimuth means:
   - [✓ (A)] The angular measurement of the object clockwise from North.
   - (B) The angle at which the radar antenna is "tipped," with respect to the earth's surface.
   - (C) The number of pulses per second.
   - (D) The pulse length.

8. The purpose of range pulses is to:
   - [✓ (A)] Enable the radar operator to determine the distance of objects to a fairly high degree of accuracy.
   - (B) Enable the radar operator to determine the azimuth of an object.
   - (C) Enable the radar operator to determine the elevation of an object.
   - (D) Enable the radar operator to determine the pulse length.

9. A radar indicator which effectively plots a map or chart of the area surrounding the radar set is called:
   - (A) Round-about-indicator.
   - [✓ (B)] Plan-position-indicator.
   - (C) Map-chart-indicator.
   - (D) Azimuth-range-indicator.

10. Basically, radar works upon the principle that:
    - (A) Almost every object radiates radio waves which can be picked up by a radar receiver.
    - [✓ (B)] Almost every object reflects radio waves, and these reflected waves can be picked up by a radar receiver.
    - (C) Almost every object radiates high frequency sound waves which can be picked up by an electronic "ear."
    - (D) Any television receiver can be used as a radar indicator.

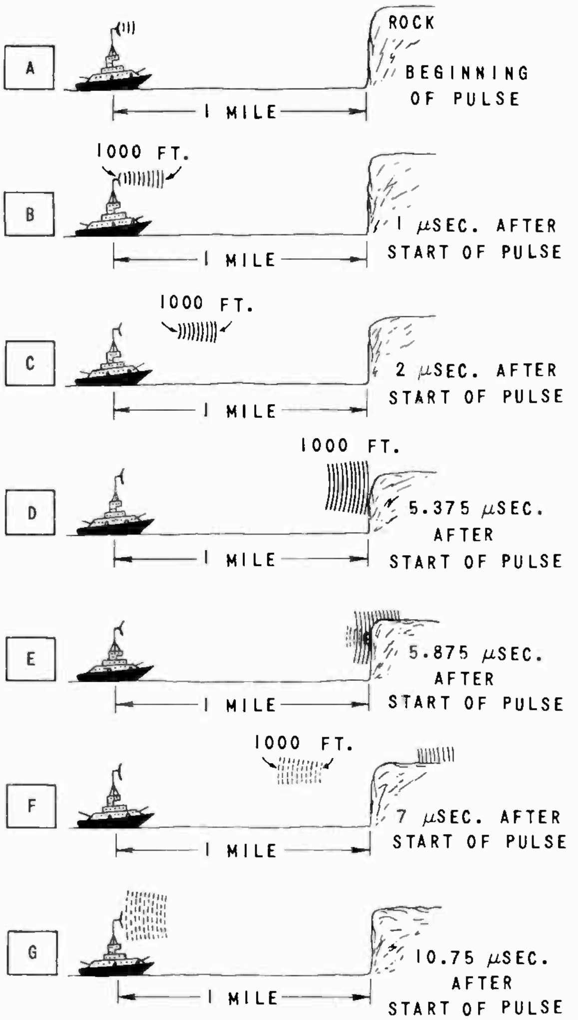


FIGURE 16

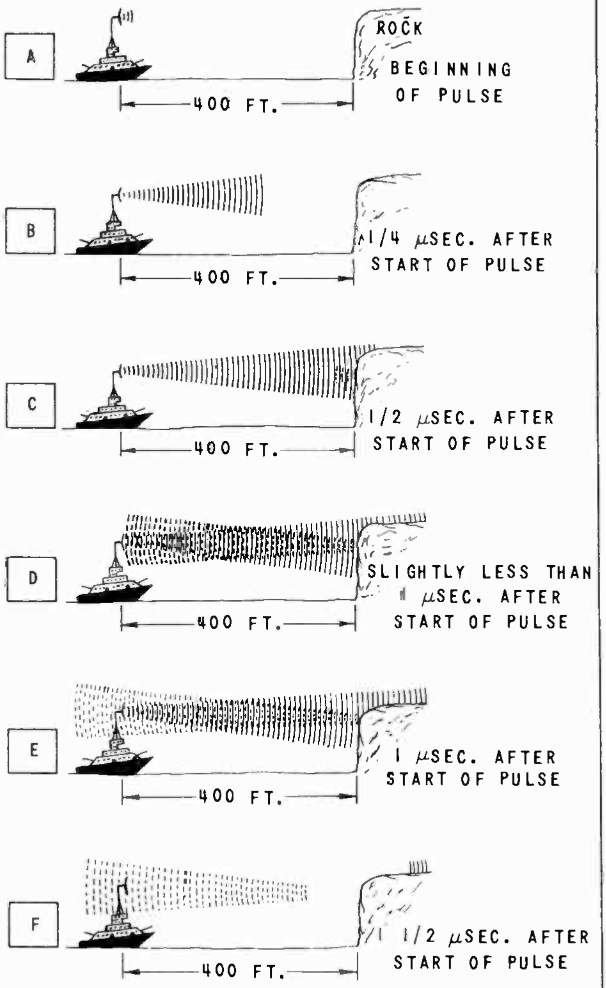


FIGURE 17

SEARCHING WITH A NARROW RADAR BEAM

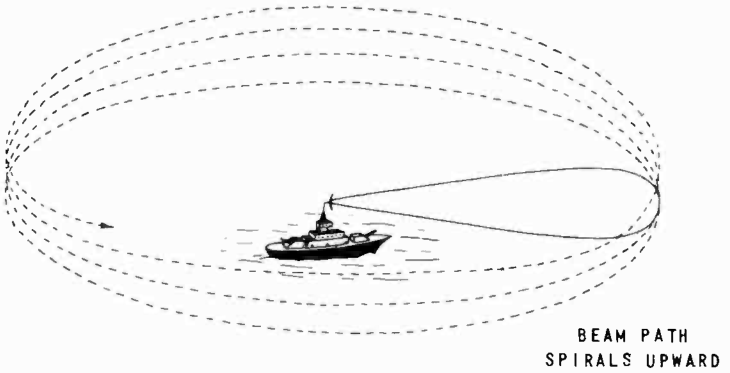
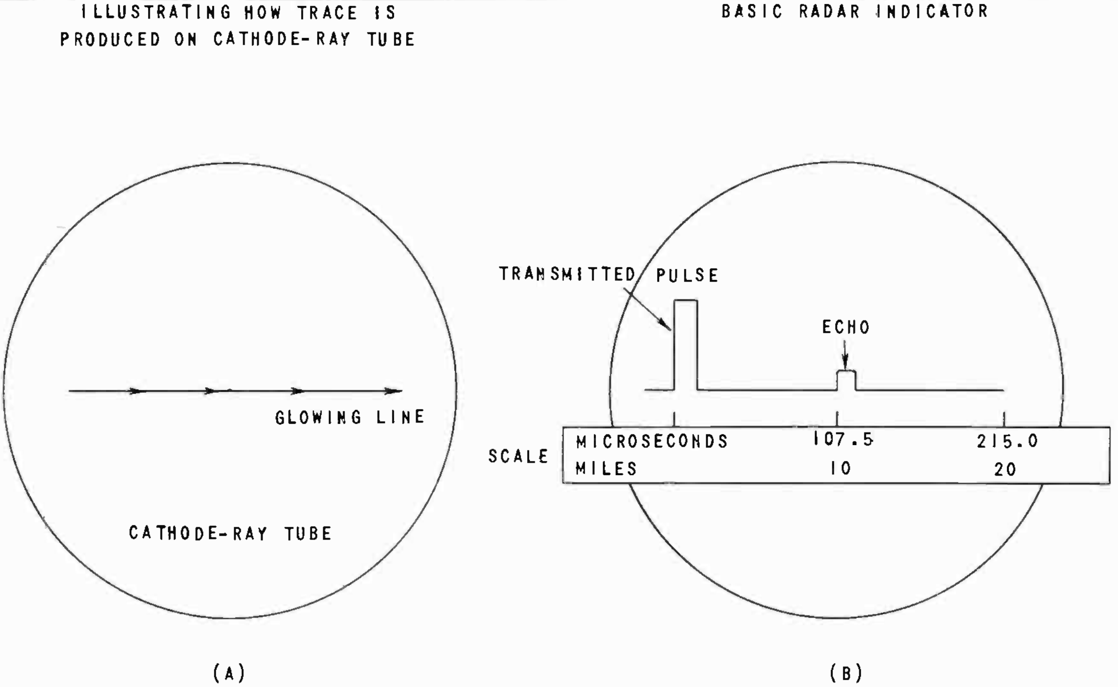


FIGURE 18

RADAR ANTENNA INSTALLATION

(Courtesy SPERRY GYROSCOPE Co.)

FIGURE 19


ILLUSTRATING HOW TRACE IS PRODUCED ON CATHODE-RAY TUBE

BASIC RADAR INDICATOR

(A)

(B)

FIGURE 20

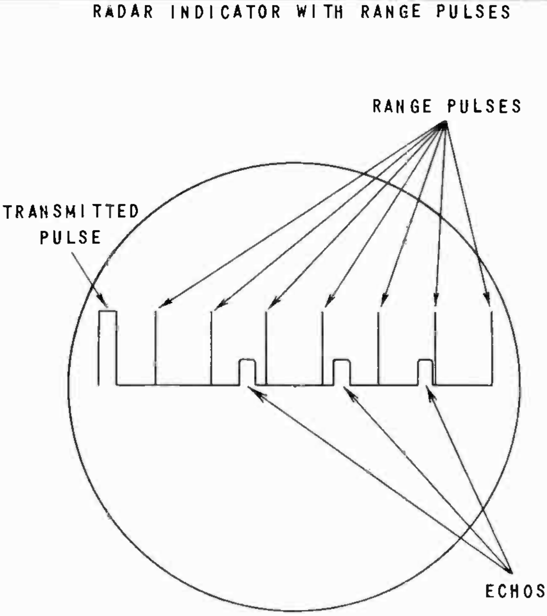

RADAR INDICATOR WITH RANGE PULSES

FIGURE 21

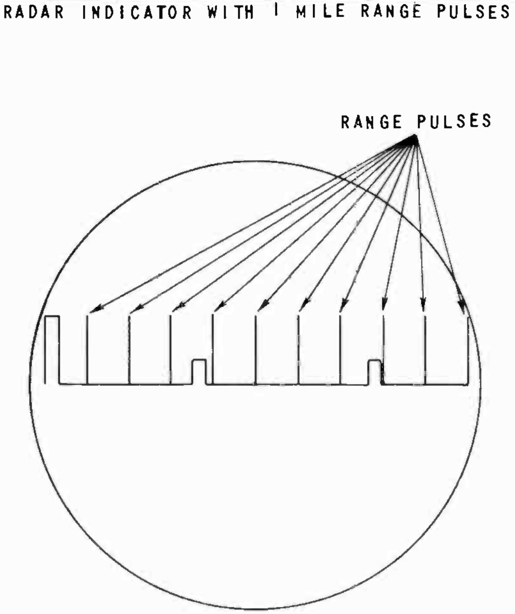
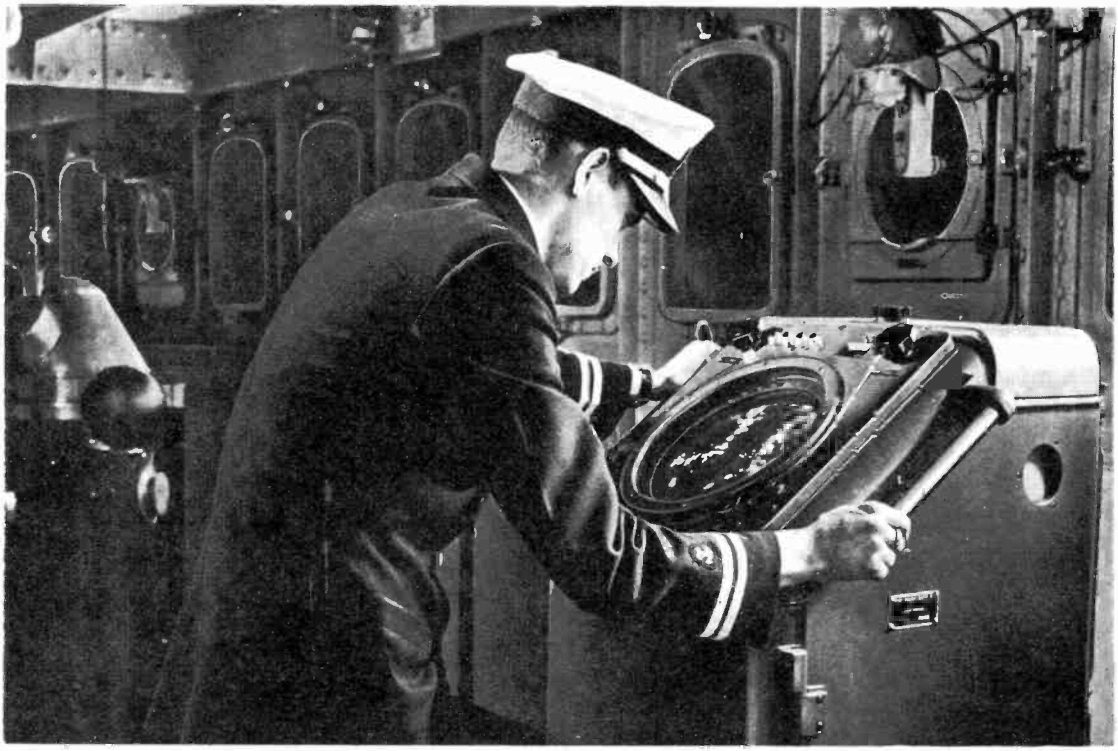

RADAR INDICATOR WITH 1 MILE RANGE PULSES

FIGURE 22

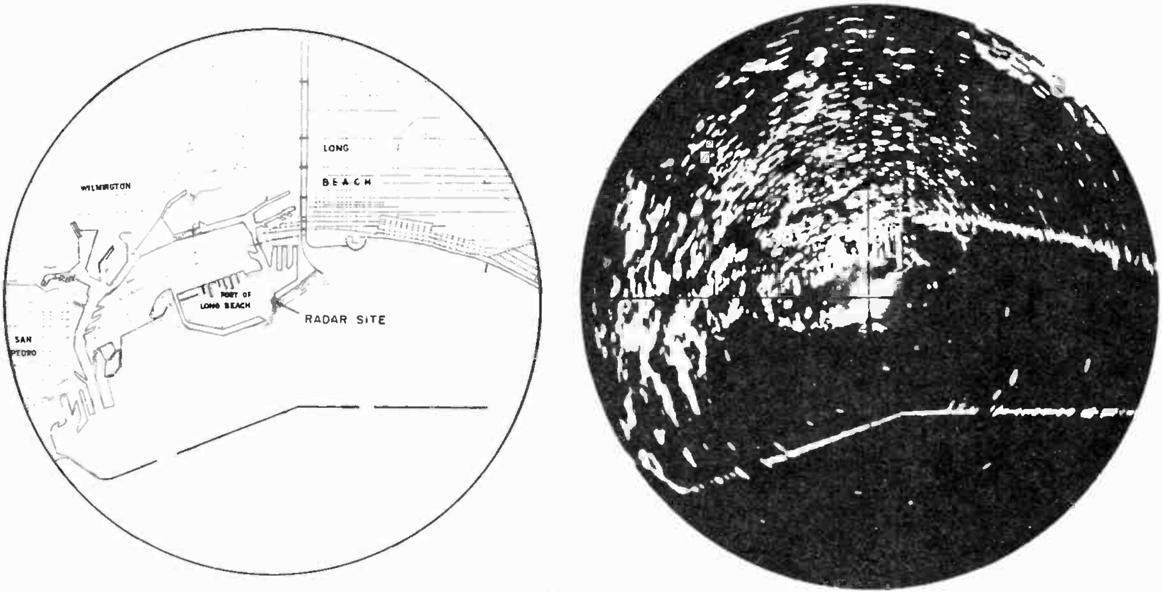
PLAN POSITION INDICATOR ON GRACE LINES, SANTA PAULA



(Courtesy SPERRY GYROSCOPE Co.)

FIGURE 23

CHART AND PPI RADAR VIEW OF PORT OF LONG BEACH, CAL.



(Courtesy SPERRY GYROSCOPE Co.)

FIGURE 24

DETERMINING DIRECTION WITH SOUND WAVES

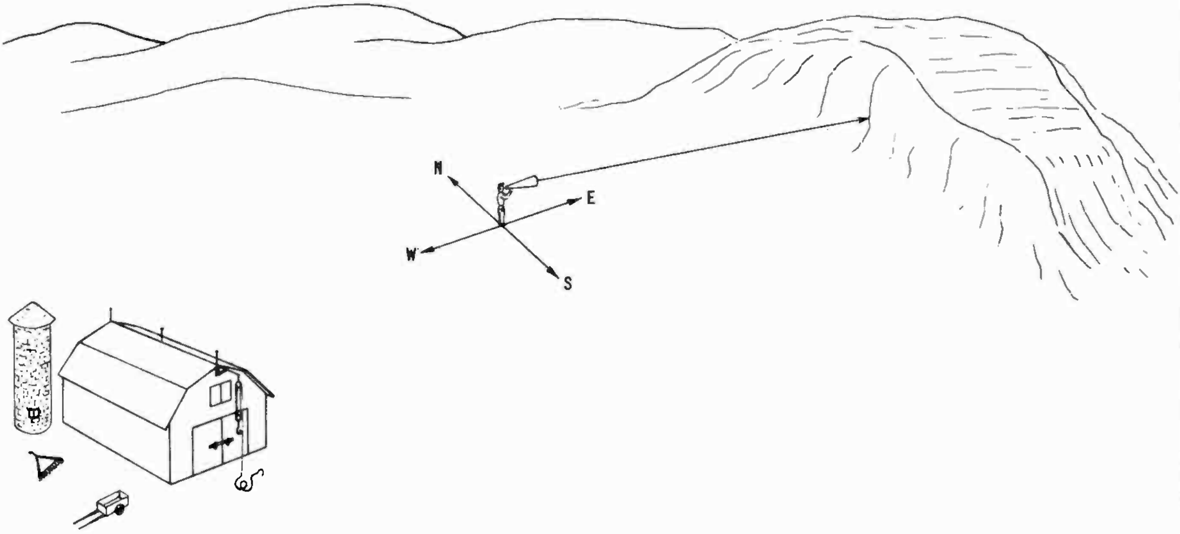
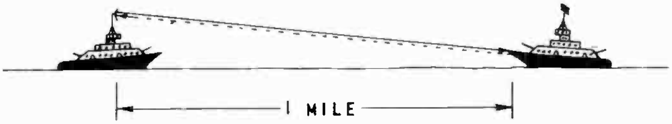


FIGURE 13

RELATIONSHIP BETWEEN TIME AND DISTANCE TRAVELED BY A RADAR WAVE

FIGURE 14

ROUND-TRIP TIME FOR A RADAR SIGNAL



TIME INTERVAL BETWEEN INSTANT RADAR WAVE IS TRANSMITTED AND INSTANT ECHO RETURNS TO RADAR SET IS EQUAL TO TIME REQUIRED FOR WAVE TO TRAVEL FROM RADAR ANTENNA TO OBJECTIVE, *PLUS* TIME REQUIRED FOR ECHO TO RETURN TO RADAR SET. IN THIS EXAMPLE THIS IS 5.375 μSEC. + 5.375 μSEC.; OR, 10.75 μSEC.

FIGURE 15

ILLUSTRATING THE EFFECT OF RADAR HORIZON

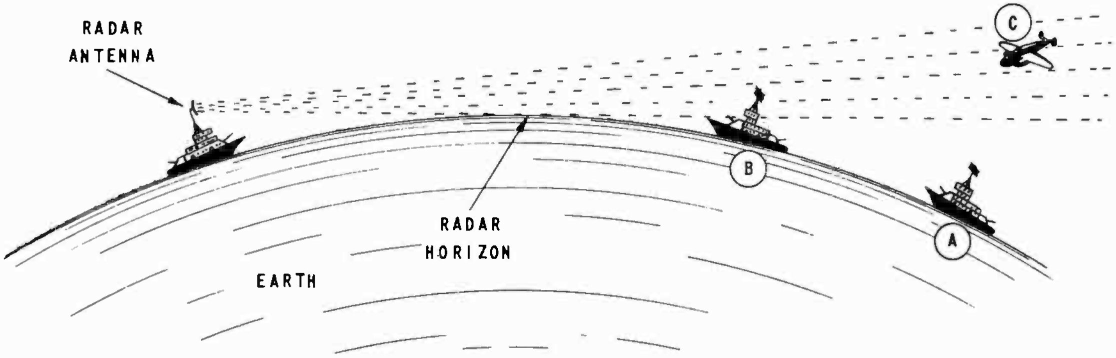
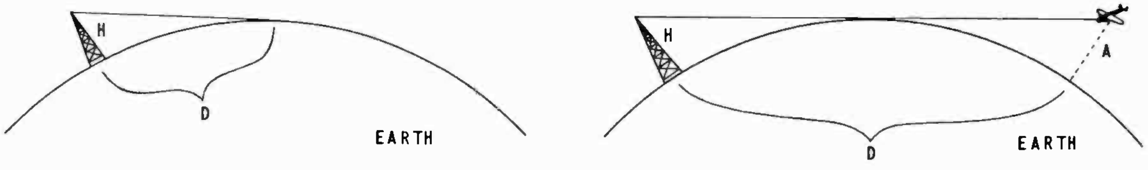


FIGURE 10

DETERMINING LINE-OF-SIGHT DISTANCES

D = DISTANCE IN MILES
H = HEIGHT IN FEET
A = ALTITUDE OF OBJECT IN FEET



$D = 1.23\sqrt{H}$ (A)

$D = 1.23(\sqrt{H} + \sqrt{A})$ (B)

FIGURE 11

ECHO EFFECT OF SOUND WAVES

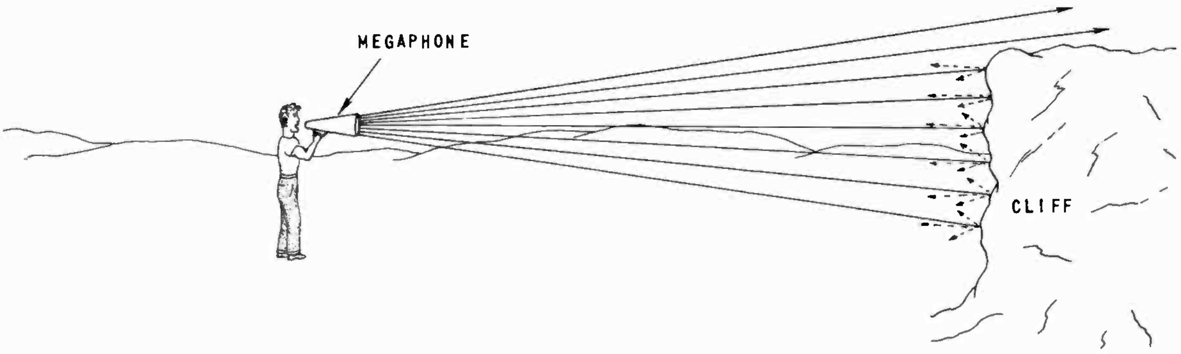


FIGURE 12

REFLECTION OF RADAR WAVES FROM TERRAIN

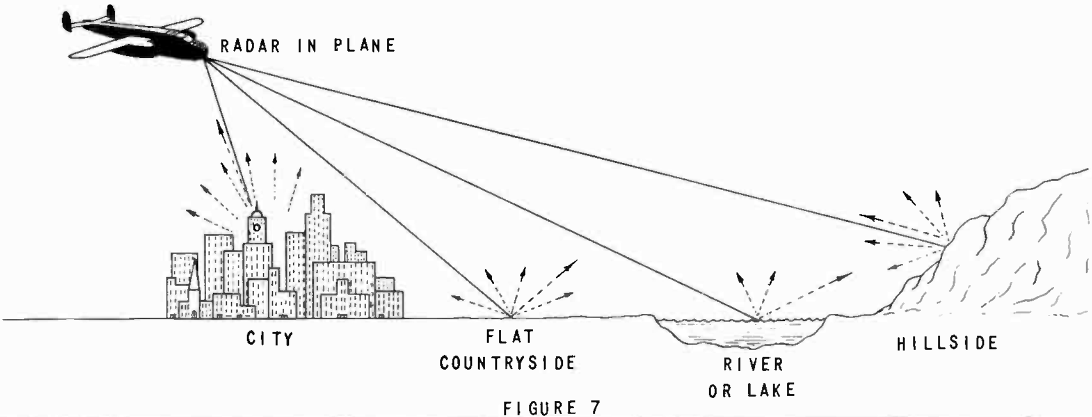
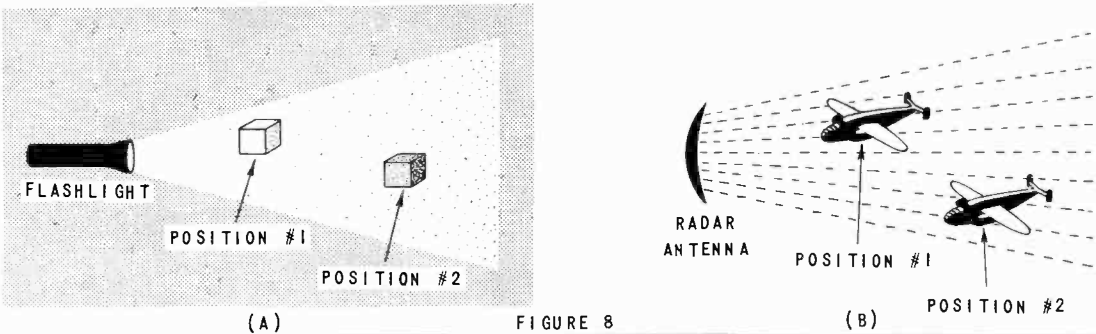


FIGURE 7

COMPARING EFFECT OF DISTANCE IN CASE OF LIGHT AND RADAR

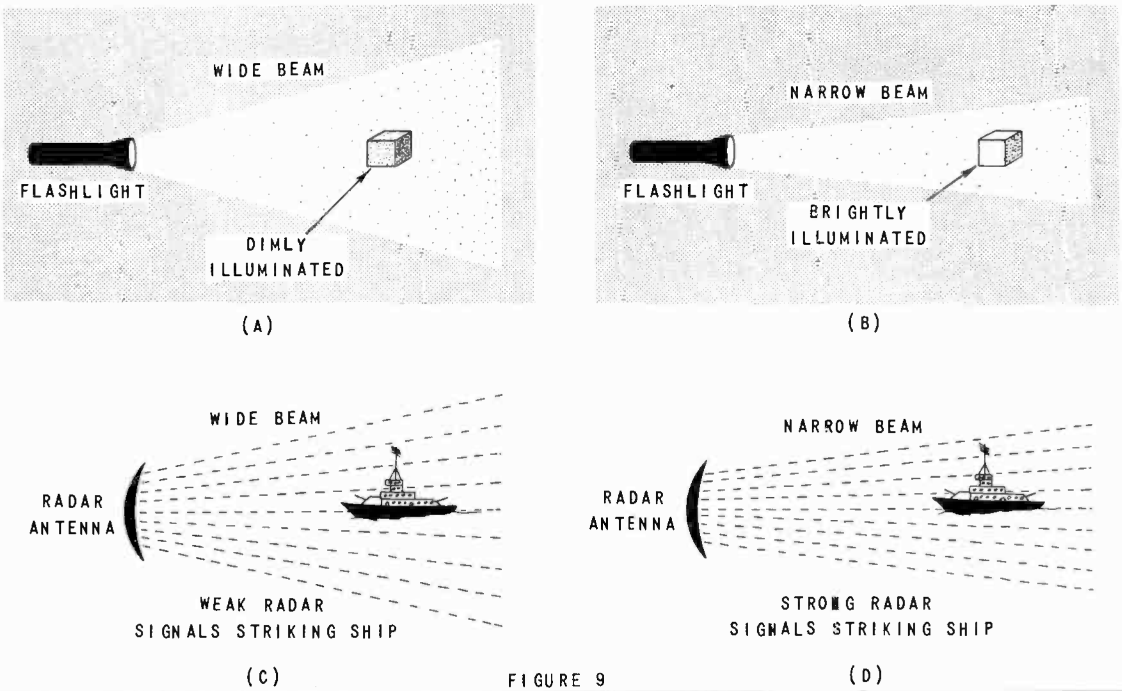


(A)

(B)

FIGURE 8

EFFECT OF BEAM WIDTH ON ILLUMINATION AND RADAR



(A)

(B)

(C)

(D)

FIGURE 9

COMPARISON OF THE REFLECTION OF LIGHT RAYS AND RADIO WAVES

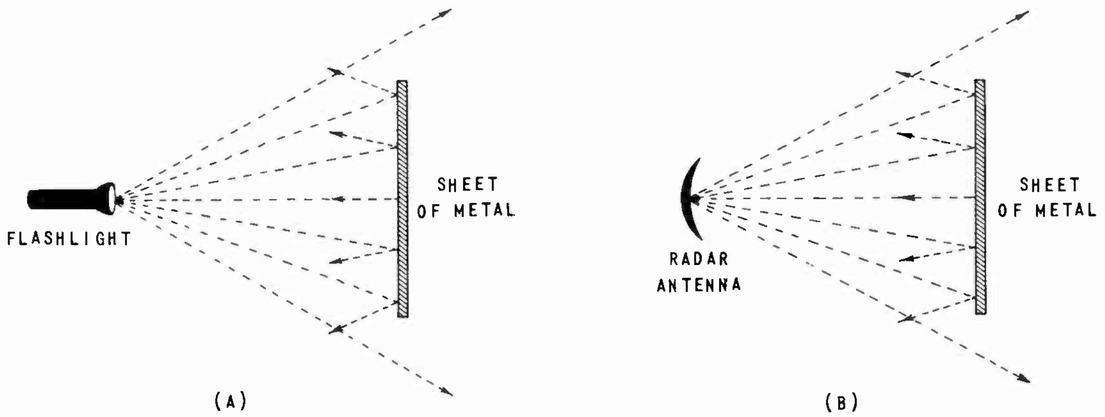


FIGURE 4

REFLECTION FROM AN IRREGULAR SURFACE

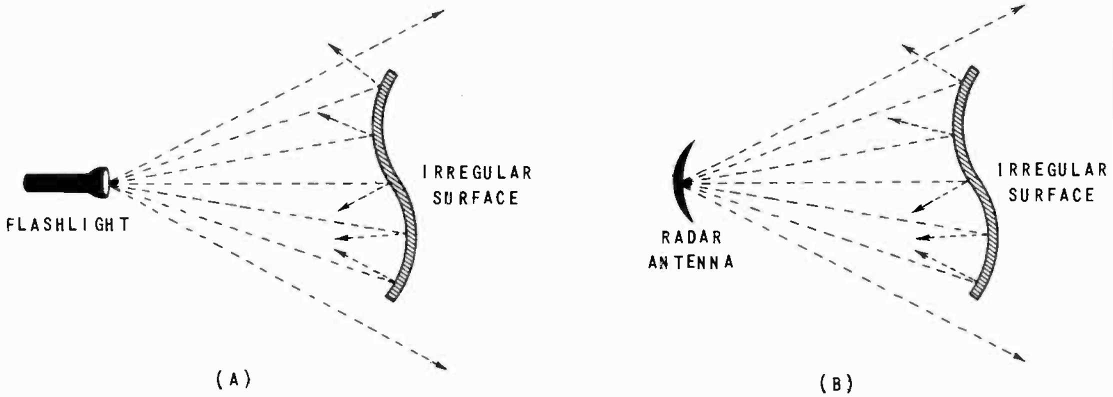


FIGURE 5

RADAR REFLECTIONS FROM SURFACE OF OCEAN AND SHIP

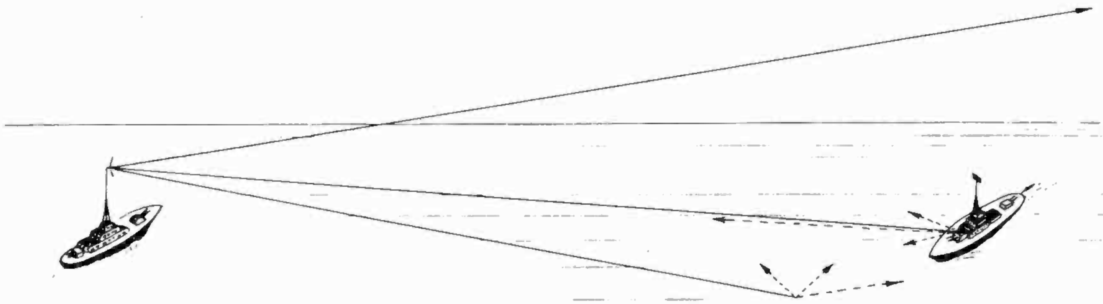


FIGURE 6

NATURE'S RADAR SYSTEM

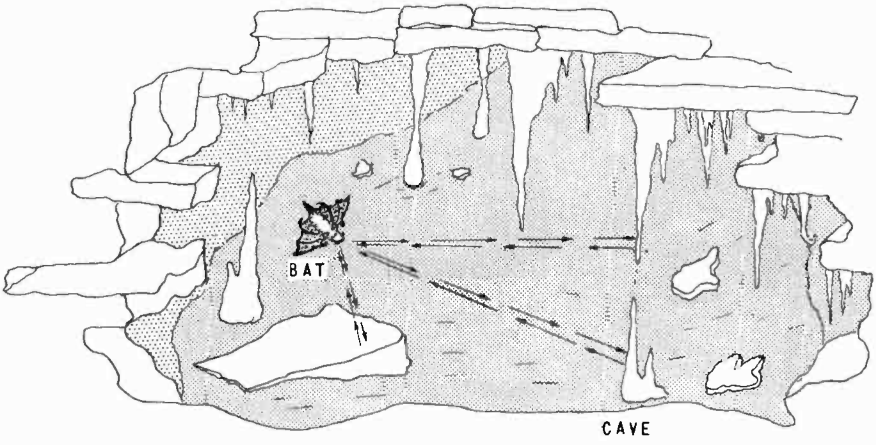


FIGURE 1

FUNDAMENTALS OF A RADAR SYSTEM

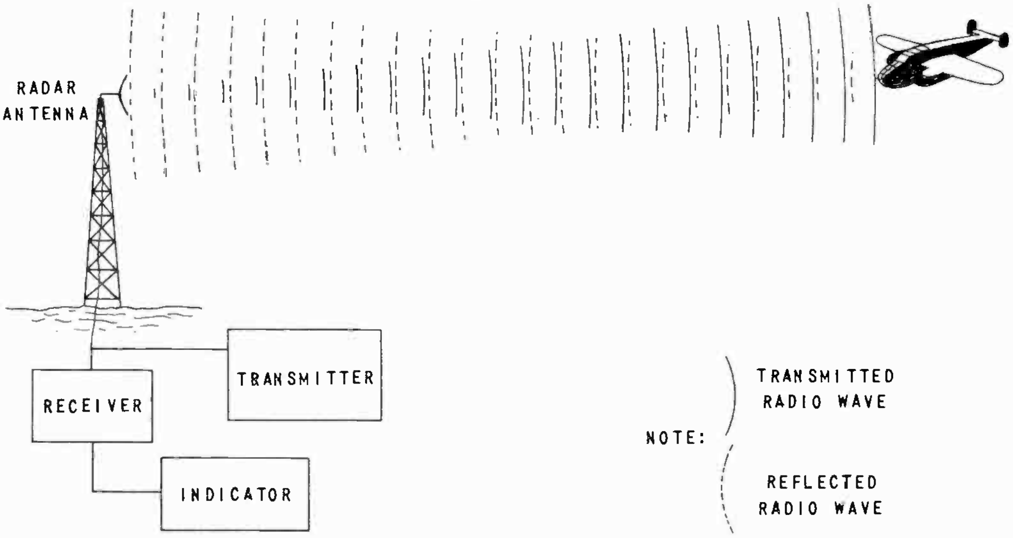


FIGURE 2

COMPARISON OF THE REFLECTION OF LIGHT RAYS AND RADIO WAVES

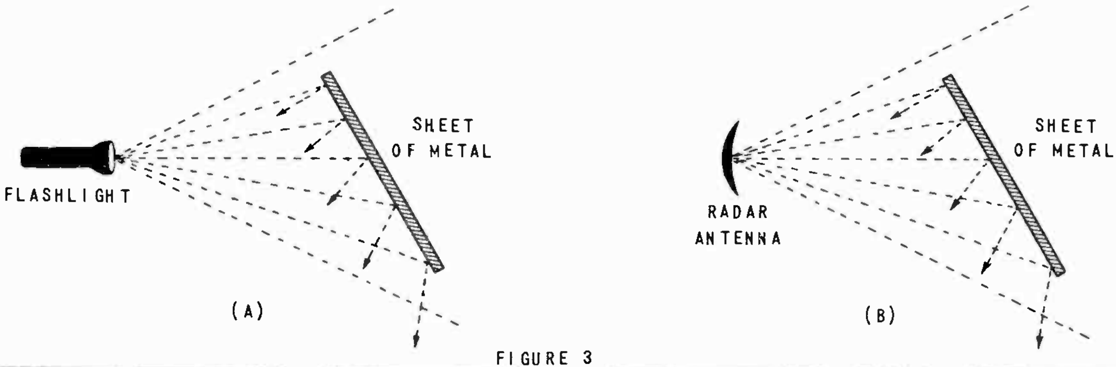


FIGURE 3