CHAPTER 18

RADIO DIRECTION FINDING

Radio direction finding (DF) is the name given to the process of determining the direction from which an incoming radio wave arrives. The direction of arrival, under normal propagation conditions, coincides with the direction of the path of shortest geographical distance (the great circle route) between the direction finder location and the source of the radio wave. Thus, if the direction of arrival of a radio wave is determined, the line of bearing of the source of the wave from the direction finder location is determined.

One of the earliest uses of radio direction finding was for navigation. If a navigating vehicle, by means of a direction finder, obtains lines of bearing to two or more radio transmitters (the lines of bearing will actually be to the transmitting antennas) of known geographical location, a fix of the location of the navigating vehicle is obtained. If the vehicle is moving, the lines of bearing must be obtained within a short time or simultaneously in order to obtain a reasonably accurate fix. The faster the vehicle is moving, the more important the requirement becomes.

If two or more direction finders of known geographical location obtain lines of bearing on a radio transmitter, a fix of the geographical location of the transmitter is obtained. This procedure is the converse of that used in radio navigation. Of course, if the radio transmitter is moving, the lines of bearing must be obtained simultaneously, or nearly so, in order to obtain an accurate fix. The procedure just described has many uses such as locating ships or aircraft in distress or determining the location and movement of enemy or unidentified units (usually referred to as targets) which use radio transmitters.

This chapter explains the basic theory of radio direction finding and discusses the AN/GRD-6 direction finding system.

RADIO WAVE PROPAGATION

The following discussion of radio wave propagation is a review of the material covered in chapter 10 and will emphasize those propagation factors which are pertinent to direction finding fundamentals.

GROUND WAVE PROPAGATION

Ground wave propagation is entirely by vertically polarized radio waves. Any horizontally polarized radio wave is rapidly attenuated by the surface of the earth. For this reason most of the signals propagated in the VLF, LF, and MF frequency ranges are of the vertically polarized type.

Ground wave propagation is not particularly dependent on the time of day or season and hence is very reliable up to the point where the refracted sky wave component can begin to add (constructively or destructively).

It is important to note that the ground wave does not necessarily arrive at the receiving site from the great circle direction of the transmitting antenna. This difference in direction is due to the ground wave being propagated over a medium such as water and then moving on to another medium such as dry earth. This difference in direction will produce an error of a large magnitude when the transmitter and receiving sites are situated on land and separated by a large body of water. The error is sometimes referred to as SHORE EFFECT.

SKY WAVE PROPAGATION

An important consideration in DF by sky wave propagation is the polarization of the reflected or refracted wave as received from the ionosphere. The polarization of the reflected or refracted wave is not necessarily the same as the incident wave. If we assume that the incident wave is vertically polarized, then the ratio of horizontal polarization to vertical polarization in the reflected wave is known as the "conversion coefficient". The reflected wave may be linearly polarized from the vertical to horizontal or it may be elliptically polarized (the polarization rotates) depending on the conversion coefficient and the relative phase between the horizontal and vertical components in the reflected or refracted wave. The reflected wave is not necessarily in phase or 180 degrees out of phase with the incident wave.

The reflection coefficient varies greatly. It is normally greater for the lower frequencies (550 kc and below) than it is for the higher frequencies. The reflection coefficient is generally greater during the night than during the day, and greater as the angle of the incident wave approaches zero degrees or tangency with the plane of the reflecting layer (longer skips).

COMBINATION OF GROUND AND SKY WAVE PROPAGATION

The arrival of a ground wave and one or more sky waves at a receiving site may cause constructive or destructive addition. The resulting polarity of the received signal may be anything from vertically polarized to elliptically polarized. The type of polarization and strength of the signal depends on the strength of the ground and sky wave, their relative phase, the angle of arrival of the sky wave, the relative bearing (azimuth direction of arrival) of the two waves, and the polarity of the sky wave (it being assumed that the ground wave will be vertically polarized).

A difference in time of arrival at a receiving site between the ground wave and a one hop sky wave is one of the factors in producing a difference in phase relationship. The other major cause for the phase difference is the phase shift caused during the sky wave reflection. Occasionally two waves will arrive at the receiver much further separated in time of arrival than those previously mentioned. This effect may be produced by the signals arriving at the receiver from opposite directions around the world. It is of course, also possible for two sky waves to arrive by a different number of skips at the receiver with a considerable difference in time. The one with the least skips would be expected to arrive first.

All of the factors which affect the polarization, phase, strength, azimuth, etc., of the ground and sky waves must be considered in the design of DF equipment and the bearing accuracy obtained in direction finding. It is important to note that the errors of most direction finding systems are dependent on the sky wave when the sky wave becomes an appreciable part of the received signal.

A radio direction finder is comprised of three essential components or equipment groups —a directional antenna, a radio receiver, and an indicating device. (See figure 18-1.) The component which actually detects the direction of arrival of the incoming wave is the antenna. Therefore, a major portion of this chapter is devoted to the discussion of the theory of direction finding antennas.

DIRECTION FINDING ANTENNAS

GENERAL

Essentially all direction finding systems operating in the HF band and below are designed for measurements on vertically polarized waves. Directional errors often result if the waves arrive with abnormal polarization. (The term "abnormal polarization" implies that polarization is neither entirely vertical nor entirely horizontal.) The amount of error will depend on the design of the system. For some systems, polarization is not critical, but optimum, reliable operation is achieved only if the waves are vertically polarized. The manner in which abnormal polarization affects operation will be pointed out later.

When a conductor is cut by magnetic lines of force, or lines of flux, a voltage is induced in the conductor. In order to cut lines of flux, the conductor must be perpendicular or must have a component that is perpendicular to the lines

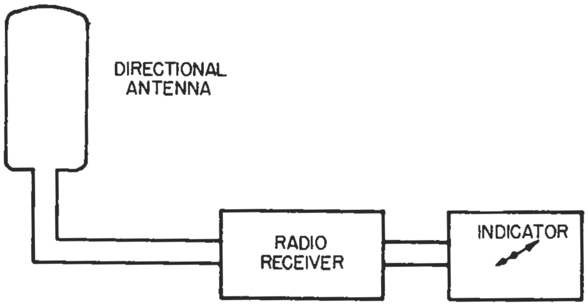

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Figure 18-1.—Essential components of a radio direction finder.

of flux, and the relative motion between flux and conductor must have a component in a direction that is perpendicular to both the lines of flux and the conductor.

The energy radiated from an antenna element is contained in two moving fields, an electric (E) field and a magnetic (H) field. As they travel through space, the lines of the E field and the lines of the H field are perpendicular to each other and the E and H field lines are mutally perpendicular to the direction of propagation according to the right-hand rule. the magnitudes of the E and H lines vary sinusoidally and are in time phase.

A vertically polarized wave has a vertical E field and a horizontal H field. Therefore, the wave induces voltage in vertical conductors only. A vertical wire, or monopole, is the simplest type of antenna. When a vertically polarized radio wave induces voltage in a monopole, the induced voltage is in phase with the incoming wave. (The amplitude of the induced signal will vary with the amplitude of the constant velocity flux (H) lines passing the monopole.) The induced voltage is the same for all directions of arrival in the horizontal plane. (See figure 18-2.)

LOOP ANTENNA

One of the earliest antennas used for direction finding, and one that still finds some application today, is the loop antenna. The response

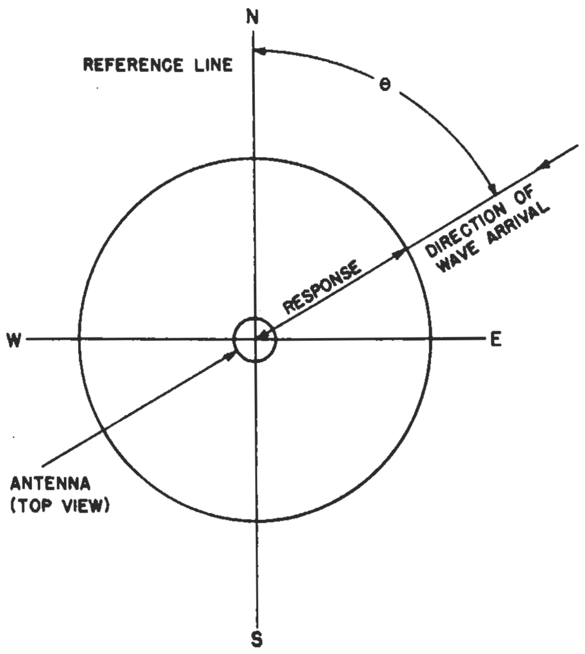

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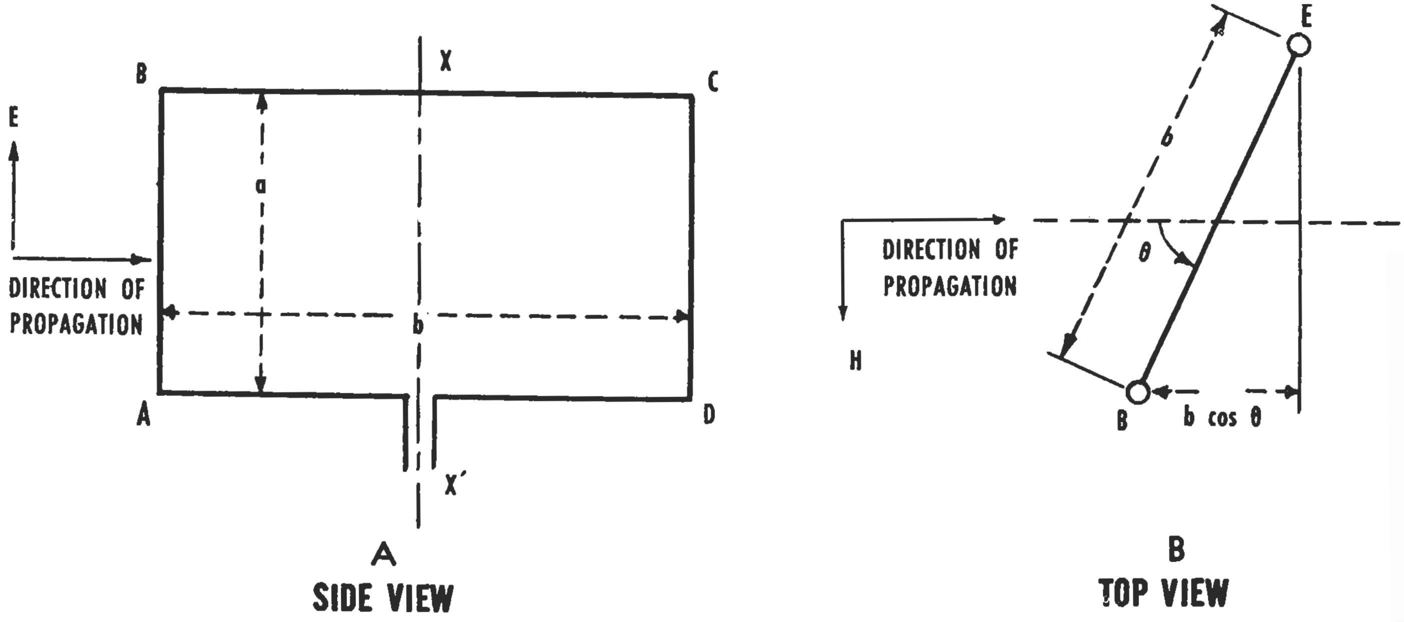
Figure 18-2.—Polar response of a monopole antenna.



A
SIDE VIEW

B
TOP VIEW

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Figure 18-3.—Loop antenna in a radiation field. A, side view; B, top view.

of the loop antenna is different from that of a vertical monopole. A rectangular single-turn loop with dimensions that are small compared to the wavelength of an incoming radio wave is shown in figure 18-3. As the loop is rotated about the axis X-X', the angle θ between the plane of the loop and the direction propagation of the wave is changed.

If the loop is placed in a radiation field like the one shown in figure 18-3, the H lines of the field cut the sides AB and CD at slightly different times because the wave travels at a constant, finite velocity. At any instant therefore, the voltage induced in arm AB is slightly different from the voltage induced in arm CD. The arms BC and AD are not affected by the H lines of a wave polarized at right angles to them and do not contribute to the induced voltage in the loop because the horizontal members are parallel to the H lines.

If the loop is turned so that its face is perpendicular to the direction of arrival of the wave—that is, $\theta = 90°$—the sides AB and CD are cut by the H lines at the same instant. The voltages induced in arms AB and CD are then the same magnitude and phase and neutralize each other, so that no current flows in the antenna loop.

The instantaneous flux density at any point along the path of arrival varies sinusoidally, as shown in figure 18-4A where the arrows represent the flux density or magnetic field strength of the arriving wave. As the magnetic field at the loop changes in phase, the flux density at the loop changes as shown at L_1, L_2, L_3, L_4, and L_5, which are top views of the loop at various phases (instantaneous times of arrival) of the wave. Actually the loop is stationary and the wave moves, but for ease in representation the loop is shown in five positions along a stationary wave. The loop is seen from the top, and the voltages are induced by the flux lines cutting the vertical sides of the loop, which are in a plane perpendicular to the page.

When the phase of the incoming wave is 0° the loop is at position L_1 with respect to the wave, and the lines of flux cutting the vertical sides of the loop are of opposite polarity. The voltages induced in the two sides are then in opposite directions, and the maximum voltage is developed in one direction around the loop. When the wave phase is 180°, the loop is at position L_4, and again the induced loop volage is maximum but in the opposite direction to that of L_1. When the phase is 90° and 270° (loop positions L_3 and L_5), the instantaneous flux cutting the two vertical arms is the same in magnitude and direction so that the resultant loop voltage is zero.

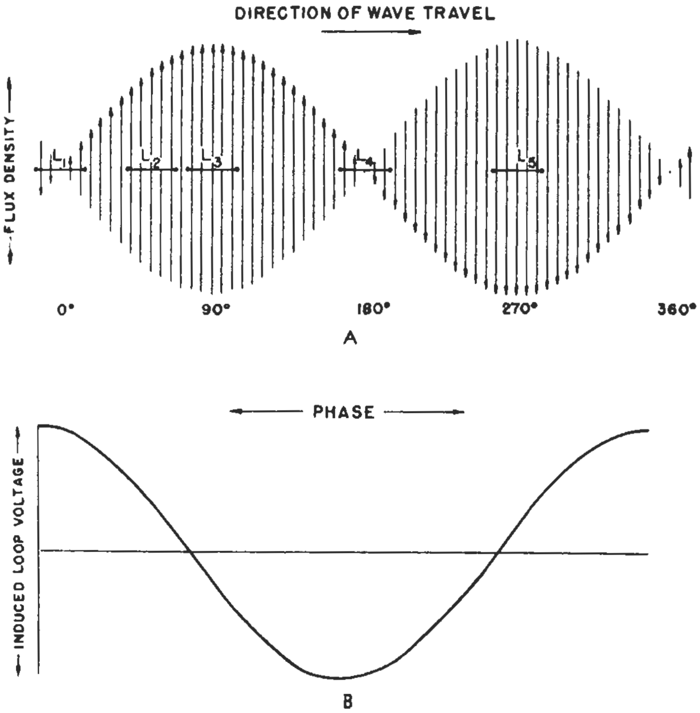

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Figure 18-4.—Induction of alternating voltage in a loop antenna. A, top view of loop at various phases of the incident wave; B, one cycle of the induced loop voltage.

The induced loop voltage for a single cycle of the incoming wave is shown in figure 18-4. Notice that the loop voltage differs in phase from the incoming wave by 90°; it is, therefore, different in phase by 90° from the signal induced in a monopole placed at the same corresponding positions. The actual voltage induced around the loop depends on the differences in voltages in opposite arms. Therefore, if the loop is small, with respect to the wavelength of the wave, the resultant loop voltage will be much smaller than the voltage induced in a monopole of the same length as the vertical arms of the loop. The foregoing facts will be illustrated mathematically in the following paragraphs.

Since the E field is in time phase with the H field, the E field of the radio wave can be expressed as $E_{max} \sin(\omega t)$. The expression retains the phase and amplitude relationship illustrated for the H field in figure 18-4. The mathematical expression which has been derived for the voltage induced in the loop is

$$e = \frac{2\pi NAE_{max}}{\lambda} \cos(\varphi) \cos(\omega t)$$

where e is the induced voltage at the output, N is the number of turns in the loop, A is the area of the loop, E_{max} is the maximum value of the E vector of the radiation field, λ is the wavelength of the incoming wave, and θ is the angle between the plane of the loop and the direction of incoming wave.

Several facts about the loop can be determined from the given equation:

1. As the voltage is proportional to cos (ωt), it is 90° out of phase with the incoming wave which varies as sin (ωt). This was illustrated previously and is important when the voltage induced in the loop is combined with the voltage induced in a monopole.

2. Since e varies as cos (θ), the response is similar to a figure-of-eight pattern, as shown in figure 18-5, which is a polar plot of the response (maximum output amplitude) of the loop versus the angle between the loop and the direction of the incoming wave.

3. The induced voltage is proportional to the area of the loop. This is true for any shape of loop because any loop can be resolved into horizontal and vertical elements. For example, a circular loop can be resolved into tiny horizontal (Δx) and tiny vertical (Δy) elements, as shown in figure 18-6. The horizontal elements are not affected by a vertically polarized wave; the vertical elements are affected in the same manner as the vertical sides of a rectangular loop.

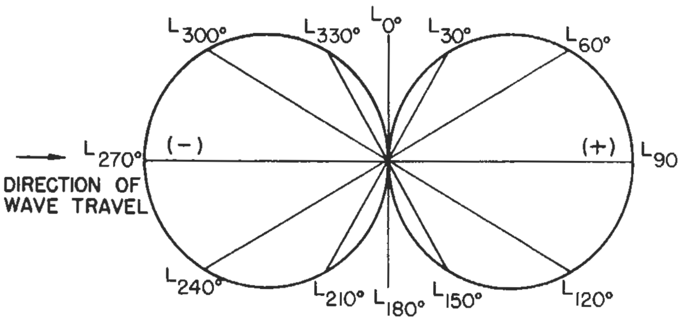

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Figure 18-5.—Polar response of a loop antenna.

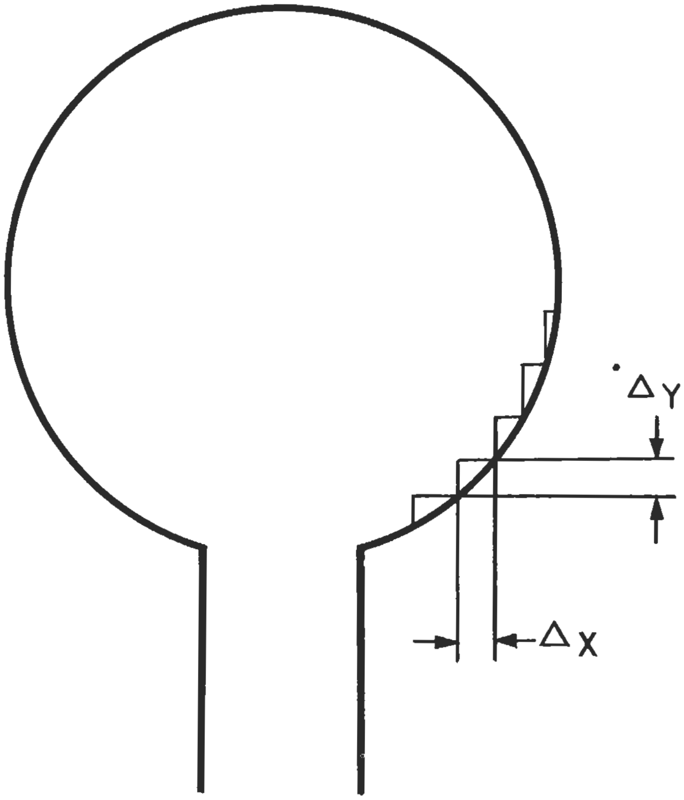

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Figure 18-6.—Loop antenna resolved into tiny horizontal elements (Δx) and tiny vertical elements (Δy).

4. The voltage (e) is inversely proportional to the wavelength of the incoming wave, or it may be said to be directly proportional to the frequency of the incoming wave.

5. An effective height for antennas can be defined as being the maximum voltage induced in an antenna for a unit field ($E_{max} = 1$). Maximum voltage in a loop antenna occurs when $\theta = 0°$. The expression for the effective height, h_e of the loop antenna is then

$$h_e = \frac{2\pi NA}{\lambda}$$

To illustrate, consider a circular loop antenna which is 24 inches (0.61m) in diameter, has eight turns, and is operating at 1500 kc (λ = 200 m). The effective height is then

$$h_e = \frac{2\pi \times 8 \times \pi \left(\frac{0.61^2}{2}\right)^2}{200} = 0.0734 \text{ m}$$

The equation means that a straight wire (vertical monopole) above ground of only 7.34 centimeters would give the same output voltage.

The directional characteristic of the loop antenna is called a cosine, or figure-of-eight, pattern. When the loop is oriented so that the received signal is a maximum, a small change in orientation produces a small change in signal. However, when the loop is at a null position, a small change in orientation of the loop produces a large change in output voltage. Furthermore, there is a reversal in the phase of the output signal as the loop passes through a null point. For these reasons, in direction finding systems which are based on figure-of-eight types of response patterns, the null points rather than the maximum response points are used to find a line of bearing.

As there are two null positions, 180° apart, the loop can give a line of bearing (the actual bearing and its reciprocal) but cannot determine the absolute direction of the transmitter from the direction finder. The determination of absolute direction, or SENSE, is obtained by adding the output of a vertical monopole antenna to that of a loop antenna. When the two antennas are properly connected, the combined response is not ambiguous.

SENSING

The figure-of-eight pattern of a loop has two null positions for one incident radio wave as shown in figure 18-5. If the outputs of a loop and a monopole are combined in phase, the response of the two antennas is the algebraic sum of their individual diagrams, as shown in figure 18-7. This figure contains four possible responses caused by differences in the relative amplitudes of the monopole and loop outputs. The response shown in figure 18-7C has one sharp null and is the desired pattern.

The output of the vertical monopole is independent of the horizontal direction of arrival of the wave. Consider it to have positive (+) polarity. Because the phase of the loop voltages changes as the loop passes through a null, one-half of the figure-of-eight pattern may be said to have positive (+) polarity and the other half to have negative (-) polarity. The addition of the loop and monopole curves gives the responses shown in figure 18-7. The shape of the resultant curves is called a cardioid because it is heart shaped.

The output of the monopole antenna is in phase with the radio wave. The output of the loop antenna, however, is 90° out of phase with the radio wave, which means that the loop voltage is a maximum when the monopole output is zero and vice versa. The cardioid pattern of figure 18-7C cannot be obtained unless the phase of the loop (or monopole) antenna signal is changed by 90°

A block diagram of a simple direction finder is shown in figure 18-8. In operation, a bilateral line of bearing would first be obtained by use of the loop alone. The operation would be accomplished by rotating the loop until a null is found. With the loop in the null position, the sense circuit would be switched in. With the sense circuit in, an output signal would be present, Rotating the loop antenna in one direction would cause the amplitude of the output to increase, and rotating the loop in the other direction would cause the amplitude of the output to decrease. The system is designed so that, by rotating the loop in a prescribed manner, the operator can determine which is the correct null. For example, assume the antenna response for the system is described by figure 18-7C, and the operator believes the radio transmitter to be in the direction of the X on the line of bearing. If he rotates the antenna in a clockwise manner and the signal amplitude increases, he knows he has chosen the correct direction.

CROSSED LOOP (BELLINI-TOSI)

If the loop antenna were rotated continuously, the output signal could be displayed on an oscilloscope to give an automatic indication of bearing. There are certain features of such a system which are not practical. In order to obtain a good null in the response of a loop, the vertical arms of the loop must be identical in every respect. This requirement means that the vertical arms must have identical capacity to ground and to any nearby objects. It is a straightforward and easily accomplished task to balance out differences in the characteristics of the vertical arms for any one particular position of the loop. However, it is impossible, for all practical purposes, to obtain such a balance through 360° of loop rotation. Therefore, it soon became apparent in the design of direction finding systems that some method was desirable for obtaining a bearing on a radio wave without rotating the loop. In 1907, the Bellini-Tosi antenna system, named after its inventors, was developed. The principle of the Bellini-Tosi is used in most

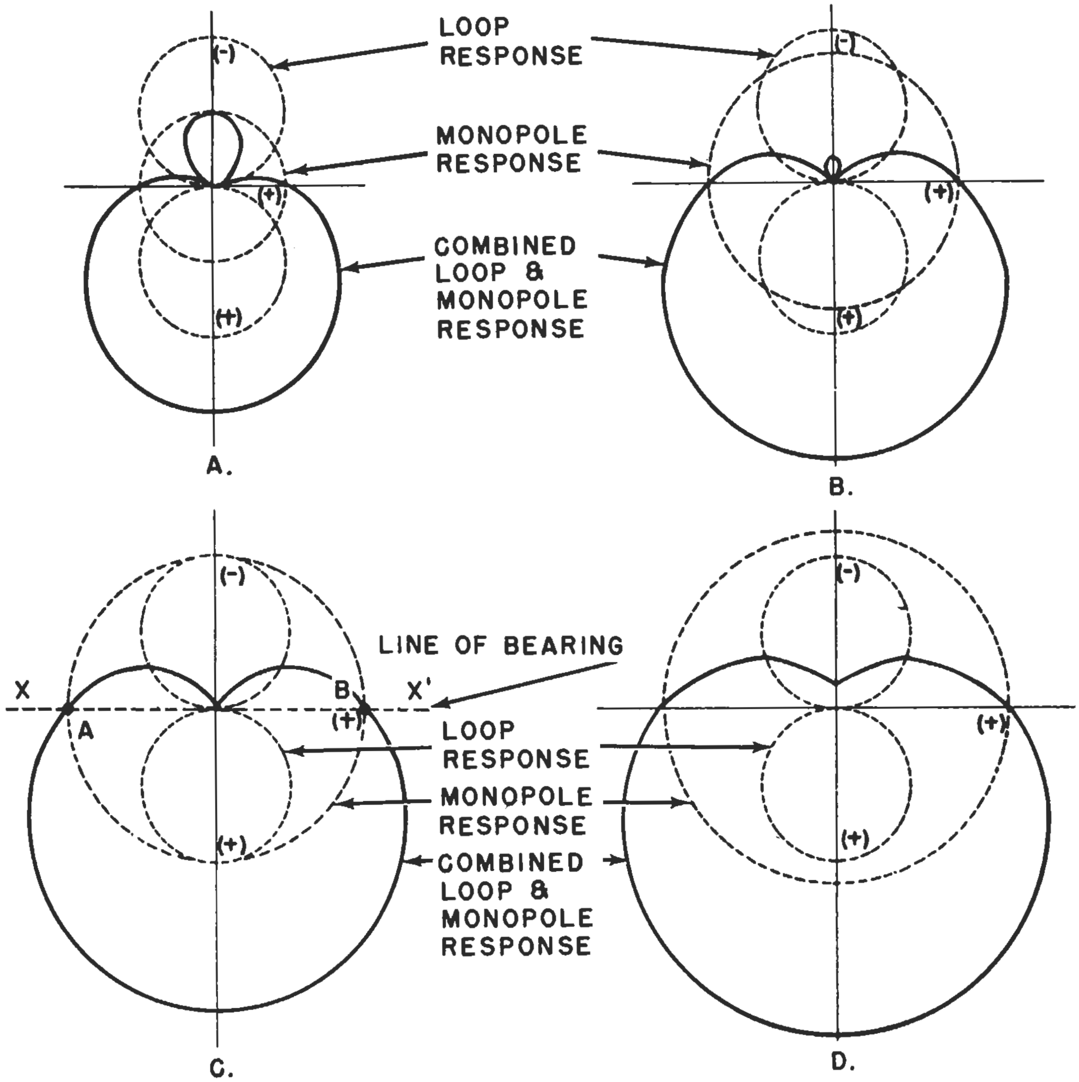

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Figure 18-7.—Response of the com'bined monopole and loop antenna.

present-day direction finding systems which operate in the h-f band and below. This principle produced results equivalent to those previously obtained by rotating a loop antenna. The method used a GONIOMETER connected to a pair of stationary crossed loops.

A schematic of the Bellini-Tosi antenna system is illustrated in figure 18-9. The two coaxially-mounted stationary loop antennas are at right angles to each other. The goniometer is comprised of three coaxially mounted coils. Two are stationary field coils (stators) mounted at right angles to each other; the other is a rotating search coil (rotor) which is inductively coupled to the field coils.

The loop voltages are coupled to the corresponding stators in the goniometer, with the voltage of loop 1 appearing across stator 1 and the voltage of loop 2 appearing across stator 2. If an incoming wave cuts loop 1 in such a direction as to produce maximum voltage in that loop, no voltage will be induced in loop 2. Therefore, there is maximum voltage across stator 1, and no voltage across stator 2. A null will be observed in the rotor voltage whenever the rotor is at right angles to stator 1. If an incoming wave cuts loop 2 in such a direction as to produce maximum voltage in that loop, no voltage will be induced in loop 1. A null in rotor voltage will then occur whenever the rotor is perpendicular to stator 2. One can easily verify that for radio waves arriving at other angles, such as the wave shown in figure 18-9, there will be a null in the rotor voltage for one angular position of the rotor. (Actually there is a null for two angular positions if 360° of rotor motion are considered.) Thus, the rotor voltage, obtained by induction from the stators connected to stationary loop antennas, has the same response characteristics as the voltage obtained by the use of a single rotating loop antenna. In figure 18-9, the rotor output is inductively coupled to a rotating transformer to eleminate the need for slip rings. Because the loops are stationary they may be permanently balanced to provide optimum response—good nulls. An important advantage of this system is that the antenna can be located at a remote position and coupled by ordinary r-f transmission line to a goniometer located at the receiver.

Since the response of the goniometer rotor is the same as that of a single rotating loop, the bearings are subject to the same ambiguity of 180°. To resolve the ambiguity, the output of the goniometer is combined with that of a monopole antenna after a line of bearing is obtained. This gives a cardioid response from which the absolute direction or sense may be determined. A simplified block diagram of a direction finder which includes a goniometer and an automatic bearing indicator is shown in figure 18-10.

LIMITATIONS OF LOOP ANTENNAS

Thus far it has been assumed that the incoming radio wave is vertically polarized, thus having all its H lines parallel to the earth's surface. If the wave were horizontally polarized, the H lines would all be perpendicular to the earth's surface. The response of a loop antenna to such a wave would also be a figure-of-eight type of response, but the nulls would be displaced 90° from those caused by vertically polarized waves with the same directions of arrival. If the incoming wave arrives with some other polarization—neither vertical nor horizontal—the nulls are displaced by some angle between 0° and 90°.

At the lower frequencies (lower portion of the m-f band and below), radio wave propagation is essentially all due to the ground wave, and thus vertical polarization is always present. However, if the frequency of the radio wave is increased, a significant portion of the wave may arrive by means of the sky wave and will have a horizontally polarized component—the H lines will have a downward velocity component. Thus, a voltage will be induced in the horizontal arms of the antenna with a resultant loop voltage at angles of arrival which ordinarily result in a null. Consequently, the null is displaced and large DF errors result. Errors due to abnormal

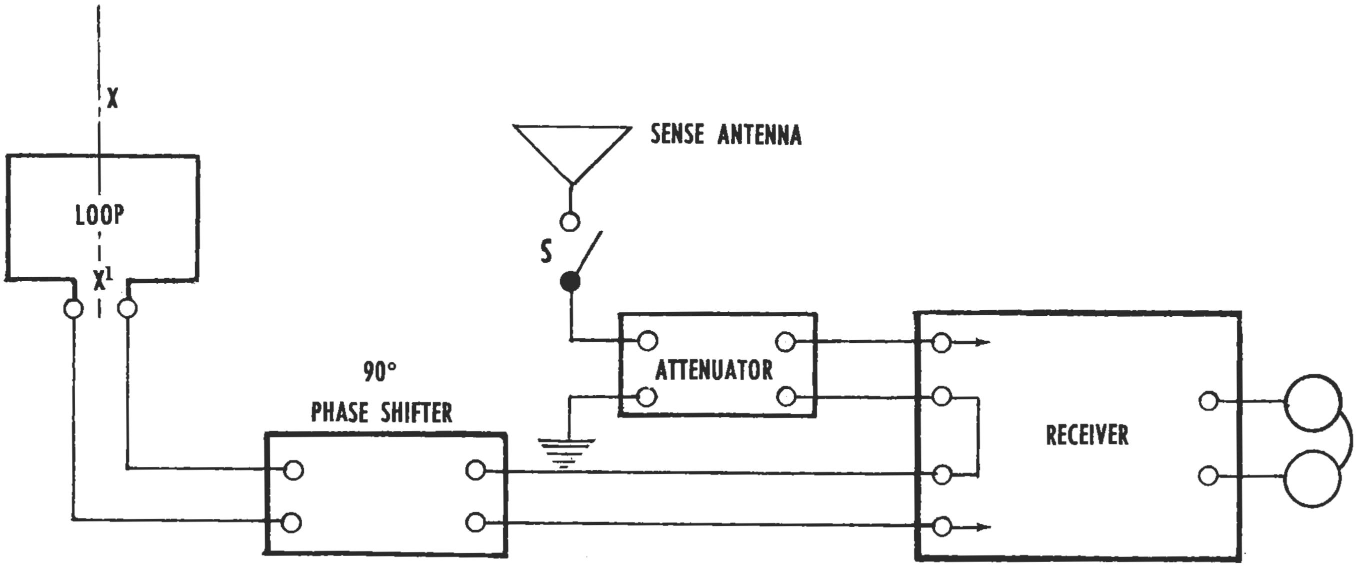

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Figure 18-8.—Block diagram of a circuit for obtaining unilateral and bilateral bearings by means of a radio direction finder.

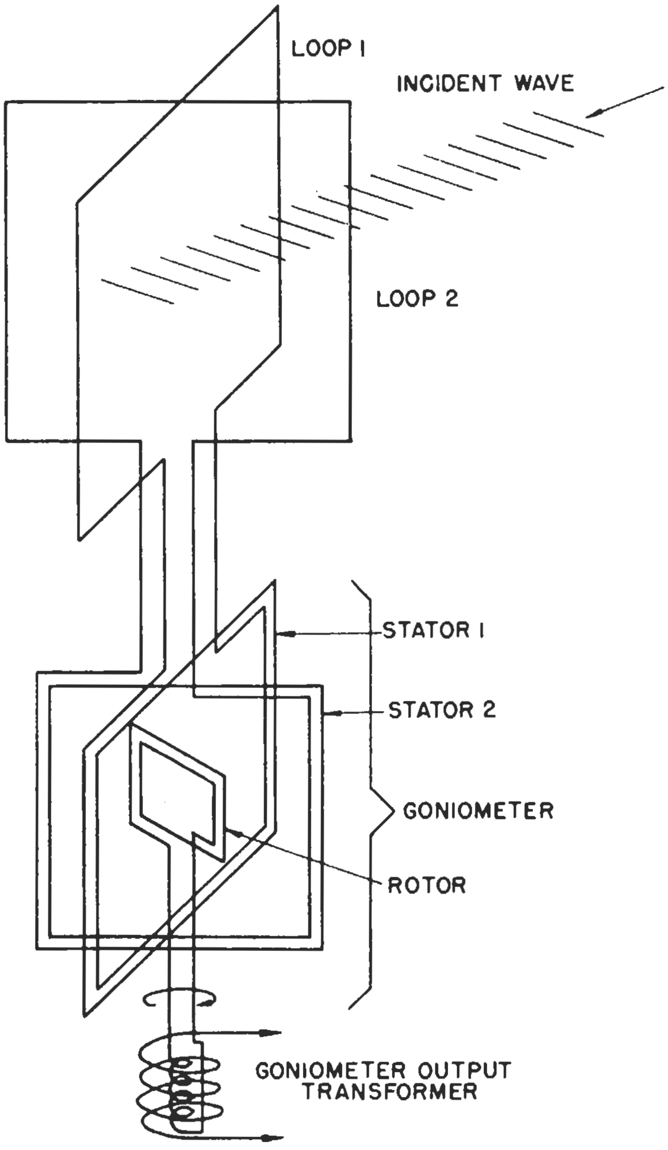

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Figure 18-9.—Schematic diagram of a goniometer used with crossed loops.

polarization of the incoming wave are known as POLARIZATION ERRORS. The effects of polarization error were first experienced on m-f direction finders at night because of the increased effect of the sky wave at that time. Therefore, polarization errors are also referred to as NIGHT EFFECT.

SPACED LOOP ANTENNAS

One method to compensate for polarization errors is to use a SPACED LOOP ANTENNA. A spaced loop antenna consists of two loops arranged parallel to each other on opposite ends of a boom which can be rotated about its center. The outputs of the loops are connected such that the loop voltages due to horizontally polarized components of incoming waves tend to cancel. The response pattern of the spaced loop antenna has four minima. However, the principal nulls—the pair in the plane of the loops—are much less affected by the horizontal component of the incoming wave than the nulls of the single loop. Spaced loop antennas are no longer widely used in Navy direction finding systems.

ADCOCK ANTENNAS

Because the loop antenna is generally useful only for vertically polarized ground waves, a different type antenna arrangement is necessary for direction finding in the h-f band where essentially all reception is due to the sky wave. The large polarization error inherent in the use of loop antennas for direction finding is caused by the horizontal elements of the loop. Because the only practical purpose of the horizontal members of the loop is to connect the vertical members in series (and to give physical rigidity in systems where the antenna is actually rotated), the directive response of the loop will not be affected if the horizontal members are shielded or removed completely. Directive loop antennas in which the horizontal conductors are shielded or removed are called ADCOCK antennas. Adcock antenna systems are used primarily for h-f and v-h-f direction finders. One type of Adcock system will be discussed in detail when the AN/GRD-6 system is discussed.

Figure 18-11 illustrates the SHIELDED U-ADCOCK antenna. The upper horizontal member has been removed completely, and the bottom horizontal member has been shielded. The resultant antenna consists only of vertical members. The directive pattern will be the same as a single turn loop with dimensions of width (w) and height (h).

The direct coupling illustrated in figure 18-11 can be replaced with transformer coupling as illustrated in figure 18-12. This arrangement is called the COUPLED ADCOCK antenna. The wires between the vertical elements and the receiver need not be shielded because they are close together and in opposite phase, thus causing their pickup to cancel.

Adcock antennas may be mounted so that they can be rotated in the same manner as described for the rotatable loop. In most present-day systems, Adcock antennas are erected in pairs at right angles and used in conjunction with goniometers similar to the crossed loop system previously discussed.

The response of the U-Adcock antenna is the same as for a single loop antenna as illustrated in figure 18-2. This response pattern is repeated in figure 18-13 with geographical references of direction. With a transmitter in the direction of N-S, the output of the antenna is maximum; in the E-W direction the output is at zero or null. The line-of-arrival of an incoming radio wave may be determined by positioning the U-Adcock for a null, or by using a fixed four-element array and a goniometer to determine a null, as previously described for loop antennas. Sensitivity and bandwidth are limited, in a conventional four-element Adcock array, by the antenna spacing; however, large spacing is required for good sensitivity down to the lowest frequency. The spacing of the elements also contributes some error, called spacing error, or octantal error, which will be discussed in the following paragraph. By using a system of eight elements it is possible to increase the spacing up to one wavelength at the highest working frequency. Such a system can result in less than two degrees of spacing error and increases sensitivity and bandwidth. Mutual coupling between elements does not affect the DF accuracy because of the symmetry of the system. The mutual effect is further minimized by using elements having a low reactive component throughout the frequency range.

A simple, or single-stage, goniometer is shown in figure 18-14 as it would be wired for use with a four-element U-Adcock array. By the use of this system, the response characteristic of a four-element U-Adcock and a goniometer, with respect to the goniometer rotor position, is identical to that of rotating a two-element U-Adcock antenna. However, there is an inherent error in the system because the directive pattern of a pair of spaced U-Adcocks is not a true cosine function. The distortion of the response pattern is due to the spacing of the elements. When the noncosinusoidal output of the spaced Adcock array is combined with a goniometer having a true cosinusoidal characteristic, an "octantal" error results (figure 18-15). Inspection of the error curve shows the error to be maximum at 22-1/2° from 0°, and to repeat a maximum error every consecutive 45°. To cancel this error, an identical four-element spaced Adcock array is mounted at 45° to the first array. (See figure 18-16.) Because of the 45° displacement, the octantal error of the new antenna will be displaced by 45° from the first antenna and will appear as the dotted curve shown in figure 18-15. In the AN/GRD-6 system,

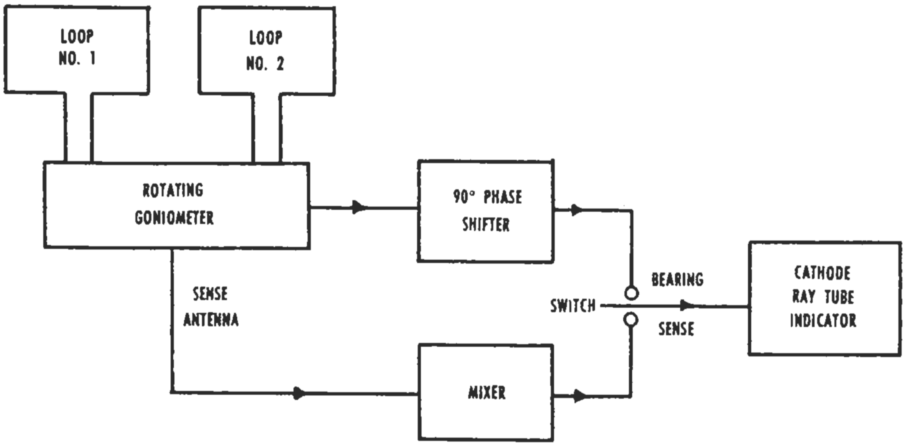

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Figure 18-10.—Simplified block diagram of an automatic-bearing-indicator unit.

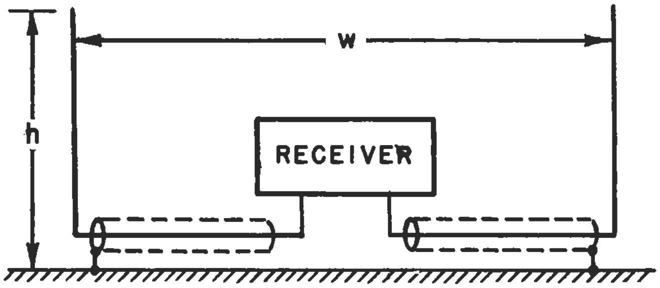

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Figure 18-11.—Shielded U-Adcock antenna.

a tandem, or two-stage, goniometer with a common rotor shaft is used. The output of the N-E-S-W array is fed into one stage of the goniometer and the output of the NE-SE-SW-NW array is fed into the second stage of the goniometer. The stator windings are so positioned that the rotor null position for an incoming wave is the same for both stages, thereby retaining the desired figure-of-eight response. The octantal error voltages, equal in magnitude for both arrays, are connected in series opposition in the goniometer rotor, thereby cancelling all octantal error in the output.

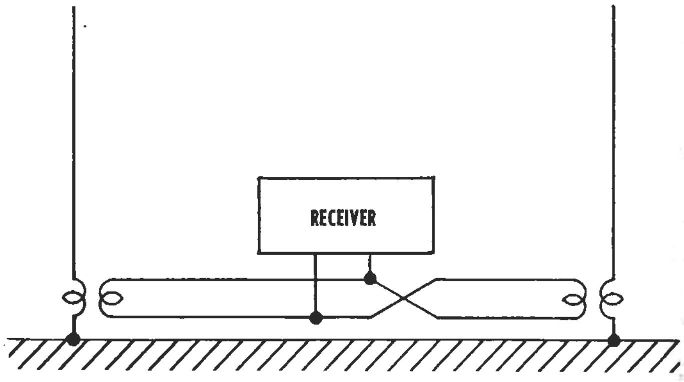
The signal nulls are used for determining the direction of arrival of an incoming radio wave. Since there are two nulls, 180° apart, there is a 180° uncertainty, or ambiguity, as to the true bearing of the transmitter. Sense, or determination of absolute direction, is obtained by combining the ouput of a vertical monopole located in the geometric center of the array with the output of the U-Adcock system in the manner described for sense determination in the loop and Adcock antenna systems. The antenna arrays of the AN/GRD-6 system, therefore, consist of nine elements: eight are used for line-of-bearing determination, and the ninth for sense determination. (See figures 18-17 and 18-18.)

CIRCULARLY DISPOSED ANTENNA ARRAY SYSTEM

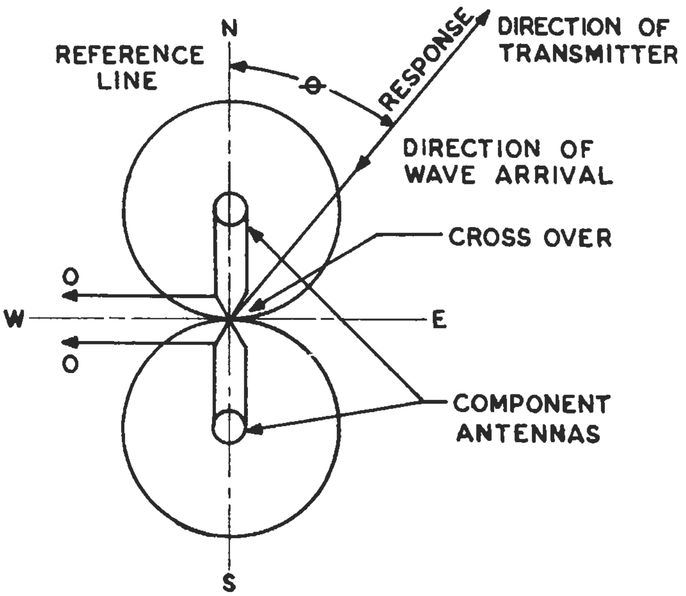
The circularly disposed antenna array (CDAA) system is a more recent development than any of the antenna systems previously discussed. It has been used primarily in the v-h-f and u-h-f bands, and is now being adapted for use in the h-f band. The CDAA system (also known as the Wullenweber system) has some gain characteristics which make it much more desirable than any other systems used for direction finding. These gain characteristics are particularly greater than those of previously designed systems for use in the h-f band. The reason for the advantage in gain will be pointed out shortly.

The CDAA consists of a group of omnidirectional antennas symmetrically spaced about the periphery of a circular reflector screen. The location of each antenna with respect to the screen and to the adjacent antennas is so designed that, by the use of a suitable antenna output scanning system, the antenna array provides high, unidirectional gain in all directions of azimuth. Figure 18-19 shows two concentric CDAAs—the outer one a high band array and the inner one a low band array. The desired signal is obtained by scanning the outputs of the antennas, around the circle. The output of the scanning system is greatest when it sweeps through the sector having high forward gain in the direction of a target transmitter. The scanning procedure results in sweeping the horizon with a direction finding beam, analogous to sweeping the horizon with a spotlight through a continuous arc of 360°.

The output of the goniometer (scanning device) at any angular position is actually the output of a monopole array—the combination of several of the monopole elements—rather than the output of a single monopole element. The resultant response will have a high forward gain (considerably greater than one) when compared to a monopole of the same dimensions as the individual antennas of the system. The output signal developed by loop and Adcock antennas, however, is actually the difference in signals of two monopole elements—the vertical components



25.110
Figure 18-12.—Coupled Adcock Antenna.



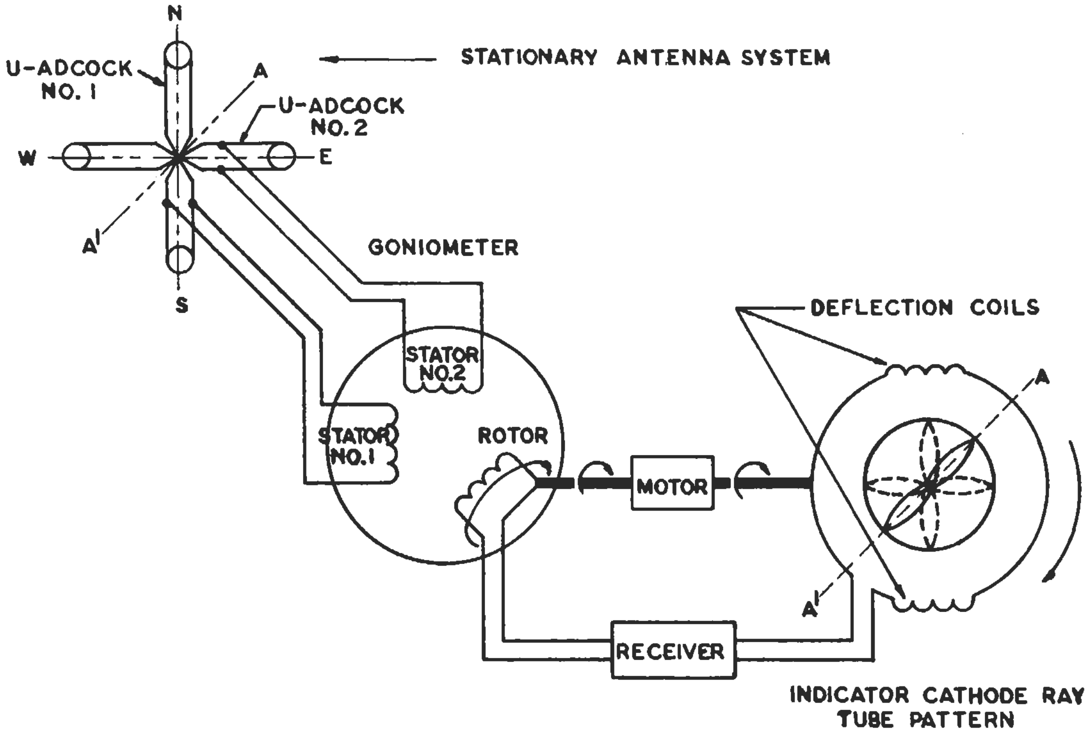
25.111

Figure 18-13.—U-Adcock antenna polar response diagram.

of the antenna. This means that the directional gain of a loop or Adcock antenna is small (much less than one) when compared to a reference monopole of the same dimensions as the vertical elements. Therefore, the CDAA has a very large increase in gain over the loop and Adcock antennas. Bearings may be obtained on incoming waves of much weaker strength and poorer quality when using the CDAA than when using loop or Adcock antennas, thereby allowing DF more distant from the DF site.

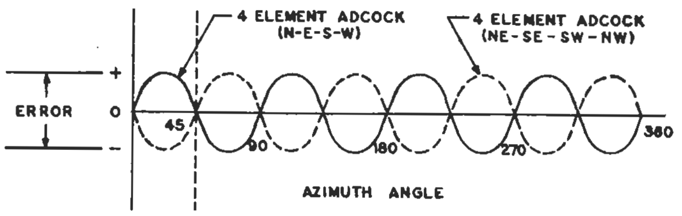
ROTATING ANTENNAS

In the u-h-f band and above, high gain unidirectional arrays can be constructed which are small in size, making it practical for direction finders operating at the higher frequencies to use some sort of rotating antenna which has a unidirectional pattern. To determine a true line of bearing to a transmitter, it is then necessary only to note which direction the array is pointed when the signal is received. Of course, in practical systems this is done automatically by



25.112

Figure 18-14.—Stationary antenna, goniometer and tube pattern diagram.



25.113
Figure 18-15.—Error cancellation.

synchronizing the indicator display of the received signal with the drive system which rotates the antenna.

DF RECEIVERS

COMPARISON WITH COMMUNICATION RECEIVERS

The outputs of loop and Adcock antennas are small compared to the average signal received from a communication antenna. Therefore, direction-finding receivers designed for use with these antenna systems must, in general, have higher sensitivity than the ordinary communications receivers. Because of the higher sensitivity requirement, the direction-finding receiver must be designed to obtain a low noise figure. Such receivers include shielding and filtering and may include noise-limiting and noise suppression circuits. However, since the principle of radio direction finding depends on measurement of changes in signal strength, automatic volume control cannot be used.

DESIGN CONSIDERATIONS

As is true for all receivers, the selectivity of direction-finding receivers must be sharp enough to suppress adjacent signals but broad enough to pass all frequencies included in the desired transmission. Navy DF receivers are usually of the superheterodyne type.

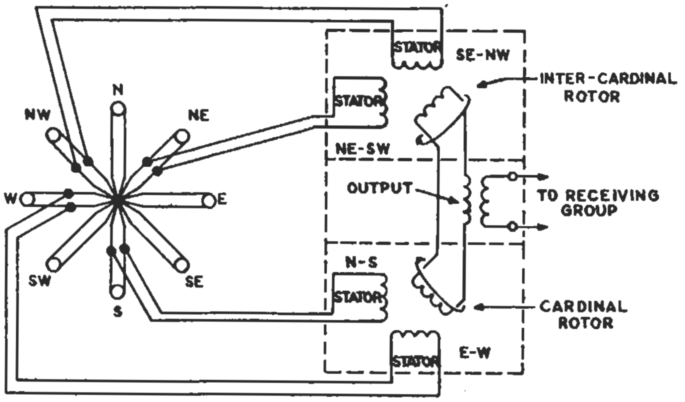
Since DF depends on the rotation of the antenna, either physically or electrically, the signal level varies from essentially zero at the null points to very large values at the maximum points. This variation requires that the amplifiers used in the receiver be designed to handle the larger signals without overload and that the detection circuits be designed to obtain linear detection signals of all levels. The requirement of linear detection is especailly hard to accomplish at the low signal levels. If linear detection of low level signals is not attained, errors are produced at the critical null points.

DF INDICATORS

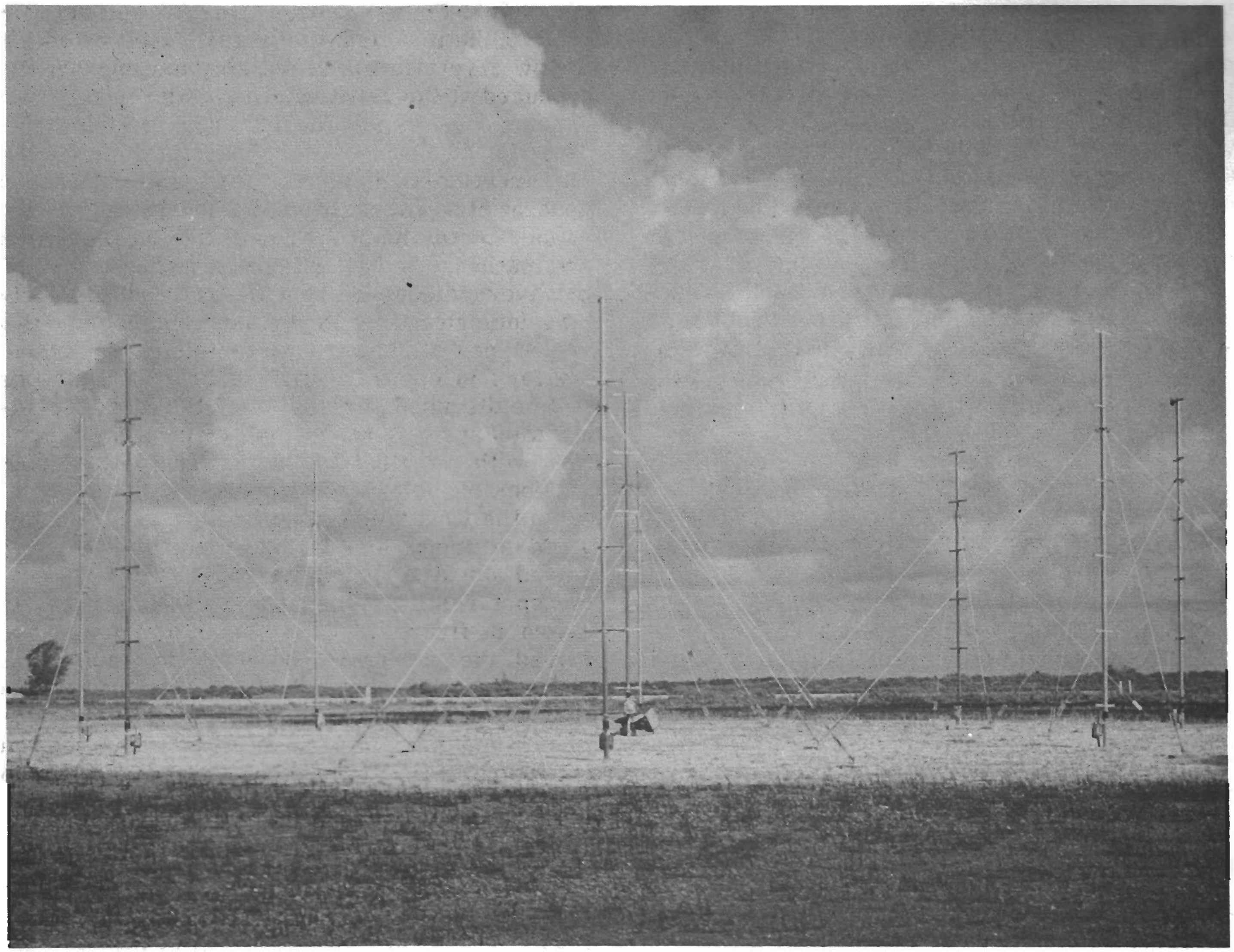
Direction-finding indicators fall into three general classes: aural (headphones or speaker), visual (meter needle or cathode-ray tube), and automatic (suitable for use with homing devices). However, for our purposes, only the cathode-ray tube indicator is of importance. There are two basic types of cathode-ray tube direction-finder displays in common use. Each of these types will be discussed briefly. Both types of cathode-ray displays generally employ magnetic deflection, with a deflection yoke which rotates about the neck of the cathode-ray tube.

In the first type of display, the yoke is energized in proportion to the strength of the received signal. When no signal is being received, the spot rests at the center of the screen, as shown in figure 18-20A. When a signal is received, the pattern which results in a polar plot of the directivity pattern of the DF antenna. The bearing of the signal is determined by the direction of maximum deflection of the spot, as shown in figure 18-20B. This type of display is ordinarily used for direction finders which employ rotating unidirectional antennas.

The second type of direction-finding display is ordinarily used for direction finders which use antenna systems having figure-of-eight response patterns. It is the type of display with which the CT will probably become most familiar. In this display, the yoke is normally



25.114
Figure 18-16.—Simplified tandem goniometer.



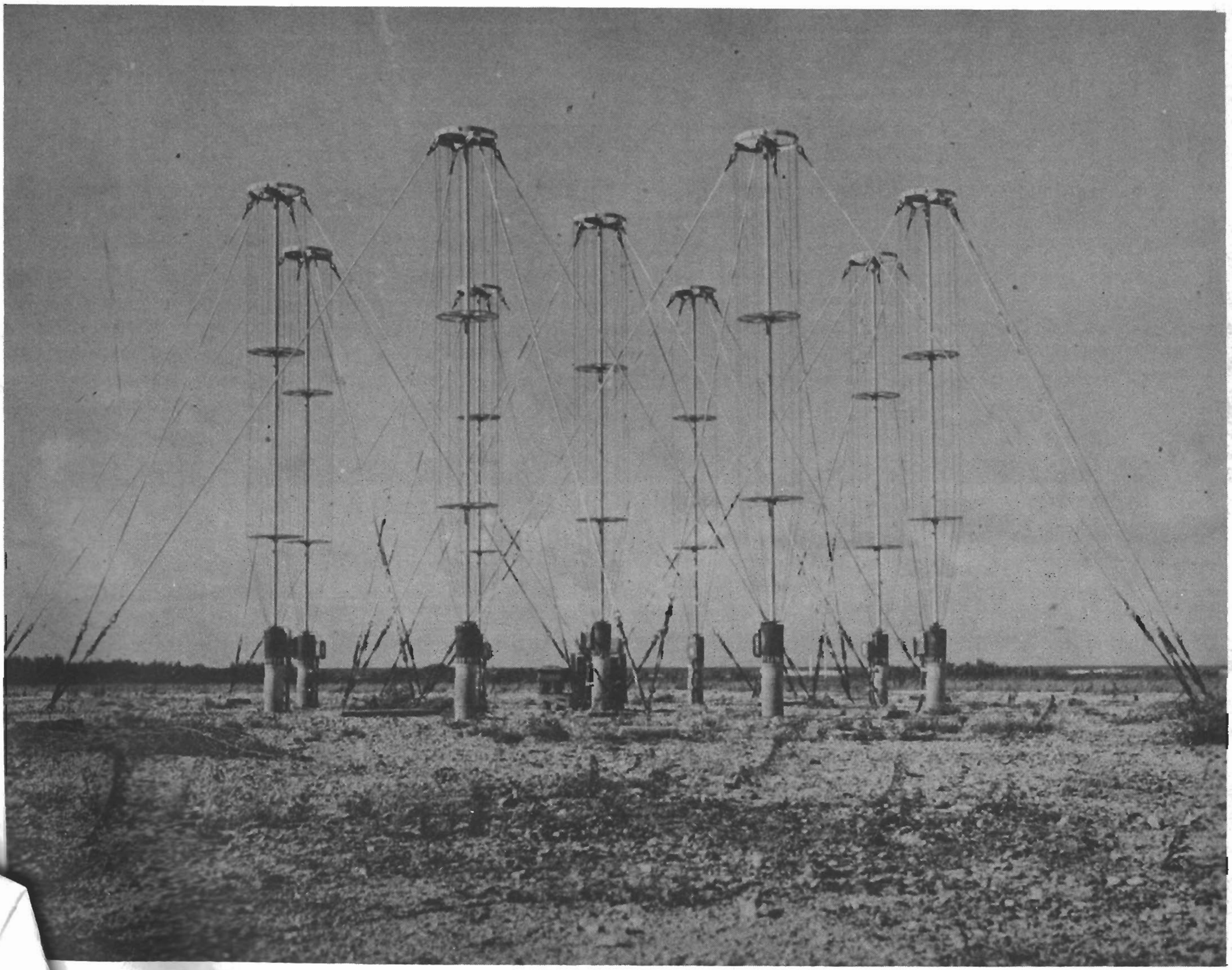
25.115

Figure 18-17.—AN/GRD-6 low band array.

energized; thus when no signal is received the spot traces a circle. When a signal is received, the spot is deflected toward the center of the screen. A block diagram of an automatic-bearing-indicator which incorporates this display is shown in figure 18-21. The goniometer rotor and the magnetic deflection coils of the cathode-ray tube are mechanically coupled together on one shaft which is rotated by a motor. For each revolution of the goniometer, the oscilloscope spot is moved once around the oscilloscope screen. The pattern on the cathode-ray tube is the output of the goniometer after amplification, detection, and inversion. The pattern is inverted so that a zero signal, such as the nulls of the figure-of-eight pattern, moves the oscilloscope pattern to the edge of the screen, and a large signal moves the spot toward the center. This action inverts the pattern from the dotted line to the solid line in figure 18-22. After inversion, the null points become the tips of the indicator pattern and the line of bearing is more easily read.

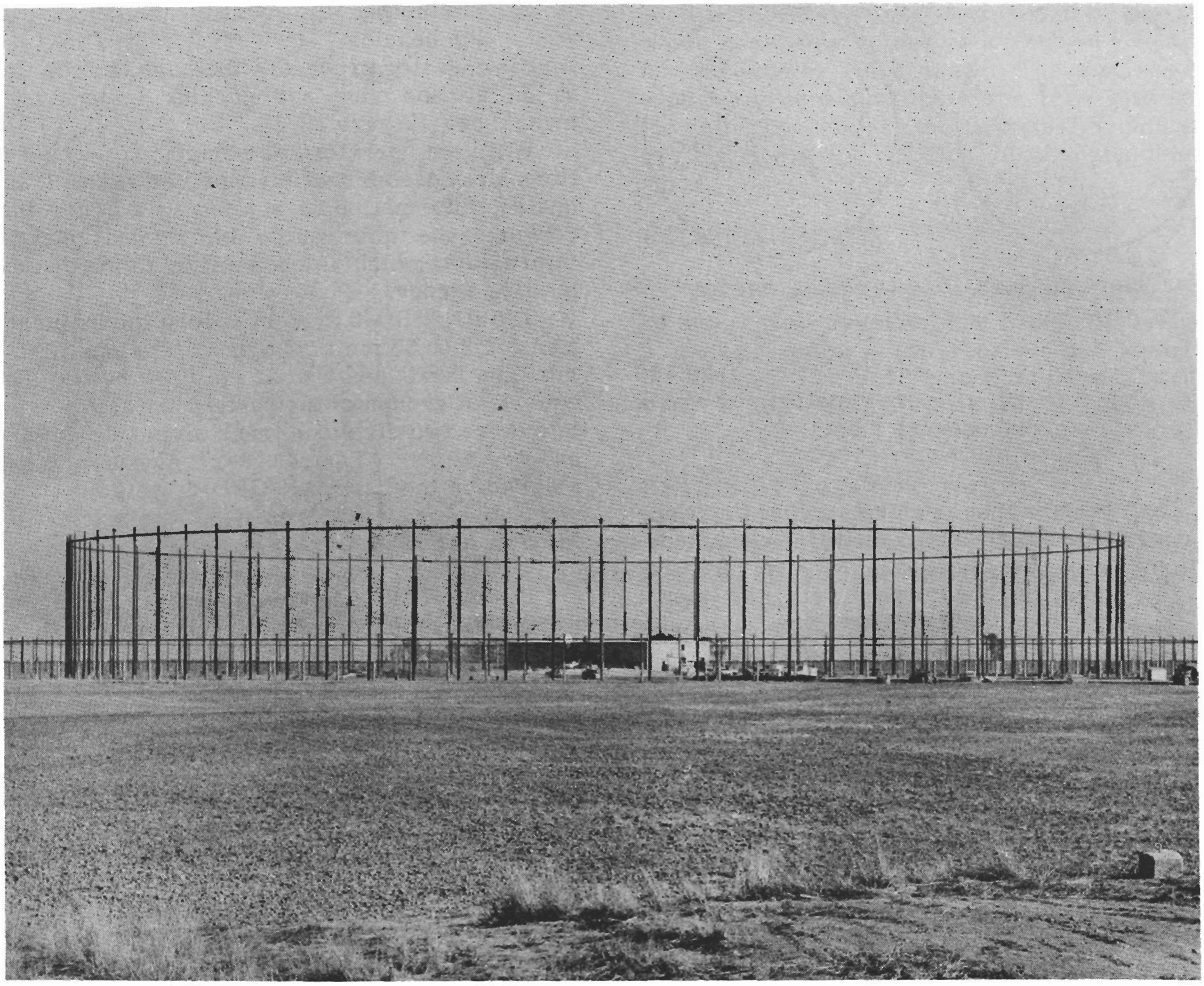
After the bearing pattern is obtained, the crossed loops of the system are combined with the sense antenna to give a cardioid pattern as shown by the dotted line in figure 18-22. The cardioid, which is inverted in the same manner as the propeller-shaped bearing pattern, is shown by the solid line in figure 18-23. It is convenient to rotate the sense pattern by 90° on the oscilloscope screen so that it is symmetrical with the bearing pattern. Rotation is accomplished automatically, in the system illustrated in figure 18-21, by switching the output of the deflection amplifier to sense deflection coils, which are advanced 90° from the bearing deflection coils. At the same time, the sense antenna is switched into the circuit. After being rotated 90°, the sense pattern appears on the screen as in figure 18-24.

In operation, the bearing pattern is obtained first. The operator then rotates a cursor on the face of the oscilloscope so that it points in the direction of one of the tips of the bearing pattern. The direction he points the cursor is the direction from which he assumes the signal to be coming. Next, the sense button is pressed. If the sense pattern falls on the "tail end" of the cursor, he has assumed the correction direction; if the sense pattern falls in the direction the cursor is pointed, the operator knows that the true bearing is 180° from the assumed direction. Figure 18-25 illustrates the bearing and sense patterns for a transmitter that has a direct bearing on 000. The sense pattern is dotted to emphasize that the two patterns are not obtained simultaneously.



25.116

Figure 18-18.—AN/GRD-6 high band array.



25.117

Figure 18-19.—Circularly Disposed Antenna Array (Wullenweber System).

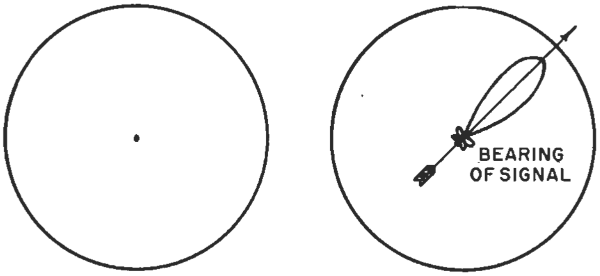
DIRECTION FINDER CENTRAL, AN/GRD-6

This section includes a description of an HFDF system. The AN/GRD-6 is used as an example to illustrate the equipments which are included in a direction finding installation. Because of the complexity of the equipments involved, this discussion is limited to a general, functional description. When a CT M is required to perform maintenance on the equipment, he will need to study carefully the instruction manual.

The AN/GRD-6 is a direction finder radio receiving system which automatically furnishes azimuth indications of radio signals within the frequency range of 2 to 32 mc.

BASIC SYSTEM OPERATION

In the AN/GRD-6 system, the direction of arrival of the signal is measured by utilizing the characteristic response of U-Adcock antennas. The actual sense of direction of the sources of r-f radiation is determined from a combined response of the U-Adcock antennas and an omnidirectional monopole "sense" antenna. The resultant antenna signals are automatically converted into visual indications by the associated operating equipment.



NO SIGNAL PRESENT
A

SIGNAL PRESENT
B

25.119

Figure 18-20.—DF presentations on a cathode-ray tube.

The operator then performs some simple operations to interpret and evaluate the visual indication. These operations, in general terms, are:

1. Lining up a cursor with the visual pattern on the indicator.
2. Determining the "sense"
3. Evaluating the quality (reliability) of the bearing.

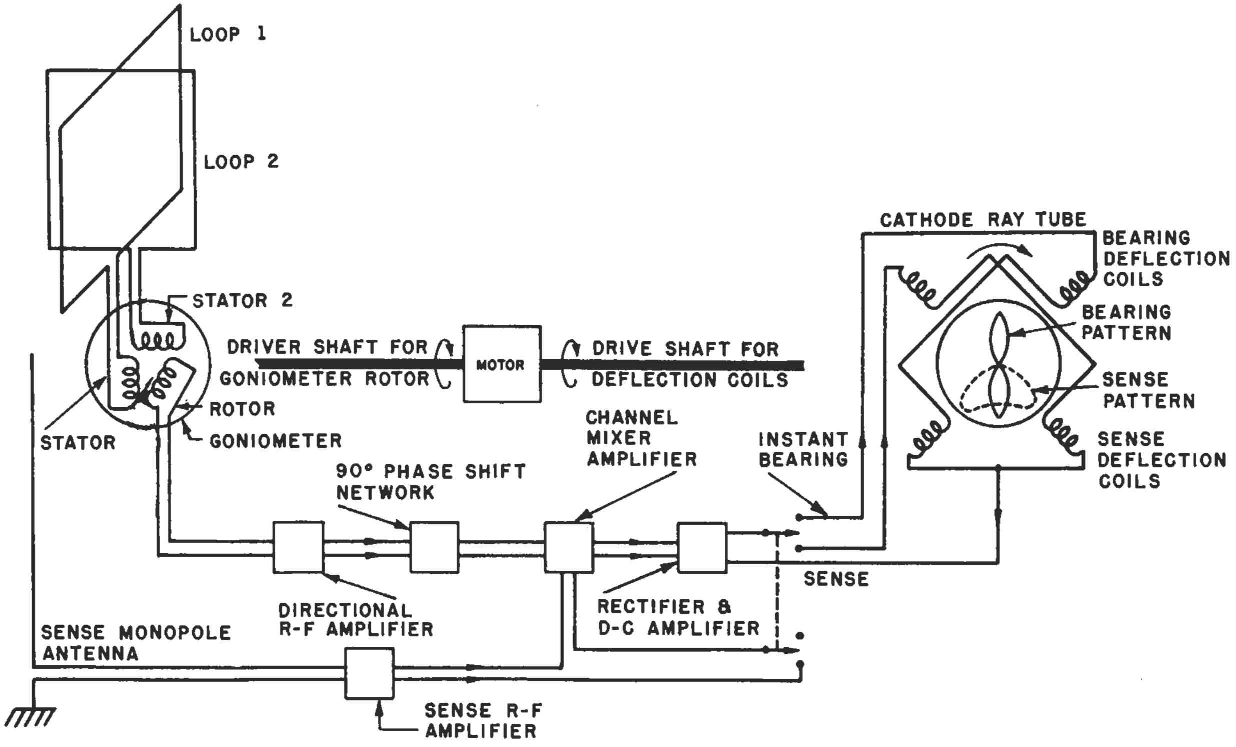
Actual operator procedure includes the rotation of an alidade ring and pushing buttons on a switchbox. (Figure 18-26.)

When the operator has performed the operations in a prescribed manner, the azimuth and quality information is applied to a coder that converts the information into coded teletype information which is transmitted to the central plotting agency.

The AN/GRD-6 system covers the frequency band of 2 to 32 mc in two band divisions, 2 to 8 mc (low band) and 8 to 32 mc (high band). The equipment groups of the system are also divided into these two divisions, each division requiring an operator. Figure 18-27 shows a block diagram of the basic AN/GRD-6 system.

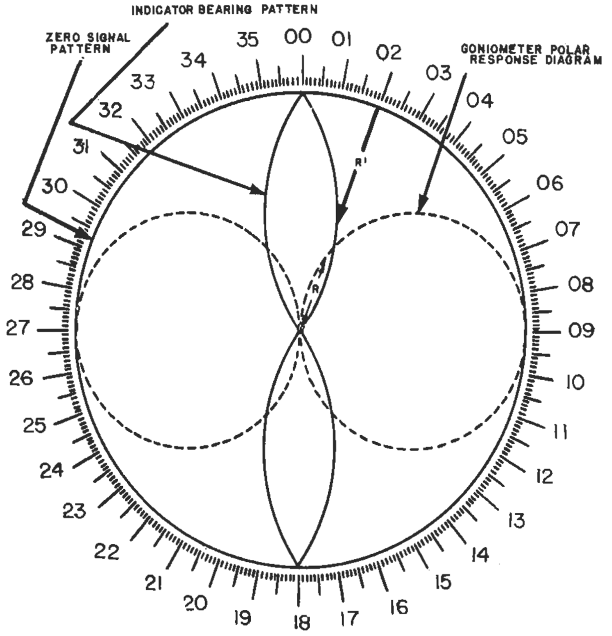
MAJOR SYSTEM GROUPS

The AN/GRD-6 system has three equipment groups that correspond directly to the three



25.120

Figure 18-21.—Block diagram of an automatic-bearing-indicator system.



25.121

Figure 18-22.—Figure-of-eight pattern inverted to give the indicator bearing pattern.

basic components of any radio direction finding system: a directional antenna array, a radio receiver, and a bearing indicator. In addition, the AN/GRD-6 system has a bearing coder group. As each of the groups is discussed, refer to figure 18-28 to associate the group's functional relationship to the system.

ANTENNA GROUP

The Antenna Group of the AN/GRD-6 system consists of two antenna arrays, one for low band (2 to 8 mc) and one for high band (8 to 32 mc) operations. The antenna elements used for both arrays are vertical monopoles forming U-Adcock antennas. The low-band elements are terminated, folder monopoles. The high-band elements are broad-band sleeve or cage-type antennas. To eliminate "loop effect," each of the individual low-band antenna elements is arranged with symmetrically disposed down leads (figure 18-29) which cause currents to be equal and opposite, thus eliminating the loop effect of the down leads while still allowing the element to operate in the normal manner.

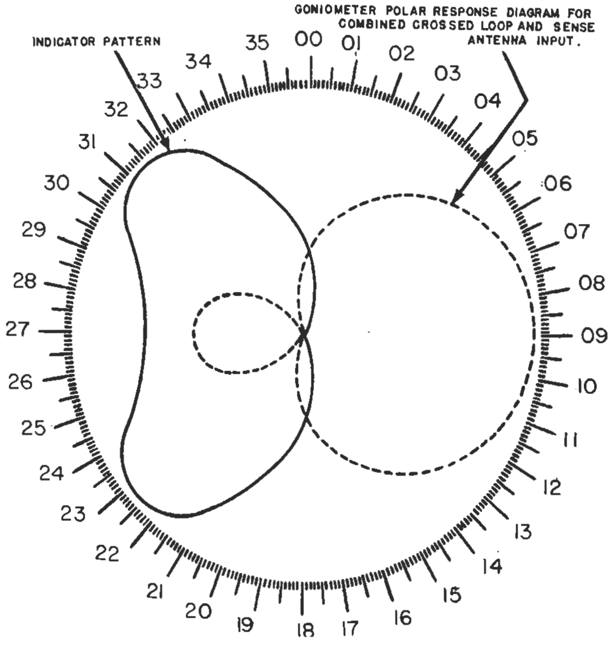
The other component of the antenna array used with the AN/GRD-6 is a pulse generator which generates pulses at a frequency equal to the goniometer rotor speed. These pulses are used for synchronization of the drive system of the deflection coils in the cathode-ray indicator to the speed of rotation of the goniometer rotor.

RECEIVING GROUP

The receiving group for each band is made up of a tunable receiver (the R-665/GRD-6) and a power supply. The receiver r-f tuning is divided into 4 bands. Band 1, 2 to 4 mc; band 2, 4 to 8 mc; band 3, 8 to 16 mc; and band 4, 16-32 mc.

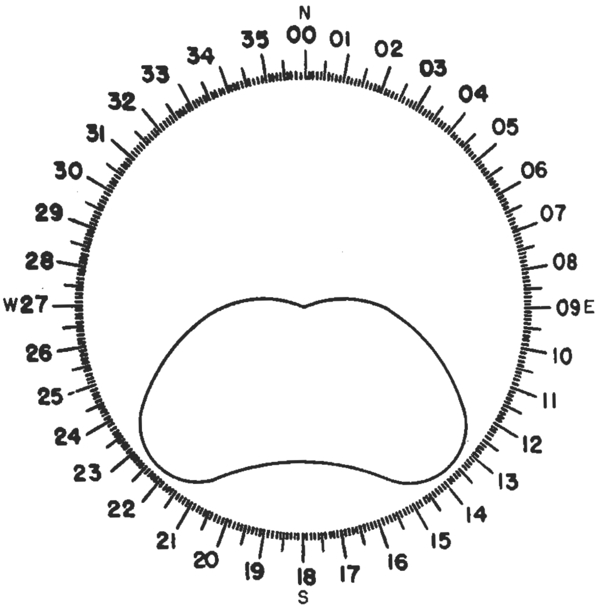
BEARING INDICATOR GROUPS

The bearing indicator groups are ordinary magnetic deflection cathode-ray tube displays with circular sweeps. The sweep speed is synchronized with the goniometer rotor speed. The deflection is adjusted in such a manner that for



25.122

Figure 18-23.—Cardioid pattern of combined loop and monopolė antennas, and inverted indicator pattern.



25.123
Figure 18-24.—Sense pattern after a rotation of 90° on indicator screen.

no signal the spot is traveling around the edge of the screen; and when the signal is maximum, the spot is at the center of the screen. With this arrangement, the familiar propeller pattern develops from the Adcock antenna system response.

Bearing Coder Group

Visual bearing azimuth indications and relative bearing information as to quality and sense determination of the bearing are observed and interpreted by the operator. This bearing data is then translated into teletype code and automatically transmitted to recording equipment by the Bearing Coder Group.

Bearing information, as observed by the operator, is set up by rotation of the alidade ring on the indicator to correspond with the bearing of the signal. This operation rotates coded disks within the alidade reader which are used to set up the resultant teletype code. After the alidade ring has been positioned, the operator pushes the sense switch on the indicator panel and notes whether the alidade pointer is pointed in the correct direction. Depending on the sense, he pushes one of two buttons (RECIPROCAL or DIRECT) on the bearing coder switch box. He next pushes one of four pushbuttons which correspond to the operator's evaluation of the quality of the determined bearing. Upon pushing the QUALITY pushbutton, the following cycle occurs:

1. A relay in the bearing sender corresponding to the quality pushbutton depressed locks up.

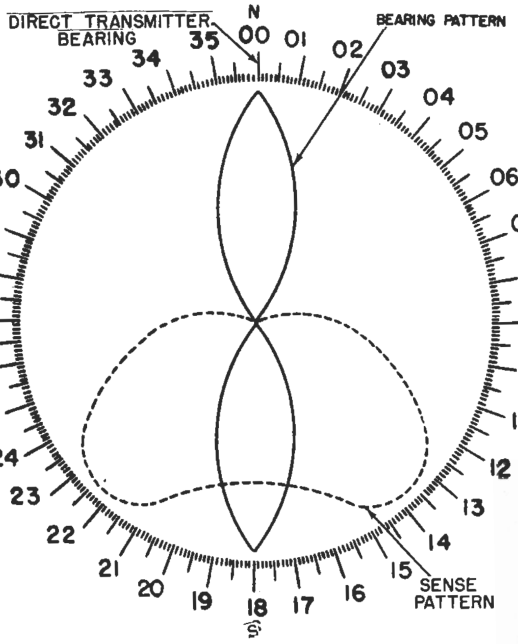
2. The relay contacts provide ground to the five-wire quality circuit according to the teletype code for the quality letter selected.

3. At the same time, a magnetic brake assembly stops rotation of the bearing translator (alidade reader) shaft and the alidade.

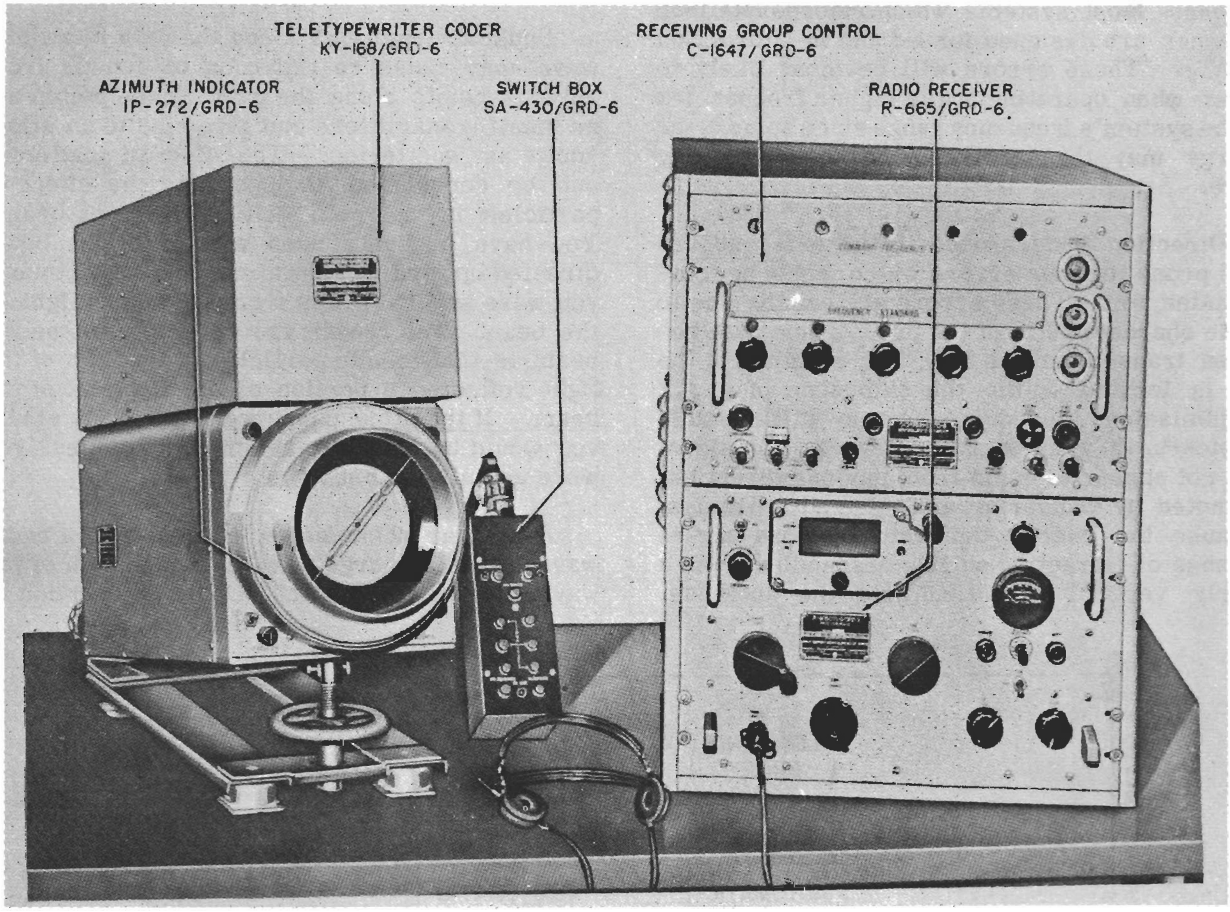
4. The alidade reader motor starts to rotate a multi-track cam against which followers are held by spring pressure.

5. The followers drop in order and allow the half-degree, the degree, and the one set of the tens and hundreds degree fingers to successively engage the slotted discs in the alidade reader.

6. The teletype distributor starts to rotate and sends out bearing information until the bearing, derived from open and closed circuits on switches associated with the half, units,



25.124
Figure 18-25.—Bearing and sense patterns.



34.36

Figure 18-26.—Typical operating position (AN/GRD-6)

tens, and hundreds fingers, and the quality letter derived from the quality relay has been sent out.

This concludes the discussion of the AN/GRD-6. Because of the complexity of the equipment, it has been impossible to outline the details of electrical and mechanical operation. When corrective maintenance is required on the AN/GRD-6, the procedures outlined in chapter 7 of the instruction manual should be carefully studied and followed. Chapter 7 includes charts to assist the technician in localizing the faulty portion of the equipment and charts to assist in analyzing the probably cause of the fault. The procedures for routine preventive maintenance, as outlined in chapter 6 of the instruction manual, should be performed at least as frequently as called for in the manual. In addition to assuring proper performance of the equipment, the routine maintenance checks are valuable to the maintenance technician in that they will familiarize him with the equipment—and familiarization is a prerequisite to competent performance of corrective maintenance.

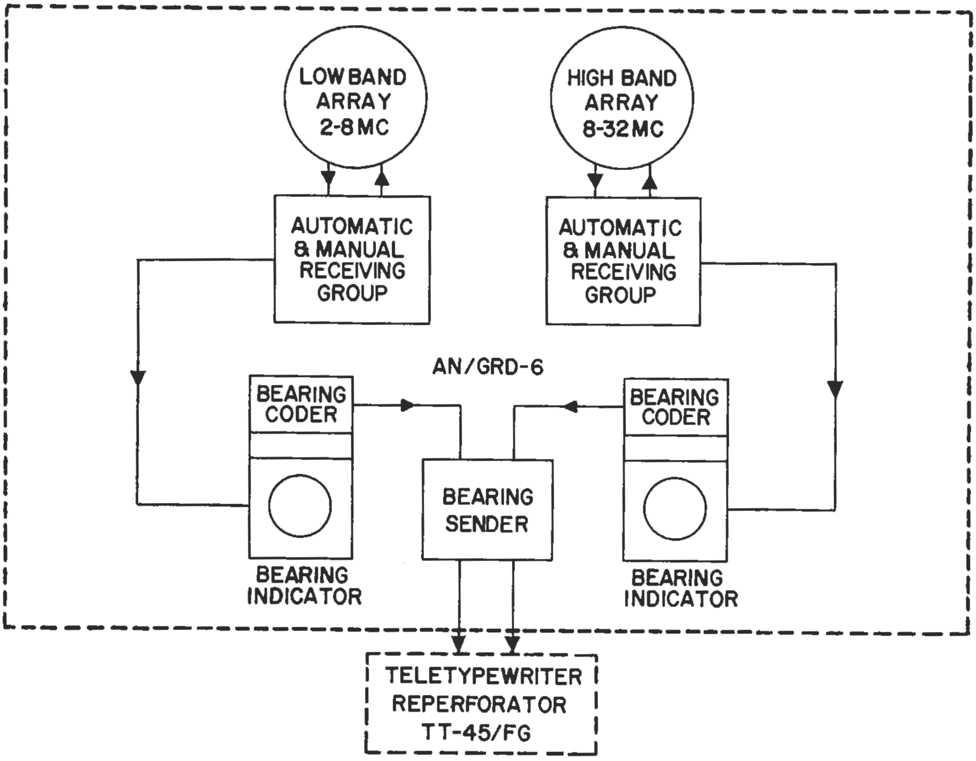
DIRECTION FINDER ERRORS AND CALIBRATION

Some of the errors of direction finders have already been discussed; for example, loop effects. If the direction finder antenna system has horizontal components, polarization error or night effect will cause erroneous DF bearings. The susceptibility of a DF system to polarization errors is a result of its design; little can be done to compensate for these errors. Most systems which incorporate loop antennas are designed for l-f and m-f direction finding. These errors will be most likely to occur when operating at the higher frequencies of the system's frequency range since some of the energy may then arrive by means of the sky wave.

Direction finders used in the h-f band are also prone to some errors which cannot be compensated for. These errors are usually due to some characteristic of the propagation path between transmitter and DF. For example, if the DF is located within the skip zone of an HF transmission, the equipment may still be able to pick up a weak signal. However, the signal will not appear to come from any one direction, as noted by wandering and unsteady displays, because the energy that actually does arrive because of refraction will be descending from a nearly vertical direction onto the antennas. Thus, the angle of incidence in the horizontal plane is extremely difficult to determine.

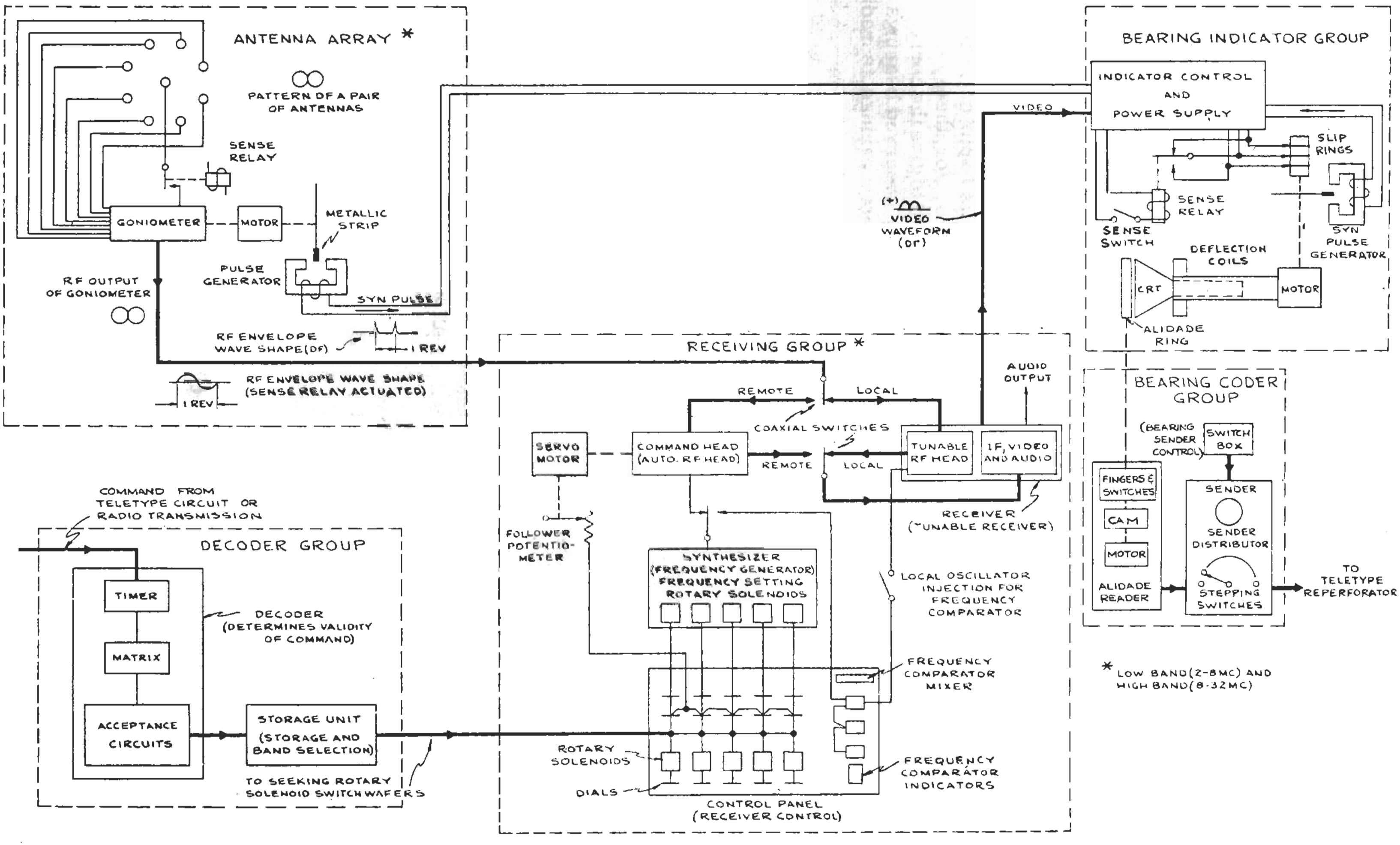
Unusual conditions along the path of a radio wave may cause re-radiation of signals from various points along the path. These points act as small transmitters and give rise to an effect known as "scattering." The effect of scattering can be considered analogous to the effect of particles in the path of a searchlight beam. You have probably seen a searchlight beam directed upward into the atmosphere even though you were several miles from the searchlight or the beam. The reason you were able to see the beam is that minute particles in the path of the light reflected a portion of the light out of the beam. If the atmosphere were perfectly clear, you would be unable to see the beam unless you were actually within it.

A similar phenomenon occurs with a radio wave. Small charged areas in the path of the wave tend to reflect or "scatter" a portion of



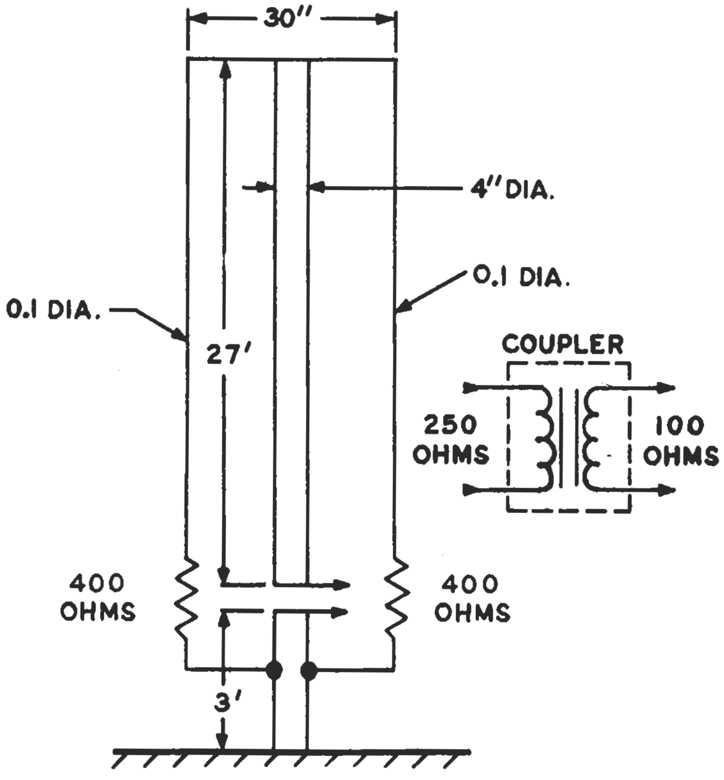
25.125

Figure 18-27.—Direction finder central AN/GRD-6, function block diagram.



25.126

Figure 18-28. —Direction finder central AN/GRD-6, simplified over all block diagram.



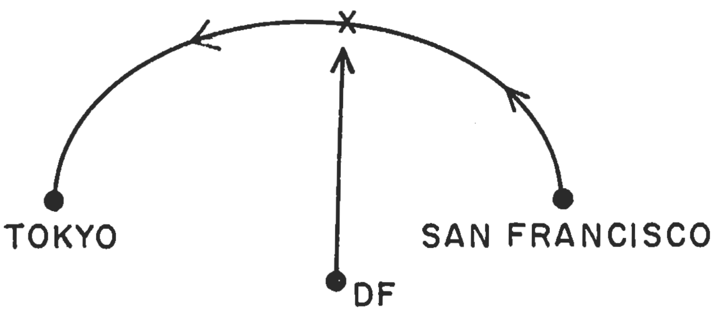
25.127
Figure 18-29.—Terminated folded monopole.

the wave from its normal path. A dense "charge cloud," such as might be created by a meteor or comet trail in the path of a radio wave, would reflect a large amount of energy. Reception due to scattering produces many confusing effects on a DF. The scatter points may cause a DF within the skip zone or far beyond the normal range of a signal to receive a strong signal. The DF bearing obtained will be on the scatter point, not on the transmitting station, and the scatter point may be far removed from the great circle path between the DF and the original transmitter. Thus, it is possible to obtain bearings which are up to 180° in error because of the effects of scattering. Figure 18-30 illustrates the effects of scatter points on DF. Fortunately, at most times when scattering causes reception within the skip zones, or causes distortion of signals received within the ordinary area of reception, the display tends to wander, thus giving the operator warning as to the reliability of the bearing.

A source of error in all DF systems is caused by locally re-radiated signals which may be caused by the reflecting effect of wires, masts, buildings, trees, etc. in the vicinity of the DF antenna. The effect of re-radiated fields on a DF antenna is known as the quadrature effect because it causes an induced voltage component in the DF antenna which is a quadrature (90°) with the voltage induced by the true signal. The result of re-radiation of the r-f wave is to deviate, or displace, the null of the DF antenna response. Direction finders which are located in confined areas, such as on board ships, are almost certain to have deviation of their nulls because it is impossible to completely isolate the DF antenna system from other antennas, masts, etc. Therefore, it is necessary for such DF systems to make experimental measurements of direction to radio transmitters of known bearings. The DF bearings obtained on these stations of known bearings are compared with the true bearings to plot calibration curves, or deviation curves, for the system. These curves are consulted to give the correction which must be applied to observed bearings in order to obtain the correct bearings to radio transmitters.

Direction finders located at fixed sites are generally located in remote areas where the effect of local re-radiation can be removed or at least minimized. In order to ensure the accurate performance of a fixed DF, however, local error tests are conducted periodically in accordance with the instruction book for the particular system. These tests are normally conducted semi-annually or after any major change in equipment or site area.

The general procedure for local error calibration of an HF direction finder is as follows. A small target transmitter is accurately positioned in azimuth (by the use of a transit) at a prescribed distance from the DF antenna. For each position of the target transmitter, DF



25.128
Figure 18-30.—Reception from scatter point.

bearings are taken at a series of frequency check points. While the bearings are being taken, extreme care must be taken that no persons or metallic tools, tapes, wires, etc. are in the vicinity of the DF array or the transmitter. Any such items will tend to re-radiate the signal and cause an error in the observed bearing. This procedure is repeated at prescribed intervals of azimuth. (For the AN/GRD-6 the intervals are every 10°.) Errors noted by this procedure (for each frequency) are usually plotted versus azimuth and compared with the error curves obtained from the previous calibration checks. The maximum error at any frequency and azimuth check point should be no greater than plus or minus 3 degrees.

It should be noted that the local error test just described is valuable in determining, insofar as possible, the performance of a DF installation. The error curves obtained are not, however, used as correction curves on the bearings of actual targets. In most instances the error curves obtained in the local error test would be quite different from the error curves which would result from long-range signals. Because of the extreme difficulty (or impossibility) of performing a long-range calibration test, operations personnel have a prescribed method for determining the accuracy of a given DF station. Daily bearing checks are observed on stations of known azimuth and frequency to ensure that normal operating conditions exist. Any radical departure from normal operation should be easily determined by the operator. In addition to the local daily bearing checks, the central plotting agency of a DF net ordinarily requires the stations of the net to take bearings on known fixed targets. The bearings obtained by the individual stations are recorded and tabulated. A statistical analysis of the bearings is made to provide a measure of performance for evaluation and comparison of direction finders. Of the various quantities which can be obtained by statistical analysis, the systematic error (arithmetic mean error) and the standard deviation are the most commonly used. The systematic error is an average value, which balances out both accurate and inaccurate readings, both positive and negative, and furnishes a measure of the performance of the direction finder as an overall system. The standard deviation is a measure of the spread of the bearings about the systematic error. A systematic error which is as small as possible is desired as an indication of the absence of site and equipment error. Likewise, a small standard deviation is desirable since it indicates that the spread of the bearings about the systematic error is narrow and the bearings are consistent.

MAPS USED IN DF PLOTTING

Radio waves travel in great circle paths along the earth's surface. For DF plotting purposes, it is desirable that these great circle paths be shown as straight lines on a map to simplify the problem of plotting. A special map projection having this quality has been designed, the Gnomonic projection, but although great circles appear as straight lines, distances and shapes must be distorted, and hence the maps are of use only for DF and navigational purposes. Other maps which can be used for DF plotting are the Lambert conformal conic projection and the Mercator projection. The Mercator projection can be used for fairly accurate results up to a distance of 50 miles without correction and from 50 to 200 miles with correction for angular distortion, but should not be used at distances greater than 200 miles because of extreme distortions which result. The location of a transmitter can be determined by plotting several intersecting bearings on a map; this process is sometimes called radio position finding. The term "cut" designates one station's bearing on a target and a "fix" is the intersection of two or more cuts.