Chapter 10

Radio direction finding

10.1 Introduction

With the advent of the GPS and the massive leaps forward in microelectronic technology, the system of radio direction finding (RDF) looks distinctly aged. It is, of course, the oldest of the position fixing systems having been around in one form or another since the First World War. RDF systems used throughout the last century owed their existence to Sir R. A. Watson-Watt who invented the original concept and to Adcock who designed the non-rotating antenna system that eliminated the earlier troublesome mechanical rotating antenna. To this day, RDF system principles remain unchanged, it is the signal processing and computing functions offered by modern microelectronics that has propelled RDF into the 21st century.

Once the mainstay of maritime position fixing the medium frequency RDF receivers and the large loop antenna that once dominated a ship's superstructure, have now been assigned to the scrap heap. But RDF is still alive and modern vessels do carry VHF RDF equipment. It is still an efficient system for localized position fixing and remains the only method for finding the bearing of a transmitter in an unknown location. If the relative bearings taken by two suitably equipped ships are laid-out on a chart, the two bearing lines will intersect at the position of the unknown transmitting station. Such a station need not be a radio beacon. It could be a vessel in distress and thus the two receiving ships are able, by triangulation, to pinpoint the distress position at the intersection of vectors drawn on a chart from their two known locations. Naturally, the same holds true for two land-based RDF stations.

Because the use of RDF at sea has diminished over the years, its description in this book has been simplified. Whilst the system principles remain the same, the standard of the receiving equipment has dramatically improved and automatic direction finders now dominate the field. The nature of radio waves and the antenna system is of prime importance in understanding the system and Chapter 1 should be read before continuing with this chapter.

10.2 Radio waves

Radio direction finders work efficiently when using the properties of ground waves or space waves travelling parallel to the earth's surface. Sky waves reflected from the ionosphere seriously affect system accuracy and should be disregarded.

A propagated radio wave shown in Figure 10.1 possesses both electrostatic and electromagnetic fields of energy. It is the plane of the electrostatic field that is used to denote the polarization characteristic of the wave. A radio wave possessing a vertical electrostatic field therefore indicates a vertically polarized transmission. An electromagnetic field lies in quadrature to the vertical electrostatic field. Maritime direction finders use the properties of this horizontally polarized field transmitted from an omnidirectional antenna system.

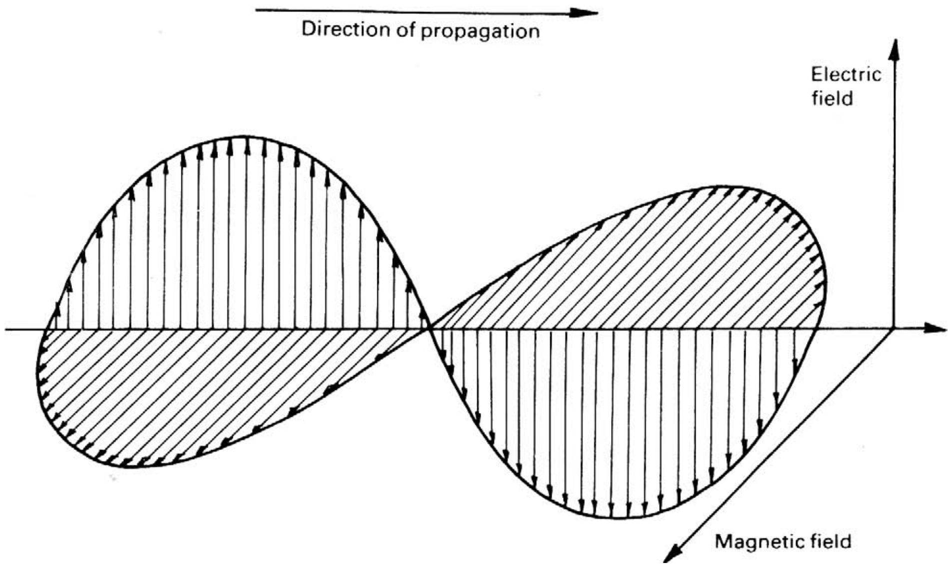

Figure 10.1 A propagated radio wave illustrating the relationship between both fields of energy and the direction of propagation.

10.3 Receiving antennae

This is without doubt the critical component in a RDF system. The electromagnetic component of the radio wave induces tiny voltages termed electromotive forces (e.m.f.) into any vertical conductor (antenna) in its path. If the conductor is a single vertical wire (an omnidirectional antenna), a tiny current will be caused to flow along its length under the influence of the induced e.m.f. The amplitude of the current flow, when applied to the input of a receiver, depends upon a number of factors, but for a given transmitter with a constant power output, it is effectively governed by the distance between the transmitter and the receiver. The frequency of the induced e.m.f. will, of course, be the same as the transmitted frequency.

10.3.1 A dipole antenna

A vertical dipole antenna possesses the ability to transmit or receive equally well in all directions and is therefore termed omnidirectional. If a transmitter is arranged to follow a circle at a constant distance from an omnidirectional antenna, the induced e.m.f., at the receiver input, will be constant for all vectors. The pattern thus produced is called the azimuth gain plot (AGP), or sometimes the polar diagram, and illustrates the receptive properties of a vertical antenna as shown in Figure 10.2.

By measuring the induced e.m.f. for all receiving vectors, it is a simple matter to produce an AGP for any antenna. The length of the radial vectors corresponds to amplitude and therefore, in this case, the strength of the signal produced at the receiver input will be constant throughout 360°. This antenna has been designed to be omnidirectional and is used in RDF systems as a 'sense' antenna to eliminate bearing ambiguity.

Other antennae are carefully designed to be highly directional. A simple example of this is a Yagi antenna, which is commonly used to receive television pictures and sound. In fact it is possible to use a Yagi antenna and its maximum strength signal indication, to determine the bearing of the

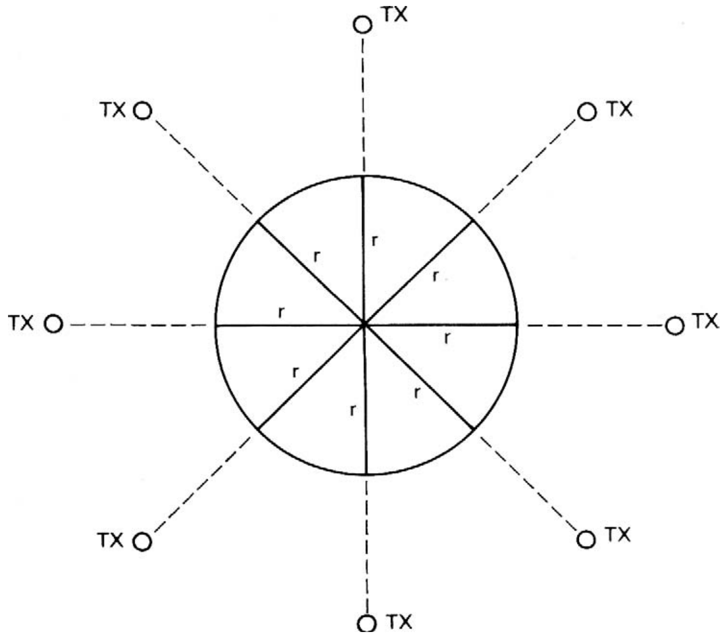

Figure 10.2 The AGP reception plot for a vertical antenna. The antenna is at the centre of the circle.

transmitting station. Maritime RDF systems, however, use the properties of a simple loop antenna or an Adcock array, and produce a relative bearing indication from a zero or null signal strength.

10.3.2 A loop antenna

A simple loop antenna consists of two vertical conductors closed at the top and base to permit current to flow. If the effect of sky waves is ignored (see Polarization error), the shape of the loop is unimportant and for convenience it is often circular. Figure 10.3 shows two vertical antenna joined at the top and at the base via a coil to enable the antenna to be coupled to the input of a receiver.

To be effective the distance between the vertical conductors must be less than one wavelength of the received frequency. For this description, if we assume the distance between the vertical arms to be half of one wavelength and the direction of propagation as shown in the diagram, then maximum e.m.f.s will be induced in both arms AB and CD. The e.m.f.s will cause current to flow through the coil under the influence of an e.m.f. that is the product of the two vertical portion e.m.f.s.

$$\text{Resultant e.m.f.} = (\text{e.m.f. AB}) + (\text{e.m.f. CD})$$

If the direction of the received wave is in the plane shown, or 180° away from it, the resultant current flowing through the pick-up coil will be at its greatest and a maximum signal input to the receiver will result. The single electromagnetic wavelength shown will be at 90° in relation to the vertical antenna arms.

With the transmitter at any angular position from the loop, e.m.f.s will be induced in both vertical arms. The relationship between the plane of the loop and the wavefront will determine the polarity of the induced e.m.f.s, which in turn determines the direction and amplitude of the resultant current

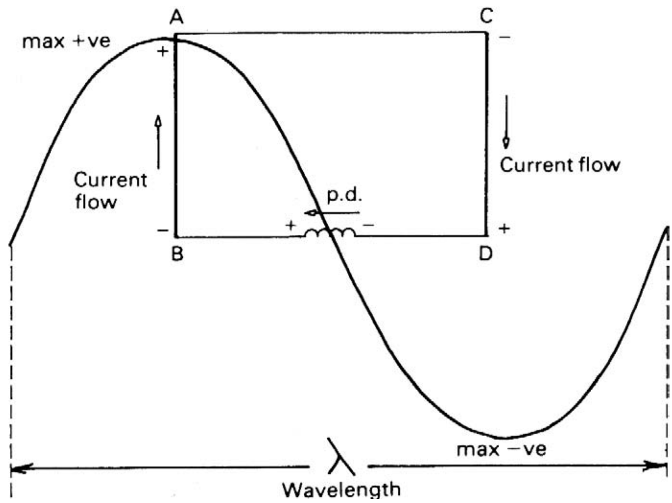

Figure 10.3 Signal currents induced in the vertical arms of a loop antenna produce a resultant potential difference across the input coil to a receiver.

flowing through the inductor. For convenience we shall consider the plan view of the loop and the wavefront of the propagated signal.

Figure 10.4(a) shows that when the wavefront is parallel to the plane of the loop the e.m.f.s induced in both arms will be of equal amplitude and the same polarity. The two will therefore cancel producing no resultant current flow in the inductor and hence no input to the receiver. This is called a null position because at this point the audio output from a receiver drops to zero. Clearly there will be a second null position, 180° away from the first.

If the loop is turned so that its plane is now 90° with respect to the wavefront, two e.m.f.s will again be induced in both vertical arms, but they will be of equal amplitude but opposite polarity. This causes a maximum circulating current to flow through the coil and a maximum output from the receiver (Figure 10.4(b)). This situation corresponds to a maximum input to the receiver. Once again there will be a second maximum 180° away from the first, the only difference being that the resultant current will flow in the opposite direction through the coupling coil. The AGP produced by such a rotating antenna is shown in Figure 10.5 and for obvious reasons is called a 'figure-of-eight' diagram.

A transmitter bearing north or south produces a resultant null output. A transmitter bearing east or west produces a resultant maximum output.

10.4 A fixed loop antenna system

At the heart of this system are two permanently fixed loop antennae, mounted on the same mast or base at 90° to each other, one on the fore-and-aft line and the other on the port-and-starboard line of a vessel. An early manual RDF input system is shown in Figure 10.6 to illustrate the principle.

In this case each precisely mounted loop antenna is connected to a pair of precisely aligned fixed coils in a goniometer, a tiny transformer arrangement recreating the electromagnetic fields of the loop antennas. A search coil, able to rotate through 360° inside the fixed coils is tuned to the incoming frequency by the tuning capacitor, C. The resultant circulating current flows through the primary winding of T2 to provide the input to the receiver. The vertical antenna is coupled to the circuit via

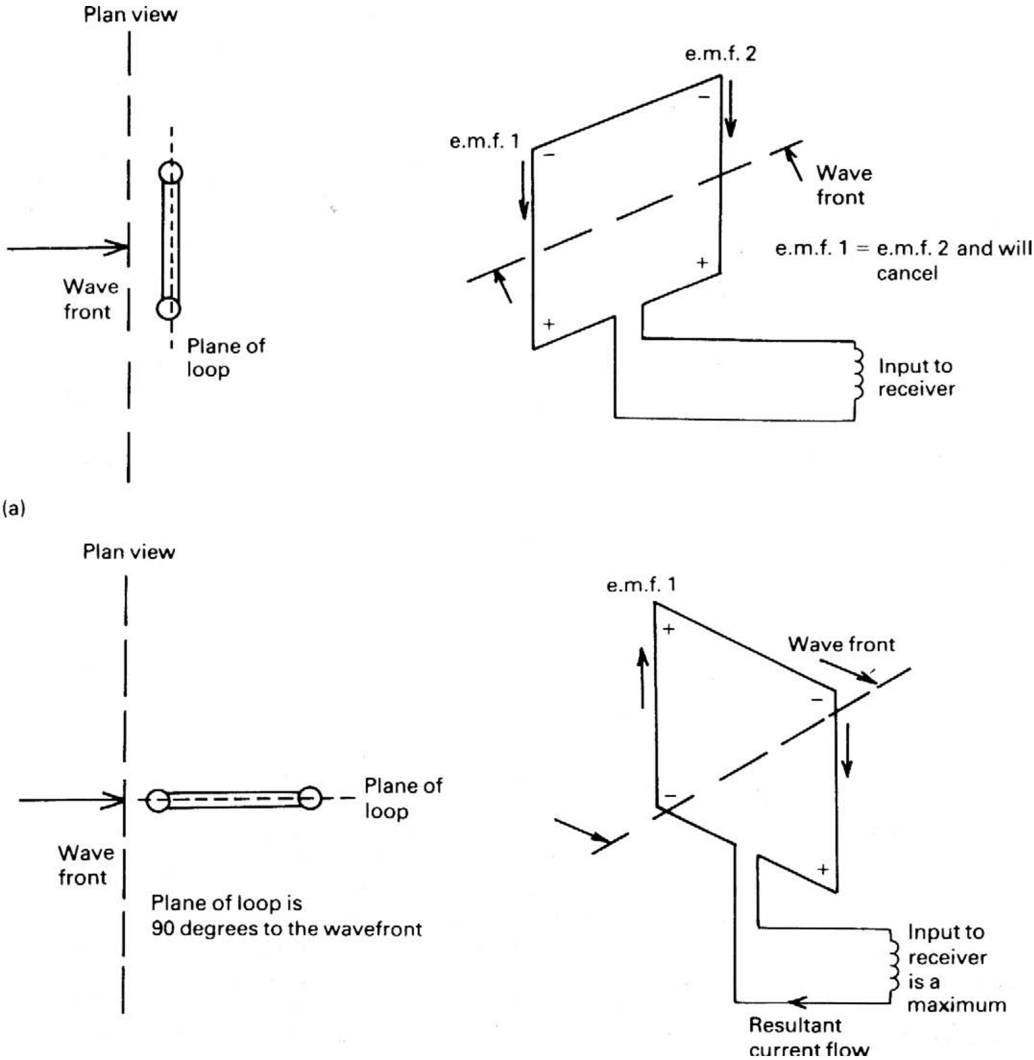

Figure 10.4 (a)The resultant input to a receiver is zero if the plane of the loop is parallel with the travelling wavefront.(b)The input is a maximum if the loop plane is at 90° to the received signal.

T1. In effect, the goniometer has created a miniaturized version of the rotating loop antenna system without its mechanical disadvantages.

Induced currents in each loop are caused to flow through corresponding fixed field coils in the goniometer. The amplitude and phase relationship of each of the currents will depend upon the relationship between the plane of each fixed loop and the wavefront of the received signal. Current flows will create a magnetic field around the fore-and-aft, and port-and-starboard field coils of the goniometer. A fully rotatable search coil is inductively coupled to each of the field coils. In this way the mutual inductance between the search coil and the field coils follows a true cosine law for any angular position of the search coil to the field coils through 360° of rotation. If the search coil is rotated fully the input to the receiver will consist of a varying signal producing two maxima and two

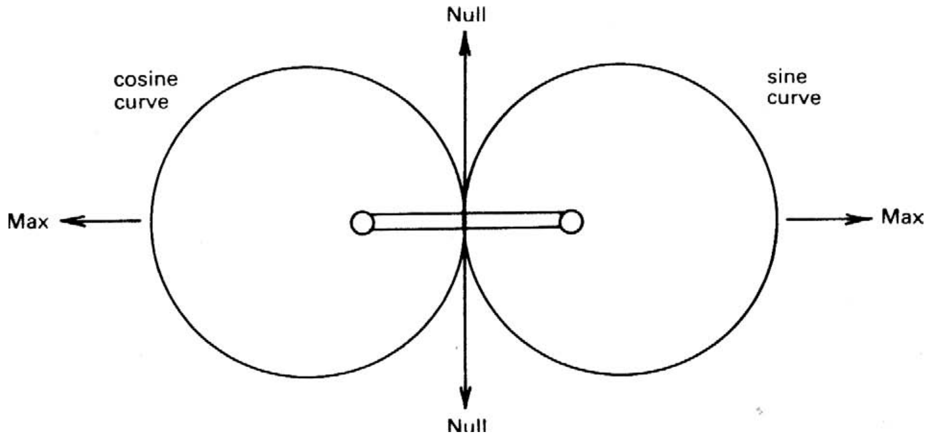

Figure 10.5 The figure-of-eight azimuth gain plot for a loop antenna.

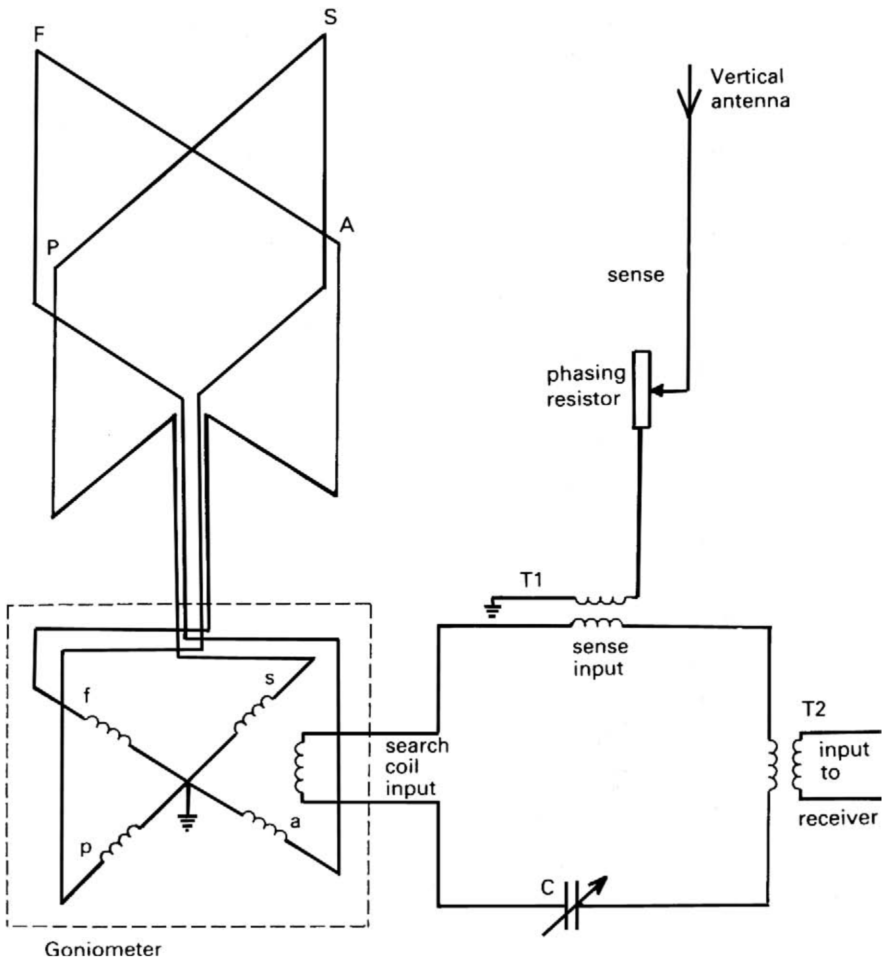

Figure 10.6 A simple receiver input circuitry for a fixed loops system.

minima positions. A figure-of-eight polar diagram will be created artificially in the confined environment of the goniometer.

Obviously the construction of the goniometer is critical. Early automatic RDF equipment used a tiny servomotor to rotate the search coil but modern equipment dispenses with the mechanical interface and uses software processing to eliminate the reciprocal bearing and produce a true indication.

10.4.1 The Adcock antenna

Adcock arrays are capable of covering wide frequency ranges, but for maritime VHF use, the bandspread is relatively small and simple antennas can be used. An Adcock element pair is constructed using two omnidirectional antennas spaced apart by a fraction of the received frequency wavelength in the horizontal plane. Such an arrangement produces an AGP as shown in Figure 10.5. In practice two Adcock pairs are mounted at right angles to each other forming an array.

As in the loop system, Adcock elements are spaced at a fraction of a wavelength apart, often in the region of one-eighth to one-third of the received carrier wavelength. In practice Adcock arrays produce more sharply defined figure-of-eight plots if the spacing between active elements (d) is small. Taking the marine VHF communications band at approximately 150 MHz (Channel 16 is 156.8 MHz), one half a wavelength is approximately 1 m and one-eighth wavelength is 25 cm or 10 inches. In Figure 10.7(b), the Adcock array is mounted on a ground conducting base plate, called a ground plane, and the active elements are insulated from it. Distance d between the active elements is a constant.

Figure 10.7(c) shows the electrical equivalent of an Adcock array. Induced signal currents $i1$ and $i2$ produce a resultant difference current in the receiver input circuitry. The magnitude of this current is proportional to the element spacing d and the length L of the elements. Currents induced into the horizontal portions of the array, shown dotted in the diagram, are of equal magnitude and direction and will cancel. Like the loop antenna, the resultant azimuth gain plot is a double figure-of-eight with maximum gain being achieved in line with each pair of dipoles (see Figure 10.8). The length of the active elements L is also related to wavelength and because each arm is effectively a dipole antenna, L is likely to be one-quarter wavelength or a further subdivision of one wavelength.

On the arrangement shown in Figure 10.7(b), the central element is a sense antenna, the output from which is used to eliminate bearing ambiguity.

Eliminating the reciprocal bearing indication

The minima or null positions of the figure-of-eight AGP have been chosen to indicate the direction of the bearing because the human ear (used extensively for determining bearings in early systems) is more responsive to a reducing signal than to one that is increasing. For a single Adcock array or loop antenna, there are two null positions, one that indicates the relative (wanted) bearing and the other the reciprocal. Dual antenna arrays create quadruple null indications.

In many cases, reciprocal null indications pose no problem because the relative bearing will be the one that lies within the expected bearing quadrant from a known receiver. However, when taking the bearing of an unknown vessel, for triangulation plotting, it is not known in which quadrant the bearing will lie and therefore a second input to the receiver is required in order that the other null positions can be eliminated. To simplify the explanation, AGPs for a single loop antenna and a vertical antenna have been used. The result of adding the vertical antenna signal, sometimes called a 'sense' input, to the resultant loop signal for a single loop is yet another AGP which for obvious reasons is called a cardioid and is shown in Figure 10.9.

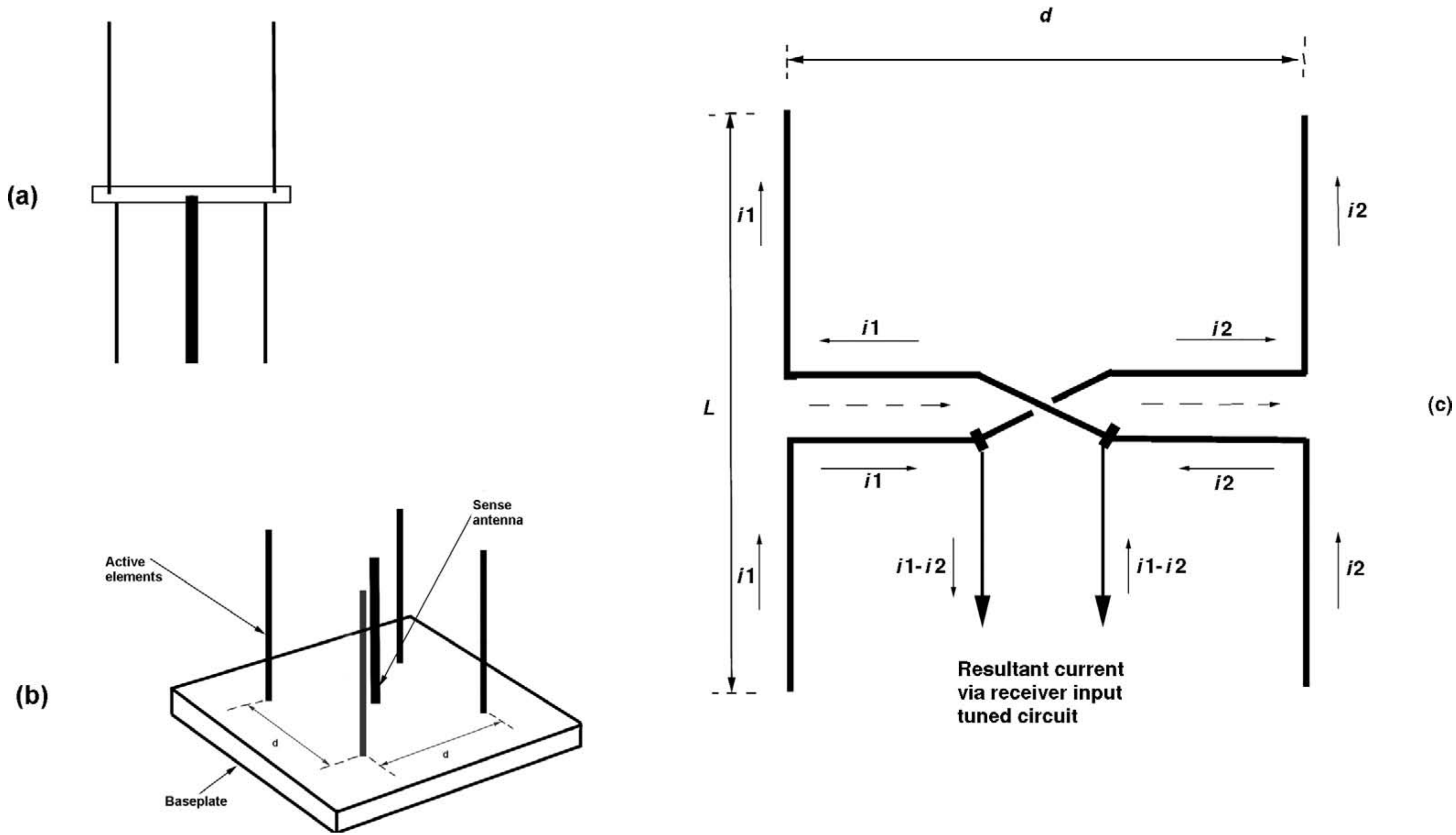

Figure 10.7 (a) A pole-mounted Adcock antenna and (c) its electrical equivalent. (b) A base plate-mounted Adcock array.

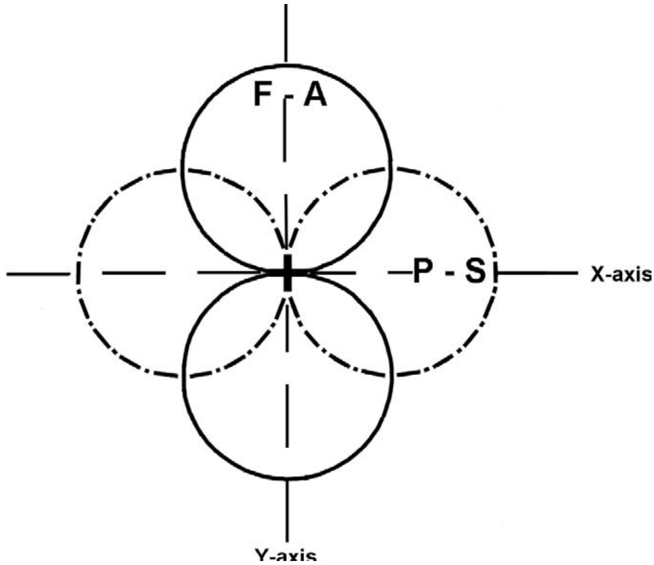

Figure 10.8 AGP diagram for an Adcock (or a crossed loop) pair.

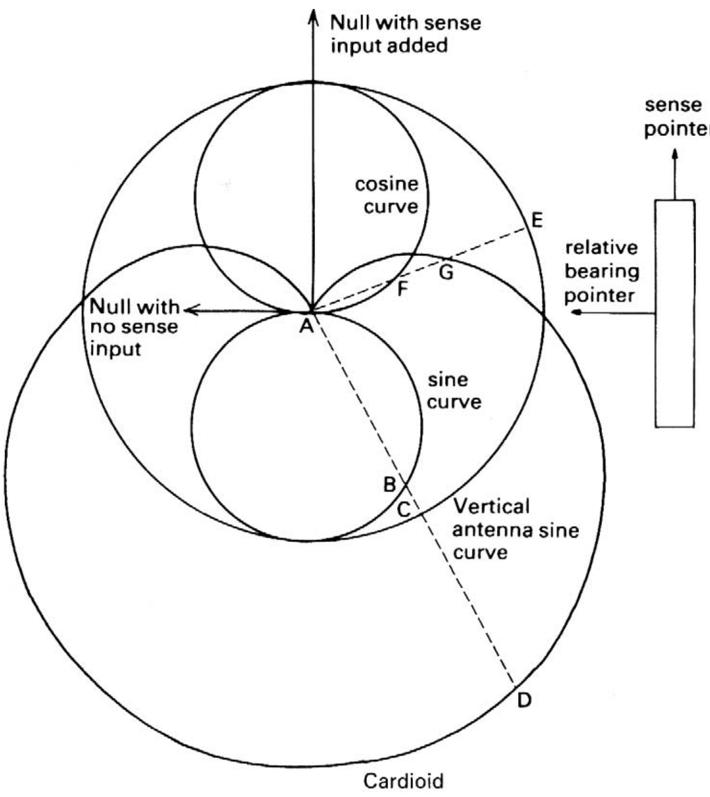

Figure 10.9 The resultant cardioid AGP produced by the addition of the figure-of-eight and circular plots.

The signal produced by the sense antenna is an omnidirectional sine curve whereas that of the loop figure-of-eight curve possesses both sine and cosine properties. The resultant cardioid is created by radially adding and subtracting the two signal levels. For the sine portion of the loop diagram, AB + AC = AD and for the cosine portion, AE – AF = AG. Unfortunately, although a new single null position has been produced, it has been shifted by 90°. This error is compensated for in the receiver bearing processing circuitry.

The result of adding a sense signal input to a dual loop or Adcock array is to produce a double cardioid and the further bearing ambiguity thus produced is again eliminated during computing. In fact it is possible for modern RDF receivers to produce a relative bearing without a sense antenna input. The microelectronic circuitry computes a virtual sense input for every position in azimuth.

10.5 Errors

Although RDF systems are subject to errors, caused mainly by environmental effects, if a fixed loop or Adcock RDF system is correctly installed and accurately calibrated the errors can be reduced to virtually zero. As with any electronic system, it is important to appreciate the error causes and cures. The major error factors affecting RDF systems installed on merchant ships are listed below. Some of these have minimal effect at VHF but they have been included here for reference.

10.5.1 Quadrantal error

This error is zero at the compass cardinal points rising to a maximum at 045, 135, 225 and 315°. Each maximum error vector falls into a quadrant and hence the error is termed quadrantal. The cause of the error is a re-radiated signal produced, mainly along the fore-and-aft line of the vessel, by the ship's superstructure receiving and re-radiating the electromagnetic component of the signal. All metallic structures in the path of an electromagnetic wave will cause energy to be received and then re-radiated. In this case the re-radiated signal is in phase with the received wave. The two signals arriving at the RDF antenna will be of the same frequency and phase and will therefore add vectorially causing the relative bearing to be displaced towards the fore-and-aft line of the vessel, as shown in Figure 10.10.

The new bearing is a vector sum of the received and re-radiated signals. The magnitude of the error depends mainly upon the vessel's freeboard and the position of the loop antenna along the fore-and-aft line. For a loop mounted in the after-quarter of the vessel, the effect will be greatest in the two forward quadrants, and vice versa for a loop antenna mounted in the forward quarter. Fortunately the error, for a given mounting position, is constant and is able to be eliminated. For a fixed crossed loop system, the fore-and-aft loop antenna, which is under greater influence from the unwanted signal than the port-and-starboard loop antenna, is made smaller. Also quadrantal error correction is more accurately achieved by placing a quadrantal error variable corrector coil in parallel with the fore-and-aft loop coil.

The effect of varying the inductance of such a coil during calibration is to reduce the signal pick-up along the fore-and-aft line of the vessel. Modern equipment also includes a smaller compensation coil across the port-and-starboard loop circuit. Correct alignment of these coils reduces the effect of quadrantal error.

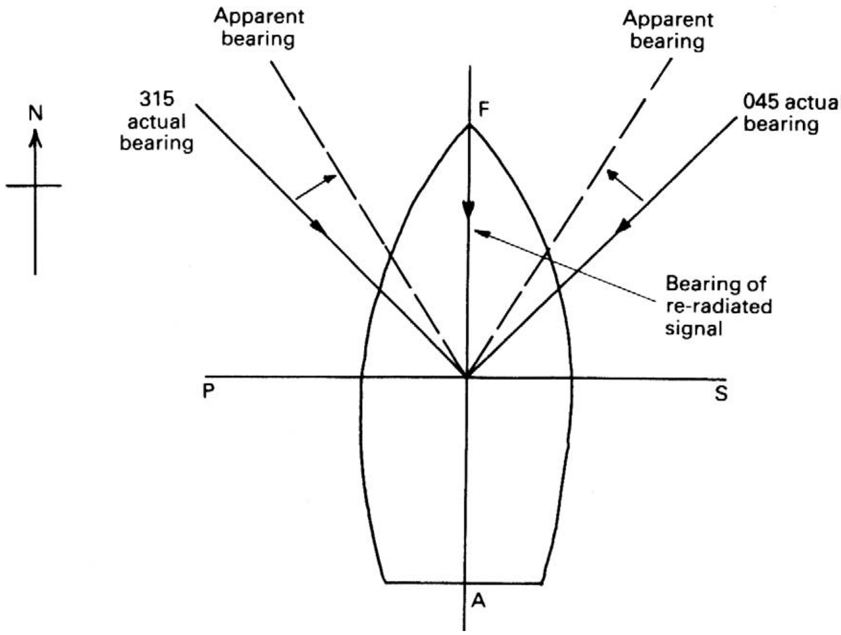

Figure 10.10 The effects of quadrantal error are to pull the bearing indication towards the vessel's lubber line.

10.5.2 Semicircular error

As with quadrantal error, semicircular error is caused by a re-radiated signal arriving at the loop antenna along with the received radio wave. In this case the re-radiated signal is produced by vertical conductors in the vicinity of the loop antenna. This re-radiated signal from such conductors is out of phase with the primary signal and will therefore cause an error that rises to a maximum in two semicircles. Conductors that produce an out of phase re-radiated signal possess a resonant length that is close to the half a wavelength of the received signal.

The most obvious of these conductors are the vessel's various antennae, but wire stays will also have the same effect. For re-radiation to occur, induced current must be able to flow in the conductor. To prevent current flow, wire stays may be isolated by inserting electrical insulators along their length.

10.5.3 Polarization error or night effect

A RDF system works on the principle that the electromagnetic component of a propagated space wave parallel to the earth's surface will cause small e.m.f.s to be induced in the vertical arms of an antenna. Under some conditions propagated radio waves are refracted by the ionosphere and will return to earth some distance away from the transmitter. The 'skip distance', the surface range between the transmitter and the receiver, in which radio waves may be returned from the ionosphere, depends upon a number of factors. Two of these are

- the frequency of the propagated wave
- the density of the ionosphere.

The frequency of the radio wave is a constant, but the density of the ionosphere is far from constant as it varies with the radiation it receives from the sun. If two radio waves from the same transmitter are received at a RDF antenna, one directly and the other as a skip from the ionosphere, e.m.f.s will be induced in both the vertical and the horizontal portions of the antenna. Under such conditions it may not be possible to determine the direction of the transmitting station by rotating the loop or search coil because the angular position of the horizontal portions of the loop with respect to the sky wave cannot be changed. The relationship between the ground wave and the sky wave will be constantly changing in phase, amplitude and polarization, which in turn will cause considerable fading and null position shifting to occur when attempting to take a bearing.

Although there is no cure for night effect, using an Adcock array with no horizontal limbs effectively eliminates pick-up from sky waves. However, because the effect is most prevalent 1 h either side of the time of sunrise and sunset, when the ionosphere is most turbulent, if using a loop antenna, it is advisable to treat bearings taken at this time with suspicion.

10.5.4 Vertical effect

The error known as vertical effect has been virtually eliminated by the careful construction of a loop antenna. The error was caused by unequal capacitances between the unscreened vertical arms of the loop antenna and the ship's superstructure. Depending upon the shape of a vessel's superstructure, the effect produced an imbalance in the loop antenna symmetry, which in turn produced errors that varied in each quadrant. Mounting the loop conductors inside an electrostatic tubular screen eliminates this error.

As shown in Figure 10.11 the loop conductors are mounted precisely in the centre of the tube, which has the effect of swamping the imbalance of the external capacitance. The loop screening tube is earthed at its centre and is supported at the pedestal by two insulation blocks. The blocks effectively prevent the electrostatic screen from becoming an electromagnetic screen that would block the passage of electromagnetic waves and cause the input to the receiver to fall to zero.

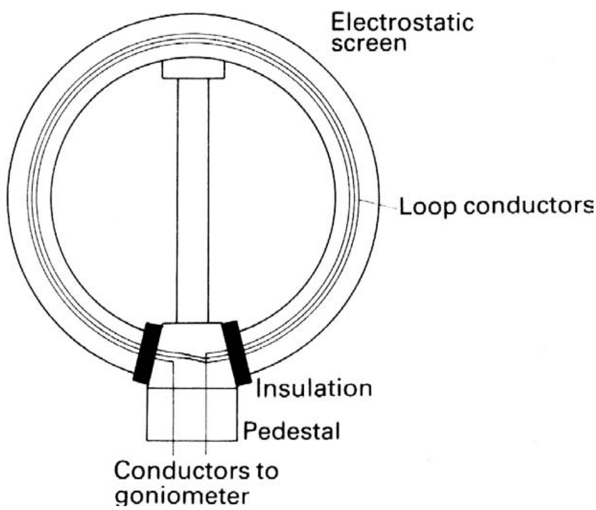

Figure 10.11 Electrostatic screening of a single loop to minimize vertical error.

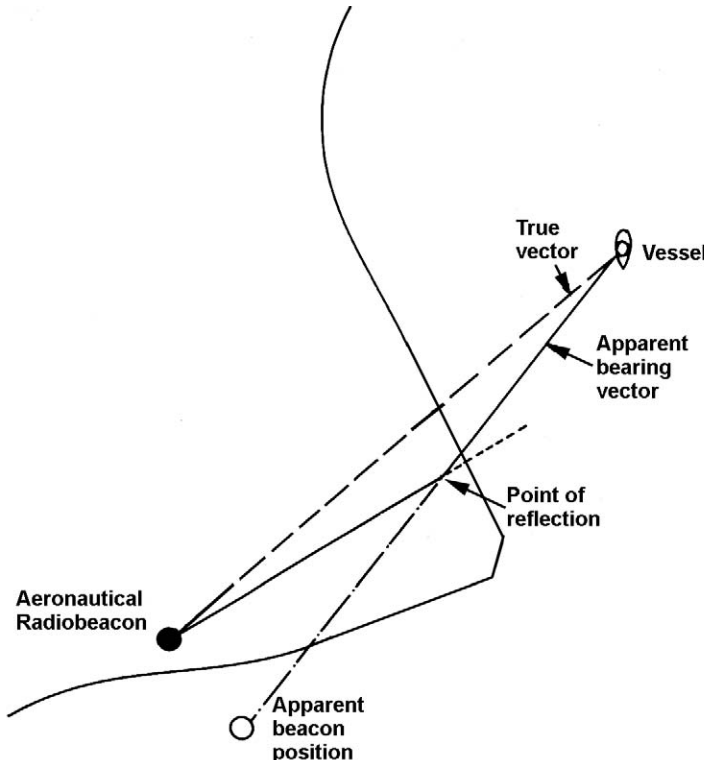

Figure 10.12 Error introduced by a reflected VHF radio wave.

10.5.5 Reflected bearings

Originally, maritime RDF systems relied on the reception of medium frequency ground waves, the velocity of which is influenced by the conductivity of the surface over which the wave is travelling. This factor gave rise to an effect known as 'coastal refraction' when bearings were taken from a beacon inland and the radio wave crossed from land to water.

Although VHF space waves do not suffer from velocity changes caused by ground absorption, they do suffer from reflection and it is possible for a RDF bearing to be in error if it is taken from a reflected wave. This can happen when bearings are taken from inland beacons, such as aeronautical VHF beacons, that may be close to high rise buildings or objects (see Figure 10.12). Unless there is published documentation advising of errors, it is advisable to treat bearings taken from aeronautical beacons with suspicion.

10.6 RDF receiving equipment

In the early days of radio direction finding, receivers were almost always manually operated. Today however, all RDF equipment is automatic. The first automatic receivers depended upon the use of a servomotor to physically drive the RDF compass card to indicate the relative bearing.

10.6.1 An automatic system using a servomotor

This type of RDF has at its heart a low power two-phase servo that, via a mechanical drive mechanism, rotates the goniometer search coil and bearing pointer. This type of system was popular because the bearing is displayed on a compass-like card that revolves to indicate the relative bearing.

First, it is necessary to generate the servomotor signal requirements. A low frequency oscillator generates the necessary two signals, one phase shifted by 90°, to drive the servo. Figure 10.13 illustrates the operational characteristics of the two-phase induction servo used in this type of system.

Two signals, one a reference signal and the other a 90° phase-shifted control signal, are applied, via power amplifiers, to the two stator windings of the servo. Current flows through each of the coils producing magnetic fields along the two axes shown. Each magnetic field causes small e.m.f.s to be induced in the squirrel cage rotor causing it to rotate under their influence. The relative bearing

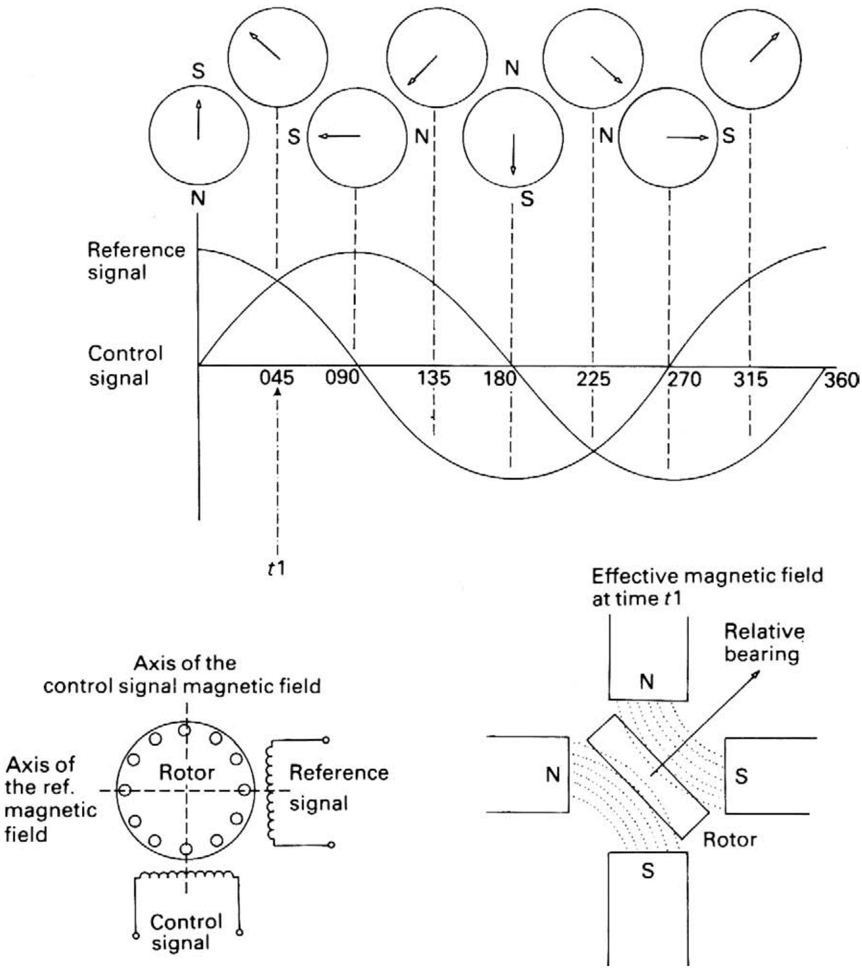

Figure 10.13 The rotating magnetic field produced in the stator windings of a two-phase induction system.

pointers shown above the two phase-related signals indicate the instantaneous position of the rotor at each of the 45° positions of one cycle of input. The resultant magnetic field produced by the two alternating currents will be continually changing and will create a rotating magnetic field turning the rotor and the search coil in the goniometer via the mechanical linkage.

The search coil continues to rotate as long as the two servo windings are under the influence of the phase quadrature signals. If one signal (the control) disappears the rotor will stop. If the phase relationship between the two signals changes the servo will again stop, unless the change is 180° when the servo rotor will rotate in the opposite direction. This characteristic is exploited in the automatic RDF where the control signal is coupled via the receiver circuits to the control winding of the servo. The control signal is therefore under the influence of the received resultant loop signal amplitude.

Once the electrical signals have been generated and the reference signal is applied to the servo, it is necessary to modulate the control signal with the received bearing signal. This is done by a modulator that is placed between the antenna signal line and the input to the receiver as shown in Figure 10.14.

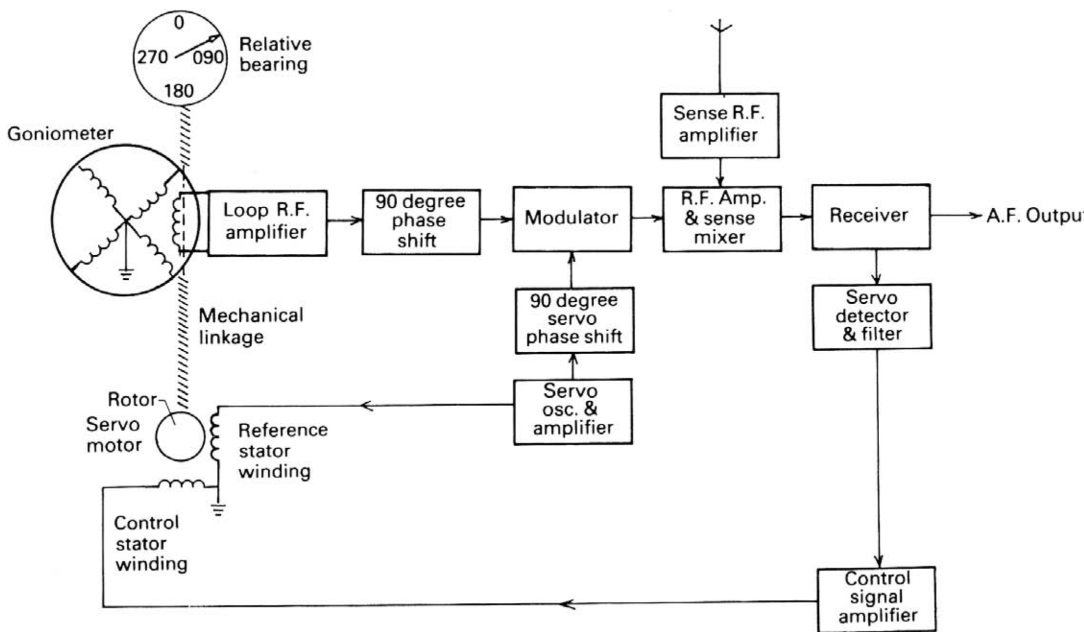

Figure 10.14 System diagram of a servo-controlled automatic RDF system.

Assuming that the search coil is stationary and sitting 90° away from a relative bearing position, a maximum signal output from the search coil to the loop amplifier results. This signal is then phase shifted by 90° to eliminate the error that will occur when the permanently connected sense input is applied at a later stage.

The control signal is now applied to a Cowan modulator where it is both amplitude- and phase-modulated. The output waveform from the modulator is an alternately 180° phase-shifted signal as shown in Figure 10.15.

In the next radio frequency amplifier, the vertical sense antenna signal is added to the output of the modulator causing the loop signal to be returned to its original phase. This signal is now an amplitude-modulated radio frequency and is processed by the superhet receiver in the normal way. Chopping the

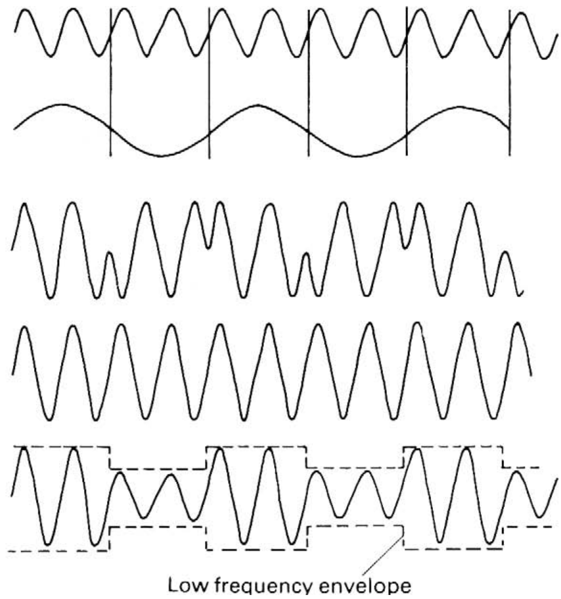

Figure 10.15 Illustration of the waveform mixing process to produce the servo control signal envelope.

loop signal in the Cowan modulator and then re-constituting it with the sense input signal ensures that the servo cannot rotate if the sense input fails. Thus a failsafe system has been introduced to eliminate the possibility that the servo would stop the search coil on the reciprocal null position of the relative bearing if the sense antenna failed.

The servo detector circuit now detects the amplitude variation of the intermediate frequency and couples the resultant signal through a series resonant filter to the control winding of the servomotor. The filter ensures that only the low frequency servo signal is amplified to become the servo control signal. The rotor now rotates moving the search coil of the goniometer towards a bearing. This in turn will causes the loop signal to the radio frequency amplifier to reduce in amplitude. The output from the modulator reduces causing the output from the servo detector to fall. As the control signal amplitude falls, the magnetic field created around the control stator winding reduces and the rotor slows down. Eventually a null position will be reached where the loop signal falls to zero, no modulation takes place and the servo stops.

Theoretically it is possible for the servo to stop on the reciprocal null position. In practice, however, the reciprocal null position is very unstable due to noise and thus the system will only remain steady in the relative bearing position. To prevent null position overshoot, which may be produced by the torque of the servo as it swings rapidly towards a null, an opposing magnetic field is created within the servo, by a d.c that is introduced when the rotor has moved within prescribed limits of the relative bearing position.

10.6.2. A computer-controlled RDF system

A computer-controlled RDF system is shown in Figure 10.16. The description of the system is based upon the discrete logic circuitry of an early RDF receiver manufactured by the STC International Marine Company. It has been used here because of its clarity of operation.

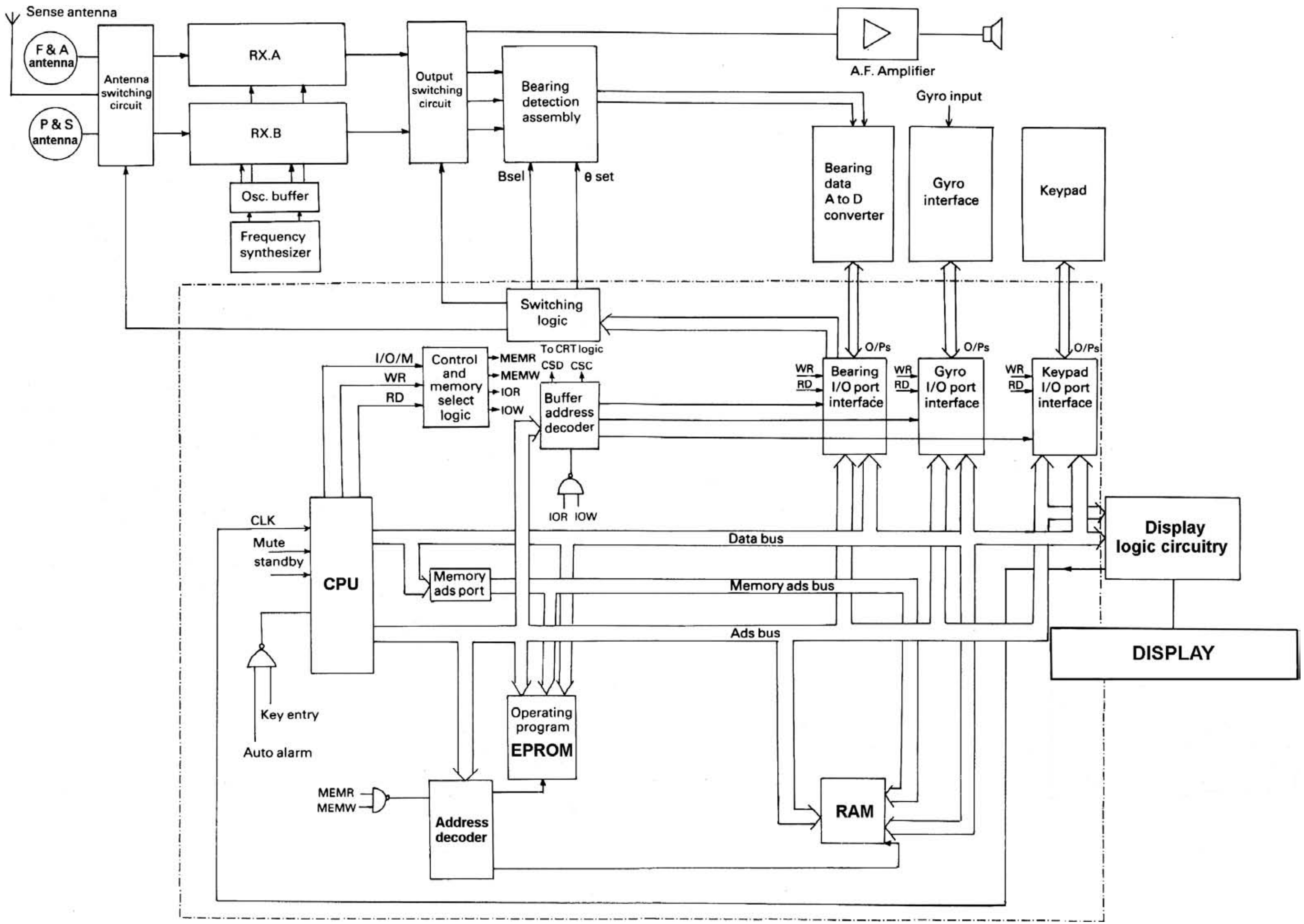

Figure 10.16 A system diagram for a computer-controlled RDF.

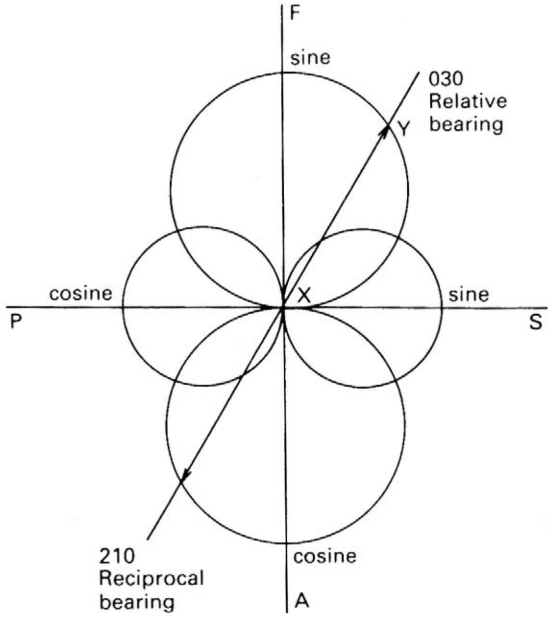

Figure 10.17 AGP plots of the input to the receiver.

The output signal amplitude of both the port-and-starboard antenna and the fore-and-aft antenna will vary with the azimuth angle of the received radio wave relative to the ship's heading. Figure 10.17 illustrates the resultant polar diagrams produced by the two antennae for a transmission received on a relative bearing of 030°. In this case the output from the fore-and-aft antenna is greater in amplitude than that obtained from the port-and-starboard antenna. The vector XY is an indication of the resultant signal amplitude corresponding to the relative bearing.

Antenna signals are switched to independent receivers where their corresponding amplitudes are compared. The strongest signal, in this case the one from the fore-and-aft antenna, is then switched to the primary receiver. Obviously the fore-and-aft antenna polar diagram also indicates a reciprocal bearing null at 210°. To remove this ambiguity the sense antenna is now connected to receiver B. The phase relationship between the fore-and-aft signal and the sense antenna signal is now compared in the bearing detection assembly board to determine the relative bearing. This process is extremely complex. It is controlled by the θ-set (phase comparison initiation pulse) and the B-sel line (bearing select) both of which originate in the microprocessor. Basically the decoded phase relationship is used to clock an up/down logic counter under command of the B-sel line input. The output from the counters is then connected via an analogue-to-digital converter to the interface circuits of the computer.

Bearing computation is software commanded by a dedicated program held in an EPROM. Central control is from a CPU that, via data and address bus lines, commands all functions. I/O/M, WR (write), and RD (read) control lines are gated to provide four memory and port control lines MEMR (memory read), MEMW (memory write), IOR (input/output port read) and IOW (input/output port write). MEMR and MEMW are further gated to command both the EPROM and RAM memory capacity. Lines IOR and IOW, via the buffer address decoder, control the three data input/output ports: bearing data, gyro data and keypad data.

Operation in bearing mode

Keypad commands are read onto the data bus from the I/O port that has been enabled by the RD line. The line 02 output from the buffer address decoder is also be enabled. The CPU commands receiver and bearing detection assembly functions to produce bearing data at I/O port IC3. Using the RAM as storage, and EPROM software, the CPU inputs bearing and gyro data to complete the computation and produce the bearing data to command the display logic.

Bearing presentation

A RDF bearing display can be as simple as a three-digit numerical readout or as complex as that of an integrated navigation system, but many navigators prefer to see the relative bearing displayed in real-time polar format. In common with all data displays, the relative bearing displayed should be unambiguous and clearly visible. It should also be capable of being displayed in a north-up or ships-head-up mode, depending upon requirements. Other data indications are signal strength, bearing quality, receiver frequency and own ship's heading.

In general there are two outputs from a modern bearing processor to feed the deflection system of a display. They are the vertical or y-axis produced from the fore-and-aft co-ordinates and the horizontal or x-axis produced from the port-and-starboard co-ordinates. Equipment using a cathode ray tube for bearing display uses the two outputs to vary the electrostatic fields generated by x-axis and y-axis deflection plates to deflect the electron beam in the direction of the relative bearing. For instance, equal amplitude positive voltages fed to both the x and y deflection plates will cause the spot

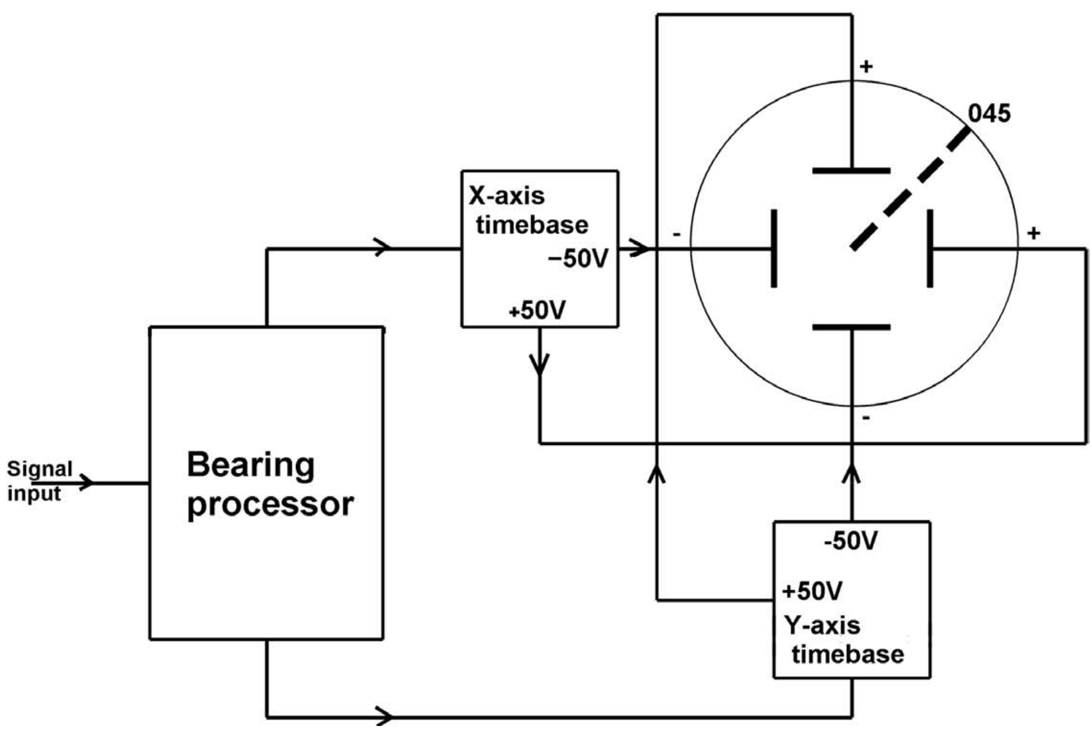

Figure 10.18 The magnitude of each x and y voltage determines both the azimuth indication and the strength of the signal as shown by the length of the vector.

to deflect to 045° (Figure 10.18). If both voltages are of equal lesser amplitude, the bearing remains the same but the trace length reduces to indicate a weaker signal. If for instance the x deflection voltage is a maximum and the y deflection voltage drops to zero, the displayed bearing will be 090°. This is a simple explanation of the principle. In practice the timebases are more complex.

Modern equipment using flat screen technology uses complex matrix technology but the principle is the same. The relative bearing may be displayed as polar diagram representation, in the form of a bar chart, or it may be in numeric form.

10.6.3 VHF scanning RDF equipment

Whilst the carriage of a radio direction finder is not a mandatory requirement on merchant vessels there is no doubt that it is a useful piece of equipment. Since the maritime medium frequency RDF system ceased to function, the number of companies manufacturing and selling maritime RDF equipment has fallen to a mere handful. One traditional marine equipment supplier, Koden, produces a range of RDF equipment designed to operate as stand-alone systems or to be interfaced with an existing VHF communications receiver. One of their models the KS538 is at the forefront of technology in this area (Figure 10.19).

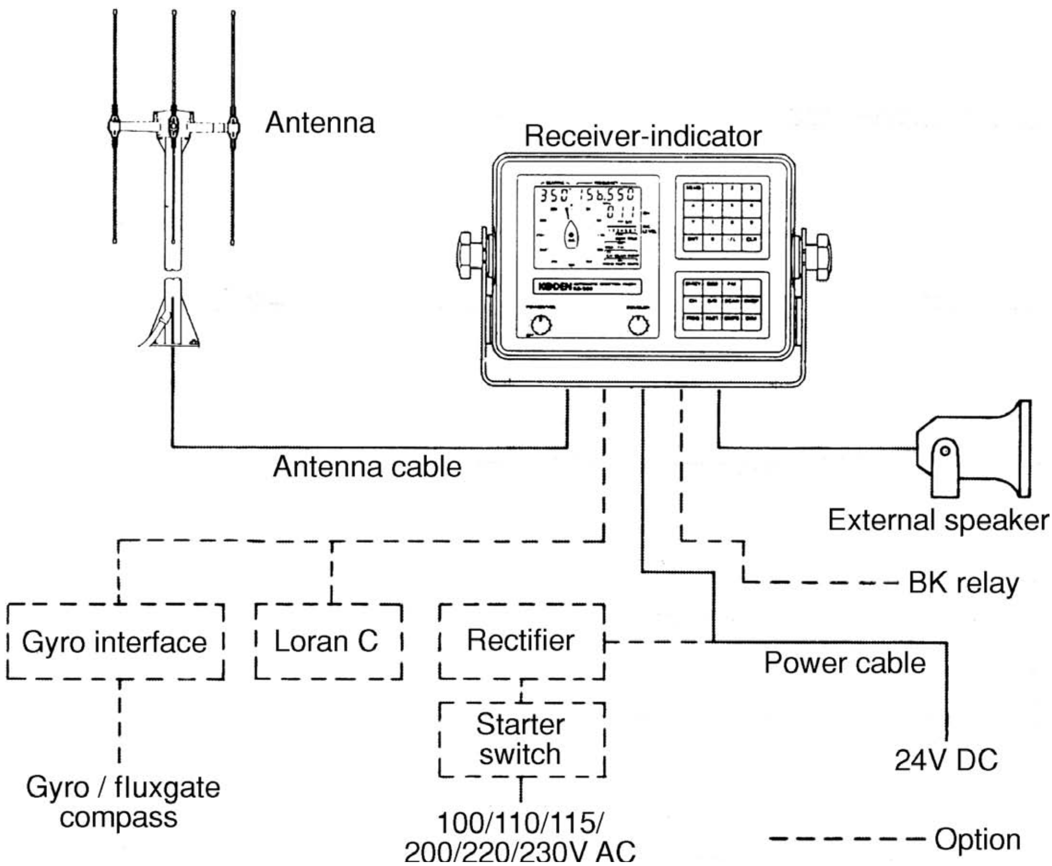

Figure 10.19 A modern RDF installation showing interface details. (Reproduced courtesy of Koden Electronics Co. Ltd.)

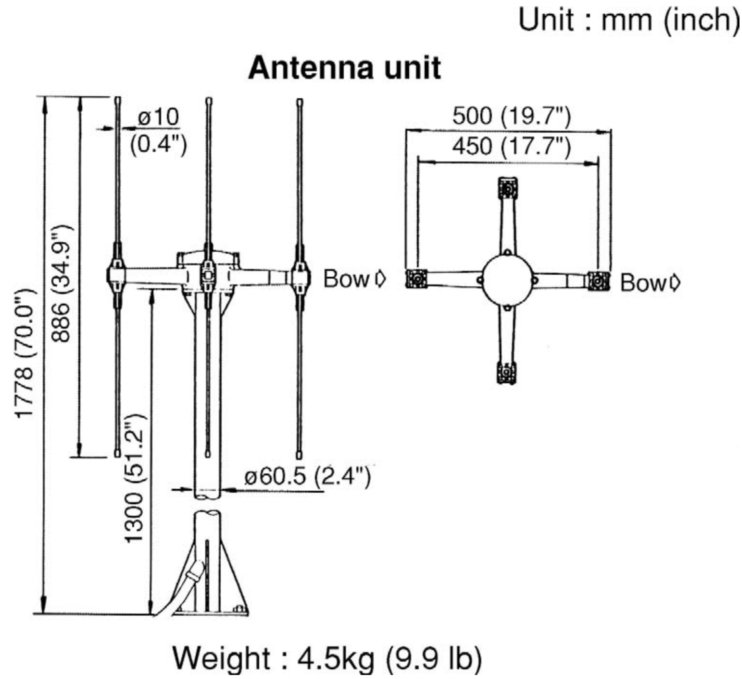

Figure 10.20 Construction detail of the Adcock antenna unit. (Reproduced courtesy of Koden Electronics Co. Ltd.)

As has previously been stated, a RDF is basically a high quality communications receiver with the addition of a specialized antenna and a suitable visual display. Central to the Koden unit, shown in Figure 10.19, is a fully synthesized VHF receiver able to receive frequencies in the range 110–179·999 MHz in 1 kHz steps. All VHF channels are held in memory including 55 international channels, four US weather channels, three Scandinavian fishing channels, two pleasure craft channels, and the international distress channels. In addition, 99 other channels are operator programmable. Each channel is selected via an alphanumeric keypad and all channels can be automatically scanned.

The system uses a four-element Adcock array antenna for bearing location (see Figure 10.20). Element spacing is approximately 450 mm and the length is 886 mm, which as a subdivision of the short VHF wavelength puts the receptive properties well within the required band.

In common with most modern manufacturers, Koden makes good use of the large backlit LCD display (Figure 10.21). Bearings are presented in the preferred polar form as well as digitally. The dominant feature of the display is the representation of a compass card that clearly shows the relative bearing. It is displayed as a large black triangle, in this case 247° relative. If compass data is interfaced with the unit, a second indication showing the vessel's course appears and bearing data may be shown as a three-digit true bearing for laying-off on charts during a triangulation exercise.

Other display data includes the received frequency and channel number, the signal strength, relative (bow) or true bearing indication, signal modulation, channels and sweep rate, and the period of data presentation.

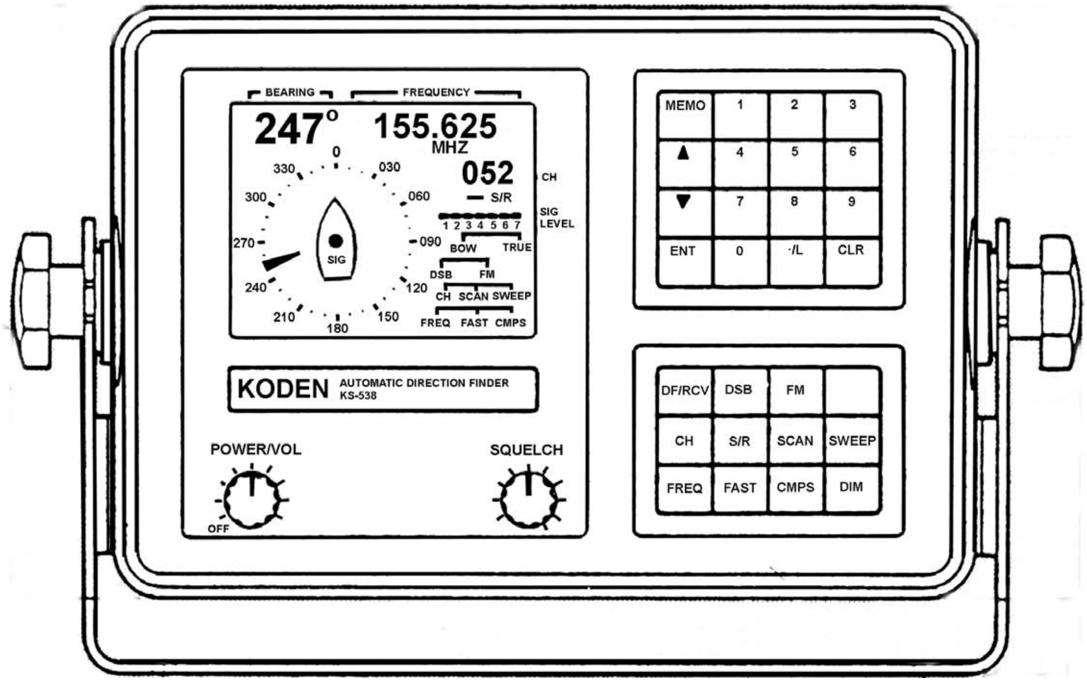

Figure 10.21 The Koden KS-538 RDF system display is a good indication of the information presented to the user of a modern equipment. (Reproduced courtesy of Koden Electronics Co. Ltd.)

10.7 Glossary

Adcock antenna	A directional antenna constructed from a number of dipole pairs.
Azimuth gain plot (AGP)	The radiation or reception pattern of an antenna when drawn in azimuth. Occasionally called a polar diagram.
Dipole antenna	A vertical antenna with the ability to receive equally from all directions.
Loop antenna	A directional antenna constructed from a coil of wire. Need not be circular; square or triangular shapes are also popular.
Null	The zero signal condition that indicates the true bearing in manual RDF systems.
Polar diagram	See azimuth gain plot.
Polarization error (night effect)	Caused by receiving signal refracted from the ionosphere.
Quadrantal error	An error existing in all azimuth quadrants of a RDF system.
Reciprocal bearing	The opposite bearing to the true bearing.
Semicircular error	Caused by out-of-phase re-radiated signals from structures in the vicinity of the receiving antenna.
Sense antenna	An omnidirectional antenna providing an input signal to eliminate the reciprocal (unwanted) bearing.

10.8 Summary

- RDF systems operate by receiving ground or space radio waves, not sky waves.
- By triangulating RDF azimuth bearings on a chart it is possible to locate a transmitter at an unknown location.
- Early systems used rotating antenna but modern equipment is automatic and uses fixed receiving antenna.
- A loop antenna is highly directional and two fixed at 90° to each other are used to determine the direction of a transmitter in azimuth.
- An Adock antenna system possesses the same properties as a loop antenna and is often used in RDF systems.
- The input from a dipole antenna, called a sense input, is used to eliminate the reciprocal (unwanted) bearing.
- A number of errors affect system accuracy but they are mostly predictable and are eliminated.
- Modern RDF systems use frequencies in the VHF band and consequently small antenna may be used. Maritime VHF channels are held in memory in modern equipment.
- Modern RDF equipment may be a stand-alone unit or it may be an addition to the bridge VHF equipment fitted on all commercial vessels.

10.9 Revision questions

1 How are two RDF-equipped vessels able to triangulate the position of an unknown vessel?
2 How is it possible to produce a null or zero signal at the input to a receiver merely by rotating an antenna?
3 A single loop or Adcock antenna produces an AGP with two nulls. How may the reciprocal (unwanted) null be eliminated?
4 How do sky waves affect the accuracy of an RDF system?
5 How do reflected radio waves affect the accuracy of the indicated bearing?