CHAPTER 23

RADAR NAVIGATION

PRINCIPLES OF RADAR OPERATION

2300. Introduction

Radar determines distance to an object by measuring the time required for a radio signal (moving at the speed of light) to travel from a transmitting antenna to the object, reflect off that object, and return as a received echo.

Distance, or range, can be found by the simple formula:

range = 1/2 (C x t)

where range is in nautical miles
C = the speed of light in nautical miles per second, and
t = the time in seconds from the time of pulse transmission to echo reception.

Because the value of C is very large (162,000 NM/sec), t is very small, 0.0001 sec for a target at a range of 10 miles for example.

Such measurements can be converted into lines of position (LOP's) comprised of circles with radius equal to the distance to the object. Since marine radars use directional antennae, they can also determine an object's bearing. However, due to its design, radar's bearing measurements are much less accurate than its distance measurements. Understanding this concept is crucial to ensuring the optimal employment of the radar for safe navigation.

2301. Signal Characteristics

In most marine navigation applications, the radar signal is pulse modulated. Signals are generated by a timing circuit so that energy leaves the antenna in very short pulses, usually less than one millionth of a second (or 1 μsec) in duration. When transmitting, the antenna is connected to the transmitter but not the receiver. As soon as the pulse leaves, an electronic switch disconnects the antenna from the transmitter and connects it to the receiver. Another pulse is not transmitted until after the preceding one has had time to travel to the most distant target within range and return. Since the interval between pulses is long compared with the length of a pulse, strong signals can be provided with low average power. The duration or length of a single pulse is called **pulse length**, **pulse duration**, or **pulse width**. This pulse emission sequence repeats a great many times, perhaps 1,000 per second. This rate defines the **pulse repetition rate** (**PRR**). The returned pulses are displayed on an indicator screen or *display*.

2302. The Transmitter

In traditional marine radar sets, those produced since the 1940s, the transmitter is a special electronic oscillator diode tube known as a magnetron. The magnetron produces very high power microwaves (25 KW and greater) for very short periods of time.

Recently, another type of radar has been introduced into the commercial marine industry know as solid state or *coherent* radar. In modern solid state radars, the pulses generated by special circuitry in the transmitter are of much less power, much longer in length, and of varying frequency. This type of radar does not use a magnetron and generates an entirely different waveform. Presently, solid state radar is only available in the S-Band and will be further discussed in the following sections.

2303. The Receiver

The function of the receiver is to amplify the strength of the very weak return echoes. The enhanced signals can then be used to produce video signals which are presented as targets on the display. The amplifiers in a traditional magnetron radar have to deal with only one frequency, either 3000 MHz or 10000 MHz depending on the radar set.

A solid state radar receiver however, must process a much more complex signal with changing frequency. This variable frequency, or chirp, necessitates signal processing within the receiver known as pulse compression, which shortens the comparatively long, 5 - 18 microsecond transmitted pulse into a pulse of similar length to traditional radars (0.05 - 1.0 μsec), while at the same time increasing signal amplitude, thus yielding the same detection and range measuring capabilities. A very great advantage of solid state radars over magnetron radars is their superior ability to filter out rain and sea clutter effects and therefore assist the radar observer in identification of land targets used in radar navigation.

2304. The Antenna

Nearly all modern commercial marine radars use a type of antenna known as a slotted waveguide. See Figure 2304 Slotted waveguide antenna. Both solid state and magnetron radar sets utilize this antenna configuration because it is simple, efficient, and produces a beam that minimizes unwanted side lobes (side lobes will be discussed later in this chapter).

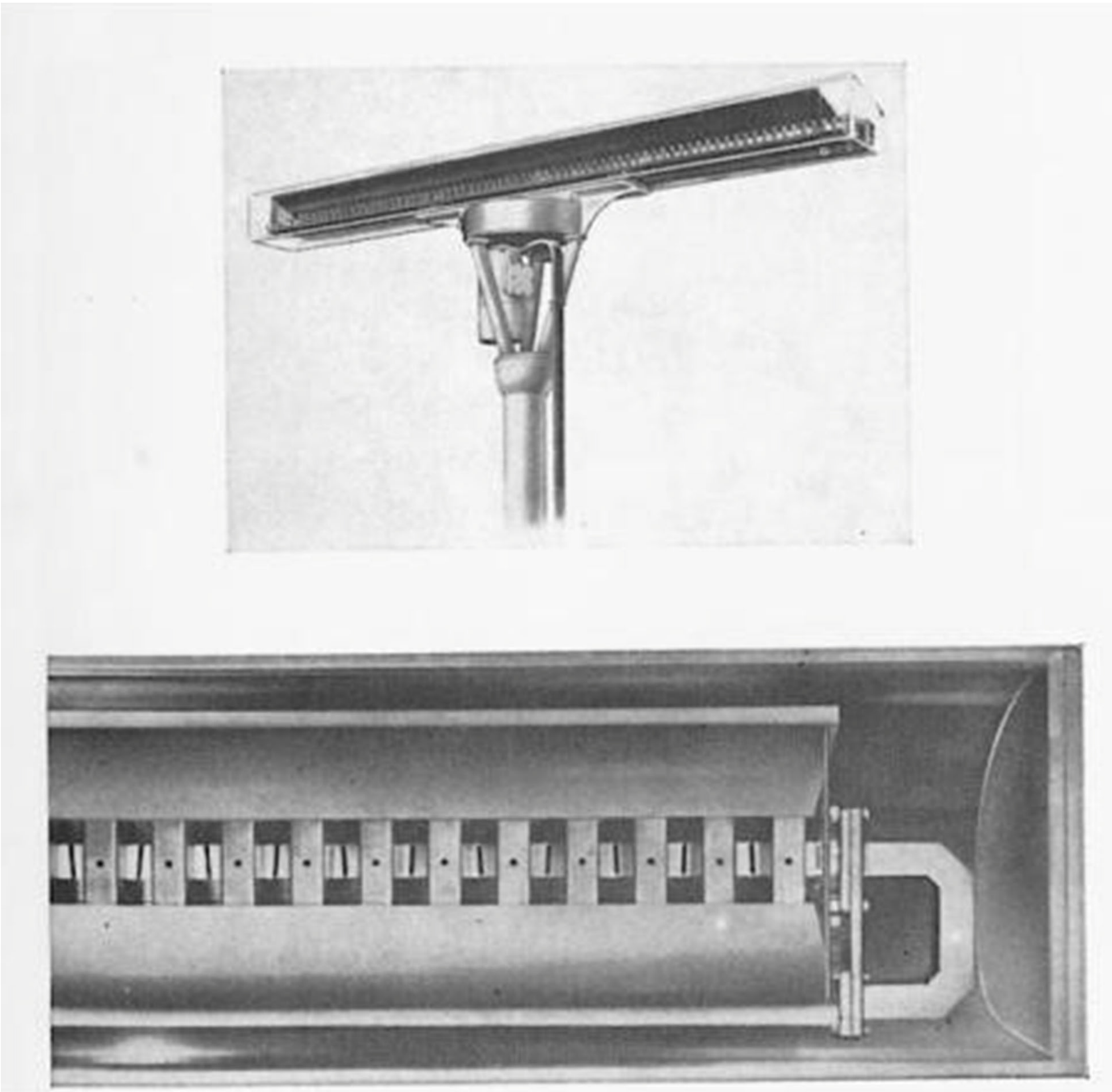

Figure 2304. Slotted waveguide antenna.

2305. The Display

The radar display is often referred to as the **plan position indicator (PPI)**. On a PPI, the sweep appears as a radial line, centered at the center of the scope and rotating in synchronization with the antenna. Any returned echo causes a brightening of the display screen at the bearing and range of the object. The glow continues after the sweep rotates past the target.

On a PPI, a target's actual range is proportional to its distance from the center of the scope. A movable cursor helps to measure ranges and bearings. In the "heading-upward" presentation, which indicates relative bearings, the top of the scope represents the direction of the ship's head. In this destabilized presentation, the orientation changes as the ship changes heading. In the stabilized "north-upward" presentation, gyro north is always at the top of the scope.

2306. The Radar Beam

The pulses of energy comprising the radar beam would

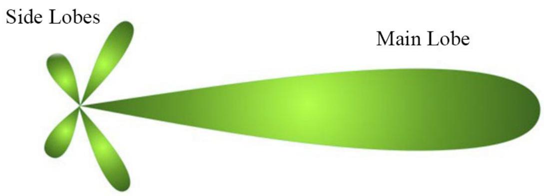

Figure 2306a. Freespace radiation pattern.

form a single lobe-shaped pattern of radiation if emitted in free space. Figure 2306a shows this free space radiation pattern, including the undesirable minor lobes or side lobes associated with practical antenna design. This radiation pattern, as well as the effects of diffraction, reflection and attenuation described below, are common to both magnetron and solid state generated radar signals. Although the radiated energy is concentrated into a relatively narrow main beam by the antenna, there is no clearly defined envelope of the energy radiated, although most of the energy is concentrated along the axis of the beam.

The radiation diagram shown in Figure 2306b depicts

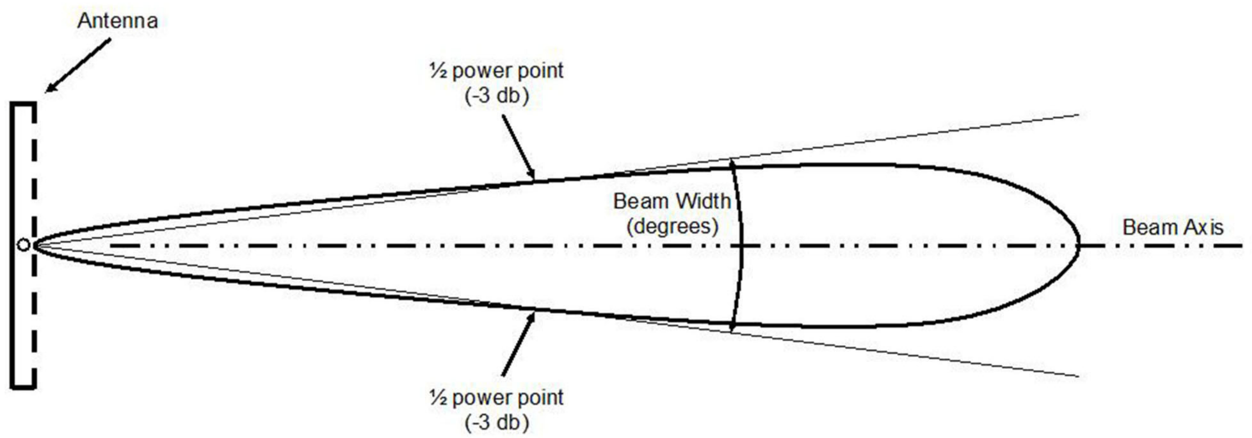

Figure 2306b. Radiation diagram.

relative values of power in the same plane existing at the same distances from the antenna or the origin of the radar beam. Maximum power is in the direction of the axis of the beam. Power values diminish rapidly in directions away from the axis. The beam width is taken as the angle between the half-power points.

The beam width depends upon the frequency or wavelength of the transmitted energy, antenna design, and the dimensions of the antenna. For a given antenna size (antenna aperture), narrower beam widths result from using shorter wavelengths. For a given wavelength, narrower beam widths result from using larger antennas, or i.e., beam width is inversely proportional to antenna aperture. Because marine radar antennas are long in the horizontal dimension and narrow in the vertical dimension, they produce a beam that is narrow in the horizontal direction and somewhat wider in the vertical direction. The narrow horizontal beam is desirable for bearing accuracy while the wide vertical beam is needed to account for the pitching and rolling of a vessel in a seaway. If the vertical beam was as narrow as the horizontal beam, a vessel in rough weather would experience intermittent target response as the beam would not intersect the horizon at all times.

The main lobe of the radar beam is composed of a

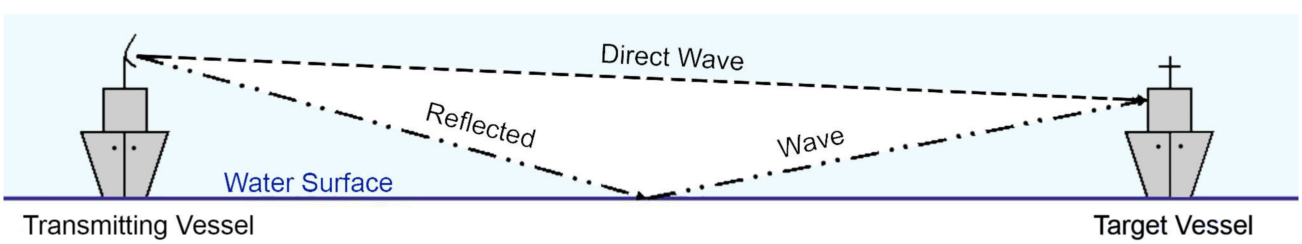

Figure 2306c. Direct and indirect waves.

number of separate lobes in the vertical dimension, as opposed to the single lobe-shaped pattern of radiation as emitted in free space. This phenomenon is the result of interference between radar waves taking a direct line-ofsight path to a target, and those waves that are reflected from the surface of the sea before striking the target. There is a slight difference in distance between which the direct and indirect waves must travel. See Figure 2306c. These reflected (indirect) waves interfere either constructively or destructively with the direct waves depending upon the waves' phase relationship. This sets up the possibility of poor target response for objects at certain ranges from own ship.

2307. Effects of Distance, Target Response, Attenuation and Diffraction

Just as a light source reflected in a mirror appears much dimmer than the direct image, radar echoes are much weaker than the transmitted pulses due to the general spreading out of the radar signal energy with distance. The strengths of these echoes are also dependent upon the amount of transmitted energy striking the targets and the size and reflecting properties of the targets known as *radar cross section*.

Attenuation is the scattering and absorption of the energy in the radar beam as it passes through the atmosphere. It causes a decrease in echo strength. Attenuation is greater in 3-cm rather than 10-cm radar. Atmospheric water particles (heavy fog, rain and snow) can significantly degrade the performance of a 3-cm radar system. During periods of heavy precipitation, the radar observer should switch to the 10-cm set if one is available.

Diffraction is the bending of a wave as it passes an obstruction. Because of diffraction there is some illumination of the region behind an obstruction or target by the radar beam. Diffraction effects are greater at the lower frequencies with longer wavelengths (S-Band). Thus, the radar beam of 10-cm radar tends to illuminate more of the shadow region behind an obstruction than the beam of X-Band radar of 3-cm wavelength.

2308. Refraction

If the radar waves traveled in straight lines, the distance to the radar horizon would be dependent only on the power output of the transmitter and the height of the antenna. In other words, the distance to the radar horizon would be the same as that of the geometrical horizon for the antenna height. However, atmospheric density gradients bend radar rays as they travel to and from a target. This bending is called **refraction**.

The distance to the radar horizon does not always limit the distance from which echoes may be received from targets. Assuming that adequate power is transmitted, echoes may be received from targets beyond the radar horizon if their reflecting surfaces extend above it. The distance to the radar horizon is the distance at which the radar rays pass tangent to the surface of the Earth.

The following formula, where h is the height of the antenna in feet, gives the theoretical distance to the radar horizon in nautical miles:

$$D = 1.22\sqrt{h} \ .$$

D = the range in nautical miles
h = height of the antenna.

2309. Factors Affecting Radar Interpretation

Radar's value as a navigational aid depends on the navigator's understanding its characteristics and limitations. Whether measuring the range to a single reflective object or trying to discern a shoreline lost amid severe clutter, knowledge of the characteristics of the individual radar used are crucial. Some of the factors to be considered in interpretation are discussed below:

- **Resolution in Range.** In Part A of Figure 2309a, a transmitted pulse has arrived at the second of two targets of insufficient size or density to absorb or reflect all of the energy of the pulse. While the pulse has traveled from the first to the second target, the echo from the first has traveled an equal distance in the opposite direction. At B, the transmitted pulse has continued on beyond the second target, and the two echoes are returning toward the transmitter. The distance between leading edges of the two echoes is twice the distance between targets and so the display will indicate two distinct targets. The correct distance between targets will be shown on the display, which is calibrated to show half the distance traveled out and back. At C the targets are closer together and the pulse length has been increased. The two echoes merge, and on the scope they will appear as a single, large target. At D the pulse length has been decreased, and the two echoes appear separated. The ability of a radar to separate targets close together on the same bearing is called *resolution in range*. It is related primarily to pulse length. The minimum distance between targets that can be distinguished as separate is one half the pulse length. This (half the pulse length) is the apparent depth or thickness of a target but in no way represents that actual size of a small isolated target like a buoy or boat. Thus, several ships close together on nearly the same bearing may appear as an island. Echoes from a number of small boats, piles, breakers, or even a single large ship close to the shore may blend with echoes from the shore, resulting in an incorrect indication of the position and shape of the shoreline.

- **Resolution in Bearing**. Echoes from two or more targets close together at the same range may merge to form a single, wider echo. The ability to separate targets close together at the same range is called *resolution in bearing*. Bearing resolution is a function of two vari-

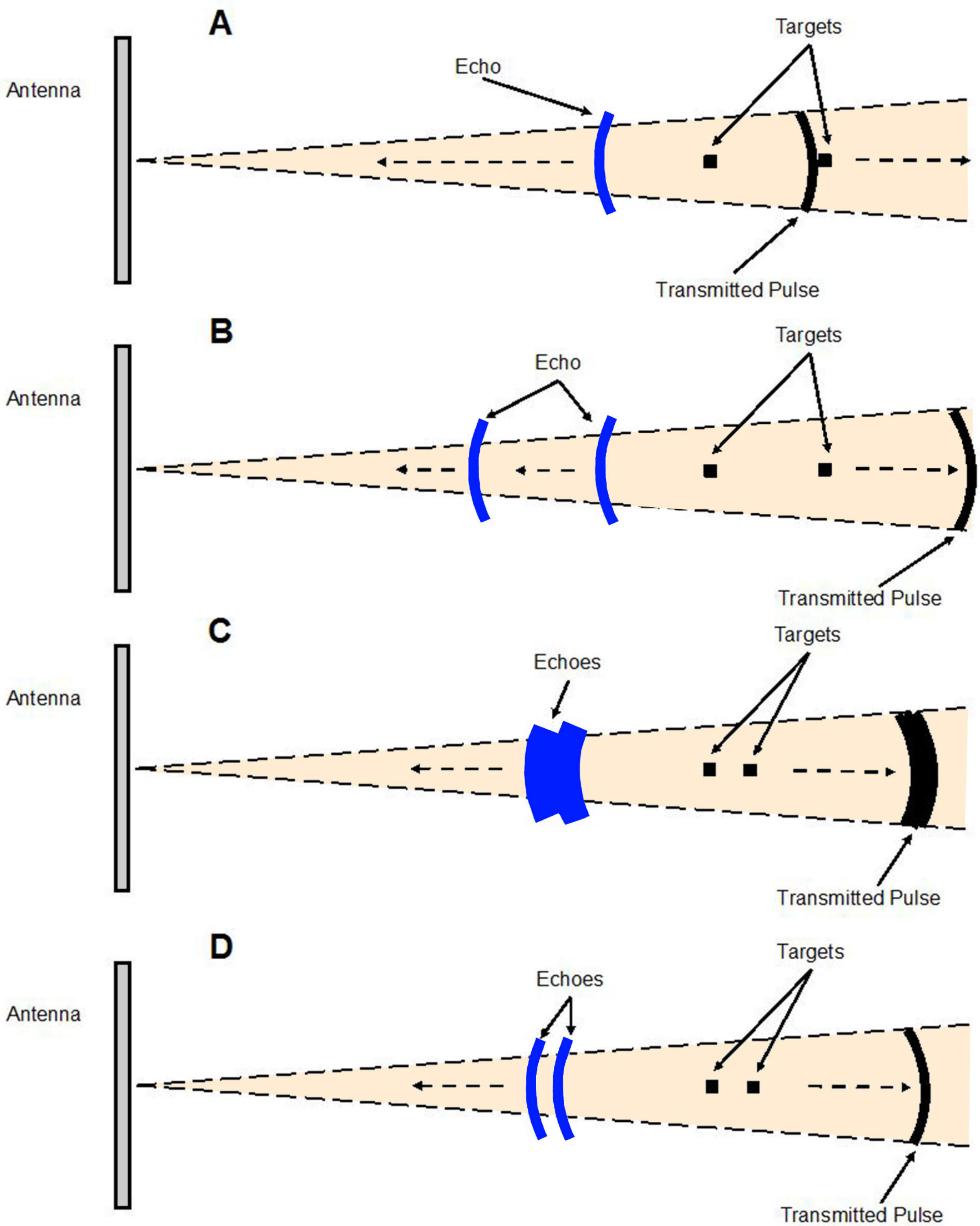

Figure 2309a. Resolution in range.

ables: horizontal beam width and range to the targets. A narrower horizontal beam and/or a shorter distance to the objects will allow for better bearing resolution.

- **Height of Antenna and Target**. If the radar horizon is between the transmitting vessel and the target, the lower part of the target will not be visible. A large vessel may appear as a small craft, or a shoreline may appear at some distance inland.

- **Reflecting Quality and Aspect of Target**. Echoes from several targets of the same size may be quite different in appearance. A metal surface reflects radio waves more strongly than a wooden surface. A surface perpendicular to the beam returns a stronger echo than a non-perpendicular one. A vessel seen broadside returns a stronger echo than one heading directly toward or away. Some surfaces absorb most radar energy rather that reflecting it.

- **Frequency**. A 3-cm radar has the ability to discern smaller targets than a 10-cm set. For example, a very small boat or a submarine periscope might be invisible in S-Band but detectable in X-Band. In a calm sea, a 3-cm radar, properly tuned, can detect a single bird or even a soda can.

Atmospheric noise, sea return, and precipitation complicate radar interpretation by producing **clutter**. Clutter is usually strongest near the vessel. Strong echoes from targets of interest can sometimes be discerned by reducing receiver gain to eliminate weaker signals. By watching the display during several rotations of the antenna, the operator can often discriminate between clutter and a target even when the signal strengths from clutter and the target are equal. The echoes from real targets will remain relatively stationary on the display while those caused by clutter will appear to move around randomly with each sweep.

Another major problem lies in determining which features in the vicinity of the shoreline are actually represented by echoes shown on the display. Particularly in cases where a low lying shore remains below the radar horizon, there may be considerable uncertainty.

A related problem is that certain features on the shore will not return echoes because they are blocked or shadowed from the radar beam by other physical features or obstructions. This shadowing effect in turn causes the image painted on the display to differ from the charted image of the area.

If the navigator is to be able to interpret the presentation on the radar display, he or she must understand the characteristics of radar propagation, the capabilities of his radar set, the reflecting properties of different types of radar targets, and the ability to analyze his chart to determine which charted features are most likely to reflect the transmitted pulses or to be shadowed. Experience gained during clear weather comparison between radar and visual images is invaluable.

Land masses are generally recognizable because of the steady brilliance of the relatively large areas painted on the PPI. Also, land should be at positions expected from the ship's navigational position. Although land masses are readily recognizable, the primary problem is the identification of specific land features. Identification of specific features can be quite difficult because of various factors in addition to shadowing, including distortion resulting from beam width and pulse length, and uncertainty as to just which charted features are reflecting the echoes

Sand spits and smooth, clear beaches normally do not appear on the PPI at ranges beyond 1 or 2 miles because these targets have almost no area that can reflect energy back to the radar. Such a smooth horizontal surface will reflect all radar signals away from the antenna and so are essentially invisible. If waves are breaking over a sandbar, echoes may be returned from the surf. Waves may, however, break well out from the actual shoreline, so that ranging on the surf may be misleading.

Mud flats and marshes normally reflect radar pulses only a little better than a sand spit. The weak echoes received at low tide disappear at high tide. Mangroves and other thick growth may produce a strong echo. Areas that are indicated as swamps on a chart, therefore, may return either strong or weak echoes, depending on the density type, and size of the vegetation growing in the area.

Sand dunes covered with vegetation are usually well back from a low, smooth beach, and the apparent shoreline determined by radar appears at the line of the dunes rather than the true shoreline. This can lead navigators to believe they are farther away from the beach than they really are, a potentially hazardous situation.

Lagoons and inland lakes usually appear as blank areas on a PPI because the smooth water surface returns no energy to the radar antenna. In some instances, even the sandbar or reef surrounding the lagoon may not appear on the PPI because it lies too close to the water.

Coral atolls and long chains of islands may produce long lines of echoes when the radar beam is directed perpendicular to the line of the islands. This indication is especially true when the islands are closely spaced. The reason is that the spreading resulting from the width of the radar beam exceeds the radar's resolution in bearing and causes the echoes to blend into continuous lines. When the same chain of islands is viewed lengthwise, or obliquely, however, each island may produce a separate return if the distance between the islands does not exceed the radar's resolution in range.

Surf breaking on a reef around an atoll produces a ragged, variable line of echoes. Even the smallest of rocks projecting above the surface of the water may be discerned depending on their shape and distance from own ship.

If the land rises in a gradual, regular manner from the shoreline, no part of the terrain produces an echo that is stronger than the echo from any other part. As a result, a general haze of echoes appears on the PPI, and it is difficult to ascertain the range to any particular part of the land.

Blotchy echoes are returned from hilly ground, because the crest of each hill returns a good echo though the area beyond is in a radar shadow. If high receiver gain is used, the pattern may become solid except for very deep depressions.

Low islands ordinarily produce small echoes. When thick palm trees or other foliage grow on the island, strong echoes often are produced because the horizontal surface of the water around the island forms a sort of corner reflector with the vertical surfaces of the trees. As a result, wooded islands give good echoes and can be detected at a much greater range than barren islands.

Sizable land masses may be missing from the radar display because of shadowing. A shoreline which is continuous on the PPI display when the ship is at one position, may not appear continuous when the ship is at another position and scanning the same shoreline. The radar beam may be blocked from a segment of this shoreline by an obstruction such as a promontory. An indentation in the shoreline, such as a cove or bay, appearing on the PPI when the ship is at one position, may not appear when the ship is at another position nearby. Radar shadowing alone can cause considerable differences between the PPI display and the chart presentation. This effect in conjunction with beam width and pulse length distortion of the PPI display can cause even greater differences, possibly leading to confusion and navigational error.

The returns of objects close to shore may merge with the shoreline image on the PPI, because of distortion effects of horizontal beam width and pulse length. Target images on the PPI are distorted angularly by an amount equal to the effective horizontal beam width. Also, the target images always are distorted radially by an amount at least equal to one-half the pulse length (150 meters per microsecond of pulse length).

See Figure 2309b. It illustrates the effects of own ship position, horizontal beam width, and pulse length on the radar image of a coastline. Because of beam width distortion, a straight, or nearly straight shoreline often appears crescent-shaped on the PPI. This effect is greater with the wider beam widths. Note that this distortion increases as the angle between the beam axis and the shoreline decreases. Figure 2309c, Figure 2309d and Figure 2309e correspond to positions A, B and C in Figure 2309b.

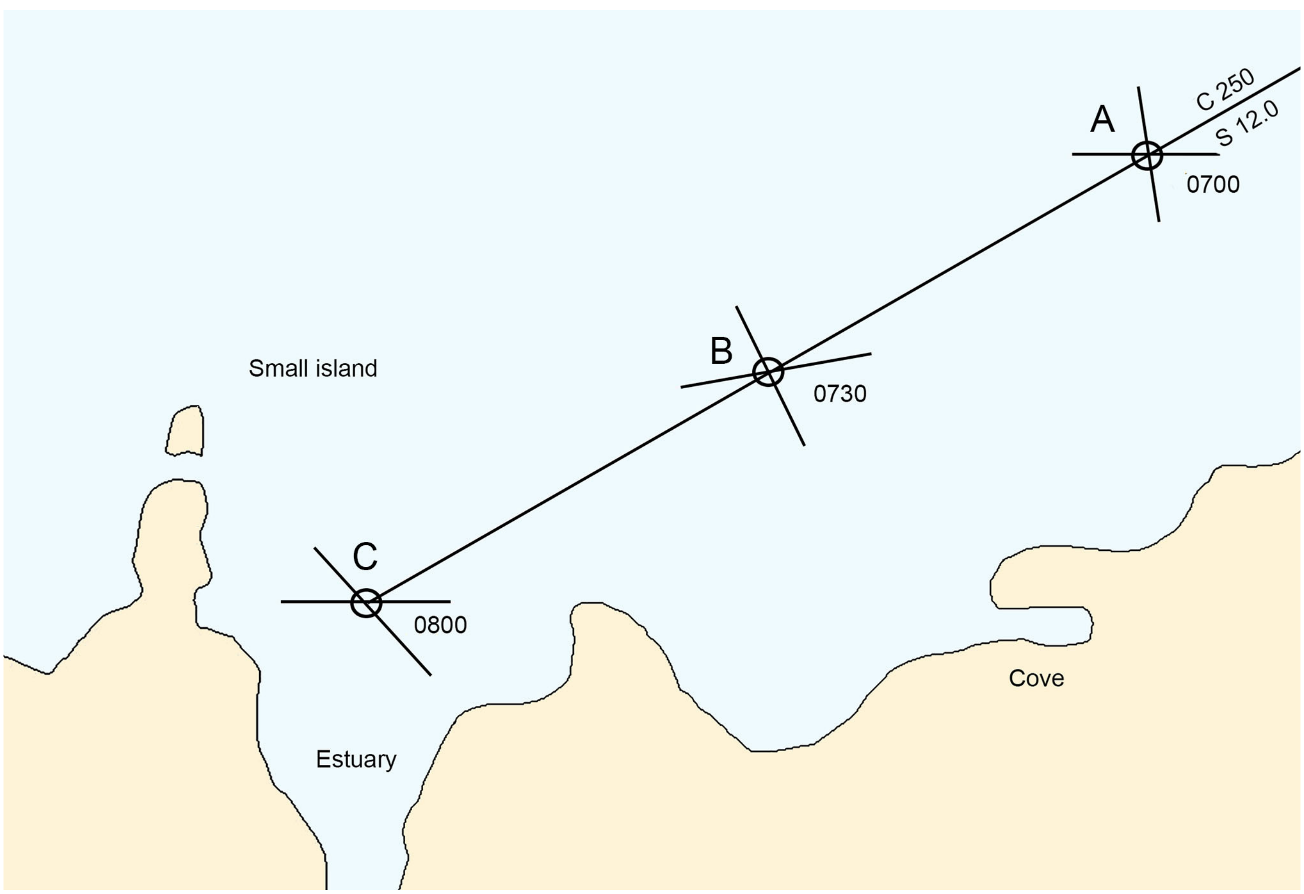

Figure 2309b. Effects of ship's position, beam width, and pulse length on radar shoreline. Figure 2309c*,* Figure 2309d *and* Figure 2309e *correspond to position A, B and C in the image above.*

See Figure 2309f. View A shows the actual shape of the shoreline and the land behind it. Note the steel tower on the low sand beach and the two ships at anchor close to shore. The heavy line in View B represents the shoreline on the PPI. The dotted lines represent the actual position and shape of all targets. Note in particular:

1. The low sand beach is not detected by the radar.
2. The tower on the low beach is detected, but it looks like a ship in a cove. At closer range the land would be detected and the cove-shaped area would begin to fill in; then the tower could not be seen without reducing the receiver gain.

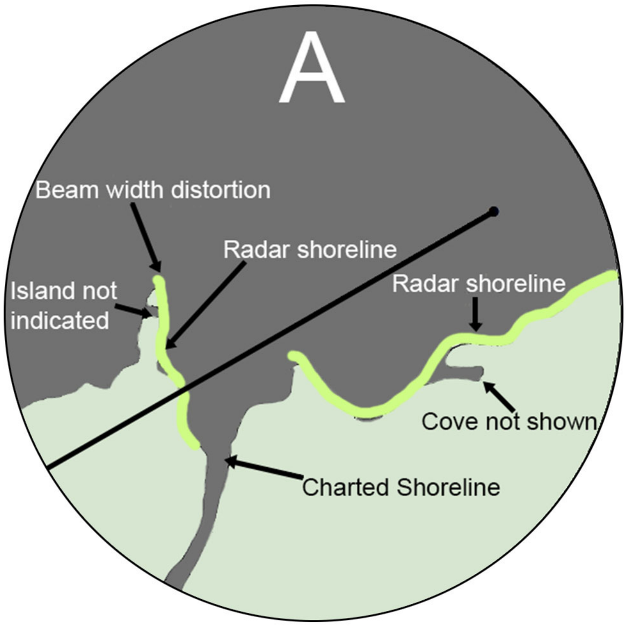

Figure 2309c. 12 mile scale. off-center display at 0700 position. See position A in Figure 2309b.

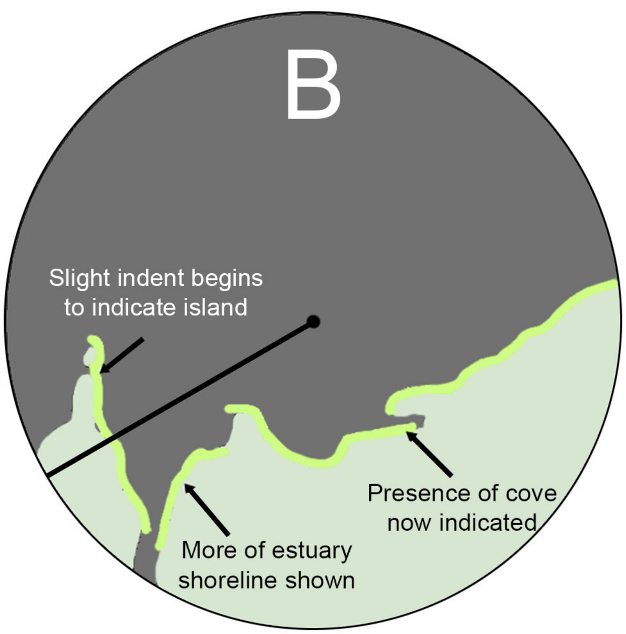

Figure 2309d. 12 mile scale display centered at 0730 position. See position B in Figure 2309b.

3. The radar shadow behind both mountains. Distortion owing to radar shadows is responsible for more confusion than any other cause. The small island does not appear because it is in the radar shadow.
4. The spreading of the land in bearing caused by beam width distortion. Look at the upper shore of the peninsula. The shoreline distortion is greater to the west because the angle between the radar beam and the shore

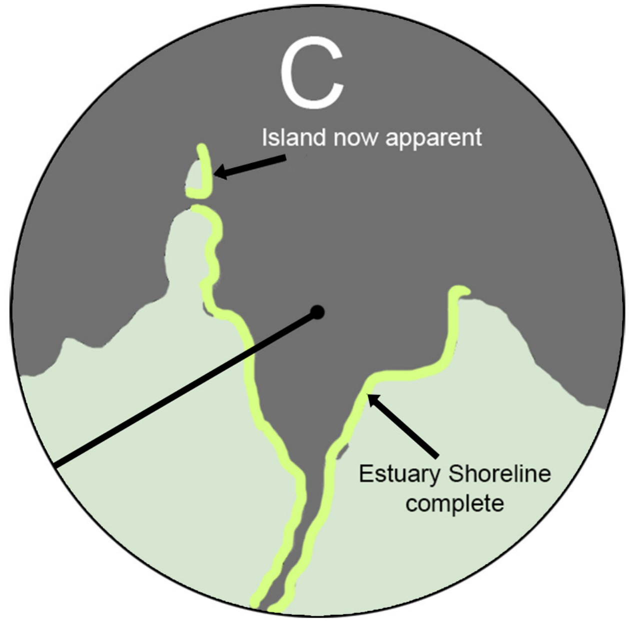

Figure 2309e. 6 mile scale. display center at 0800 position. See position C in Figure 2309b.

is smaller as the beam seeks out the more westerly shore.
5. Ship No. 1 appears as a small peninsula. Its return has merged with the land because of the beam width distortion.
6. Ship No. 2 also merges with the shoreline and forms a bump. This bump is caused by pulse length and beam width distortion. Reducing receiver gain might cause the ship to separate from land, provided the ship is not too close to the shore. The rain clutter control could also be used to attempt to separate the ship from land by effectively reducing the pulse lengths within the receiver.

2310. Recognition of Unwanted Echoes

Indirect or **false echoes** are caused by reflection of the main lobe of the radar beam off own ship's structures such as masts, stacks, kingposts or deck cargo, especially containers. When such reflection from obstructions does occur, the echo will return from a legitimate radar contact to the antenna by the same indirect path. Consequently, the echo will appear on the PPI at the bearing of the reflecting surface. As shown in Figure 2310a, the indirect echo will appear on the PPI at the same range as the direct echo received, assuming that the additional distance by the indirect path is negligible.

Characteristics by which indirect echoes may be recognized are summarized as follows:

1. Indirect echoes will often occur in shadow sectors.
2. They are received on substantially constant relative bearings (the direction of the obstruction), although the true bearing of the radar contact may change

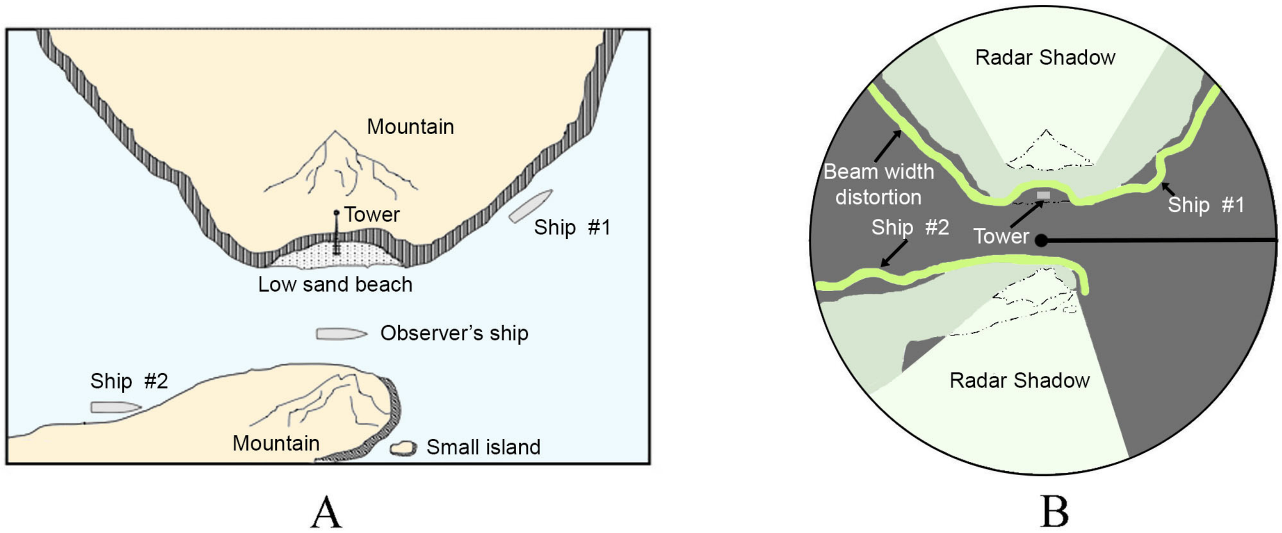

Figure 2309f. Distortion effects of radar shadow, beam width, and pulse length.

appreciably.

3. They appear at the same ranges as the corresponding direct echoes.
4. When plotted, their movements are usually abnormal.
5. Their distorted or fuzzy shapes may indicate that they are not direct echoes.

Side-lobe effects are readily recognized in that they produce a series of echoes (See Figure 2310b) on each side of the main lobe echo at the same range as the latter. Semicircles, or even complete circles, may be produced. Because of the low energy of the side-lobes, these effects will normally occur only at the shorter ranges. The effects may be minimized or eliminated, through use of the gain and anti-clutter controls, but always at the risk of failing to detect weaker targets like buoys or small boats. The introduction of slotted wave guide antennas has drastically reduced the side-lobe problem. Nevertheless, when strong reflecting targets are present at close range, side lobe effects will still be encountered and may be difficult to eliminate entirely without severely reducing gain.

Multiple echoes may occur when a strong echo is received from another ship at close range. A second or third or more echoes may be observed on the radarscope at double, triple, or other multiples of the actual range of the radar contact (Figure 2310c).

Second-trace echoes (multiple-trace echoes) are echoes received from a contact at an actual range greater than the radar range setting. If an echo from a distant target is received after the next pulse has been transmitted, the echo will appear on the display at the correct bearing but not at the true range. Second-trace echoes are unusual, except under abnormal atmospheric conditions, or conditions under which super-refraction or ducting is present. Second-trace echoes may be recognized through changes in their positions on the display when changing range scales with different pulse repetition rates (PRR), their hazy, streaky, or distorted shapes (especially noticeable with large land targets), and their erratic movements on plotting.

As illustrated in Figure 2310d, a target echo is detected on a true bearing of 090° at a distance of 7.5 miles. On changing the PRR from 2,000 to 1,800 pulses per second in Figure 2310e, the same target is detected on a bearing of 090° at a distance of 3 miles. The change in the position of the target indicates that the echo is a second-trace echo. The actual distance of the target is the distance as indicated on the PPI plus half the distance the radar waves travel between pulses. In this case,

(162,000 NM/sec ÷ 2000 PPS ÷ 2) + 7.5 = 48 nautical miles.

Naturally, since we are on the 12-mile scale, the target should not be visible and so must be a second-trace echo.

Electronic interference effects, which may occur when near another radar operating in the same frequency band as that of own ship, are usually seen on the radar as a large number of small bright dots either scattered at random or in the form of curving dotted lines extending from the center to the edge of the PPI.

Interference effects are greater at the longer radar range scale settings. Interference effects can be distinguished easily from normal echoes because they do not appear in the same places on successive rotations of the antenna. Most radar systems have interference rejection controls (IR) that eliminate most of the unwanted interference effects.

Stacks, masts, containers, and other structures, may cause a reduction in the intensity of the radar beam beyond these obstructions, especially if they are close to the radar antenna. If the angle at the antenna subtended by the obstruction is more

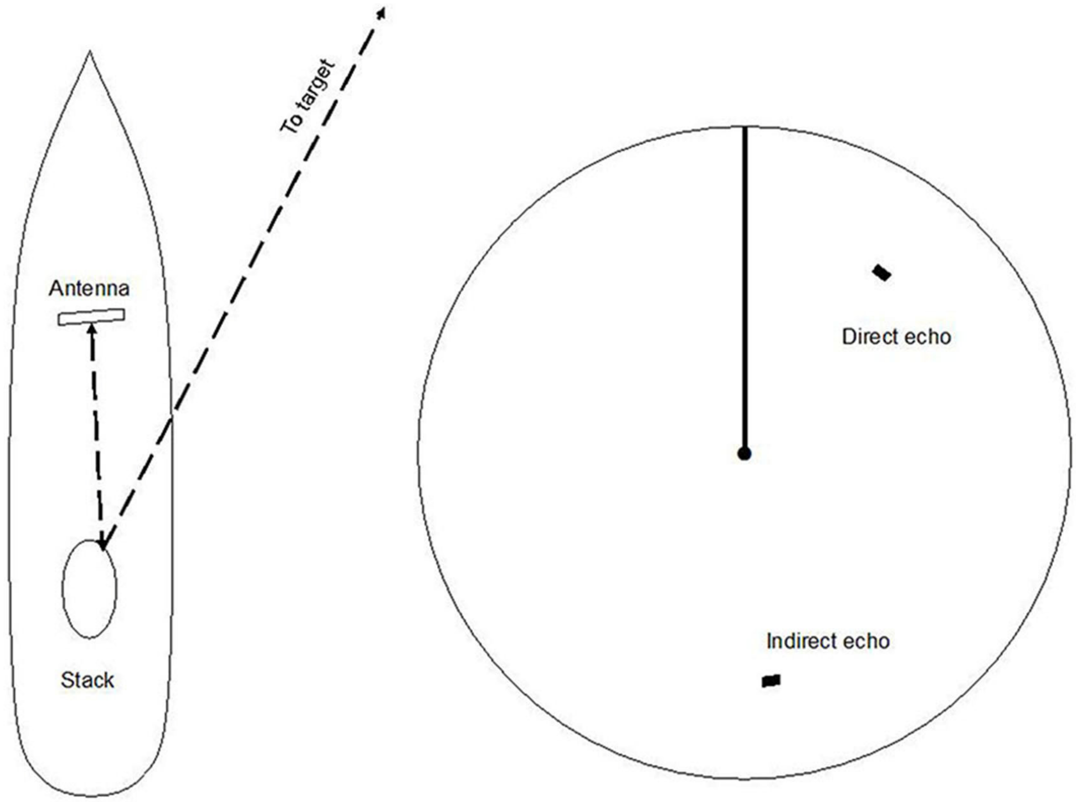

Figure 2310a. Indirect echo.

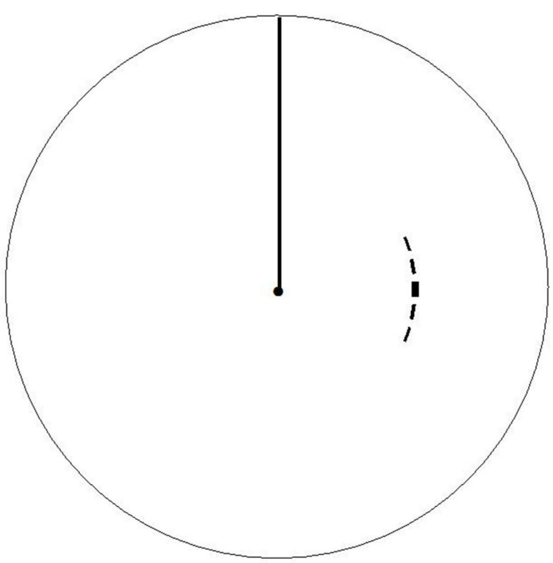

Figure 2310b. Side lobe effects.

than a few degrees, the reduction of the intensity of the radar beam beyond the obstruction may produce a blind sector. Less reduction in the intensity of the beam beyond the obstructions may produce shadow sectors. Within a shadow sector, small targets at close range may not be detected, while larger targets at much greater ranges will appear.

The echo from an overhead power cable can be wrongly identified as the echo from a ship on a steady bearing and decreasing range. Course changes to avoid the contact are ineffective; the contact remains on a steady bearing, decreasing range. This phenomenon is particularly apparent for the power cable spanning the Straits of Messina.

2311. Aids to Radar Navigation

Radar navigation aids help identify radar targets and increase echo signal strength from otherwise poor radar targets.

Buoys are particularly poor radar targets. Weak, fluctuating echoes received from these targets are easily lost in the sea clutter. To aid in the detection of these targets, **radar reflectors**, designated corner reflectors, may be used. These reflectors may be mounted on the tops of buoys or designed into the structure.

Each corner reflector, as shown in Figure 2311a, consists of three mutually perpendicular flat metal surfaces. A radar wave striking any of the metal surfaces or plates

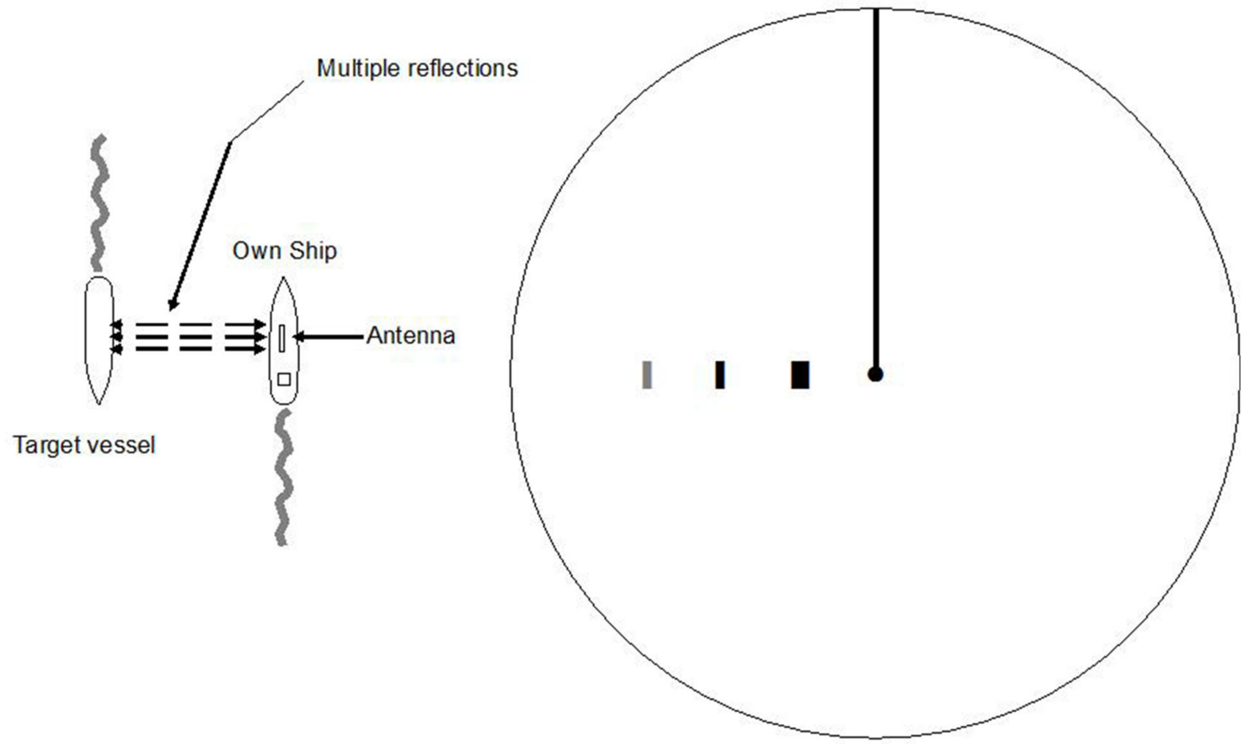

Figure 2310c. Multiple echoes.

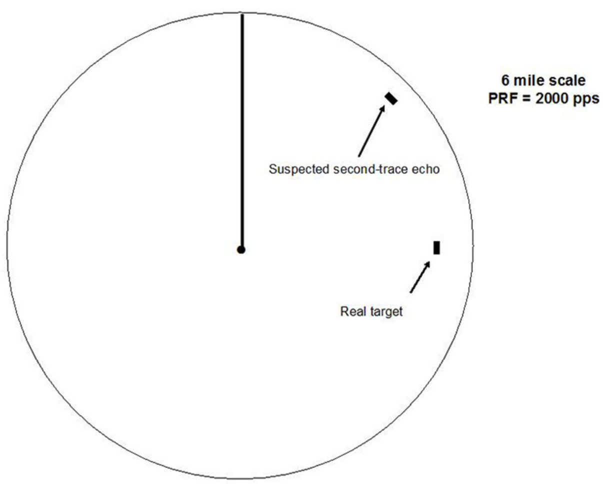

Figure 2310d. Second-trace echo.

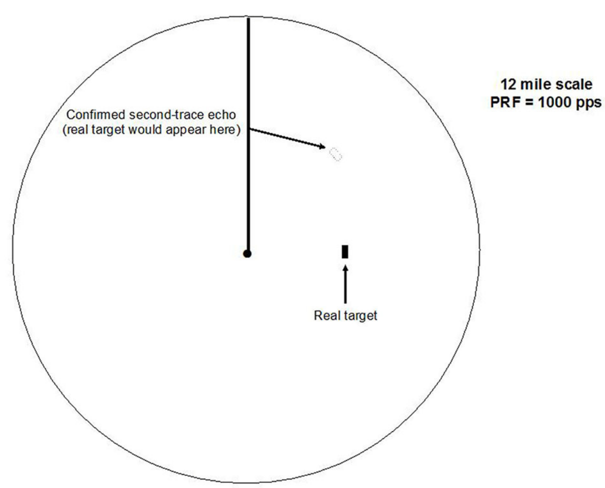

Figure 2310e. Second-trace echo after altering PRR.

will be reflected back in the direction of its source. Maximum energy will be reflected back to the antenna if the axis of the radar beam makes equal angles with all the metal surfaces. Frequently, corner reflectors are assembled in clusters to maximize the reflected signal.

Although radar reflectors are used to obtain stronger echoes from radar targets, other means are required for more positive identification of radar targets. **Radar beacons** are transmitters operating in the marine radar frequency band, which produce distinctive indications on the radar displays of ships within range of these beacons. There are two general classes of these beacons: **racons**, which provide both bearing and range information to the target, and **ramarks** which provide bearing information only. However, if the

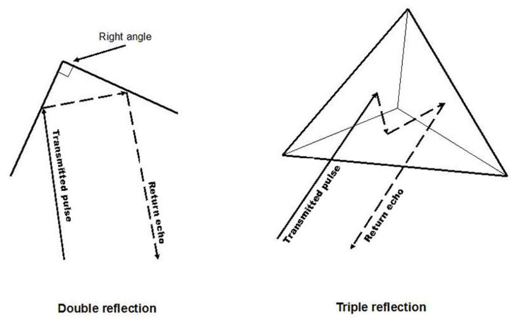

Figure 2311a. Corner reflectors.

ramark installation is detected as an echo on the display, the range will be available also.

A racon is a radar transponder which emits a characteristic signal when triggered by a ship's radar. The signal is emitted on the same frequency as that of the triggering radar, in which case it is superimposed on the ship's radar display automatically. However, the only racons in service are "in band" beacons which transmit in one of the marine radar bands, usually only the 3-centimeter band.

The racon signal appears on the PPI as a radial line originating at a point just beyond the position of the radar beacon, or as a Morse Code signal as shown in Figure 2311b, emanating from the beacon in a direction radially outward from the center of the display. The Morse Code symbol of the racon signal helps to identify important navigational aids on the navigator's chart.

A ramark is a radar beacon which transmits either continuously or at intervals. The latter method of transmission is used so that the PPI can be inspected without any clutter introduced by the ramark signal on the scope. The ramark signal as it appears on the PPI is a radial line from the center. The radial line may be a continuous narrow line, a broken line a series of dots, or a series of dots and dashes (See Figure 2311c). Ramarks are not as common as racons and are not as useful for navigational purposes as they do not indicate the range to the transmitting beacon.

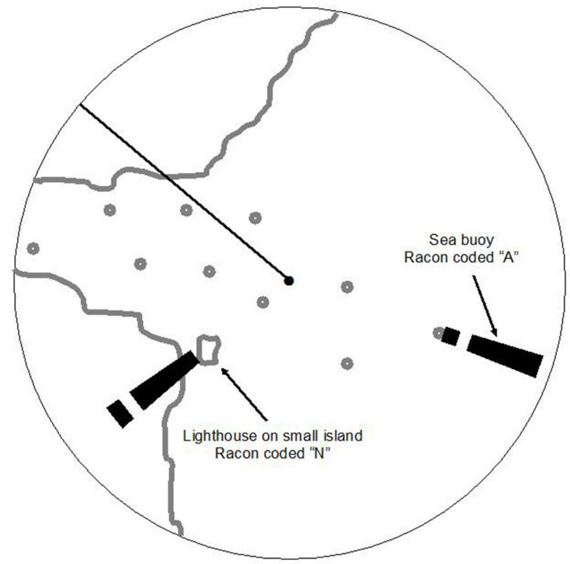

Figure 2311b. Coded racon signal.

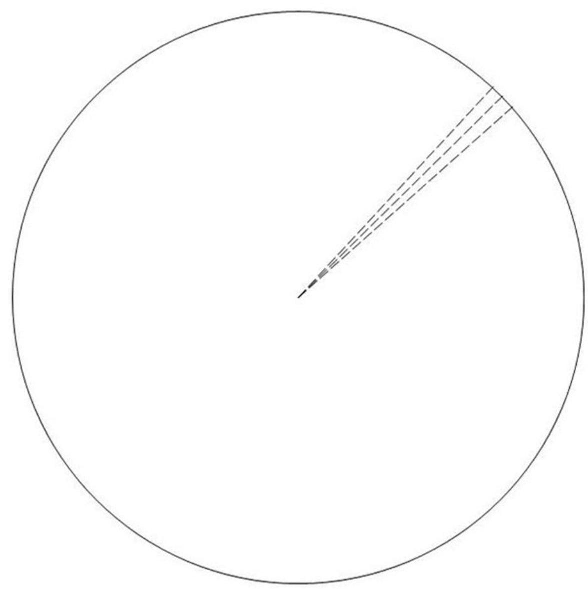

Figure 2311c. Ramark appears a broken radial line.

RADAR PILOTING

2312. Introduction

When navigating in restricted waters, a mariner most often relies on visual piloting to provide the accuracy required to ensure ship safety. Visual piloting, however, requires clear weather; often, mariners must navigate through fog or other conditions of restricted visibility. When weather conditions render visual piloting impossible on a vessel not equipped with ECDIS, radar navigation provides a method of fixing a vessel's position with sufficient accuracy to allow safe passage. See Chapter 10 Piloting for a detailed discussion of integrating radar into a piloting procedure on a vessel using paper charts. However, even on ECDIS equipped vessels, radar provides a vital positional cross-checking capability that is paramount to the practice of safe and prudent navigation.

2313. Fix by Radar Ranges

Since radar can more accurately determine ranges than bearings, the most accurate radar fixes result from measuring and plotting a series of ranges to two or more objects. If one measures the range to objects directly ahead or astern first and objects closest to the beam last, the time of the fix will be the time the ranges were measured to objects ahead or astern. In other words, the fix time is the time that distances were measured to objects with the greatest rate of change of range (range rate) due to own ship's motion. This minimizes measurement time delay errors without resorting to the use of running fixes. Record the ranges to the navigation aids used and lay the resulting range arcs down on the chart. Theoretically, these lines of position should intersect at a point coincident with the ship's position at the time of the fix. Where possible, use objects widely separated in bearing (60^o-90^o) for the greatest accuracy. See Figure 2313.

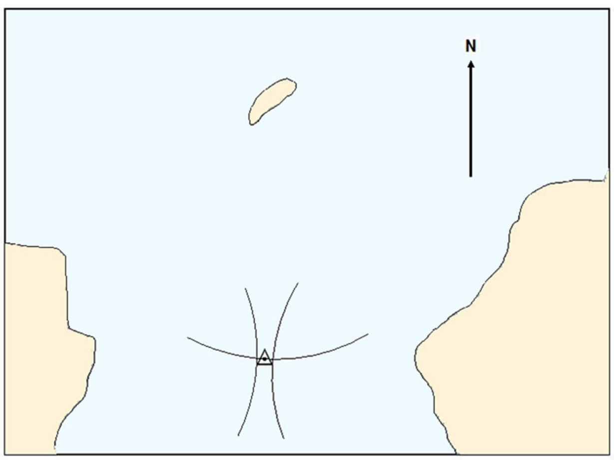

Figure 2313. Fix by radar ranges.

Though verifying soundings is always a good practice in all navigation scenarios, its importance increases when piloting using only radar. One of the most common and serious errors in radar navigation involves object misidentification. These errors can be discovered through correlation of fathometer readings with expected charted depths. Assuming proper operation of the fathometer, soundings give the navigator invaluable conformation on the reliability of radar fixes.

2314. Fix by Radar Bearings

When determining a fix by radar bearings (or visual bearings) take bearings of objects on the beam first and those ahead or astern last. The time of the fix will be the time that the objects abeam were measured. This is because the rate of change of bearing is highest for objects on the beam and lowest for those ahead and astern. Again, this procedure minimizes the fix error due to the time delay in taking a round of bearings.

But the inherent inaccuracy of fixes composed solely of radar bearings as discussed above makes this method less accurate than fixing position by radar ranges. Use this method to plot a position quickly on the chart when approaching restricted waters to obtain an approximate ship's position for evaluating radar targets to use for range measurements. This method is not suitable while piloting in restricted waters and should only be used if no more accurate method (combining visual bearings with radar ranges for example) is available.

2315. Fix by Range and Bearing to One Object

Visual piloting requires bearings from at least two objects; radar, with its ability to determine both bearing and range from one object, allows the navigator to obtain a fix where only a single navigation aid is available. An example of using radar in this fashion occurs in approaching a harbor whose entrance is marked with a single, prominent object such as Chesapeake Light at the entrance of the Chesapeake Bay. Well beyond the range of any land-based visual navigation aid, and beyond the visual range of the light itself, a shipboard radar can detect the light and provide bearings and ranges for the ship's piloting party. But care should be taken. Navigators must ensure they take fixes on the navigation aid and not some nearby stationary vessel.

This methodology is limited by the inherent inaccuracy associated with radar bearings; typically, a radar bearing is accurate to within about 5° of the true bearing due to factors such as beam width distortion. Therefore, the navigator must carefully evaluate the resulting position, possibly checking it with a sounding. If a visual bearing is available from the object, use that bearing instead of the radar bearing when laying down the fix. This illustrates the basic concept discussed above: radar ranges are inherently more accurate than radar bearings. One must also be aware that even though the radar is gyro stabilized, there may be a gyro error of more than a degree or so. Radar and visual bearings will be in error by that amount.

Prior to using this method, navigators must ensure they have correctly identified the object from which the bearing and range are to be taken. Using only one navigation aid for both lines of position can lead to disaster if the navigation aid is not properly identified.

2316. Fix Using Tangent Bearings and Range

This method combines bearings tangent to an object with a range measurement from some point on that object. The object must be large enough to provide sufficient bearing spread between the tangent bearings; often an island or peninsula works well. Identify some prominent feature of the object that is displayed on both the chart and the radar display. Take a range measurement from that feature and plot it on the chart. Then determine the tangent bearings to the feature and plot them on the chart. The range LOP should not intersect where the tangent bearing LOPs intersect but somewhat farther out. The fix position will be the point midway between the tangent bearing lines along the range LOP (see Figure 2316).

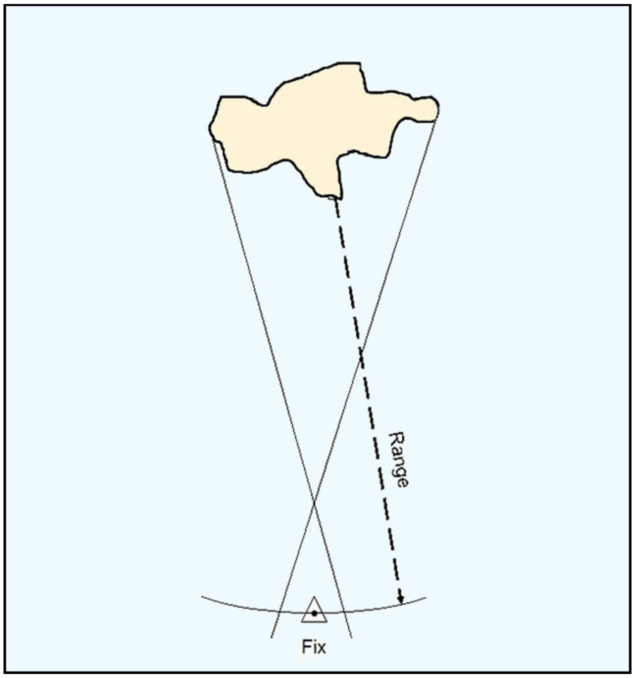

Figure 2316. Fix using tangent bearings and range.

Steep-sided features work the best. Tangents to low, sloping shorelines will seriously reduce accuracy, as will tangent bearings in areas of excessively high tides, which can change the location of the apparent shoreline by many meters.

2317. Parallel Indexing

Whenever a vessel is being navigated in confined waters, traditional position fixing methods become inadequate. The time lag inherent in taking a visual bearing, radar bearing or radar range, plotting positions on a nautical chart, obtaining a fix, and then acting on the information with a possible course change may be as much as five minutes or more, even for experienced navigators. If sea room is severely restricted and there are hazards to navigation in the area, such delays could lead to disaster. What we must do in this unforgiving situation is to monitor the vessel's position constantly through continuous position fixes. ECDIS is of course greatly preferable to paper chart navigation in these circumstances but suffers from complete reliance on GPS position fixes. Radar can provide similar real-time navigation capability not reliant on GPS utilizing a technique known as parallel indexing.

A properly prepared parallel indexing plot will quickly show the navigator when the vessel begins to deviate from the desired track. This will enable corrective measures to be taken immediately without resorting to time-consuming standard fixing methods. Parallel indexing can be indispensable when a vessel must be navigated through confined waters during restricted visibility or when executing a critical turn. Also, in areas with few or unreliable navigational aids, parallel indexing can prove decisive to safe navigation.

The first step in setting up a parallel indexing plot is to examine the nautical chart where the piloting will take place. Imagine that we wish to follow a track line that leaves a small island or rock to starboard at a distance of 2 miles off when abeam. The track line course is 045º (see Figure 2317). If we are able to place an electronic line on the radar screen bearing 045º-225º at a range of 2 miles to starboard, all we will have to do when the island comes onto the radar display is to maneuver the ship to keep the island on that line which in turn locates (indexes) the vessel on the track line.

One way to conduct parallel indexing on a modern radar display is to utilize the Electronic Bearing Line (EBL) feature. Most radars have the ability to offset the EBL from the center of the display. This allows it to be used as a single parallel index line. Once the EBL bearing is set to that of the vessel's track line, the origin can be floated out to the desired distance tangent to a Variable Range Marker (VRM) set to that distance.

Modern radar sets are usually fitted with a dedicated parallel indexing (PI) feature that may take many forms depending on the radar manufacturer, and are easier to use than the floating EBL. While the details of these PI features may be quite different, they all have the following in common:

1. The display of an electronic PI line, wholly or partially across the radar screen
2. The PI line is adjustable in direction (bearing) and distance (range) from own ship
3. Once set at desired bearing and range, the PI line is fixed relative to own ship

It is vital that when placing a single PI line on the radar display, the bearing of the line is set first, then the range. If done in reverse order, the distance of the PI line from own ship to target will be less than desired.

The method described above is very basic and utilizes only a single index line and a single index target. But the level of sophistication of indexing required varies with the situation. A passage may call for many lines on different scales, multiple index targets, margin lines, danger zones and wheel over points. The more complicated the setup, of course, the more time and effort on the part of the navigator is demanded. More complex indexing schemes, however elegant, also carry a greater risk of error in construction. A point will be reached where there is little to be gained by an excessively elaborate setup because it may also lead to a more cluttered and confusing radar display. A vessel that

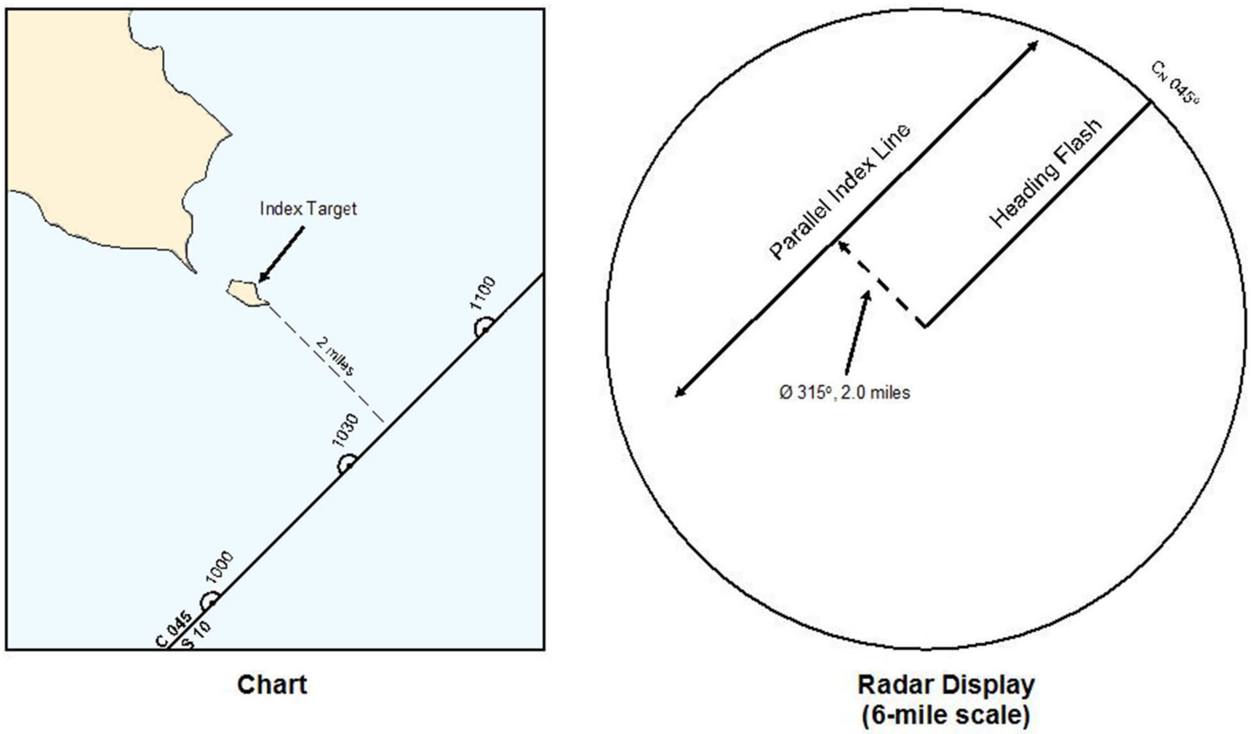

Figure 2317. Parallel indexing setup.

routinely makes passages through navigationally challenging waters would be better advised to rely more on the ECDIS and use a simpler parallel indexing setup on the radar as a backup and for cross checking.

2318. References

Pecota, S., (2006). *Radar Observer Manual*, 6th. Marine Education Textbooks. Section 2317 **reprinted with permission**.