CHAPTER 1 — BASIC RADAR PRINCIPLES AND GENERAL CHARACTERISTICS

INTRODUCTION

The word radar is an acronym derived from the phrase **RA**dio **D**etection **A**nd **R**anging and applies to electronic equipment designed for detecting and tracking objects (targets) at considerable distances. The basic principle behind radar is simple **-** extremely short bursts of radio energy (traveling at the speed of light) are transmitted, reflected off a target and then returned as an echo.

Radar makes use of a phenomenon we have all observed, that of the ECHO PRINCIPLE. To illustrate this principle, if a ship's whistle were sounded in the middle of the ocean, the sound waves would dissipate their energy as they traveled outward and at some point would disappear entirely. If, however the whistle sounded near an object such as a cliff some of the radiated sound waves would be reflected back to the ship as an echo.

The form of electromagnetic signal radiated by the radar depends upon the type of information needed about the target. Radar, as designed for marine navigation applications, is pulse modulated. Pulse-modulated radar can determine the distance to a target by measuring the time required for an extremely short burst of radio-frequency (r-f) energy to travel to the target and return to its source as a reflected echo. Directional antennas are used for transmitting the pulse and receiving the reflected echo, thereby allowing determination of the direction or bearing of the target echo.

Once time and bearing are measured, these targets or echoes are calculated and displayed on the radar display. The radar display provides the operator a birds eye view of where other targets are relative to own ship.

Radar is an active device. It utilizes its own radio energy to detect and track the target. It does not depend on energy radiated by the target itself. The ability to detect a target at great distances and to locate its position with high accuracy are two of the chief attributes of radar.

There are two groups of radio frequencies allocated by international standards for use by civil marine radar systems. The first group lies in the X-band which corresponds to a wavelength of 3 cm. and has a frequency range between 9300 and 9500 MHz. The second group lies in the S-band with a wavelength of 10 cm. and has a frequency range of 2900 to 3100 MHz. It is sometimes more convenient to speak in terms of wavelength rather than frequency because of the high values associated with the latter.

A fundamental requirement of marine radar is that of directional transmission and reception, which is achieved by producing a narrow horizontal beam. In order to focus the radio energy into a narrow beam the laws of physics prevail and the wavelength must be within the few centimeters range.

The radio-frequency energy transmitted by pulse-modulated radars consists of a series of equally spaced pulses, frequently having durations of about 1 microsecond or less, separated by very short but relatively long periods during which no energy is transmitted. The terms PULSE-MODULATED RADAR and PULSE MODULATION are derived from this method of transmission of radio-frequency energy.

If the distance to a target is to be determined by measuring the time required for one pulse to travel to the target and return as a reflected echo, it is necessary that this cycle be completed before the pulse immediately following is transmitted. This is the reason why the transmitted pulses must be separated by relatively long nontransmitting time periods. Otherwise, transmission would occur during reception of the reflected echo of the preceding pulse. Using the same antenna for both transmitting and receiving, the relatively weak reflected echo would be blocked by the relatively strong transmitted pulse.

A BRIEF HISTORY

Radar, the device which is used for detection and ranging of contacts, independent of time and weather conditions, was one of the most important scientific discoveries and technological developments that emerged from WWII. It's development, like that of most great inventions was mothered by necessity. Behind the development of radar lay more than a century of radio development.

The basic idea of radar can be traced back to the classical experiments on electromagnetic radiation conducted by the scientific community in the 19th century. In the early 1800s, an English physicist, Michael Faraday, demonstrated that electric current produces a magnetic field and that the energy in this field returns to the circuit when the current is stopped. In 1864 the Scottish physicist, James Maxwell, had formulated the general equations of the electromagnetic field, determining that both light and radio waves are actually electromagnetic waves governed by the same fundamental laws but having different frequencies. He proved mathematically that any electrical disturbance could produce an effect at a considerable distance from the point of origin and that this electromagnetic energy travels outward from the source in the form of waves moving at the speed of light.

At the time of Maxwell's conclusions there was no available means to propagate or detect electromagnetic waves. It was not until 1886 that Maxwell's theories were tested. The German physicist, Heinrich Hertz, set out to validate Maxwell's general equations. Hertz was able to show that electromagnetic waves travelled in straight lines and that they can be reflected from a metal object just as light waves are reflected by a mirror.

In 1904 the German engineer, Christian Hulsmeyer obtained a patent for a device capable of detecting ships. This device was demonstrated to the German navy, but failed to arouse interest probably due in part to its very limited range. In 1922, Guglielmo Marconi drew attention to the work of Hertz and repeated Hertz's experiments and eventually proposed in principle what we know now as marine radar.

The first observation of the radar effect was made in 1922 by Dr. Albert Taylor of the Naval Research Laboratory (NRL) in Washington, D.C. Dr. Taylor observed that a ship passing between a radio transmitter and receiver reflected some of the waves back to the transmitter. In 1930 further tests at the NRL observed that a plane flying through a beam from a transmitting antenna caused a fluctuation in the signal. The importance of radar for the purposes of tracking aircraft and ships finally became recognized when scientists and engineers learned how to use a single antenna for transmitting and receiving.

Due to the prevailing political and military conditions at the time, the United States, Great Britain, Soviet Union, France, Italy, Germany and Japan all began experimenting with radar, with varying degrees of success. During the 1930s, efforts were made by several countries to use radio echo for aircraft detection. Most of these countries were able to produce some form of operational radar equipment for use by the military at the start of the war in 1939.

At the beginning of WWII, Germany had progressed further in radar development and employed radar units on the ground and in the air for defense against allied aircraft. The ability of radar to serve as an early warning device proved valuable as a defensive tool for the British and the Germans.

Although radar was employed at the start of the war as a defensive weapon, as the war progressed, it came to be used for offensive purposes too. By the middle of 1941 radar had been employed to track aircraft automatically in azimuth and elevation and later to track targets automatically in range.

All of the proven radar systems developed prior to the war were in the VHF band. These low frequency radar signals are subject to several limitations, but despite the drawbacks, VHF represented the frontier of radar technology. Late in 1939, British physicists created the cavity magnetron oscillator which operated at higher frequencies. It was the magnetron that made microwave radar a reality. It was this technological advance that marks the beginning of modern radar.

Following the war, progress in radar technology slowed as post war priorities were directed elsewhere. In the 1950s new and better radar systems began to emerge and the benefits to the civil mariner became more important. Although radar technology has been advanced primarily by the military, the benefits have spilled over into many important civilian applications, of which a principal example is the safety of marine navigation. The same fundamental principles discovered nearly a century ago and the basic data they provide, namely target range and bearing, still apply to today's modern marine radar units.

RADAR PROPAGATION CHARACTERISTICS

THE RADIO WAVE

To appreciate the capabilities and limitations of a marine radar and to be able to use it to full advantage, it is necessary to comprehend the characteristics and behavior of radio waves and to grasp the principles of their generation and reception, including the echo display as seen by the observer. Understanding the theory behind the target presentation on the radar scope will provide the radar observer a better understanding of the art and science of radar interpretation.

Radar (radio) waves, emitted in pulses of electromagnetic energy in the radio-frequency band 3,000 to 10,000 MHz used for shipborne navigational radar, have many characteristics similar to those of other waves. Like light waves of much higher frequency, radar waves tend to travel in straight lines or rays at speeds approximating that of light. Also, like light waves, radar waves are subject to refraction or bending in the atmosphere.

Radio-frequency energy travels at the speed of light, approximately 162,000 nautical miles per second; therefore, the time required for a pulse to travel to the target and return to its source is a measure of the distance to the target. Since the radio-frequency energy makes a round trip, only half the time of travel determines the distance to the target. The round trip time is accounted for in the calibration of the radar.

The speed of a pulse of radio-frequency energy is so fast that the pulse can circumnavigate the earth at the equator more than 7 times in 1 second. It should be obvious that in measuring the time of travel of a radar pulse or signal from one ship to a target ship, the measurement must be an extremely short time interval. For this reason, the MICROSECOND (µsec) is used as a measure of time for radar applications. The microsecond is one-millionth part of 1 second, i.e., there are 1,000,000 microseconds in 1 second of time.

Radio waves have characteristics common to other forms of wave motion such as ocean waves. Wave motion consists of a succession of crests and troughs which follow one another at equal intervals and move along at a constant speed. Like waves in the sea, radar waves have energy, frequency, amplitude, wavelength, and rate of travel. Whereas waves in the sea have mechanical energy, radar waves have electromagnetic energy, usually expressed in watt units of power. An important characteristic of radio waves in connection with radar is polarization. This electromagnetic energy has associated electric and magnetic fields, the directions of which are at right angles to each other. The orientation of the ELECTRIC AXIS in space establishes what is known as the POLARIZATION of the wave. Horizontal polarization is normally used with navigational radars, i.e., the direction of the electric axis is horizontal in space. Horizontal polarization has been found to be the most satisfactory type of polarization for navigational radars in that stronger echoes are received from the targets normally used with these radars when the electric axis is horizontal.

Each pulse of energy transmitted during a few tenths of a microsecond or a few microseconds contains hundreds of complete oscillations. A CYCLE is one complete oscillation or one complete wave, i.e., that part of the wave motion passing zero in one direction until it next passes zero in the same direction (see figure 1.1). The FREQUENCY is the number of cycles completed per second. The unit now being used for frequency in cycles per second is the HERTZ. One hertz is one cycle per second; one kilohertz (kHz) is one thousand cycles per second; one megahertz (MHz) is one million cycles per second.

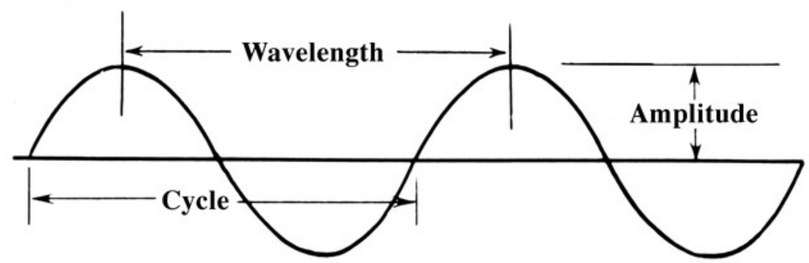


Figure 1.1 - Wave.

WAVELENGTH is the distance along the direction of propagation between successive crests or troughs. When one cycle has been completed, the wave has traveled one wavelength.

The AMPLITUDE is the maximum displacement of the wave from its mean or zero value.

Since the speed of radar waves is constant at 300,000 kilometers per second, there is a definite relationship between frequency and wavelength.

The CYCLE is a complete alternation or oscillation from one crest through a trough to the next crest.

$$\text{frequency} = \frac{\text{speed of radar waves}}{\text{wavelength}}$$

When the wavelength is 3.2 centimeters (0.000032 km),

$$\text{frequency} = \frac{300,000 \text{ km}}{\text{second}} \div \frac{0.000032 \text{ km}}{\text{cycle}}$$

$$\text{frequency} = 9375 \text{ megahertz}$$

THE RADAR BEAM

The pulses of r-f energy emitted from the feedhorn at the focal point of a reflector or emitted and radiated directly from the slots of a slotted waveguide antenna would, for the most part, form a single lobe-shaped pattern of radiation if emitted in free space. Figure 1.2 illustrates this free space radiation pattern, including the undesirable minor lobes or SIDE LOBES associated with practical antenna design. Because of the large differences in the various dimensions of the radiation pattern, figure 1.2 is necessarily distorted.

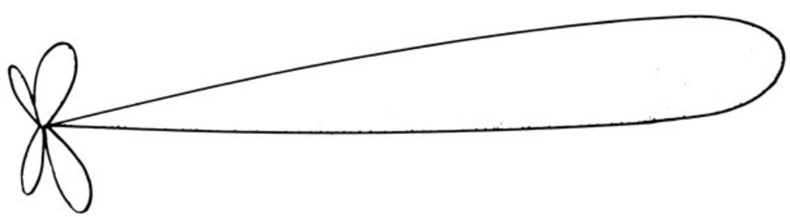


Figure 1.2 - Free space radiation pattern.

Although the radiated energy is concentrated or focused into a relatively narrow main beam by the antenna, similar to a beam of light from a flashlight, there is no clearly defined envelope of the energy radiated. While the energy is concentrated along the axis of the beam, its strength decreases with distance along the axis. The strength of the energy decreases rapidly in directions away from the beam axis. The power in watts at points in the beam is inversely proportional to the square of the distance. Therefore, the power at 3 miles is only 1/9th of the power at 1 mile in a given direction. The field intensity in volts at points in the beam is inversely proportional to the distance. Therefore, the voltage at 2 miles is only one-half the voltage at 1 mile in a given direction. With the rapid decrease in the amount of radiated energy in directions away from the axis and in conjunction with the rapid decreases of this energy with distance, it follows that practical limits of power or voltage may be used to define the dimensions of the radar beam or to establish its envelope of useful energy.

Beam Width

The three-dimensional radar beam is normally defined by its horizontal and vertical beam widths. Beam width is the angular width of a radar beam between points within which the field strength or power is greater than arbitrarily selected lower limits of field strength or power.

There are two limiting values, expressed either in terms of field intensity or power ratios, used conventionally to define beam width. One convention defines beam width as the angular width between points at which the field strength is 71 percent of its maximum value. Expressed in terms of power ratio, this convention defines beam width as the angular width between HALF-POWER POINTS. The other convention defines beam width as the angular width between points at which the field strength is 50 percent of its maximum value. Expressed in terms of power ratio, the latter convention defines beam width as the angular width between QUARTER-POWER POINTS.

The half-power ratio is the most frequently used convention. Which convention has been used in stating the beam width may be identified from the decibel (dB) figure normally included with the specifications of a radar set. Half power and 71 percent field strength correspond to -3 dB; quarter power and 50 percent field strength correspond to -6 dB.

The radiation diagram illustrated in figure 1.3 depicts 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 in this case is taken as the angle between the half-power points.

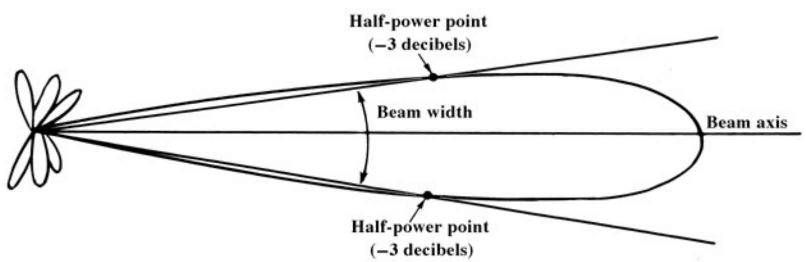


Figure 1.3 - Radiation diagram.

For a given amount of transmitted power, the main lobe of the radar beam extends to a greater distance at a given power level with greater concentration of power in narrower beam widths. To increase maximum detection range capabilities, the energy is concentrated into as narrow a beam as is feasible. Because of practical considerations related to target detection and discrimination, only the horizontal beam width is quite narrow, typical values being between about 0.65° to 2.0°. The vertical beam width is relatively broad, typical values being between about 15° to 30°.

The beam width is dependent 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 are obtained when using shorter wavelengths. For a given wavelength, narrower beam widths are obtained when using larger antennas.

The slotted waveguide antenna has largely eliminated the side-lobe problem.

EFFECT OF SEA SURFACE ON RADAR BEAM

With radar waves being propagated in the vicinity of the surface of the sea, the main lobe of the radar beam, as a whole, is composed of a number of separate lobes 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 directly transmitted and those waves which are reflected from the surface of the sea. The vertical beam widths of navigational radars are such that during normal transmission, radar waves will strike the surface of the sea at points from near the antenna (depending upon antenna height and vertical beam width) to the radar horizon. The indirect waves (see figure 1.4) reflected from the surface of the sea may, on rejoining the direct waves, either reinforce or cancel the direct waves depending upon whether they are in phase or out of phase with the direct waves, respectively. Where the direct and indirect waves are exactly in phase, i.e., the crests and troughs of the waves coincide, hyperbolic lines of maximum radiation known as LINES OF MAXIMA are produced. Where the direct and indirect waves are exactly of opposite phase, i.e., the trough of one wave coincides with the crest of the other wave, hyperbolic lines of minimum radiation known as LINES OF MINIMA are produced. Along directions away from the antenna, the direct and indirect waves will gradually come into and pass out of phase, producing lobes of useful radiation separated by regions within which, for practical purposes, there is no useful radiation.

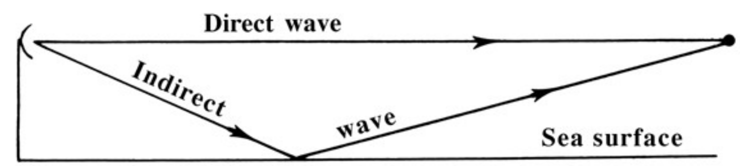


Figure 1.4 - Direct and indirect waves.

Figure 1.5 illustrates the lower region of the INTERFERENCE PATTERN of a representative navigational radar. Since the first line of minima is at the surface of the sea, the first region of minimum radiation or energy is adjacent to the sea's surface.

From figure 1.5 it should be obvious that if r-f energy is to be reflected from a target, the target must extend somewhat above the radar horizon, the amount of extension being dependent upon the reflecting properties of the target.

A VERTICAL-PLANE COVERAGE DIAGRAM as illustrated in figure 1.5 is used by radar designers and analysts to predict regions in which targets will and will not be detected.

Of course, on the small page of a book it would be impossible to illustrate the coverage of a radar beam to scale with antenna height being in feet and the lengths of the various lobes of the interference pattern being in miles. In providing greater clarity of the presentation of the lobes, non-linear graduations of the arc of the vertical beam width are used.

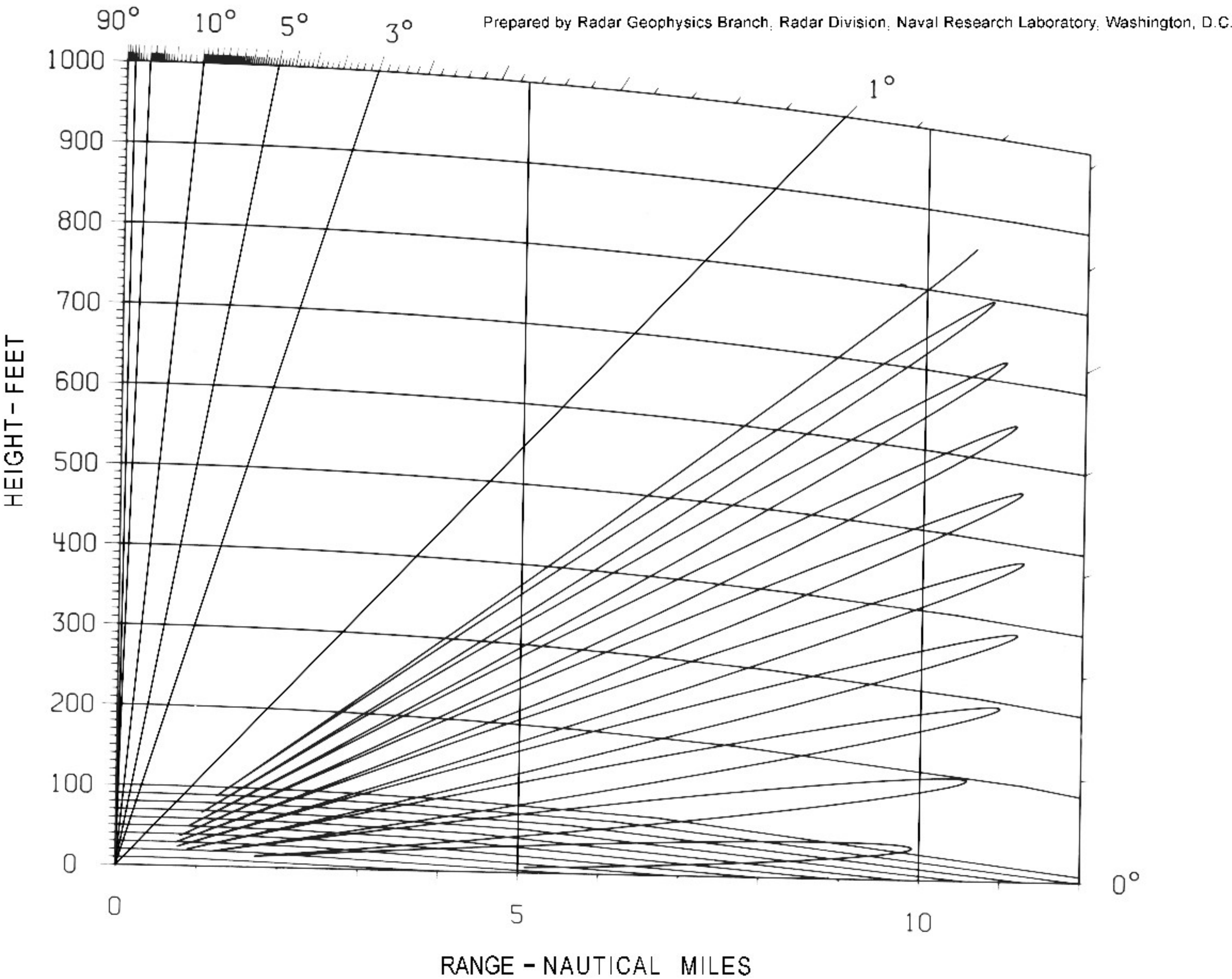


Figure 1.5 - Vertical-plane coverage diagram (3050 MHz, antenna height 125 feet, wave height 4 feet).

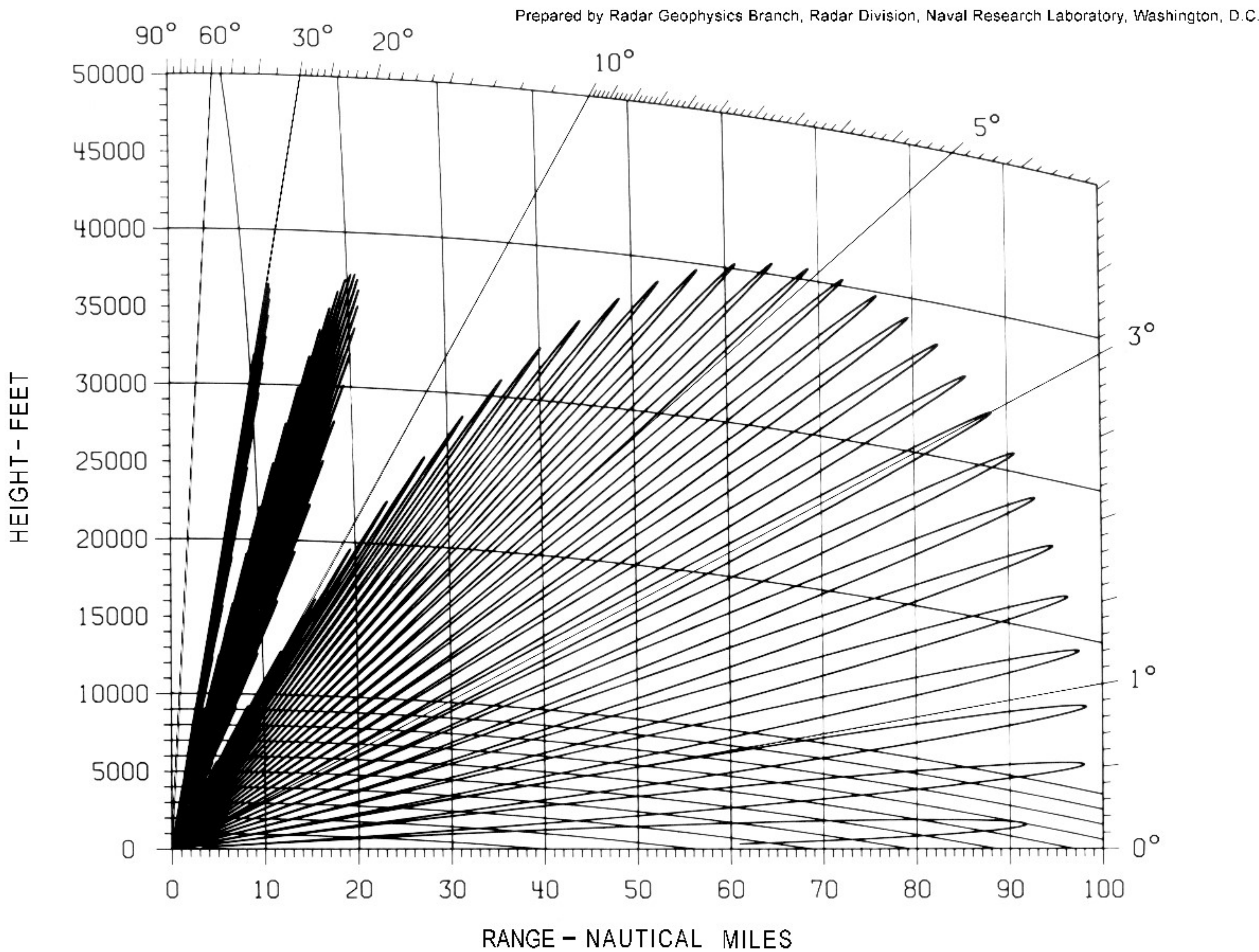


Figure 1.6 - Vertical-plane coverage diagram (1000 MHz, vertical beam width 10˚, antenna height 80 feet, wave height 0 feet).

The lengths of the various lobes illustrated in figures 1.5 and 1.6 should be given no special significance with respect to the range capabilities of a particular radar set. As with other coverage diagrams, the lobes are drawn to connect points of equal field intensities. Longer and broader lobes may be drawn connecting points of equal, but lesser, field intensities.

The vertical-plane coverage diagram as illustrated in figure 1.6, while not representative of navigational radars, does indicate that at the lower frequencies the interference pattern is more coarse than the patterns for higher frequencies. This particular diagram was constructed with the assumption that the free space useful range of the radar beam was 50 nautical miles. From this diagram it is seen that the ranges of the useful lobes are extended to considerably greater distances because of the reinforcement of the direct radar waves by the indirect waves. Also, the elevation of the lowest lobe is higher than it would be for a higher frequency. Figure 1.6 also illustrates the vertical view of the undesirable side lobes associated with practical antenna design. In examining these radiation coverage diagrams, the reader should keep in mind that the radiation pattern is three-dimensional.

Antenna height as well as frequency or wavelength governs the number of lobes in the interference pattern. The number of the lobes and the fineness of the interference pattern increase with antenna height. Increased antenna height as well as increases in frequency tends to lower the lobes of the interference pattern.

The pitch and roll of the ship radiating does not affect the structure of the interference pattern.

ATMOSPHERIC FACTORS AFFECTING THE RADAR HORIZON

THE RADAR HORIZON

The affect of the atmosphere on the horizon is a further factor which should be taken into account when assessing the likelihood of detecting a particular target and especially where the coastline is expected.

Generally, radar waves are restricted in the recording of the range of low-lying objects by the radar horizon. The range of the radar horizon depends on the height of the antenna and on the amount of bending of the radar wave. The bending is caused by diffraction and refraction. Diffraction is a property of the electromagnetic wave itself. Refraction is due to the prevailing atmospheric conditions. There is, therefore, a definite radar horizon.

DIFFRACTION

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. Thus, the radar beam of a lower frequency radar tends to illuminate more of the shadow region behind an obstruction than the beam of radar of higher frequency or shorter wavelength.

REFRACTION

Refraction affects the range at which objects are detected. The phenomenon of refraction should be well-known to every navigation officer. Refraction takes place when the velocity of the wave is changed. This can happen when the wave front passes the boundary of two substances of differing densities. One substance offers more resistance to the wave than the other and therefore the velocity of the wave will change. Like light rays, radar rays are subject to bending or refraction in the atmosphere resulting from travel through regions of different density. However, radar rays are refracted slightly more than light rays because of the frequencies used. If the radar waves actually traveled in straight lines or rays, the distance to the horizon grazed by these rays would be dependent only on the height of the antenna, assuming adequate power for the rays to reach this horizon. Without the effects of refraction, the distance to the RADAR HORIZON would be the same as that of the geometrical horizon for the antenna height.

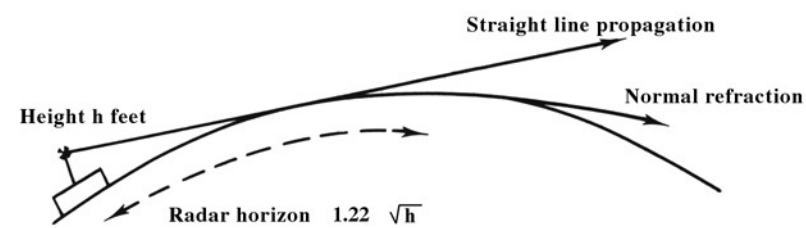
Standard Atmospheric Conditions

The distance to the radar horizon, ignoring refraction can be expressed in the following formula. Where h is the height of the antenna in feet, the distance, d, to the radar horizon in nautical miles, assuming standard atmospheric conditions, may be found as follows:

$$d = 1.22\sqrt{h}$$

With the distances to the geometrical or ordinary horizon being $1.06\sqrt{h}$ and the distance to the visible or optical horizon being $1.15\sqrt{h}$. We see that the range of the radar horizon is greater than that of the optical horizon, which again is greater than that of the geometrical horizon. Thus, like light rays in the standard atmosphere, radar rays are bent or refracted slightly downwards approximating the curvature of the earth (see figure 1.7).

The distance to the radar horizon does not in itself 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. Note that the distance to the radar horizon is the distance at which the radar rays graze the surface of the earth.



Reproduced by Courtesy of Decca Radar Limited, London.

Figure 1.7 - Refraction.

In the preceding discussion standard atmospheric conditions were assumed. The standard atmosphere is a hypothetical vertical distribution of atmospheric temperature, pressure, and density which is taken to be representative of the atmosphere for various purposes.

Standard conditions are precisely defined as follows:

Pressure = 1013 mb decreasing at 36 mb/1000 ft of height
Temperature = 15˚C decreasing at 2˚C/1000 ft of height
Relative Humidity = 60% and constant with height.

These conditions give a refractive index of 1.00325 which decreases at 0.00013 units/1000 ft of height. The definition of "standard" conditions relates to the vertical composition of the atmosphere. Mariners may not be able to obtain a precise knowledge of this and so must rely on a more general appreciation of the weather conditions, the area of the world, and of the time of the year.

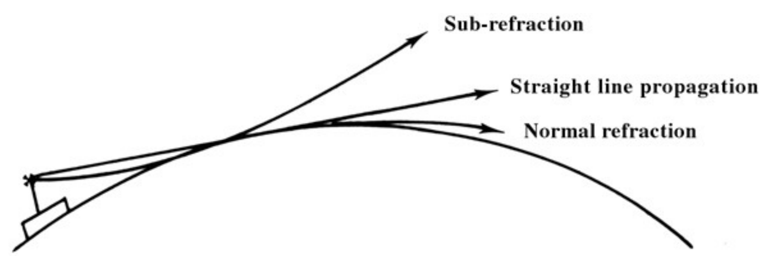
While the atmospheric conditions at any one locality during a given season may differ considerably from standard atmospheric conditions, the slightly downward bending of the light and radar rays may be described as the typical case.

While the formula for the distance to the radar horizon ($d = 1.22\sqrt{h}$) is based upon a wavelength of 3cm, this formula may be used in the computation of the distance to the radar horizon for other wavelengths used with navigational radar. The value so determined should be considered only as an approximate value because the mariner generally has no means of knowing what actual refraction conditions exist.

Sub-refraction

The distance to the radar horizon is reduced. This condition is not as common as super-refraction. Sub-refraction can occur in polar regions where Arctic winds blow over water where a warm current is prevalent. If a layer of cold, moist air overrides a shallow layer of warm, dry air, a condition known as SUB-REFRACTION may occur (see figure 1.8). The effect of sub-refraction is to bend the radar rays upward and thus decrease the maximum ranges at which targets may be detected.

Sub-refraction also affects minimum ranges and may result in failure to detect low lying targets at short range. It is important to note that sub-refraction may involve an element of danger to shipping where small vessels and ice may go undetected. The officer in charge of the watch should be especially mindful of this condition and extra precautions be administered such as a reduction in speed and the posting of extra lookouts.

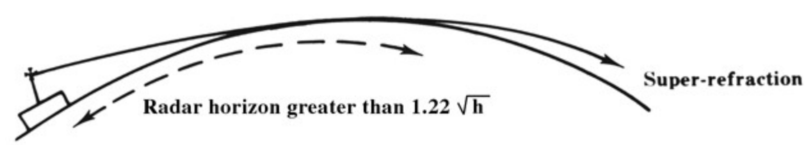


Reproduced by Courtesy of Decca Radar Limited, London.

Figure 1.8 - Sub-refraction.

Super-refraction

The distance to the radar horizon is extended. In calm weather with no turbulence when there is an upper layer of warm, dry air over a surface layer of cold, moist air, a condition known as SUPER-REFRACTION may occur (see figure 1.9). For this condition to exist, the weather must be calm with little or no turbulence, otherwise the layers of different densities will mix and the boundary conditions disappear. The effect of super-refraction will increase the downward bending of the radar rays and thus increase the ranges at which targets may be detected. Super-refraction frequently occurs in the tropics when a warm land breeze blows over cooler ocean currents. It is especially noticeable on the longer range scales.



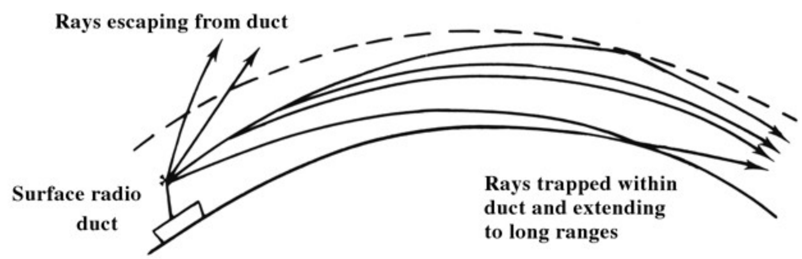
Reproduced by Courtesy of Decca Radar Limited, London.

Figure 1.9 - Super-refraction.

Extra Super-refraction or Ducting

Most radar operators are aware that at certain times they are able to detect targets at extremely long ranges, but at other times they cannot detect targets within visual ranges, even though their radars may be in top operating condition in both instances.

These phenomena occur during extreme cases of super-refraction. Energy radiated at angles of 1˚ or less may be trapped in a layer of the atmosphere called a SURFACE RADIO DUCT. In the surface radio duct illustrated in figure 1.10, the radar rays are refracted downward to the surface of the sea, reflected upward, refracted downward again within the duct, and so on continuously.



Reproduced by Courtesy of Decca Radar Limited, London.

Figure 1.10 - Ducting.

The energy trapped by the duct suffers little loss; thus, targets may be detected at exceptionally long ranges. Surface targets have been detected at ranges in excess of 1,400 miles with relatively low-powered equipment. There is a great loss in the energy of the rays escaping the duct, thus reducing the chances for detection of targets above the duct.

Ducting sometimes reduces the effective radar range. If the antenna is below a duct, it is improbable that targets above the duct will be detected. In instances of extremely low-level ducts when the antenna is above the duct, surface targets lying below the duct may not be detected. The latter situation does not occur very often.

Ducting Areas

Although ducting conditions can happen any place in the world, the climate and weather in some areas make their occurrence more likely. In some parts of the world, particularly those having a monsoonal climate, variation in the degree of ducting is mainly seasonal, and great changes from day to day may not take place. In other parts of the world, especially those in which low barometric pressure areas recur often, the extent of nonstandard propagation conditions varies considerably from day to day.

Figure 1.11 illustrates the different places in the world where known ducting occurs frequently. Refer to the map to see their location in relation to the climate that exists in each area during different seasons of the year.

Atlantic Coast of the United States (Area 1). Ducting is common in summer along the northern part of the coast, but in the Florida region the seasonal trend is the reverse, with a maximum in the winter season.

Western Europe (Area 2). A pronounced maximum of ducting conditions exists in the summer months on the eastern side of the Atlantic around the British Isles and in the North Sea.

Mediterranean Region (Area 3). Available reports indicate that the seasonal variation in the Mediterranean region is very marked, with ducting more or less the rule in summer. Conditions are approximately standard in winter. Ducting in the central Mediterranean area is caused by the flow of warm, dry air from the south, which moves across the sea and thus provides an excellent opportunity for the formation of ducts. In winter, however, the climate in the central Mediterranean is more or less the same as Atlantic conditions, therefore not favorable for duct formation.

Arabian Sea (Area 4). The dominating meteorological factor in the Arabian Sea region is the southwest monsoon, which blows from early June to mid-September and covers the whole Arabian Sea with moist-equatorial air up to considerable heights. When this meteorological situation is developed fully, no occurrence of ducting is to be expected. During the dry season, on the other hand, conditions are different. Ducting then is the rule, not the exception, and on some occasions extremely long ranges (up to 1,500 miles) have been observed on fixed targets.

When the southwest monsoon begins early in June, ducting disappears on the Indian side of the Arabian Sea. Along the western coasts, however, conditions favoring ducting may still linger. The Strait of Hormuz (Persian Gulf) is particularly interesting as the monsoon there has to contend with the shamal (a northwesterly wind) over Iraq and the Persian Gulf from the north. The strait itself lies at the boundary between the two wind systems; a front is formed with the warm, dry shamal on top and the colder, humid monsoon underneath. Consequently, conditions are favorable for the formation of an extensive duct, which is of great importance to radar operation in the Strait of Hormuz.

Bay of Bengal (Area 5). The seasonal trend of ducting conditions in the Bay of Bengal is the same as in the Arabian Sea, with standard conditions during the summer southwest monsoon. Ducting is found during the dry season.

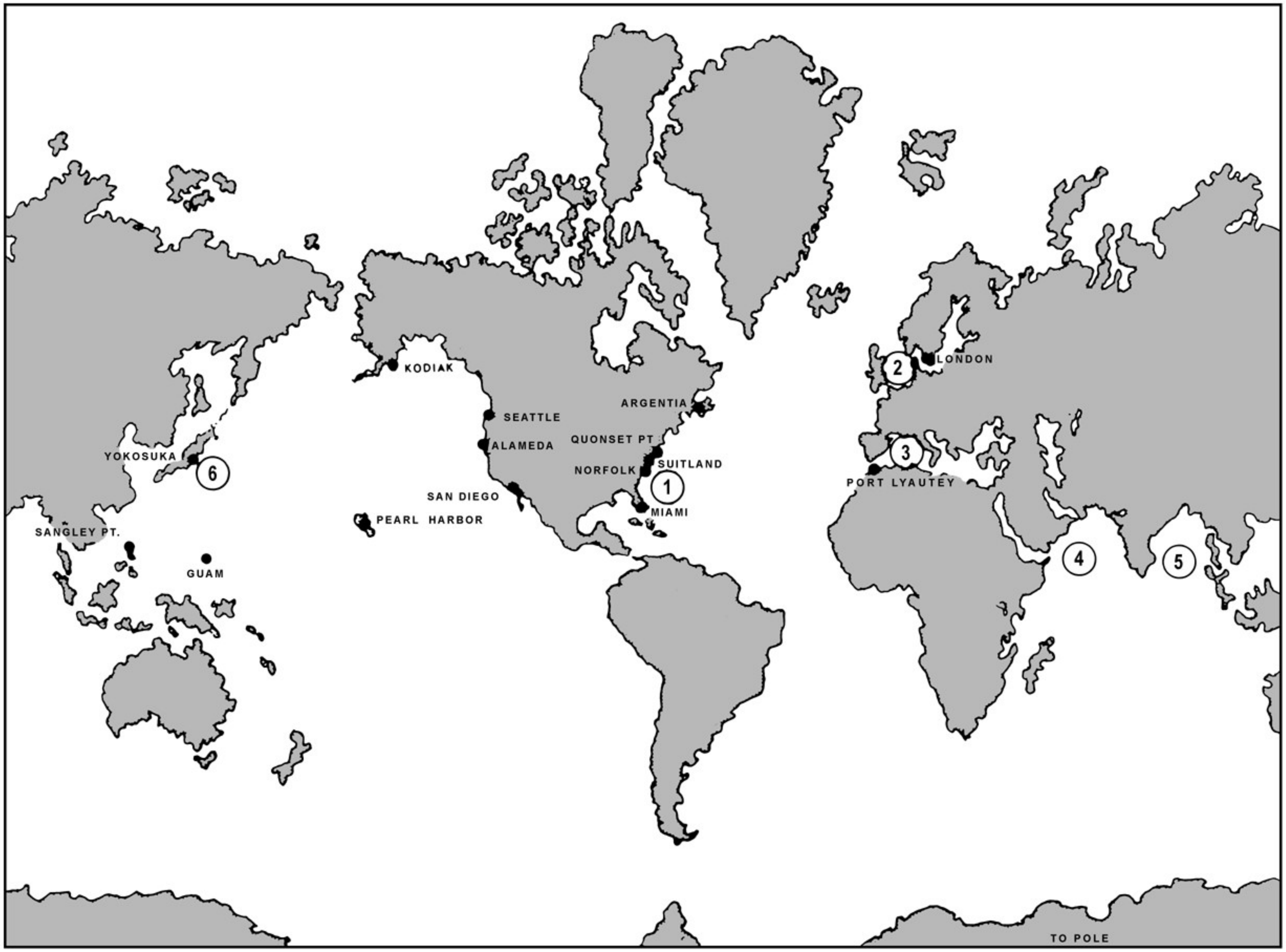


Figure 1.11 - Ducting areas.

Pacific Ocean (Area 6). Frequent occurrences of ducting around Guadalcanal, the east coast of Australia, and around New Guinea and Korea have been experienced. Observations along the Pacific coast of the United States indicate frequent ducting, but no clear indication of its seasonal trend is available. Meteorological conditions in the Yellow Sea and Sea of Japan, including the island of Honshu, are approximately like those of the northeastern coast of the United States. Therefore, ducting in this area should be common in the summer. Conditions in the South China Sea approximate those off the southeastern coast of the United States only during the winter months, when ducting can be expected. During the rest of the year, the Asiatic monsoon modifies the climate in this area, but no information is available on the prevalence of ducting during this time. Trade winds in the Pacific quite generally lead to the formation of rather low ducts over the open ocean.

WEATHER FACTORS AFFECTING THE RADAR HORIZON

The usual effects of weather are to reduce the ranges at which targets can be detected and to produce unwanted echoes on the radarscope which may obscure the returns from important targets or from targets which may be dangerous to one's ship. The reduction of intensity of the wave experienced along its path is known as *attenuation.*

Attenuation is caused by the absorption and scattering of energy by the various forms of precipitation. The amount of attenuation caused by each of the various factors depends to a substantial degree on the radar wavelength. It causes a decrease in echo strength. Attenuation is greater at the higher frequencies or shorter wavelengths.

Attenuation by rain, fog, clouds, hail, snow, and dust

The amount of attenuation caused by these weather factors is dependent upon the amount of water, liquid or frozen, present in a unit volume of air and upon the temperature. Therefore, as one would expect, the affects can differ widely. The further the radar wave and returning echo must travel through this medium then the greater will be the attenuation and subsequent decrease in detection range. This is the case whether the target is in or outside the precipitation. A certain amount of attenuation takes place even when radar waves travel through a clear atmosphere. The affect will not be noticeable to the radar observer. The effect of precipitation starts to become of practical significance at wavelengths shorter than 10cm. In any given set of precipitation conditions, the (S-band) or 10cm will suffer less attenuation than the (X-band) or 3cm.

Rain

In the case of rain the particles which affect the scattering and attenuation take the form of water droplets. It is possible to relate the amount of attenuation to the rate of precipitation. If the size of the droplet is an appreciable proportion of the 3cm wavelength, strong clutter echoes will be produced and there will be serious loss of energy due to scattering and attenuation. If the target is within the area of rainfall, any echoes from raindrops will further decrease its detection range. Weaker target responses, as from small vessels and buoys, will be undetectable if their echoes are not stronger than that of the rain. A very heavy rainstorm, like those sometimes encountered in the tropics, can obliterate most of the (X-band) radar picture.

Continuous rainfall over a large area will make the center part of the screen brighter than the rest and the rain clutter, moving along with the ship, looks similar to sea clutter. It can be clearly seen on long range scales. This is due to a gradual decrease in returning power as the pulse penetrates further into the rain area.

Fog

In most cases fog does not actually produce echoes on the radar display, but a very dense fogbank which arises in polar regions may produce a significant reduction in detection range.

A vessel encountering areas known for industrial pollution in the form of smog may find a somewhat higher degree of attenuation than sea fog.