CHAPTER 6

RADIO WAVE PROPAGATION

The transmission of radio waves through space is known as WAVE PROPAGATION. An electromagnetic wave must be propagated through space to a receiving antenna to establish a useful communications system. In any radio communications system, energy in the form of electromagnetic waves is generated by the transmitter and fed to an antenna by means of a transmission line. The antenna radiates this energy out into space at the speed of light. Receiving antennas, placed in the path of the traveling radio wave, absorb part of the radiated energy and send it through a transmission line to a receiver. Figure 6-1 shows an example of a simple radio communication network.

Successful communication by means of radio waves depends on the power of the transmitter, the frequency used, the distance between the transmitter and receiver, and the sensitivity of the receiver. The ability of the earth's atmosphere to conduct energy to its destination, together with the nature of the terrain between the sending and receiving points, may be responsible for the frequency used to transmit the radio signal. Interferring signals can make reception impossible at a desired time. Also, the amount of noise present at the signal frequency and transmission line losses may combine to make unintelligible an otherwise good signal.

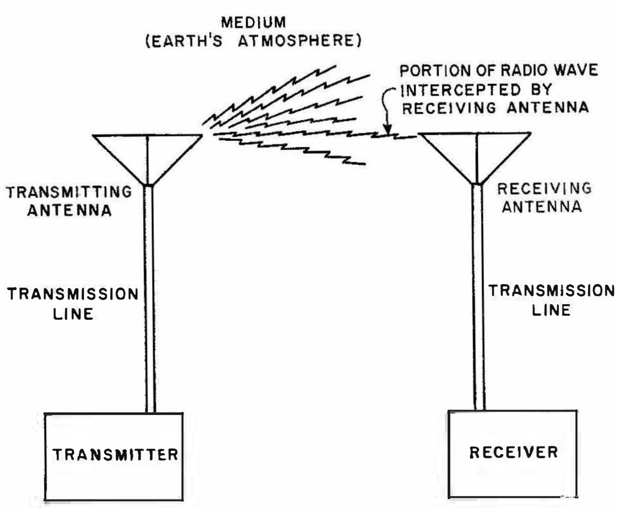

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Figure 6-1.—Simple Radio Communication Network.

Depending upon the frequency used, the primary medium for transmission may be the surface of the earth or the free space surrounding the earth, (normally both). By far the more complex of these two mediums is free space. Therefore, it is necessary that the nature of free space be known so that its effects on the quality of transmission may be predicted. Weather conditions, changes in the level of radiation from the sun, and physical obstructions on the earth's surface all affect the quality and reliability of transmission. Because we cannot control the phenomena existing in the propagating mediums, our knowledge of them is of primary importance to achieve successful communications.

TERMS AND DEFINITIONS

In our discussion of radio wave propagation, a number of terms are used that could tend to confuse you, if the terms are not understood. Therefore, the following list of defined terms is provided for your reference.

ATMOSPHERE—The mass of space surrounding the earth, including the troposphere, stratosphere, and ionosphere. Also called "free space".

ATTENUATION—The decrease in signal strength of a radio wave.

CONDUCTIVITY—A measure of the ability of a material to act as a path for electron flow. (Measured in mhos per meter).

CRITICAL FREQUENCY—That frequency below which an electromagnetic wave is bent back to earth by a layer in the ionosphere.

DIFFRACTION—The bending of an electromagnetic wave around the edge(s) of a solid object.

DIRECT WAVE—A radio wave that is propagated in a straight line through space from the transmitting to the receiving antennas.

DISTORTION—An undesired change in an electromagnetic waveform.

FADING—The variation of radio signal strength, usually gradual, during the time of reception.

GIGAHERTZ (GHz)—An expression denoting 1000 MHz.

GROUND WAVE—A radio wave that travels (propagates) close to the earth's surface and reaches the receiving antenna without being influenced by the ionosphere. The ground wave includes all components of a radio wave traveling over the earth except the sky (ionospheric) wave.

HERTZ (Hz)—Cycles per second.

INCIDENT WAVES—A term denoting that portion of a radio wave passing from one medium into another which will result in that wave being reflected, refracted, diffracted, or scattered.

IONOSPHERE—That part of the earth's outer atmosphere where ionization is present in sufficient quantity to affect the propagation of radio waves. Also known as that portion of the atmosphere above the stratosphere.

MAXIMUM USABLE FREQUENCY (MUF)—The highest frequency or frequencies that may be used at a specified time of day for radio communications between two points.

NOISE—Any extraneous electrical disturbance tending to interfere with the normal reception of a transmitted signal.

FREQUENCY OF OPTIMUM TRANSMISSION (FOT)—The most reliable frequency for propagation at a specific time.

LOWEST USABLE FREQUENCY (LUF)—The lowest frequency that may be used during a specific time, depending upon power and bandwidth requirements.

PROPAGATION—The transmission of electromagnetic (radio) waves from one point to another.

REFLECTION—The phenomenon occurring when a radio wave strikes the surface of the earth at some distance from the antenna and is returned upward toward the ionized layer of air.

REFRACTION—The phenomenon occurring when a radio wave obliquely passes from one medium to another of different density, causing the wave to change direction.

SPACE WAVE—Sometimes called the tropospheric wave. A radio wave that travels entirely through the earth's troposphere.

SKY WAVE—A radio wave that is propagated or acted upon by the ionosphere.

SUNSPOT NUMBERS—The number of dark, irregularly shaped areas on the surface of the sun caused by violent solar eruptions. Counted and averaged over a period of time, they are used to predict the average sunspot activity. The average of these numbers is called "smooth sunspot numbers".

SURFACE WAVE—That part of the groundwave that is affected chiefly by the conductivity of the earth.

STRATOSPHERE—That part of the earth's atmosphere lying between the troposphere and the ionosphere.

TROPOSPHERE—The lower part of the earth's atmosphere, lying between the surface of the earth and the stratosphere.

DIFFRACTION, REFLECTION, AND REFRACTION

One of the many problems encountered in the propagation of radio waves is the changeable conditions of the transmission path through the various mediums. As a radio wave is traveling through space, it can be affected adversely or in such a manner as to enhance communications. It may change direction, velocity, or be completely absorbed within the propagating medium.

The atmosphere of the earth is the common medium for propagation and a study of radio propagation is concerned chiefly with properties and effects of this medium. Radio waves travel in two ways from a transmitter to a receiver: by means of GROUND WAVES, which travel close to the surface of the earth or by SKY WAVES, which travel up to electrically conducting regions of the earth's atmosphere and are returned to earth, (see figure 6-2). Some forms of transmission are combinations of both ground waves and sky waves.

Like other forms of electromagnetic radiation, radio waves can be diffracted, reflected, and refracted. Ground waves are affected partially by the curvature and electrical characteristics of the earth. Sky waves are affected in varying degrees by the constant changes taking place in the upper atmosphere.

Diffraction

A radio wave is bent when it passes the edge of an object. If a beam of light shines on the edge of an opaque screen in a room, it can be observed that the screen does not cast a perfectly outlined shadow. The edges of the shadow are not outlined sharply because the light rays are bent around the edge of the screen which decreases the area of total shadow. The bending, called DIFFRACTION, results in a change of direction of part of the energy from the line-of-sight path.

Figure 6-3 shows the diffraction of waves around a solid object. The lower the frequency of the wave, or the longer the wavelength, the greater the bending of the wave. Thus, sound waves are diffracted more than radio waves. Diffraction aids in explaining why radio waves of proper frequency can be received on the far side of a mountain or down in a valley and why sound waves can readily be heard around the corner of a building. In the propagation of radio waves at a distance, diffraction is a significant consideration because the largest object to be contended with is the bulge of the earth itself, which prevents a direct passage of the wave from the transmitter to the receiver. By using high power and very low frequencies, the waves of a transmitted signal can be made to encircle the earth by diffraction.

Reflection

Radio waves may be reflected from any sharply defined substances or objects of suitable characteristics and dimensions which are

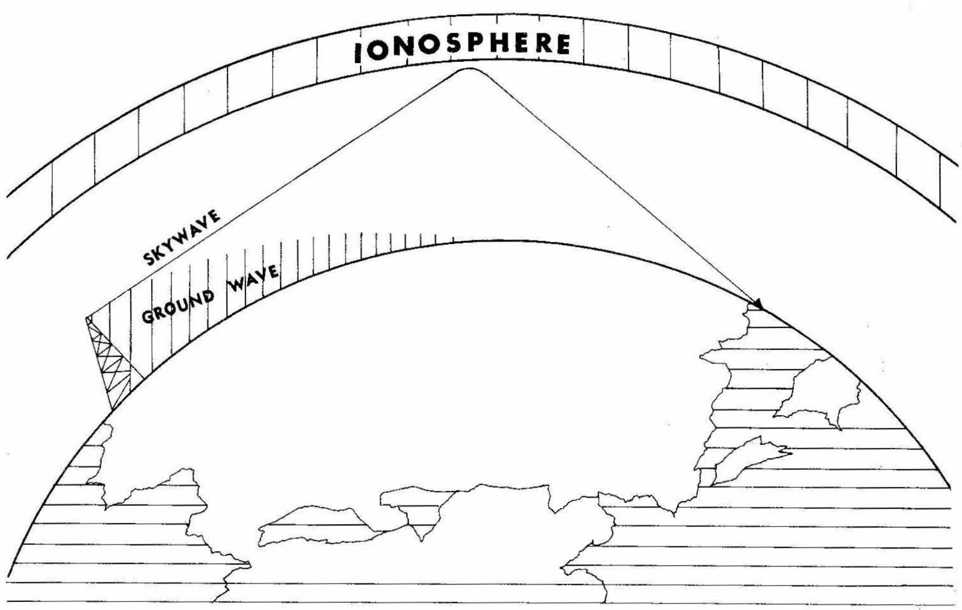

Figure 6-2.—Groundwaves and Skywaves. 179.495

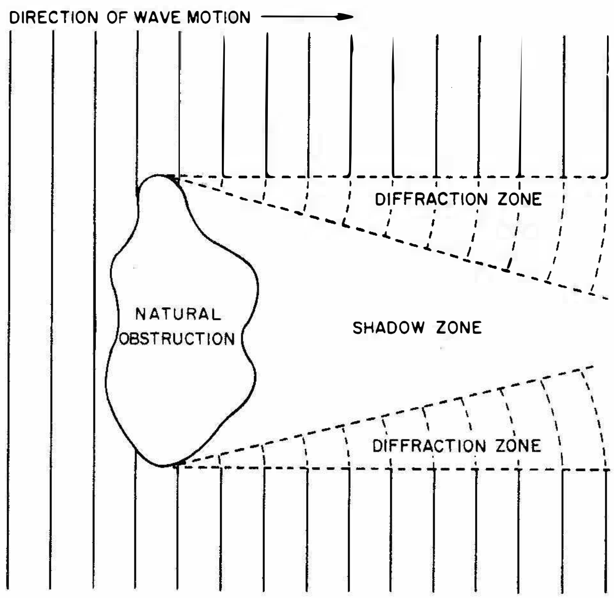

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Figure 6-3.—Diffraction of Waves around a solid object.

encountered in the medium of travel. For reflection to occur, the object, or material doing the reflecting, must have the right type of surface, and it must be larger than the wavelength of the incident wave. Figure 6-4 shows an incident radio wave striking water. Water is a good conductor and reflector of radio waves. Large, smooth metal surfaces of good electrical conductivity (such as copper) are efficient reflectors.

As previously mentioned, reflection takes place only when the reflecting surface is large compared to the wavelength of the incident wave and smooth for an appreciable portion of a wavelength. When these conditions are not met, scattering occurs. Scattering is undesirable for certain types of communications, but it is utilized to a great extent in others.

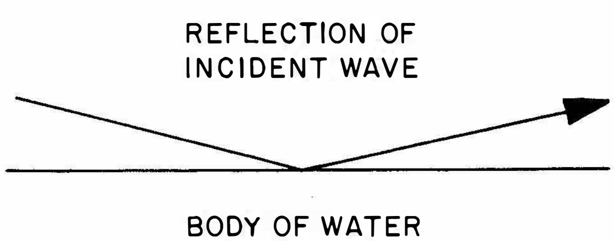

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Figure 6-4.—Reflection of Incident Wave from body of water.

Refraction

Whenever a radio wave passes from one medium into another of different density, it will be bent to some degree. Figure 6-5 shows a radio wave striking the surface of a body of water. The water, being more dense than air, tends to bend the radio wave back toward the "normal". The denser medium tends to slow and bend the radio wave. The amount of bending that takes place is referred to as the "Index of Refraction". The higher the index of refraction, the greater the bending.

Whenever a radio wave passes from a dense to a less-dense medium, it bends away from the normal. Figure 6-6 illustrates this principle. The "more dense" mediums and the "less dense" ones are normally layers that exist in the atmosphere. It must be remembered that whenever a radio wave is propagated, it is constantly being diffracted, reflected, and refracted, simultaneously.

A common error is the assumption that reflection and refraction are very similar because

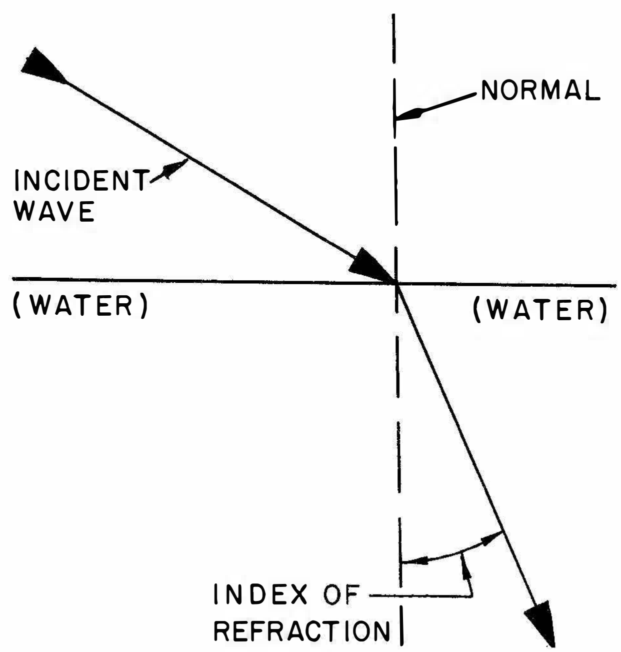

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Figure 6-5.—Radio Wave striking the surface of a body of water.

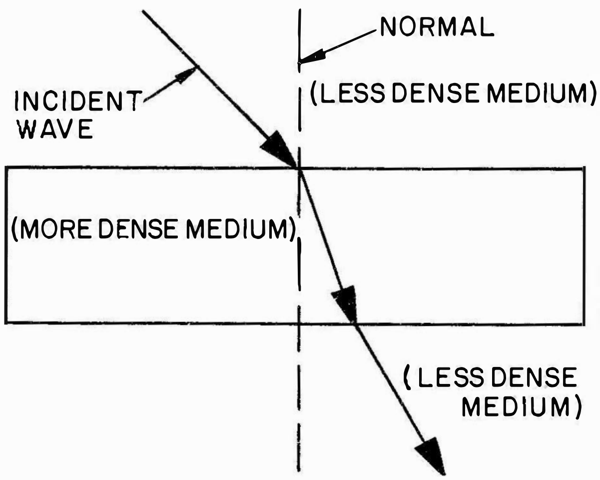

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Figure 6-6.—Radio Wave passing from a more dense medium to a less dense medium.

they return radio waves back to earth for reception. However, as shown in figure 6-7, the refracted wave is "bent" back to earth. As radio waves are propagated, some of them make large angles with respect to the horizontal along the earth (fig. 6-7(A)). These waves are refracted a small amount and pass on through the various layers of the atmosphere and into outer space. Still other waves of the same radio signal make small angles (fig. 6-7(B & C)), thereby travelling a greater distance in the layered medium and may be bent back towards earth gradually. The net result is as though the wave had been reflected back to earth.

COMPOSITION OF THE EARTH'S ATMOSPHERE

The atmosphere about the earth is not uniform. Changes in moisture content, temperature, and density occur at different heights and geographical locations or even with changes in

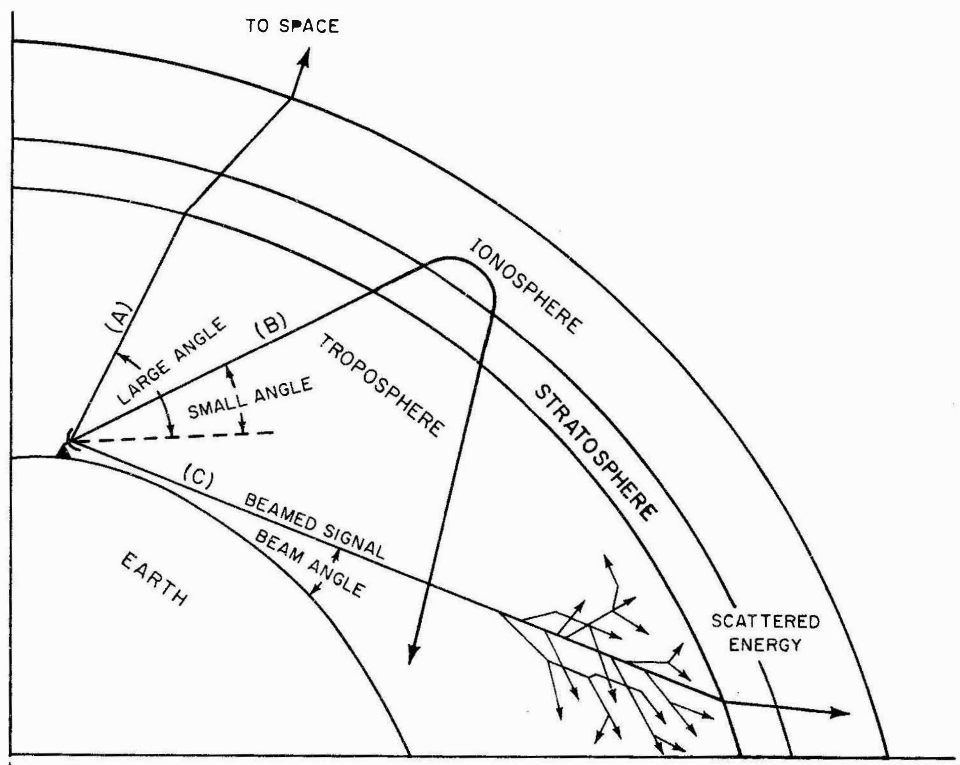

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Figure 6-7.—Refraction of Radio Waves in atmosphere.

time of day, night, season, or year. To assist in understanding the effects of these changes on radio waves, three regions have been identified in the atmosphere. These three regions are the troposphere, stratosphere, and ionosphere. Their positions with relation to each other are shown in figure 6-8. The troposphere extends from the earth's surface to heights of about 6 to 10 miles. The stratosphere, lying between the troposphere and ionosphere, extends from approximately 10 miles to 50 miles above the earth's surface. The ionosphere extends from approximately 50 miles to 250 miles above the earth's surface.

TYPES OF RADIO WAVE PROPAGATION

The radio wave that is transmitted from an antenna has two major components: the ground wave and the sky wave. The ground wave component of the transmitted radio wave consists of two parts. One part travels along the ground and follows the curvature of the earth and is called the surface wave. The second part is the space wave, which undergoes refraction, reflection, or scattering in the troposphere. The sky wave, is radiated in an upward direction and may be returned to earth at some distant location due to refraction or scattering from the ionosphere. The amount of bending of the sky wave by the ionosphere depends upon the frequency of the wave and the density of the layers in the ionosphere. The higher the frequency of the radio wave, the farther it penetrates the ionosphere, and the less it tends to be bent back toward earth.

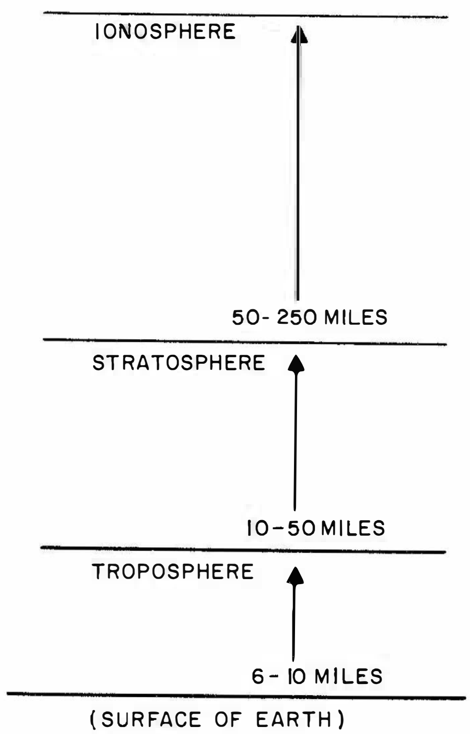

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Figure 6-8.—Positions of atmospheric mediums in relation to each other.

Surface Wave

A surface wave is that part of the ground wave that is affected chiefly by the conductivity of the earth and is able to follow the curvature of the earth's surface. The surface wave is not confined to the earth's surface. Parts of it extend upward to considerable heights in the troposphere, diminishing in strength as it increases height.

The earth itself is a partial conductor and, upon contact with its surface, some of the energy of the surface wave is absorbed and rapidly wasted in the form of heat. Losses suffered by surface waves are sometimes extensive, resulting in a badly attenuated (weakened) communications signal. The amount of attenuation depends on the relative conductivity of the earth's surface, which may vary according to terrain. Table 6-1 gives the relative conductivity for various types of surface. As can be seen, sea water is the best type of

Table 6-1.—Relative conductivity of surface types

Type of surface	Relative conductivity
Sea Water	Good
Large bodies of fresh water	Fair
Wet soil	Fair
Flat, loamy soil	Fair
Dry, rocky terrain	Poor
Desert	Poor
Jungle	Unusable

76.47

surface for surface wave transmission. Sea water makes possible the long-distance coverage attainable by fleet broadcasts that use surface wave transmissions of very low frequencies.

In general, the surface wave is transmitted as a vertically polarized wave and remains vertically polarized at appreciable distances from the antenna. Vertical polarization is used because the earth has a short-circuiting effect on a horizontally polarized wave. Overall, vertical polarization is superior to horizontal polarization except in heavily wooded or jungle areas. The reason is that most foliage grows vertically and absorbs vertically polarized energy.

Space Wave

While the characteristics of the surface wave serve to explain long-range propagation of very low frequencies using high power, they do not seem to apply to reception of higher frequencies within and slightly beyond the radio horizon. Such signals are considered to be propagated via the space wave.

Space waves are composed of two components: DIRECT WAVES and GROUND-REFLECTED WAVES. The direct waves travel in a direct line-of-sight path from a transmitting antenna to a receiving antenna. This component is limited only by the distance to the horizon (or line of sight) from the transmitter plus the small distance added by the atmospheric diffraction of the wave around the curvature of the earth. This distance can be extended by increasing the height of either the transmitting or receiving antenna, effectively extending the radio horizon. Figure 6-9 shows the possible routes that a ground wave might take.

A ground-reflected wave, as its name indicates, reaches the receiving antenna after it is reflected from the ground or sea. In figure 6-10, it may be seen that the waves start out with fronts of equal phase, continuing in phase up to the point of reflection of the ground component. Beyond this point, corresponding waves are 180-degrees out of phase. This phase reversal is important in determining the effect of the combining of the reflected wave with the direct wave upon arrival at the point of reception. Because the reflected wave travels a longer time in reaching its destination, a phase displacement (over and above the 180-degree shift

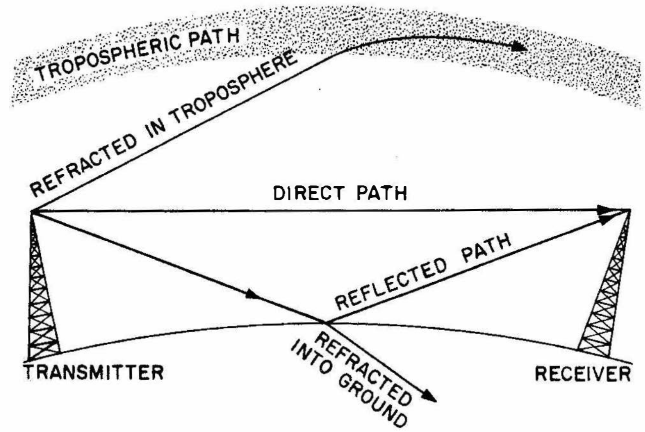

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Figure 6-9.—Possible routes for groundwaves.

caused by reflection) results. Thus, the reflected wave arrives at the receiving antenna, nearly 180-degrees out of phase with the direct wave. An undesirable cancellation of signal energy results.

Sky Wave

That portion of the radio wave which moves upward and outward and is not in contact with the earth is called the sky wave. It behaves similarly to the ground wave in that some of the energy is refracted, reflected, and scattered, and some of the energy is lost in dissipation within the atmospheric layers. A receiver located in the vicinity of the returning sky wave will receive strong signals even though the receiver is several hundred miles beyond the range of the ground wave.

Ionospheric refracted sky waves are generally the only usable waves for long range communications. Figure 6-11 illustrates some of the many possible paths that radio waves of various frequencies may take between a transmitter and a receiving station by refraction in the ionosphere. Notice that some of the waves, which are assumed to be of too high a frequency for refraction in the ionosphere, pass on through and are lost into space. Other radio waves, which are assumed to be of the correct frequency for refraction from the ionosphere, are returned to earth and provide communications.

In figure 6-11, notice that the term SKIP DISTANCE is the distance from the transmitting antenna to the nearest point at which the refracted waves return to earth. Also notice the difference between the skip distance and the SKIP ZONE. The skip zone is the zone between the end of the ground wave and the point where the sky wave first returns to earth. The skip distance depends upon the density of the ionosphere. The skip zone depends upon propagation characteristics of the ground wave in relation to the sky wave. The zone itself may vary from minute to minute for the same signal as propagation conditions change. Generally, however, the zone is relatively stable and remains approximately the same.

BASIC TROPOSPHERIC PROPAGATION

Tropospheric radio wave propagation depends on weather conditions. Weather conditions in the troposphere vary from minute to minute, making it the least predictable layer of the atmospheric medium. The troposphere is the lowest region of the atmosphere, extending from the earth's surface to a height of from 6 to 10 miles above the surface. Virtually all weather phenomena occur in this region of the atmosphere.

Refraction of radio waves in the troposphere is a function of various meteorological variables. Because of the uneven heating of the earth's surface, the air in the troposphere is in constant motion. This motion causes small turbulences, or eddies, to be formed. These turbulences are quite similar to whirlpools of water. The turbulence is at its greatest intensity near the surface of the earth and gradually diminishes with altitude.

Tropospheric Wave

A tropospheric wave is that component of the ground wave that is refracted in the lower atmosphere by rapid changes in humidity, atmospheric pressure, and temperature. At heights of a few thousand feet to approximately 1 mile, huge masses of warm and cold air exist near to each other, causing rapid changes in temperature and pressure. The resulting refraction and reflection make it possible to communicate over greater distances than that possible using the ground wave alone.

Temperature inversion is a common cause of tropospheric refraction, especially when warm layers of air are located above cooler layers. This may result from the rapid cooling of the earth's surface after sunset or the heating of air above a cloud layer by reflection of sunlight from the upper surface of clouds.

Forward Propagation Tropospheric Scatter Communications

The troposphere is used for many types of communications, such as radiotelephone, radioteletype, and data transmission. Much of this is made possible through a system known as forward propagation tropospheric scatter (FPTS), also known as "tropo-scatter". Basically, tropo-scatter utilizes the reflective and refractive properties within the troposphere. When a radio signal is beamed to an area in the troposphere, part of it goes through a complex series of partial reflection and refraction, causing energy to be scattered and to become partly diffused. This "beaming" is done via parabolic antennas such as those in figures 6-12 and 6-13. These antennas are very directional, hence lending themselves well to this type of communications. Figure 6-14 illustrates the way that these parabolics are used for tropo-scatter.

The scattering phenomenon in the troposphere is based on the theory that turbulences prevailing in the troposphere cause scattering of the signal beyond the horizon. The term "scattering" tends to imply that the signal is spread in all directions. However, this is not the case. A characteristic of tropo-scatter is that the energy in the main beam is scattered in a forward direction, hence the use of the term "forward-propagated". The lower the angle of the beam with respect to the horizon, the better the forward-propagation characteristics of the signal. A receiving parabolic, beamed at the same area in the troposphere as the transmitting antenna, will pick up the transmitted energy for further processing.

The amount of received energy decreases as the height of the scatter is increased. There are two reasons for this: (1) the scatter angle increases as the height is increased, thus decreasing the forward propagation characteristics,

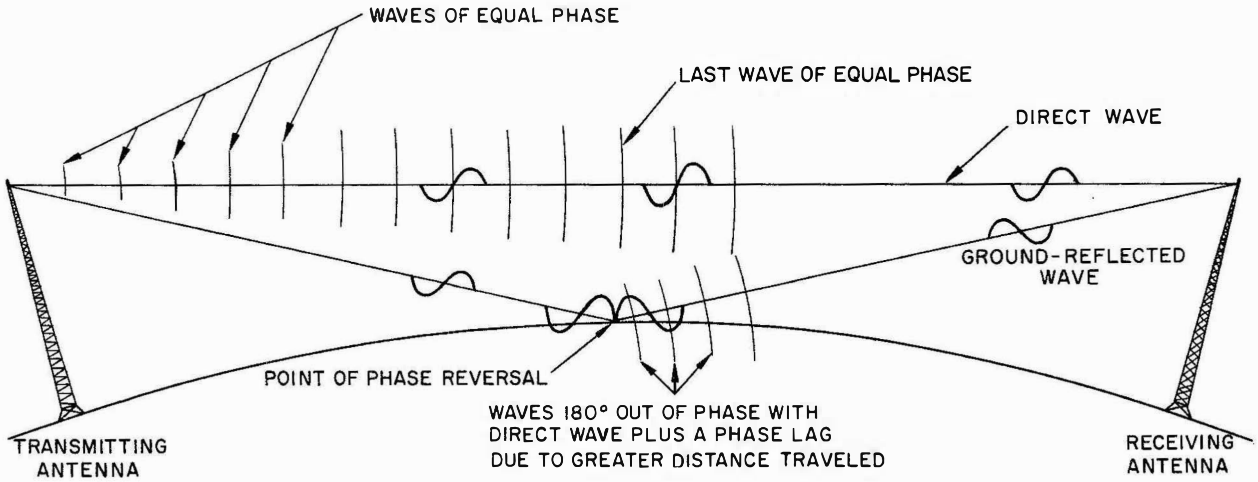

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Figure 6-10.—Direct and Ground-reflected waves are out of phase.

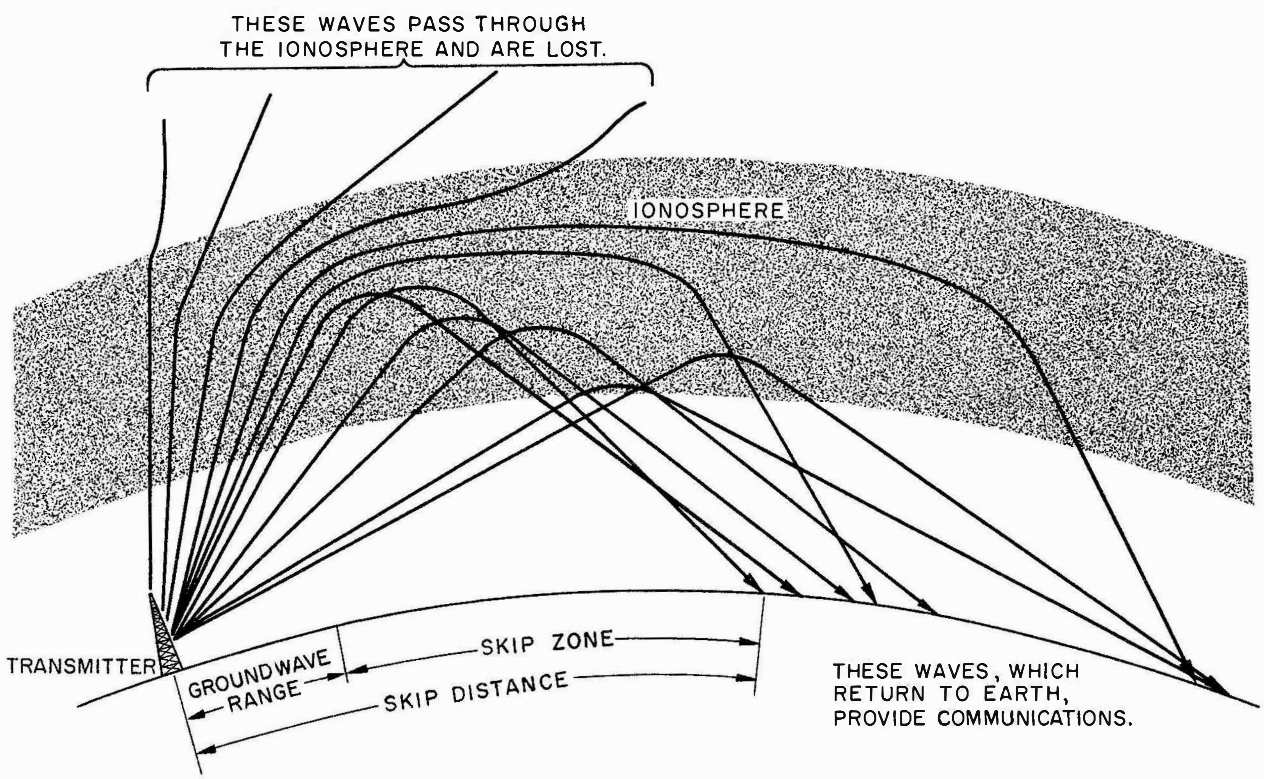

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Figure 6-11.—Possible paths for radio waves.

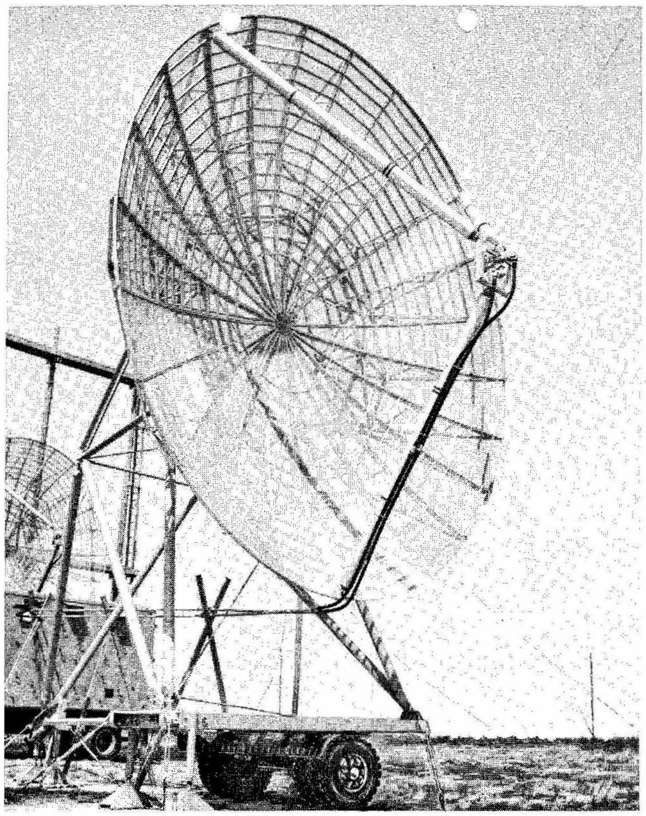

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Figure 6-12. — Mobile Tropo-scatter antenna.

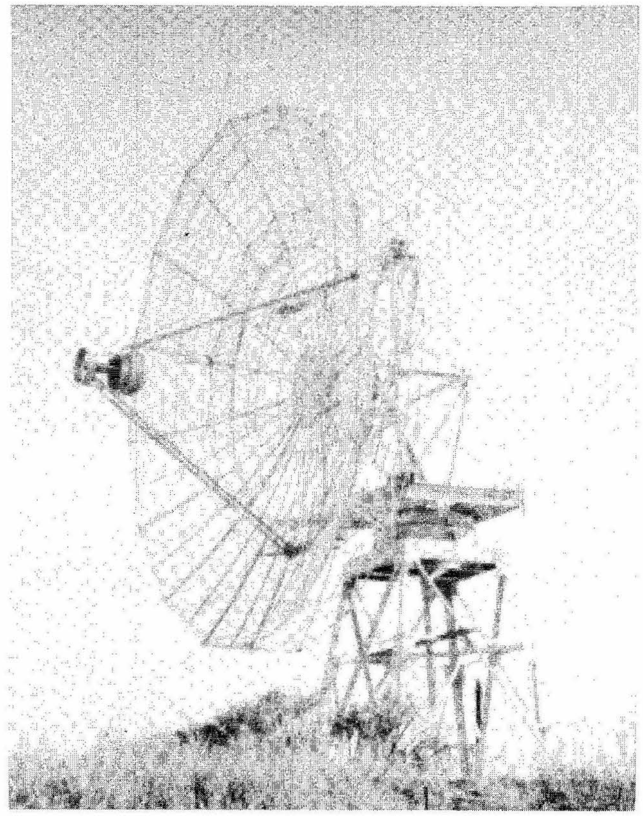

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Figure 6-13. — Tropo-scatter antenna.

and (2) the amount of turbulence decreases with the height in the troposphere, thus reducing the amount of reflection and refraction taking place at any one time in the beamed signal. It should be noted that as greater distance is attempted with FPTS, the received signal level decreases. This is because the angle must be increased to achieve greater height, thus decreasing the receive potential. The beam take-off angle of transmitting and receiving antennas for FPTS is always kept as low as possible, depending upon local terrain and general geographical location.

Since tropospheric scatter depends on turbulences in the atmosphere, changes in atmospheric conditions will affect the received signal level. Both daily and seasonal variations are noted. These changes are associated with a term known as "long-range fading" characteristics. There is also a term known as "rapid-fading", which is associated with multi-path transmissions or multi-path propagation. The signals received at any one time are the sum of all the signals received from each of the turbulences in the main beam. Since turbulent conditions are constantly changing, the transmission paths and individual signal levels are also changing, resulting in a rapidly changing signal. Although the signal level is constantly changing, the average signal level is relatively consistent. Therefore, no complete signal fade-out occurs.

Another characteristic of a tropospheric scatter signal is that most of the transmitted beam is not picked up by the receiving antenna, the efficiency is very low, and the signal level at the receiving station is very low. To compensate for this low efficiency in the scatter, the incident power must be high. Thus, high-power transmitters and high-gain antennas are used to concentrate the transmitted power into the beam, thus increasing the intensity of energy radiated. The receiving antennas are also very

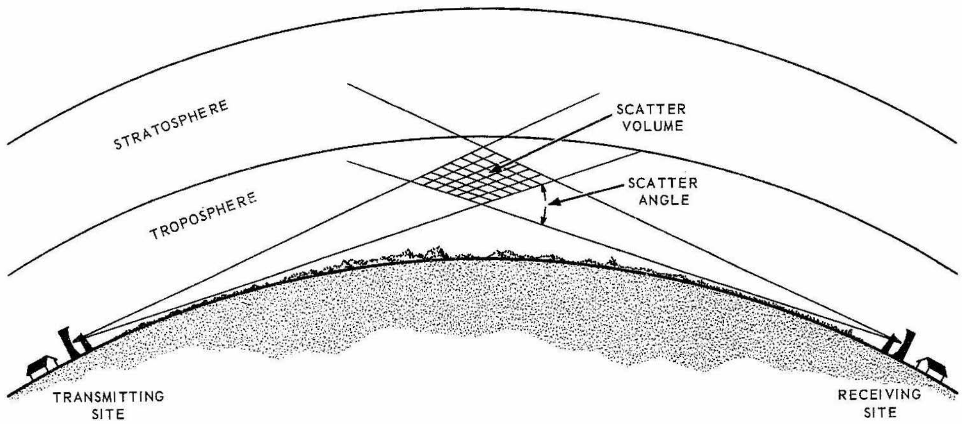

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Figure 6-14.—Tropo-scatter propagation.

sensitive, thus enabling them to detect low-level signals for further processing. Since tropo-scatter is considered to be relatively short-range, a series of relay stations with built-in signal amplifiers are used to achieve long-range transmission.

BASIC IONOSPHERIC PROPAGATION

The ionosphere is found in the rarefied atmosphere, beginning at approximately 40 to 50 miles above the earth. It differs from other atmospheric layers in that it contains a much higher number of positive and negative ions. It is known that the atmosphere is under constant bombardment by radiation and particle showers from the sun as well as by cosmic rays. Radiation from the sun includes not only light rays that can be seen, but also the entire spectrum, ranging from infrared rays to ultraviolet rays. Radiation from the sun is capable of dislodging some loosely bound electrons from gas atoms that make up the dense gases in the upper atmosphere. Therefore, the ionosphere has a large number of ionized gas atoms as well as free electrons unassociated with any atom.

At altitudes above 350 miles, the particles of air are far too sparse to permit large-scale energy transfer. Ultraviolet radiations from the sun are absorbed in passage through the upper layers of the ionosphere so that below an elevation of 40 miles, very few ions exist that would affect sky wave communications. Therefore, sky wave communications depends primarily upon the ionospheric conditions existing at the time of transmission.

Densities of ionization at different heights make the ionosphere appear to have layers. Actually, there is thought to be no sharp dividing line between the various layers, but they do exist and will be separated here for explanation and clarity.

Figure 6-15 shows the various layers associated with the ionosphere at night and during the day. The ionized atmosphere at an altitude of between 40 and 50 miles is called the "D" layer. Its ionization is low and has little effect on the propagation of radio waves except for the absorption of energy from the

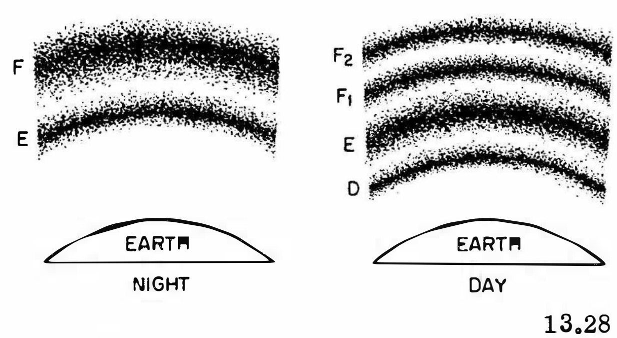

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Figure 6-15.—Ionospheric layers at night and during day.

waves as they pass through it. The D layer is present only during the day. Its presence reduces the field intensity of radio wave transmissions during the day.

The "E" layer exists at altitudes between 50 and 90 miles. It is a well defined layer with greatest density at an altitude of about 70 miles. This layer is strongest during daylight hours and is also present, but much weaker, at night. The maximum density of the E layer appears at about mid-day. During this part of the day, the ionization of the E layer is sometimes sufficient to refract frequencies in the upper HF band back to earth. This action is of great importance to daylight transmissions for distances up to 1,500 miles.

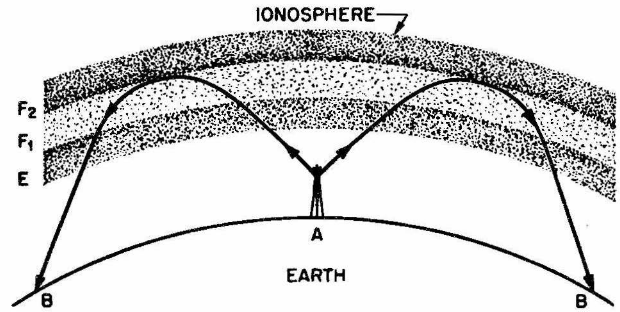

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Figure 6-16.—Ionosphere "bends" waves back to earth.

The "F" layer extends approximately from the 90 mile level to the upper limits of the ionosphere. During daylight hours the F layer is divided into two sections: the F_1 and the F_2 layers. Shortly after sunset, the F_1 and the F_2 layers combine into the single F layer.

In addition to the layers of ionized atmosphere that appear regularly, erratic patches of ionized atmosphere occur at E layer heights in the manner that clouds appear in the sky. These patches are referred to as "Sporadic-E" ionizations. These sporadic ionizations may appear in considerable strength and prove quite harmful to electronic transmissions.

Effect Of Ionosphere On The Sky Wave

The ionosphere has many characteristics. Some waves penetrate and pass entirely through it into space, never to return. Other waves penetrate but bend. Generally, the ionosphere acts as a conductor and absorbs energy in varying amounts from the radio wave. The ionosphere also bends (refracts) the sky wave back to the earth, as shown in figure 6-16.

The ability of the ionosphere to return a radio wave to the earth depends upon the angle at which the sky wave strikes the ionosphere, the frequency of the radio wave, and the ion density. When the wave from an antenna strikes the ionosphere at an angle, the wave begins to bend. If the frequency and angle are correct and the ionosphere is sufficiently dense, the wave will eventually emerge from the ionosphere and return to earth. The sky wave in figure 6-17 is assumed to be composed of rays that emanate from the antenna in three distinct groups that are identified according to the angle of elevation. The angle at which the group 1 rays strike the ionosphere is nearly vertical and will not be returned to earth. The radio wave strikes the ionosphere, is bent out of line slightly, but passes completely through the ionosphere and is lost.

The angle made by the group 2 waves is called the CRITICAL ANGLE for that frequency. Any wave that leaves the antenna at an angle greater than this angle (θ) will penetrate the ionosphere.

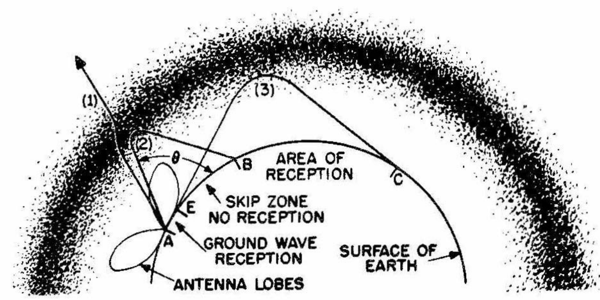

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Figure 6-17.—Three groups of radio waves according to angle of elevation.

Group 3 waves strike the ionosphere at the smallest angle that will be refracted and still be returned to earth. At any smaller angle, the waves will be refracted but will not return to earth.

As the frequency increases, the initial angle decreases. Low frequencies can be projected straight upward and will be returned to the earth. The highest frequency that can be sent directly upward and still be refracted back to the earth is called the CRITICAL FREQUENCY. At sufficiently high frequencies, regardless of the angle at which the rays strike the ionosphere, the wave will not be returned to earth. The critical frequency is not constant but varies from one locality to another, with the time of day, with the season of the year, and with the sunspot cycle.

Because of this variation in the critical frequency, frequency tables are issued that predict the maximum usable frequency (MUF) for every hour of the day for every locality in which transmissions are made. These frequency tables are prepared from data obtained experimentally from stations scattered all over the world. All of this information is pooled, and the results are tabulated in the form of long range predictions that remove some of the guesswork from transmissions.

Absorption In The Ionosphere

As a radio wave passes into the ionosphere, it loses some of its energy to the free electrons and ions contained in this part of the atmosphere. Since absorption of energy is dependent upon collision of particles, the greater the density of the ionized layer, the greater the probability of collision, and therefore, the greater the absorption. The highly dense D and E layers provide the greatest absorption for the ionospheric wave.

Variations In The Ionosphere

Sky wave intensity varies from minute to minute, month to month, and year to year because of variations in the ionosphere. Since the ionosphere exists primarily because of the radiation of the sun, any variation in the strength of this radiation will cause a corresponding change in the ion density of the upper atmosphere. Some of the variations in the ionosphere are periodic and their effects on radio frequencies can be anticipated. Others are unpredictable, and while their effects are pronounced, there is little that can be done but to realize that they may occur. Periodic variations can be divided into daily, seasonal, and sunspot cycle variations. Unpredictable variations are usually the result of the sporadic E layer and Short Wave Fadeouts (caused by sudden solar flare-ups).

Periodic Variations

Daily variations are caused by the 24-hour rotation of the earth about its axis. In the daytime, the ionosphere consists of the four ionized layers previously mentioned. At night in the F region, only the F2 layer exists insofar as regular HF propagation is concerned. The nighttime F2 layer is formed by a combination of the daytime F1 and F2 layers that merge during evening hours.

Seasonal variations occur as the intensity of the ultra-violet light which reaches any given spot in the earth's atmosphere varies with the position of the earth in its orbit around the sun.

Sunspot activity varies in conformance to an 11-year cycle. Sunspots are proportional to approximate solar radiation and to the total ionization of the atmosphere. During periods of high sunspot activity, ionization of various layers is greater than usual, resulting in higher critical frequencies for the E, F1, and F2 layers, and higher absorption in the D layer. Consequently, higher frequencies can be used for communication over long distances at times of greatest sunspot activity. Increased absorption in the D layer, which has the greatest effect on the lower frequencies, requires higher frequencies. The overall effect is a general improvement in propagation conditions during years of maximum sunspot activity.

FADING

Fading is the variation of radio signal strength at the receiving end of a transmission. Signals received over an ionospheric path may vary in intensity over short periods of time. There are three major reasons for fading. When the radio wave is refracted in the ionosphere or reflected from the earth's surface, random variations in polarization of the wave may occur, causing changes in the received signal level because of the inability of the antenna to receive polarization changes. Fading may also occur if the operating frequency selected is too close to the MUF (Maximum Usable Frequency). If this is the case, any slight change in the ionosphere might cause a change in signal strength. Fading also results from absorption of the signal energy in the ionosphere. Absorption fading occurs for a longer period of time than other types of fading because of the length of time required for an ionized layer to change in ionization potential. However, the major cause of fading on ionospheric circuits is caused by multipath propagation.

Multipath Fading

"Multipath" is the term used to describe the types of propagation that undergo changes en route to the receiving site, causing them to arrive in a time frame that is later than the signal reflected from the ionosphere.

Figure 6-18 shows the various paths a signal can travel between two sites. One signal, the ground wave, may follow the path XYZ. Another signal, refracted from the E layer (XEA), is received at A, but not at Z. Still another path (XFZFA), results from a greater angle of incidence and two refractions from the F layer. At point Z, the received signal is a combination of the ground wave and the sky wave. If these two waves are received out of phase, they will produce a weak or fading signal. If they are received in phase, the waves will produce a stronger signal. Small alterations in the transmission path may change the phase relationship of the two signals, causing periodic fading. This same addition of signal components occurs at point A. At this point, the double-hop signal from the F layer may be in or out of phase with the signal arriving from the E layer.

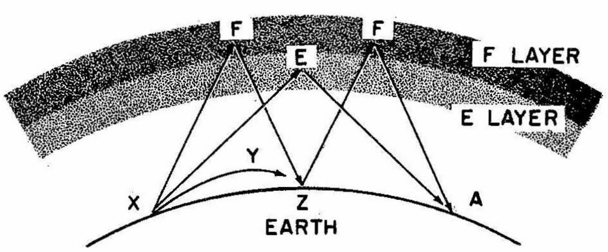

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Figure 6-18.— Various paths of signal travel.

Selective Fading

Fading resulting from multipath propagation is variable with frequency since each frequency arrives at the receiving site via a different path. When a wide band of frequencies, such as multichannel single sideband, is transmitted, the frequencies in the sideband will vary in the amount (if any) of fading. This variation is called selective fading. Whenever selective fading occurs, all frequencies within the envelope of the transmitted signal may not retain their original phase relationship and relative amplitudes. This fading may cause severe distortion of the signal and limit the total bandwidth which can be transmitted.

FREQUENCY BANDS AND CHARACTERISTICS

For practical purposes, it is convenient to classify RF emissions into frequency bands (see Table 6-2). Whereas each band of frequencies has similar propagation effects, they also have very recognizable differences. These differences are not always sharply defined because of the nearness of the upper ends of some bands with respect to the lower end of the next higher band. The greatest difference in propagation characteristics occur near mid-band between two bands. Normally, when an upper or lower limit of frequency is designated for a certain propagation effect, it does not mean that such an effect stops at those limits, but that it becomes negligible beyond such limits.

Medium-Frequency Band (MF)

Only the upper and lower ends of the MF band (0.3 - 3 MHz) have naval use because of the commercial usage of this band near mid-range (0.55 - 1.70 MHz). Frequencies in the lower portion of the MF band are used mainly for ground wave transmission for moderate distances over water and moderate to short distances over land. The Navy utilizes the upper portion of the MF band (2 - 3 MHz) quite extensively. The range of communication in the upper portion is generally moderate and dependent upon the type of antenna used and the output power of the transmitter. Usually, because of the rather long antennas required, this band is utilized with horizontal wire antennas where antenna space is unrestricted. In mobile applications, whip antennas are normally used in this frequency range.

Table 6-2.— Radio-Frequency Spectrum

FREQUENCY	DESCRIPTION	ABBREVIATION
30GHz-300GHz	extremely high frequency	EHF
3GHz-30GHz	super high frequency	SHF
300MHz-3GHz	ultra high frequency	UHF
30MHz-300MHz	very high frequency	VHF
3MHz-30MHz	high frequency	HF
300kHz-3MHz	medium frequency	MF
30kHz-300kHz	low frequency	LF
3kHz-30kHz	very low frequency	VLF

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High-Frequency Band (HF)

The HF band (3 - 30 MHz) employs ionospheric propagation for long-range sky wave communication. The HF band is the principal frequency range used for Navy ship-to-shore communication circuits. Communications publications that predict propagation conditions for this band are published periodically, (NTP-6, Supp-1 Series).

Ultra-High Frequency Band (UHF)

Almost all of the energy transmitted from point to point in the UHF band (300 - 3000 MHz) is propagated through the troposphere along a curved path. The refracted path may be assumed to be a straight line path extending to distances of approximately four-thirds times the true horizon. However, the transmission range of this band may be extended several hundred miles further by means of tropo-scatter propagation.

Ground reflections are still present at ultrahigh frequencies and can cause multipath fading due to interference, although such reflections become less important at the higher end of this band. However, a second type of multipath fading can occur when parts of the wave are refracted through higher layers of the atmosphere and become bent sufficiently to return and combine with the wave received over a lower, more direct path.

Atmospheric and man-made noise in this frequency band is extremely low. Most noise encountered emanates from the equipment itself, both transmitting and receiving. This is due to the circuit design inherent in most UHF equipments. Because of the increased frequency, component parts and assemblies are normally smaller and spacing more critical. Inductive and capacitive reactances are normally high, hence the greater noise associated with UHF equipment.

Super And Extremely High Frequencies (SHF and EHF)

The Super and Extremely High frequency bands have very limited application in Naval Communications. Although future plans call for the use of these two frequency bands, the primary utilization at the present time is in the lower SHF band (3-13 GHz) for satellite communication systems.

Transmission at the SHF and EHF bands is very difficult because of the nature of the radiated wave. Wavelengths at these frequencies are very small, causing a great deal of reflection of the incident wave. Almost any object will act as a reflecting surface in this frequency range, almost as if the atmosphere were made up of an infinite amount of small mirrors, each reflecting the incident wave in a different direction. This phenomenon is sometimes called DIFFUSE REFLECTION and is quite prevalent in the SHF and EHF frequency ranges. In addition, incident radiation will also be absorbed by the earth's vegetation. Even rain can cause scattering and absorption in these frequency ranges. If the drop size is comparable to the wavelength of the propagated wave, a substantial portion of the transmitted energy will be reradiated from the raindrop in many directions. This phenomenon, known as SCATTERING, has an attenuating effect on radio waves. The attenuating effect is caused by the incident energy that is absorbed and virtually trapped and converted into heat.

The potential losses inherent at this frequency range are overcome through the use of sharply beamed incident waves utilizing very directional transmitting antennas. The use of directional antennas (such as parabolics) not only enhances transmission success, it also ensures the conservation of necessary incident power.