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CDC 49350B

COMMUNICATIONS-COMPUTER SYSTEMS CONTROL SPECIALIST

Volume 1. Transmission Media

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Please read the topic page for Unit 1 and begin. ➡

INTRODUCTION TO RADIO COMMUNICATIONS AND WAVE PROPAGATION

Page

Now that you have completed the first half of the 49350 CDCs, you are ready to get into the "real meat" of the career field. In this volume, we cover the different types of transmission media that you, as a systems controller, must be familiar with and understand to do your job. You will study some of the physical and operational characteristics of tropospheric scatter, microwave, high frequency, satellite, and cable systems.

1-1. Radio Communications

As you can see, four of the five transmission media we commonly work with are radio communication transmissions. Before we actually begin to cover the five different media, we give you an introduction to radio communications and wave propagation.

001. Why radio communications were developed

History of Radio Communications. Radio communication has been around a lot longer than most people realize. Radio pioneers like Marconi were developing radio communications equipment during the mid-to-late 1800s. Because of equipment limitations, the first radio sets operated in the low- and medium-frequency bands of the radio-frequency (RF) spectrum. These two frequency bands offered pretty good voice communications, but distance was limited by the rather low-power outputs available at the time. In the 1890s, experiments began with the use of higher frequencies. Unfortunately, the ideas for the use of higher frequencies were born quite a while before the capability existed to produce components required for reliable operation. High-frequency (HF) communication was first made practical in the 1920s when the first actual system was installed in Europe. The move to higher frequencies was brought about by the need for longer range, higher capacity circuits. Until HF came about, transatlantic communication was by cable or mail. Of course, cable was very limited in capacity and extremely expensive; mail was rather slow. With HF radio, transatlantic communication became faster, had greater capacity, and was somewhat less expensive. From this point in history until the present, radio technology has increased by leaps and bounds. The events leading up to World War II had a profound impact on the use of the radio-frequency spectrum. A method was needed for providing even higher capacity communication. Naturally, the solution was to go to even higher frequency bands. During the early part of the war, a system called radar was developed. The development of components and equipment to operate at the higher radar frequencies led to the development of higher frequency radio systems.

Developments during the war, mainly the need for more reliable high-capacity communications, led to the development of very-high-frequency (VHF) and ultrahigh-frequency (UHF) radio systems. Along with these systems came the concept of line-of-sight (LOS) microwave and tropospheric (tropo) scatter systems. Unfortunately, it was found that using these higher frequency bands in microwave and tropospheric scatter caused the distance range to be shorter than with HF. So, until the late 1950s, long-range radio communication had to remain in the HF band, even with its limitations.

With the advent of the space program, radio engineers soon realized that long-range communication at the higher frequencies was possible by using satellites as radio relay stations; thus came the development of satellite communication systems. Today, practically all of our long-range, wideband communication is done by satellite links. Satellite communications have long been thought of as "the" system but, from a military viewpoint, satellite systems, and many of the other radio systems, have serious weaknesses.

Because the higher frequency systems have weaknesses associated with their method of radio-wave propagation, lower frequency systems are taking on more importance. Studies have shown that, in the event of a nuclear blast, most if not all of our higher frequency systems will be adversely affected. Since the military must have communications at all times, low-frequency (LF), very low-frequency (VLF), and extremely low-frequency (ELF) systems have been developed since the early 1960s.

As you can see, radio communication has grown rapidly over the last century There is still much to be learned, and research is ongoing in all areas of the RF spectrum.

002. Radio wave frequency bands

Frequency Bands. Now that you know some of the developmental history of radio communications systems, you should realize how important it is for every technical controller to be familiar with certain aspects of radio communications.

Table 1-1 lists all of the standard frequency bands used in radio communications systems throughout the world. The specific frequencies covered by each band are those that were agreed on at a convention held by the International Telegraph Union (ITU). Occasionally, you may see the different bands

TABLE 1-1
STANDARD FREQUENCY BANDS

BAND	FREQUENCY RANGE
ELF (Extremely Low Frequency)	3 - 30 Hz
SLF (Super Low Frequency)	30 - 300 HZ
ULF (Ultra Low Frequency)	300 - 3000 Hz
VLF (Very Low Frequency)	3 kHz - 30 kHz
LF (Low Frequency)	30 kHz - 300 kHz
MF (Medium Frequency)	300 kHz - 3000 kHz
HF (High Frequency)	3 MHz - 30 MHZ
VHF (Very High Frequency)	30 MHz - 300 MHz
UHF (Ultra High Frequency)	300 MHz - 3000 MHz
SHF (Super High Frequency)	3 GHz - 30 GHz
EHF (Extremely High Frequency)	30 GHz - 300 GHz

expressed with different frequency ranges. We will use the ranges shown in the table since they are the internationally accepted standard.

General Radio-Wave Propagation. As you know, radio waves travel at the speed of light (186,000 miles per second). From your studies of antennae at Keesler, you also know that radio waves leave an isotropic radiator in all directions, simultaneously, like an expanding bubble. In our discussion of radio systems, however, the antennae we use will nominally be constructed so as to direct radio waves in a particular direction. These types of antennae focus energy in a specific direction and thus form radio "beams."

Types of Radio Waves. Primarily, there are two types of radio waves, *ground waves* and *sky waves*. Ground waves are those that travel near the surface of the earth. These waves are greatly affected by the conductivity of the earth and any obstruction, such as mountains or buildings, on its surface. Ground-wave transmission is used primarily in local communications. Ground waves are composed of three waves—*direct wave*, *ground-reflected wave*, and *surface wave*.

A sky wave is an electromagnetic wave that is propagated at such an angle that it travels up through the atmosphere, strikes its upper layer (the ionosphere) and refracts back toward the earth. Sky-wave transmission is used in long-distance communications.

Figure 1-1 depicts the various radio wave paths. The radio beams represented are simplified, of course. All radio waves emitted by an antenna have the components shown in figure 1-1—surface, ground-reflected, direct, refracted, and sky waves. However, radio waves of different frequencies are affected by the environment in different ways. As an example, lower frequency waves are generally easier to propagate by surface waves than by any other means because they follow the contour of the earth and penetrate obstacles more easily. Higher frequency waves propagate more easily via sky and as direct waves because they are easily absorbed by obstacles. For these reasons, a particular type of antenna is usually used for a given radio system. We discuss types of antennae used with different systems in the following lessons. Familiarize yourself with the components of the radio waves shown in figure 1-1. A surface wave is sometimes referred to as a ground-wave component; we also discuss its characteristics in the next lesson.

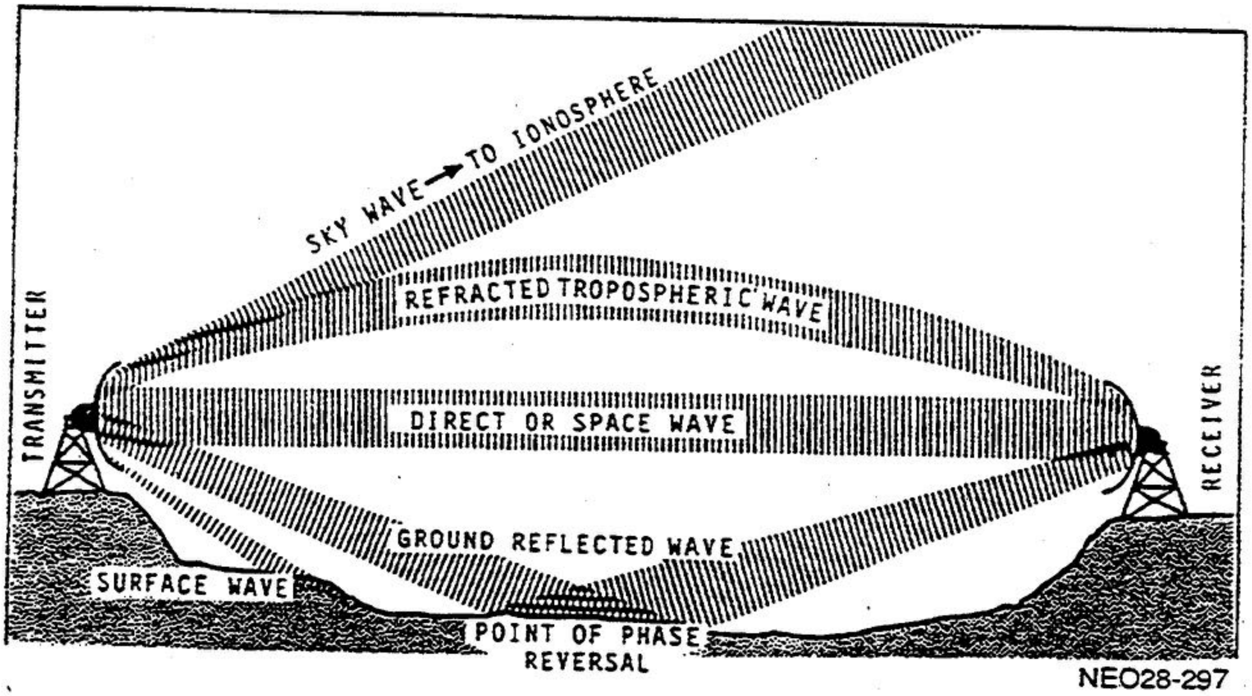

Figure 1-1. Radio propagation paths.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

001. Why radio communications were developed

1. What advantages did early radio communications offer?

2. When was satellite communications considered to be a viable communications media?

002. Radio wave frequency bands

1. Within what frequency band do you transmit if your output frequency is 22 megahertz (MHz)? 22 gigahertz (GHz)?

2. What are the two primary types of radio waves?

3. A direct wave is considered to be which type of radio wave?

1-2. Wave Propagation

After an electromagnetic wave leaves a transmitting antenna, it must be propagated through space to a receiving antenna, thereby establishing a useful communications system. Since the medium of travel for electromagnetic energy is free space, you must know the nature of free space to predict its effects on the quality of transmission. 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 transmissions. Any adverse conditions caused by variation in weather conditions and the sun's radiation level must simply be tolerated until a superior wireless communications system, not subject to these variations, can be developed.

003. Characteristics of propagated waves

Radio-Frequency Spectrum. Between the audio spectrum and the infrared spectrum is a range of frequencies known as the radio-frequency spectrum. This spectrum is subdivided and classified in table 1-2.

Surface Wave. A surface wave is the part of a ground wave that travels in contact with the earth's surface. Because of the conductivity of the earth's surface, some of the surface wave's energy is absorbed by the ground. Since the earth's surface in most locations is an excellent conductor, the passing electromagnetic energy causes eddy currents to flow in the ground. These eddy currents dissipate power and are classified as loss. Eddy current losses are greatest when a surface wave is polarized horizontally and least when it is polarized vertically. Figure 1-2 shows the rate at which a surface wave diminishes.

Since the electrical properties of the earth along which a surface wave travels are relatively constant, the signal strength from a given station at a given point should be fairly constant. This holds true in nearly all localities except those that have a distinct rainy or dry season. Changes in the amount of moisture change the soil's conductivity. If conductivity is high, absorption will be low, and transmission using the surface wave can be achieved over a considerable distance. If conductivity is low, absorption of the transmitted energy will be high, and the distance of transmission realized by use of the surface wave will be short.

Different types of terrain have various effects on the absorption of radio frequencies in a surface wave. Over water, especially salt water, a surface wave's transmitting distance will be greatly increased (fig. 1-2).

Figure 1-3 shows a surface wave being tilted toward the ground. The angle between the plane of transmission and the surface of the earth is known as the *angle of tilt*. If the conductivity of the earth's surface is high, the angle of tilt will be large, and little energy will be absorbed by the ground. On the other hand, if the conductivity of the earth is low, the angle of tilt will be low and the absorption of energy will be high.

Shore-based stations use high-power surface waves, preferably transmitted over water, to provide long-range

TABLE 1-2
RADIO-FREQUENCY SPECTRUM

DESCRIPTION	FREQUENCY	ABBREVIATION
Very low frequency	3 - 30 kHz	VLF
Low frequency	30 - 300 kHz	LF
Medium frequency	300 kHz - 3 MHz	MF
High frequency	3 - 30 MHz	HF
Very high frequency	30 - 300 MHz	VHF
Ultra high frequency	300 MHz - 3 GHz	UHF
Super high frequency	3 - 30 GHz	SHF
Extremely high frequency	30 -300 GHz	EHF

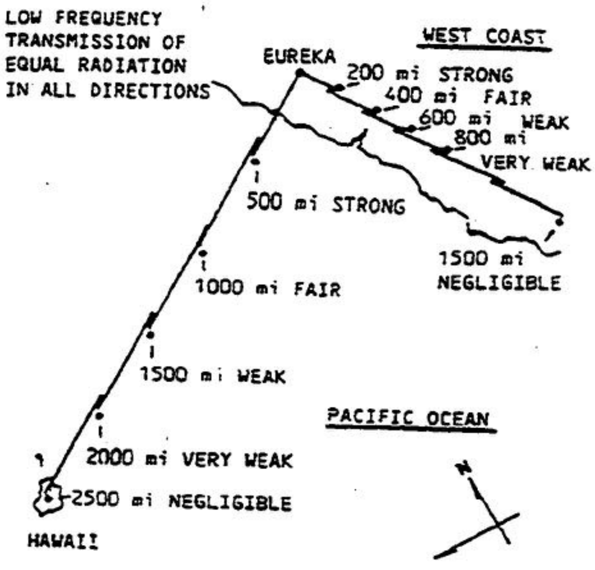

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Figure 1-2. Effectiveness of ground wave propagation over land and sea water.

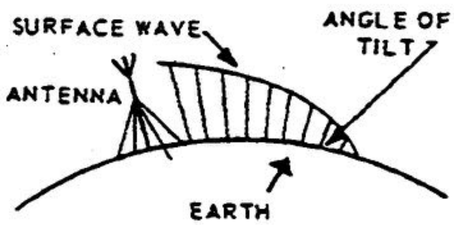

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Figure 1-3. Surface wave.

surface-wave communications over appreciable distances. Table 1-3 shows the relative conductivity of various types of terrain.

Direct and Earth-Reflected Waves. These waves are also called space waves or tropospheric waves because the medium through which they travel is the troposphere, the part of the atmosphere directly above the earth's surface. As you can see in figure 1-4, a *direct wave* is the component of a space wave that travels in an almost straight line from the transmitting to the receiving antenna. This type of transmission, strictly utilizing a direct wave, is known as *line-of-sight transmission.* In LOS transmission, the transmitting and receiving antennae are optically visible to each other.

We said that a direct wave travels in an almost straight line. The wave will be slightly bent by tropospheric *refraction.* This causes the wave to bend back toward the earth, extending transmission beyond the optical horizon. Refraction of electromagnetic energy occurs much like refraction of light.

Refraction of electromagnetic energy is "the phenomenon that causes a wave, entering another medium at an angle, to undergo a change in direction when the velocity of the wave in the second medium is different from its velocity in the first medium." At frequencies greater than 30 MHz, the attenuation of surface waves is so extensive that communication is primarily by direct waves. However, a ground reflected wave may decrease the intensity of a direct wave if the two waves reach the receiving antenna out of phase.

An *earth-reflected wave* is the part of a space wave that's reflected from the surface of the earth. The intensity with which it's reflected depends on the type of surface that it strikes. The relationship between a direct wave and a ground-reflected wave is shown in figure 1-4. To further understand the action of this reflection, consider figure 1-5. This diagram shows that the reflection of light and electromagnetic energy occur in much the same way. There is a change in the phase of the incident (wave generated from an antenna) and reflected wave, as seen by the difference in the direction of polarization. The reflected waves are 180° out of phase with the incident wave.

TABLE 1-3

RELATIVE CONDUCTIVITY OF VARIOUS SURFACES

GROUND MATERIAL	RELATIVE CONDUCTIVITY
Sea Water	4,500
Flat, rich soil	15
Average flat soil	7
Fresh water lakes	6
Rocky hills	2
Dry, sandy, flat soil	2
City residential area	2
City industrial area	1

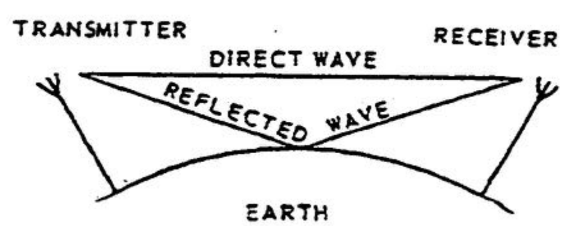

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Figure 1-4. Direct and ground-reflected waves (space waves).

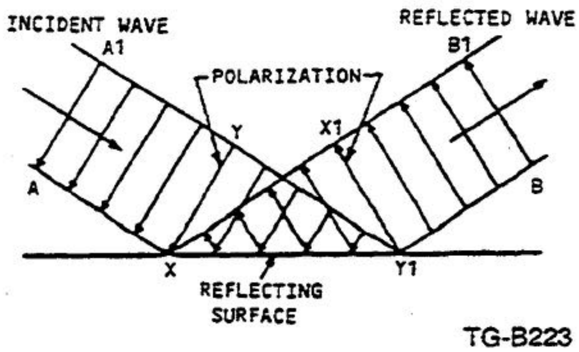


Figure 1-5. Reflection of a wave front.

A ground-reflected wave is usually undesirable because, between points lower than a few thousand feet and separated by a few miles, it can cause cancellation of the direct wave at the receiving antenna. The incident wave will be in phase with the direct wave. The reflected wave, however, will be 180° out of phase with the incident wave. If the reflected and direct waves arrive at the receiving antenna simultaneously, some cancellation will occur. The cancellation will be partial because the reflected wave takes longer to make the trip from the transmitting antenna to the ground and then to the receiving antenna than does the direct wave, which travels in almost a straight line. Therefore, the phase difference is not exactly 180°. Also, the intensity with which direct and ground-reflected waves arrive at the receiving antenna differs because the ground-reflected wave's intensity is reduced due to partial absorption of the incident wave by the ground.

The relationship of all three waves is shown in figure 1-6. Only a few lines represent these wave fronts, but the number of actual waves moving in all directions from the transmitting to the receiving antenna is very large. Also shown in the diagram are some waves that have no effect on the transmission of energy over the distance indicated but are present, nevertheless.

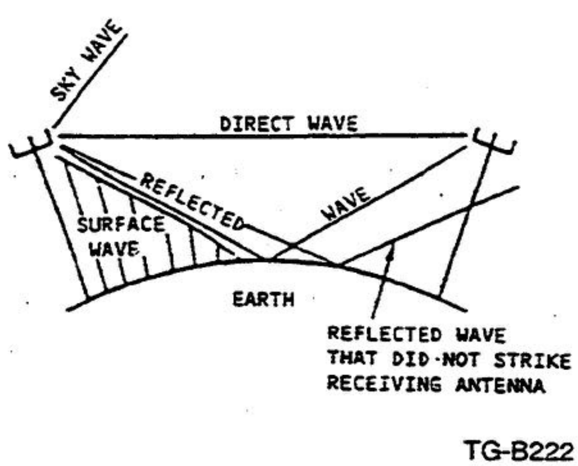


Figure 1-6. Complete ground wave with sky wave.

Thus far, we've talked about a system using LOS transmission. Suppose there's an obstruction between the transmitting and receiving antenna. If the obstruction is slightly taller than the receiving antenna, the receiving antenna won't be optically visible from the transmitting antenna. The transmission path will appear broken, but it's not. As with light waves, electromagnetic waves can bend as they pass the edge of an obstruction. This bending phenomenon, quite different from refraction, is called diffraction.

Electromagnetic waves in the radio-frequency spectrum bend around an object to a greater extent than do light waves (fig. 1-7). In fact, the lower the frequency of the energy, the greater the bending. The zone or area that is obstructed, where electromagnetic waves aren't present, is called the *shadow zone*. The earth itself will cause the diffraction of electromagnetic waves, making them follow its contour. Figure 1-7 shows electromagnetic waves being diffracted over the top and around the side of an obstruction.

Diffraction and refraction can cause the transmission distance to be greater than the LOS distance. Even if the receiving antenna is beyond the optical horizon or if it is located behind an obstruction, transmission may still be received. A new term, radio horizon, is now appropriate, referring to the actual distance between two antenna by which transmission may occur.

We said that refraction occurs when a wave passes from a medium of heavy density to a medium of comparatively light density. At times there can be such turbulence in the atmosphere that refractions are exaggerated. One of these radical atmospheric changes is called temperature inversion. Temperature inversion may be caused by several events—a warm air mass overrunning a cold air mass, the rapid cooling of surface air after sunset, the sinking of an air mass heated by compression, and the heating of air above a cloud layer by reflection of the sun's rays from the upper surface of the clouds. These temperature inversions, causing radical refractions, occur frequently and may cause signal fading at the receiving station or at least a diminished field intensity. Fading is any fluctuation in the intensity of a received signal.

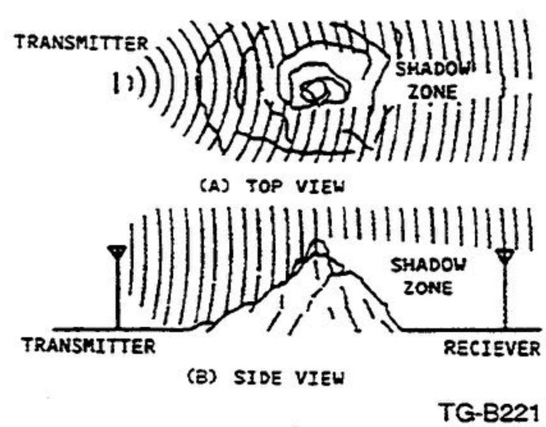


Figure 1-7. Diffraction around an object.

It should be noted that neither tropospheric refraction nor diffraction cause a phase shift, whereas reflection from a surface does.

Sky Wave. One of the most frequently used methods of long-distance transmission is by sky waves. Sky waves are waves radiated from the transmitting antenna in a direction that produces a large angle with reference to the earth. A sky wave has the ability to strike the ionosphere, be refracted from it to the ground, strike the ground, be reflected back toward the ionosphere, and so forth. The refracting and reflecting action of the ionosphere and ground is called skipping. Figure 1-8 illustrates this skipping effect.

The transmitted wave leaves the antenna at point A, is refracted from the ionosphere at point B, is reflected from the ground at point C, is again refracted from the ionosphere at point D, and arrives at the receiving antenna, point E. The distance of the path from A to C to E is known as the *skip distance*. The region from the end of the surface wave to point C is known as the quiet zone because a receiver located within these regions would receive none of the transmitted wave. It is possible, however, that a propagated wave leaving the antenna at a greater angle than the angle shown in figure 1-8 would conceivably be refracted into that region. The chance of this happening is small because the angle at which the sky wave strikes the ionosphere is critical. Notice that there is another quiet zone between points C and E.

To understand the process of skipping, you must consider the composition of the atmosphere and the factors that affect it. As far as electromagnetic radiation is concerned, there are only three layers of the atmosphere—the troposphere (already discussed), the stratosphere, and the ionosphere. The troposphere extends from the surface of the earth to an altitude of about 6.5 miles. The next layer, the stratosphere, extends from the upper limit of the troposphere to about 23 miles. From the upper limit of the stratosphere to about 250 miles lies the region known as the ionosphere. The temperature in the stratosphere is considered to be a constant, not subject to temperature inversions and unable to cause significant refractions. The constant temperature stratosphere is also called the *isothermal region.*

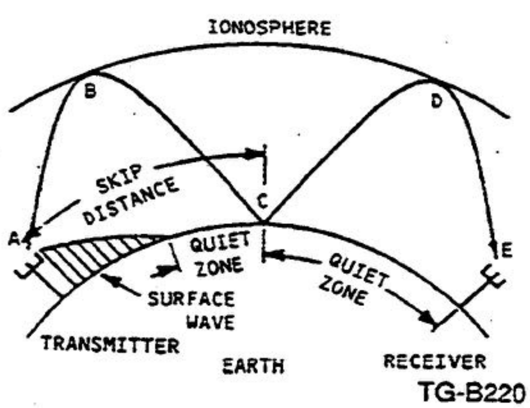


Figure 1-8. Sky wave skipping and skip distance.

The ionosphere is appropriately titled because it is composed primarily of ionized particles. The density at the upper extremities of the ionosphere is very low and becomes progressively higher as it extends downward toward the earth. The upper limit of the ionosphere is subjected to severe solar radiation in the form of photons, gamma rays, and other high-energy particles. Even though the density of the gases in the upper ionosphere is low, the radiation particles from space are of such high energy that they cause wide-scale ionization of the gas atoms that are present. This ionization extends down through the ionosphere with diminishing intensity. Therefore, the highest degree of ionization occurs at the upper extremities of the ionosphere.

The ionosphere is composed of three layers designated, respectively, from the lowest to highest level D, E, and F. The F layer is further divided into two layers designated F1 (the lower layer) and F2 (the higher layer). The presence or absence of these layers in the ionosphere and their height above the earth vary with the position of the sun. At high noon, radiation in the ionosphere directly above a given point is greatest, while at night it is minimum. When the radiation is removed, many of the particles that were ionized recombine. The interval of time between these conditions finds the position and number of ionized layers within the ionosphere changing. Since the position of the sun varies with respect to a specified point on earth daily, monthly, and yearly, the exact position and number of layers present is extremely hard to determine. However, these general statements can be made:

a. The D layer ranges from about 25 to 55 miles. Ionization in the D layer is low because it is the lowest region of the ionosphere. This can refract signals of low frequencies. High frequencies pass right through it but are attenuated in doing so. After sunset the D layer disappears because of the rapid recombination of ions.

b. The E layer limits are from about 55 to 90 miles. Here, the rate of ionic recombination is rather rapid after sunset, and the layer is almost gone by midnight. This layer can refract signals of a higher frequency than those refracted by the D layer. In fact, the E layer can refract signals as high as 20 MHz. For this reason, it can be used for communications up to about 1,500 miles.

c. The F layer exists from about 90 to 240 miles. During daylight hours, the F layer separates into two layers, the F1 and F2 layers. The ionization level in these layers is quite high and varies widely during the course of a day. At noon this part of the atmosphere is closest to the sun and the degree of ionization is maximum. Since the atmosphere is less dense at these heights, the recombination of ions occurs slowly after sunset. Therefore, a fairly constant ionized layer is present at all times. The F layers are used for high-frequency, long-distance transmission.

Figure 1-9 shows the relative distribution of the ionospheric layers. With the disappearance of the D and E layers at night, the signals normally refracted by these layers are refracted by the much higher F layer, resulting in greater skip distances at night (fig. 1-10).

The layers that form the ionosphere undergo considerable variations in altitude and density due primarily to varying degrees of solar activity. The F2 layer varies most due to solar

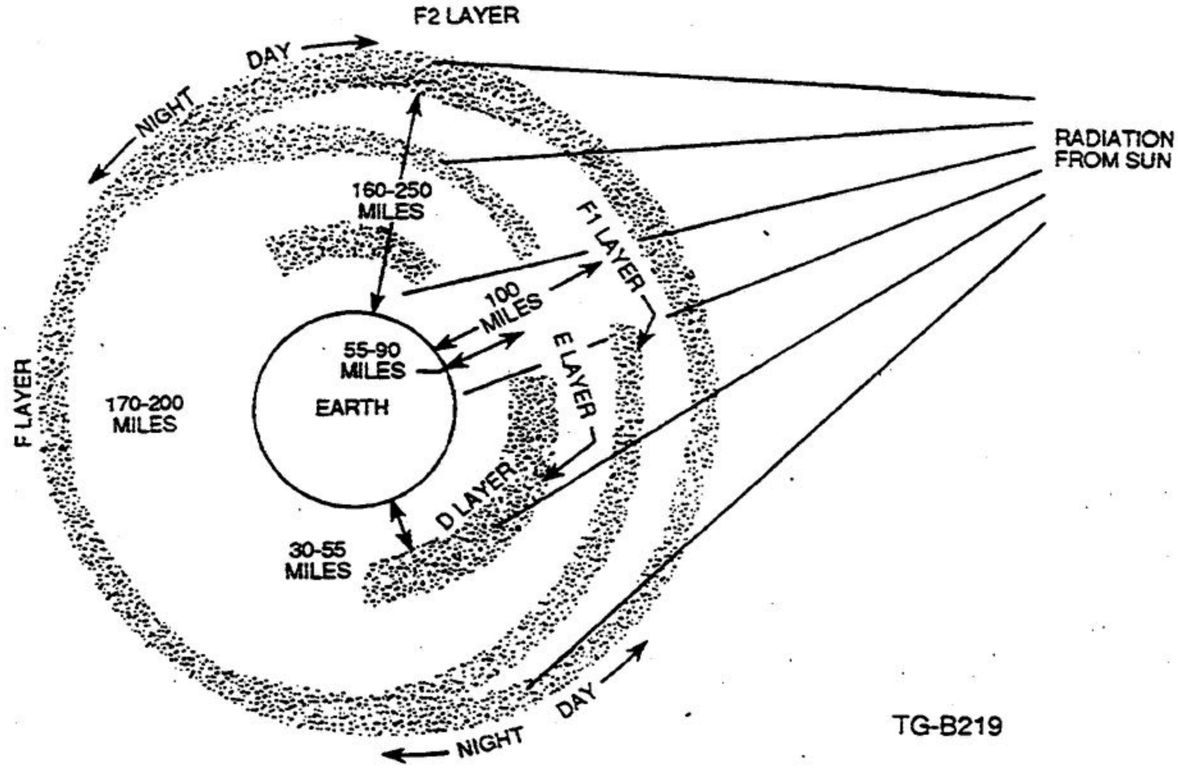


Figure 1-9. Layers of the ionosphere.

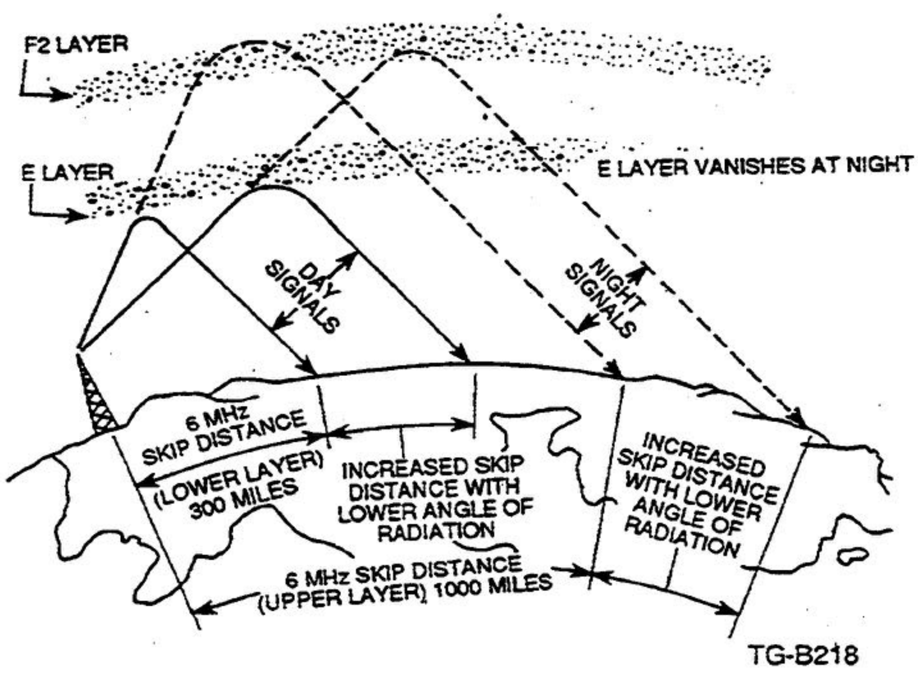


Figure 1-10. Effect on skip distance with disappearance of E layer.

disturbances (sunspot activity). There is a greater concentration of solar radiation in the earth's atmosphere during peak sunspot activity, which recurs in 11-year cycles (maximum 1981-1982, minimum 1988, maximum 1992-1993).

During periods of maximum sunspot activity, the F layer is more dense and occurs at a higher altitude, as shown in figure 1-11. Conditions are shown for transmitted fronts A and B having different angles of radiation . During periods of minimum sunspot activity, the F layer is at a lower altitude. Thus, it returns the sky waves (dotted lines) to points closer to the transmitter than the higher altitude F layer produced during maximum sunspot activity. Consequently, skip distance is affected by the degree of solar disturbance.

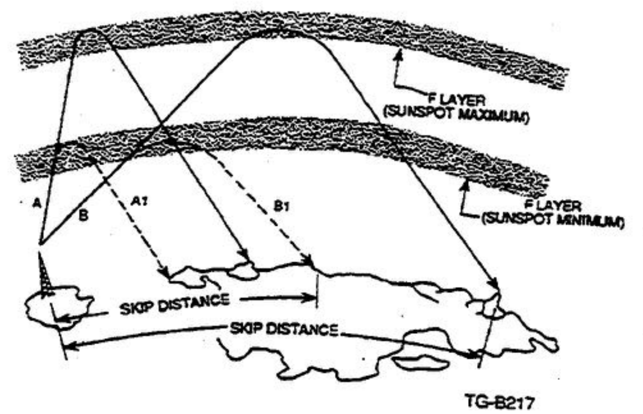


Figure 1-11. Effects of sunspot activfity on skip distance.

004. How the ionosphere effects sky wave propagation

Sky Wave Propagation. Some waves penetrate and pass through the ionosphere into space, never to return. Other waves penetrate but bend. Generally, the ionosphere acts as a conductor and absorbs energy in varying amounts from radio waves. As we discussed, the ionosphere acts as a radio mirror, refracting (bending) sky waves back to the earth.

The ability of the ionosphere to return a radio wave to the earth depends not only on the amount of ionization but also on the frequency of transmission and angle of radiation. The ionosphere's refractive power increases with an increase in the density or degree of ionization. The degree of ionization is greater in summer than in winter and during the day than at night. As we saw earlier, abnormally high densities occur during periods of peak sunspot activity.

Critical Frequency. If the frequency of a radio wave being transmitted vertically (at a 90° angle) is gradually increased, a point will be reached where the wave won't be refracted enough to curve the path back to earth. Instead, these waves continue upward to the next layer, where refraction continues. If the frequency is high enough, the wave will penetrate all layers of the ionosphere and continue on out into space. The highest frequency that will return to earth when it's transmitted vertically under given ionospheric conditions is called the critical frequency. Any frequency higher than the critical frequency, with the angle of radiation equal to 90°, will not return to the earth's surface. Generally, the higher the frequency, the more difficult the refracting or bending process. Figure 1-12 illustrates this point.

Angles of Propagation (Radiation). The angle of propagation plays an important part in determining whether a particular frequency will return to earth by refraction from the ionosphere. Above a certain frequency, waves transmitted vertically continue on into space. However, if the angle of propagation is lowered (made less vertical), part of the high-frequency waves return to earth. The highest angle at which a wave can be propagated and still return from the ionosphere is called the *critical angle* for that particular frequency. The critical angle, which can be defined in terms of the angle of incident, is the angle between the direction of travel of a wave front and a line drawn perpendicular to the ionosphere, at the point of incidence.

Figure 1-13 is a light-beam analogy to demonstrate the critical angle concept. In the figure, a light source is shown well below the surface of the ocean. When the light source generates beam A, the light is refracted slightly and escapes the medium of water. With the light source tilted to the right, beam B is refracted a sufficient amount to cause the beam to skirt the surface of the water. Further tilting of the light source results in considerably refraction so that the beam returns to the ocean floor. In this analogy, angle Θ3 (theta 3) is the critical angle.

The action of a radiated wave from an antenna is similar to that described for the light analogy above. When electromagnetic waves enter the ionosphere, they are effectively speeded up and follow curved paths, as shown in figure 1-14. For the particular frequency used, angle Θ1 represents the critical angle. Any wave that enters the ionosphere at an angle less than Θ1 will penetrate the ionosphere and continue on into space. At angles greater than the critical angle, the waves

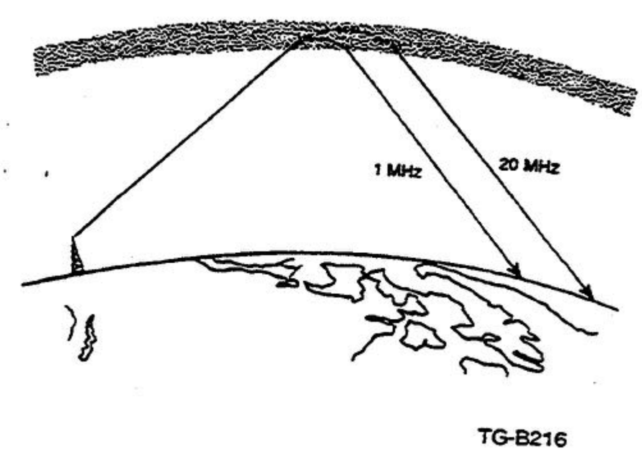


Figure 1-12. Relationship of frequency to refraction by the ionosphere.

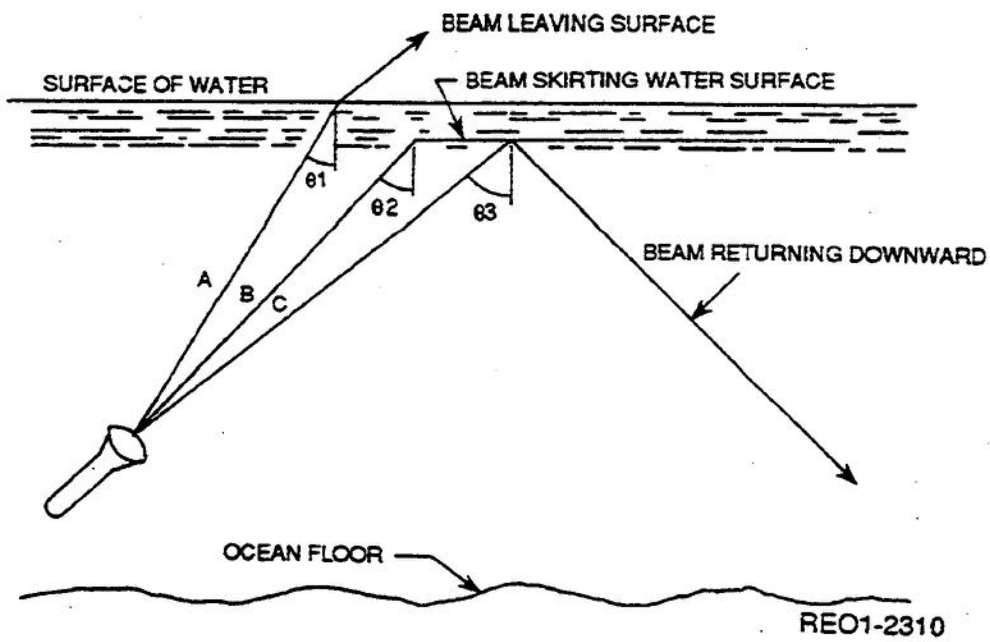


Figure 1-13. Light beam analogy showing the effects of refraction and the vertical angle.

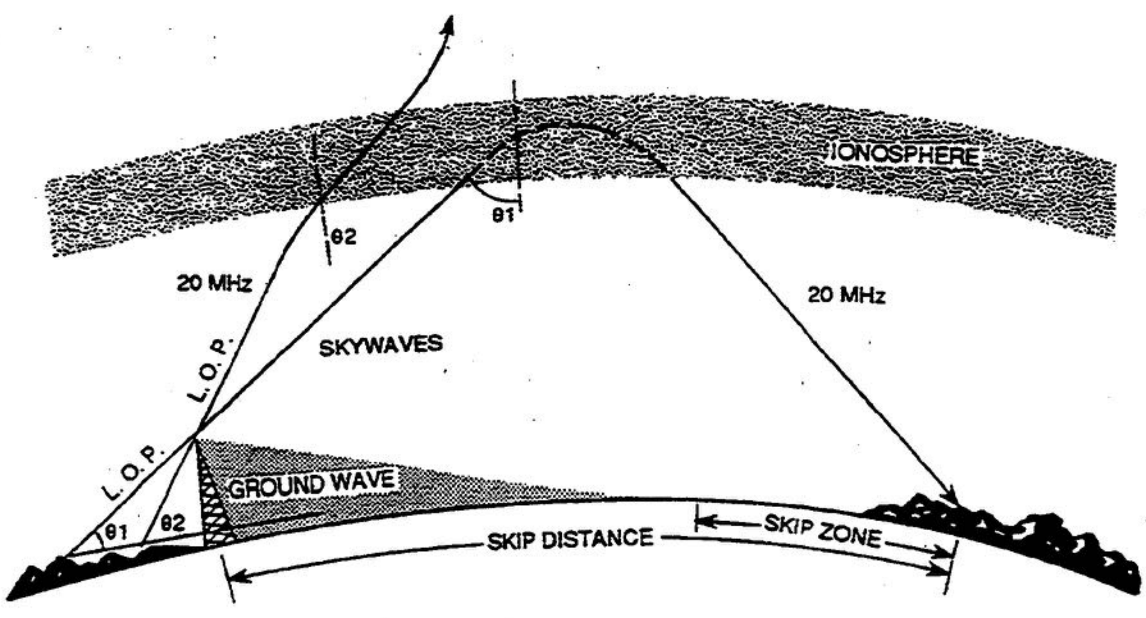


Figure 1-14. Ionospheric refraction at various angles of propagation.

are refracted back to earth. It should be noted that the skip distance decreases as the angle of propagation increases toward the critical angle.

The angle of propagation is defined as the angle between the "line of propagation" (LOP) and a line drawn tangent to the surface, illustrated in figure 1-14 as Θ1 and Θ2. Note that both skip distance and the amount of refraction decrease as Θ decreases.

You may be interested in knowing the maximum skip distances obtainable by refraction within the E and F2 layers at various angles of propagation. Table 1-4 gives the skip distances for various angles of propagation for an average E-layer height of about 70 miles and an average F2 layer height of about 200 miles.

Maximum Usable Frequency. From the previous discussion, it is obvious that there is a "best frequency." As

TABLE 1-4
SKIP DISTANCES AT VARIOUS ANGLES OF PROPAGATION.

PROPAGATION ANGLE (DEGREES)	SKIP DISTANCE FOR E LAYER (MILES)	SKIP DISTANCE FOR F2 LAYER (MILES)
0 (tangent to earth)	1,250	2,500
10	625	1,500
20	375	8,875
30	250	600
45	125	50
60	60	80
90 (vertically upward)	0	0

you can see in figure 1-15, the distance between the transmitting antenna and the point at which the wave returns to earth depends on the angle of propagation, which in turn is limited by the frequency. The highest frequency returned to earth at a given distance is called the *maximum usable frequency* (MUF) and has an average monthly value for any given time of the year. The optimum working frequency is the one that provides the most consistent communication. For transmission using the F2 layer, the optimum working frequency is about 85 percent of the MUF, while transmission via the E layer is consistent, in most cases, at any frequency near the MUF.

Because of this variation in the critical frequency, nomograms and frequency tables are issued that predict the MUF for every hour of the day for every locality in which transmission is made. Nomograms and frequency tables are

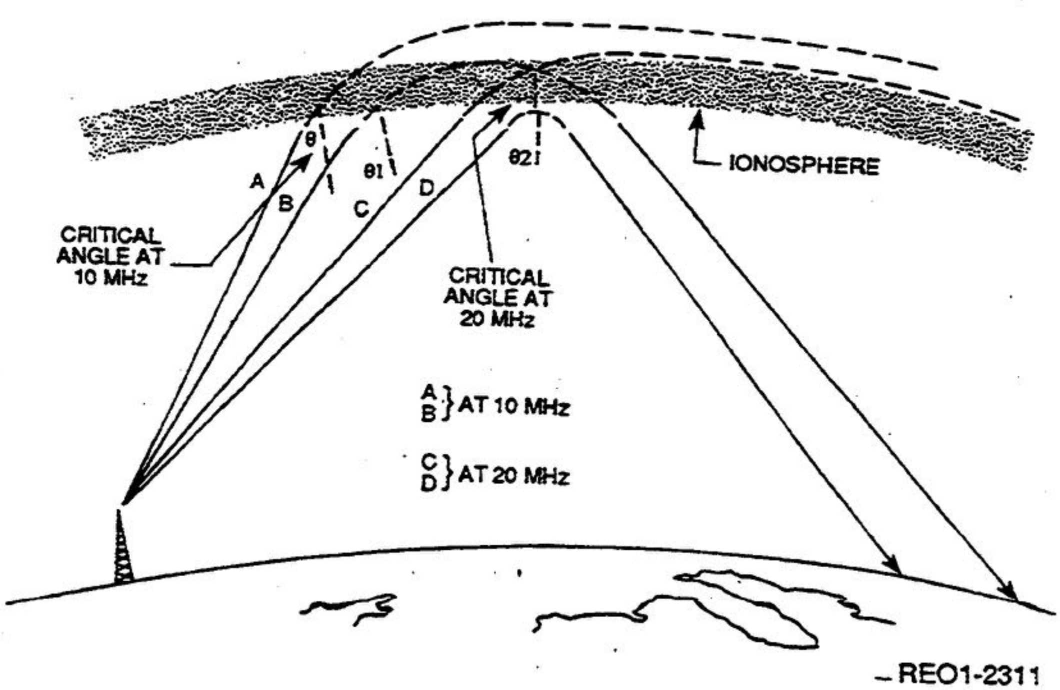


Figure 1-15. Relationships of frequency to critical angle.

prepared from data obtained experimentally from stations scattered all over the world. All this information is pooled, and the results are tabulated in the form of long-range predictions that remove most of the guess work from radio communications.

Increased ionization during the day is responsible for several important changes in sky-wave transmission. It causes sky waves to be returned to the earth nearer the point of transmission. The extra ionization increases the absorption of energy from sky waves. If a wave travels far enough into the ionosphere, it will lose all of its energy. The presence of the F1, F2, and E layers makes long-range, high-frequency communications possible at the right frequencies.

Absorption usually reduces the effective daylight communications range of low- and medium-frequency transmitters to surface-wave ranges. The high degree of ionization of the F2 layer during the day enables refraction of high frequencies that are not greatly absorbed by the lower layers.

Frequency versus Angle of Propagation. Due to the interplay of frequency and angle of propagation, long-distance communication must take into account both factors. The following information indicates the approximate angle of radiation most suitable for radio waves of different frequencies and for different distances between points of communication.

1.5 to 3 MHz. Low-angle radiation is good for long distances. High-angle radiation may cause fading of ground-wave reception. (We'll discuss this shortly.) Vertical antennae are preferable.

3 to 7 MHz. This frequency range offers good sky-wave return at any angle of radiation. High-angle radiation can be used for short to moderate ranges and low-angle radiation for long-distance communications.

7 to 12 MHz. Use this frequency range from 30 to 45° for short-to-moderate distances. Use lower angles for long-distance communications. Higher radiation angles can be used to overcome variations in ion density during peaks of sunspot activity.

12 to 30 MHz. This frequency range is not useful for short-distance sky-wave transmission. The maximum useful angle when you're operating on a frequency from 12 to 16 MHz is about 30°. As the frequency is increased to 28 MHz, the angle of propagation should be decreased to 10°. Above 28.5 MHz, use an angle less than 10°.

Fading. Fading refers to the variations in signal strength that occur at a receiver. Fading may occur at any point where both the ground and sky wave are received, as shown in figure 1-16,A. The two waves may arrive out of phase, canceling the usable signal. This type of fading is encountered in long-range communication over bodies of water where groundwave propagation extends for a relatively long distance.

In areas where sky-wave propagation is prevalent, fading may be caused by two sky waves traveling different distances, thereby arriving at the same point out of phase, as shown in figure 1-16,B. This condition may be caused by part of the transmitted wave being refracted by the E layer while another part is refracted by the F layer. A complete cancellation of the signal would occur if the two waves arrived 180° out of phase with equal amplitudes. Usually, though, one signal is weaker than the other and a usable signal is obtained.

Variations in absorption and in the length of the path in the ionosphere are also responsible for fading. Occasionally, sudden disturbances in the ionosphere cause complete absorption of all sky-wave radiation.

Receivers near the outer edge of the skip zone are subjected to fading as the sky wave alternately strikes and skips over the area. This type of fading sometimes causes the received signal strength to fall nearly to the zero level. Also, a ground-reflected wave and a direct wave can arrive at a receiver out of phase.

One method used to help reduce the effects of fading is to place two or more receiving antennae a wavelength or two apart, each antenna feeding its own receiver, with all receiver audio outputs combined. This process is known as *diversity reception*. The greater the number of antennae and receivers used, the smaller the effects of fading become.

Frequency blackouts are closely related to certain types of fading. Some are severe enough to completely blank out transmission. Changing conditions in the ionosphere shortly before sunrise and shortly after sunset may cause complete blackouts at certain frequencies. Higher frequency signals

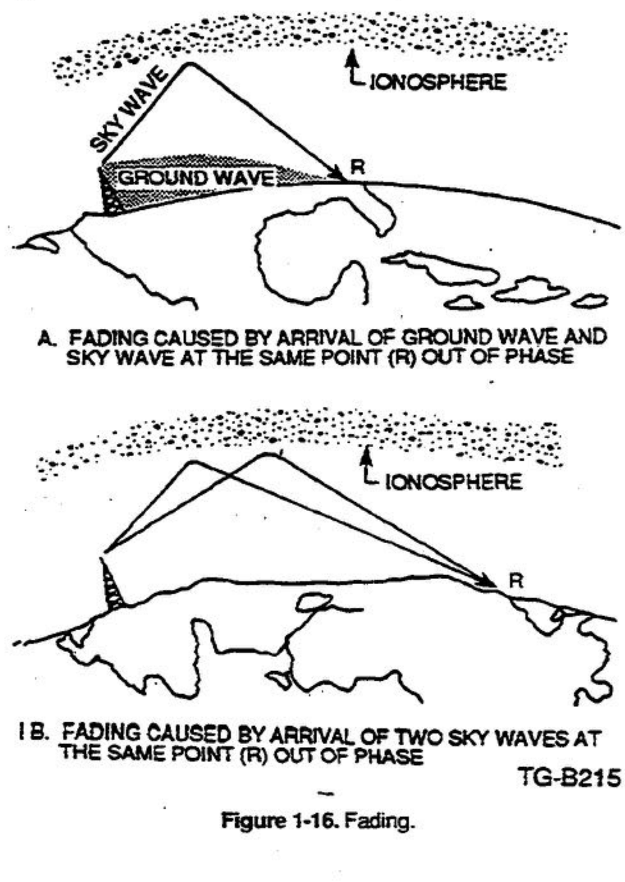
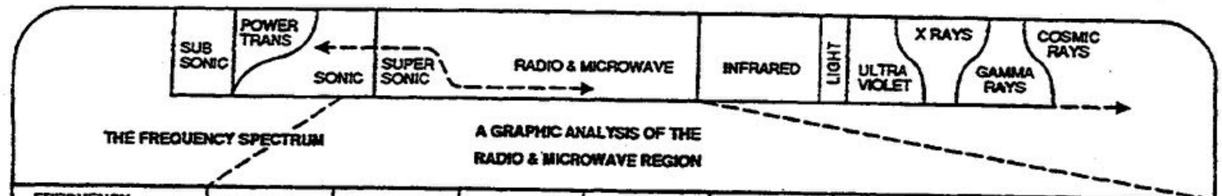


Figure 1-16. Fading.

pass through the ionosphere, while lower frequency signals are absorbed by it.

Ionospheric storms (turbulent conditions in the ionosphere) often cause radio communications to become erratic. Some frequencies will be completely blacked out, while others may be reinforced. Sometimes these storms develop in only a few minutes, and at other times they require as much as several hours to develop. A storm may last several days.

When frequency blackouts occur, operators must be alert to prevent loss of contact with sending stations. In severe storms, critical frequencies are much lower, and absorption in the lower layers of the ionosphere is much greater. Figure 1-17 shows a summary of the electromagnetic spectrum.



FREQUENCY KILOHERTZ MEGAHERTZ GIGAHERTZ		3 kHz – 30 kHz	30 kHz – 300 kHz	300 kHz – 3 MHz	3 MHz – 30 MHz	30 MHz – 300 MHz	300 MHz – 3 GHz	3 GHz – 30 GHz	30 GHz – 300 GHz
WAVE LENGTH METERS & CENTIMETERS		100,000 M – 10,000 M	10,000 M – 1000 M	1000 M – 100 M	100 M – 10 M	10 M • 1000 CM – 1 M • 100 CM	1 M • 100 CM – 1 M • 10 CM	10 CM – 1 CM	1 CM – 0.1 CM
BANDS							P, L	S, X, K	
DESIGNATION		VERY LOW FREQ V L F	LOW FREQ L F	MEDIUM FREQ M F	HIGH FREQ H F	VERY HIGH FREQ V H F	ULTRA HIGH FREQ U H F	SUPER HIGH FREQ S H F	EXTREMELY HIGH FREQ E H F
CHARACTERISTICS	MAXIMUM RANGE	5000 MI D REGION REFLECTION	3000 MI D REGION REFLECTION	900 MI E REGION REFLECTION	12,000 MI F REGION REFLECTION	LINE OF SIGHT SOME ATMOS REFLECTION	LINE OF SIGHT SPORADIC ATMOS REFLECTION	LINE OF SIGHT SOME ATMOS ABSORPTION	LIGHT OF SIGHT EXTREME ATMOS ABSORPTION
	STATIC	MAN MADE & NATURAL	MAN MADE & NATURAL	MAN MADE & NATURAL	NATURAL	LINE RESONANCE	NONE	NONE	NONE
	RF SOURCE	TRIODE SPARK GAP	TRIODE SPARK GAP	TRIODE	TRIODE	TRIODE NEW CIRCUIT TECHNIQUES	TRIODE	MAGNETRONS KLYSTRONS	MAGNETRONS KLYSTRONS (VELOCITY MOD)
	TRANSMISSION	• WIRE	• WIRE	• WIRE	• WIRE	• WIRE ○ COAXIAL	○ COAXIAL □ WAVEGUIDE	○ COAXIAL □ WAVEGUIDE	□ WAVEGUIDE
	ANTENNA	WIRE	WIRE	WIRE	WIRE	WIRE DIPOLE	DIPOLE	DIPOLE HORN	HORN
APPLICATIONS		EXPERIMENTAL (COMMUNICATIONS & NAVIGATION)	COMMUNICATIONS NAVIGATION R.C.M.	COMMUNICATIONS NAVIGATION R.C.M.	COMMUNICATIONS NAVIGATION R.C.M.	COMMUNICATIONS NAVIGATION TELEVISION CONTROL R.C.M. RADAR: • SEARCH • I.F.F. • E.W.	COMMUNICATIONS NAVIGATION TELEVISION CONTROL R.C.M. RADAR: • SEARCH • I.F.F. • GUNLAYING • E.W.	NAVIGATION CONTROL RADAR: • SEARCH • BOMBING • GUNLAYING • E.W. R.C.M.	EXPERIMENTAL (TACTICAL RADAR, ETC.)

ELECTROMAGNETIC SPECTRUM

REO1-2260

Figure 1-17. Electromagnetic spectrum.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

003. Characteristics of propagated waves

1. What RF wave is that component of the space wave that travels in an almost straight line from the transmitting to receiving antenna?

2. What is the difference between a refracted and reflected wave?

3. Name the three regions of the atmosphere that affect RF waves.

4. Name the layers of the ionosphere and state which is the least ionized and which is the most.

004. How the ionosphere effects sky wave propagation

1. What effect does the ionosphere have on a sky wave's critical frequency?

2. What is the critical angle?

3. What do you call the highest frequency that can be used for a given distance?

4. What ionospheric condition could cause radio communications to be "blacked out" at certain frequencies?

5. What effect does the ionosphere have on daytime sky waves?

ANSWERS TO SELF-TEST QUESTIONS

001

1. Transatlantic communications became faster, had greater capacity, and were somewhat less expensive than cable systems.
2. During the initial stages of the space program, which led to the development of satellite communications systems.

002

1. High radio frequency (HF); super-high radio frequencies (SHF).
2. Ground waves and sky waves.
3. A ground wave.

003

1. Direct wave.
2. A refracted wave is bent as it passes obliquely from one medium to another (in the ionosphere) as a result of the difference in the velocity of the wave from the first medium to the second. A reflected wave is reflected from the surface of the earth.
3. Troposphere, stratosphere, and ionosphere.
4. D, E, and F layers. The least ionized layer is the lower or D layer, while the most ionized is the upper or F layer.

004

1. Depending on the ionization of the atmosphere, the lower the frequency, the more easily the signal is refracted; the higher the frequency, the more difficult is the refracting, or bending, process.
2. The highest angle at which a wave can be propagated and still return from the ionosphere.
3. Maximum usable frequency (MUF).
4. Ionospheric storms.
5. Increased ionization during the day causes a sky wave to return to the earth nearer to the point of transmission. (A smaller skip distance.)

Do the Unit Review Exercises (URE) before going to the next unit. ➡

UNIT REVIEW EXERCISES

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to ECI Form 34, Field Scoring Answer Sheet. **DO NOT RETURN YOUR ANSWER SHEET TO ECI.**

1. (001) What led to the development of VHF and UHF radio systems during World War II?
   a. The need for more reliable high-capacity communications.
   b. The development of line-of-sight communications.
   c. The longer distances involved in communicating with forces in Europe.
   d. The need for more resistance to nuclear blast.

2. (001) As space programs advanced, long-range communications at the higher frequencies were made possible through the use of
   a. extremely low frequency (ELF) systems.
   b. tropospheric scatter systems.
   c. high-frequency systems.
   d. satellite systems.

3. (002) Which frequency band has a range of 3 to 30 Hz?
   a. VLF.
   b. ELF.
   c. VHF.
   d. EHF.

4. (002) An electromagnetic wave propagated at such an angle that it travels up through the atmosphere, strikes its upper layer in the ionosphere, and refracts back toward the earth is
   a. a ground wave.
   b. a surface wave.
   c. an earth reflected wave.
   d. a sky wave.

5. (003) The downward bending of a radio wave as it grazes the top of an obstruction, such as a mountain peak, is called
   a. reflection.
   b. refraction.
   c. diffraction.
   d. diffusion

6. (003) During periods of *maximum* sunspot activity, the F layer is
   a. less dense and at a lower altitude.
   b. more dense and at a lower altitude.
   c. less dense and at a higher altitude.
   d. more dense and at a higher altitude.

7. (004) How can you reduce the effects of propagation fading?
   a. Increase the angle of propagation (radiation).
   b. Use a diversity reception receive antenna system.
   c. Locate the receivers near the outer edges of the skip zone.
   d. Ensure the critical angle is close to the angle of incidence.

Please read the topic page for Unit 2 and continue. ➡

STUDENT WORK SPACE

TROPOSPHERIC SCATTER

Now that we've reviewed the fundamentals, we can start to apply them to the different types of systems. The application of the tropospheric scatter technique provides beyond-the-horizon multichannel communication and overcomes the shortcomings of other systems. For example, landlines are limited by accessibility of locations for initial installation and subsequent maintenance. Microwave equipment is less limited in this respect, but it's expensive for long-distance systems because its line-of-sight (LOS) limitation requires frequent repeater stations. VHF and HF systems, while technically capable of beyond-the-horizon, multichannel communications, can't provide this service because these bands are too crowded to allow the bandwidth needed for multichannel communications. Tropospheric scatter systems, on the other hand, offer the advantage of microwave systems without the severe restrictions to link length. Tropospheric scatter links are in operation up to 595 miles, though most links are less than 400 miles.

A development that has contributed to the success of tropospheric scatter transmission is the power amplifier klystron. Because of its high-power gain and large-voltage handling capabilities, it has met with wide acceptance for RF power generation in frequencies above 200 MHz. Tropospheric scatter systems operate with very-high path loss, and without the development of the klystron power amplifier, troposcatter transmission would not have become so successful.

2-1. General Theory

The tropospheric scatter technique grew out of the frequent reports, during World War II, of UHF radio transmissions over distances greatly exceeding the LOS limitation. Investigations and studies of these apparently abnormal transmissions showed that the effect was caused by diffusion, or scattering, of the propagated energy in the troposphere. The precise nature of this effect is uncertain, and many theories have been presented on the mechanics of tropospheric scatter. Some theories had to be withdrawn because of new data and experimentation with this phenomenon. The theory presented here is the most widely accepted.

005. The effect the troposphere has on transmitted energy and the effect of scatter angle

Theory of Tropospheric Scatter. The atmosphere surrounding the earth is divided arbitrarily into three regions, as shown in figure 2-1. The *troposphere* extends from the earth's surface to an approximate altitude of 6 miles. "Weather" occurs and there is practically no ionization of the air molecules. The *stratosphere* extends from the troposphere to an altitude of about 30 miles. There's no weather and very little ionization of the air molecules. The *ionosphere* extends from the stratosphere to about 120 miles. There is heavy ionization of the air molecules.

Heating and cooling of the water vapor in the atmosphere causes the greatest changes in its dielectric constant (capacitivity). This effect is greatest in the region extending upward from the earth's surface to about 4 miles. Because the region of the troposphere that's used for tropospheric scatter is above 4 miles and because it's the dielectric constant that determines how much the beam bends toward the earth, this region acts as a smooth refractive medium, with its dielectric constant subject to only small variations.

Since the troposphere is in a constant state of motion, with respect to the earth, small irregularities, or eddies, occur. These irregularities occur in "blobs" that are large compared to the wavelength used in scatter communications. Since they are large, they present a different index of refraction from that of the surrounding medium. The index of refraction is the ratio of the velocity of the wave in free space to that in the medium. The changes in the refractive index are a result of the variations in dielectric constant caused by the turbulent air motion and the water content.

The abrupt change in the index of refraction produces a "scattering" of an electromagnetic wave. Most of the propagated energy continues in the forward direction, but enough energy is scattered toward the earth to be usable, as shown in figure 2-1. The signals received are affected by actual conditions of the troposphere since scatter depends on turbulences in the troposphere. Thus, there is more scattering in summer than in winter and more in the tropical zone than in the arctic zones. The number of blobs in the volume common to both transmitting and receiving antenna beams, as shown in figure 2-2, determines the amplitude of the signal received. The scatter illustration shown in figure 2-2 is idealized to indicate the path geometry. Notice that both the receiving and transmitting antennae are directed above the horizon. A certain volume of the troposphere is common to both antennae. It is within this *common volume* that useful scattering takes place.

It can be proven mathematically that the scatter angle Θ (fig. 2-2) is the most important factor in determining the

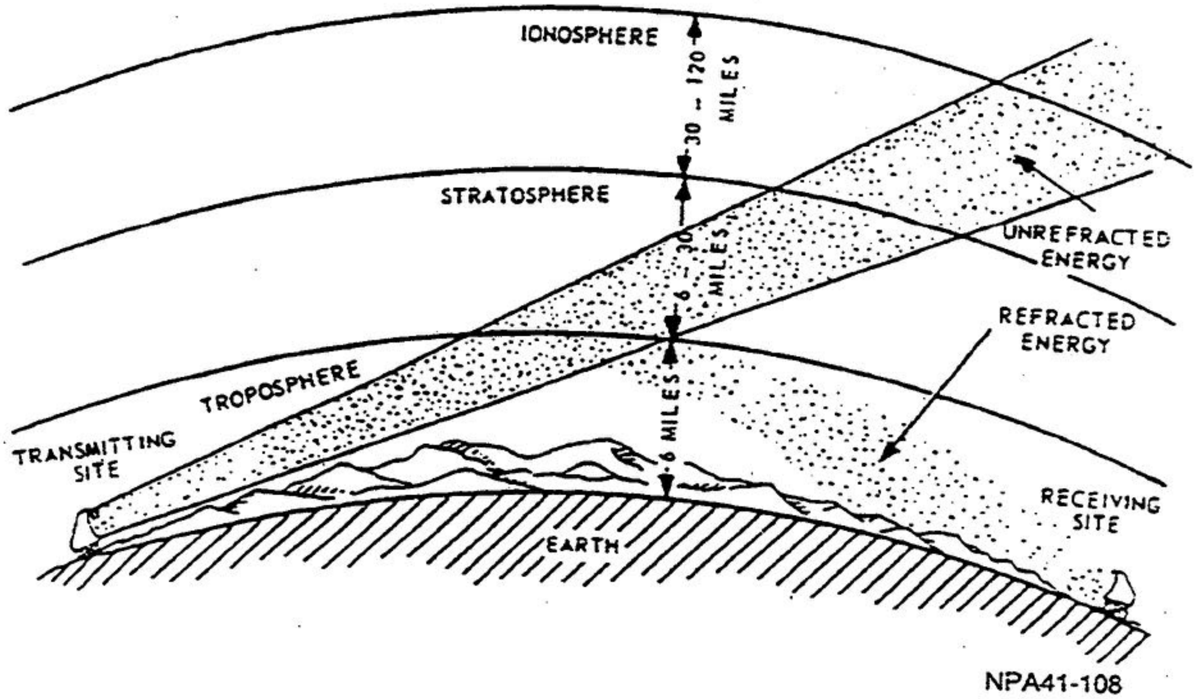


Figure 2-1. Forward tropospheric scatter principle.

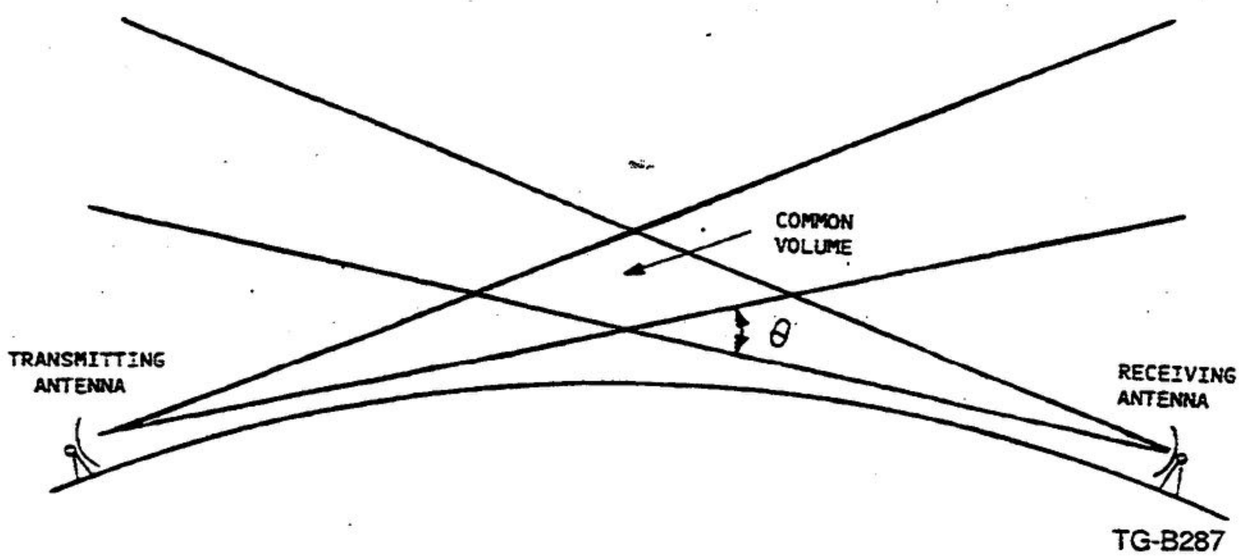


Figure 2-2. Tropospheric scatter geometry.

received power. Angle Θ is the acute angle between a ray from the transmitting antenna and one of the receiving antenna. If this scatter angle is increased, the received power falls off rapidly, falling approximately 10 dB for every degree that the angle increases. With wide-beam antennae, the scatter volume is increased, but the effective received power is decreased because of less gain in the antennae. With narrow-beam antennae, the entire common volume contributes appreciably to the received signal. There's a slightly different angle for each ray of the entire beamwidth considered. You have to sum up an infinite number of rays to get the sum of the individual contributions.

It's correct to assume, therefore, that the scatter radiation comes from an infinite number of small scatterers (turbulences) within the common volume, and that each scatterer effectively reradiates according to the amount of energy striking it from the transmission antenna. This reradiated energy occurs over a very-wide-frequency range, but there are certain frequencies that can be used for useful communications.

Frequency Characteristics. Tropospheric scatter communications systems are successful within certain frequency ranges. The frequencies used are in the 350 to 8,000-MHz (UHF-SHF) range. This frequency range is not the limit within which communications can take place, but it is the most usual range in present operations.

Frequency modulation (FM) is used in operational tropospheric scatter communications circuits, despite the wide bandwidth it requires. There are two reasons for this exclusive use of FM. The first is that the FM receiver is relatively insensitive to amplitude variations if the signal remains above the receiver threshold. The second is that high-power FM transmitters were available at the time of the initial development of the scatter mode of propagation.

Bandwidth requirements for operational tropospheric scatter systems are outlined in table 2-1. You'll note that the bandwidth requirements for FM are considerable.

TABLE 2-1
FM BANDWIDTH VS NUMBER OF CHANNELS

NO CHANNELS	MODULATING FREQUENCY (kHz)	BANDWIDTH (kHz)
12	12-60	580
24	12-108	730
36	12-156	1140
48	12-204	1500
60	12-252	1670
72	12-300	2000

006. Factors that affect reliability and how the received signal strength is determined

Reliability. The reliability of a tropospheric scatter communications system must be taken into consideration at the time the system is engineered. Some of the things to consider are atmospheric conditions, equipment failures, manmade noise, troposcatter losses, and strength of received signal. Let's see how these things affect the system.

Atmospheric conditions. Steady atmospheric noises are low even at the lower limit of the frequency band used in tropospheric scatter communications. They decline rapidly as the frequency is raised to the higher limit of the band. Noise caused by severe electrical storms near a receiving location can reduce circuit effectiveness at frequencies in the lower part of the band, but the noise also declines rapidly as the higher limits are approached. Electrical noise generated by the sun and stars (stellar noise) also has some effect within the range of frequencies used, but the average level of the electrical noise is masked by atmospheric noises. You can hear these noises in very quiet receivers as a hiss resembling the internally generated noise of the receiving set. The noise in the receiver input circuits starts to override the stellar noise around the 300-MHz region for even the quietest receivers except when extremely high-gain antennae are used.

Equipment failures. The effect of equipment failure can be reduced by the use of multiple transmitters and receivers. For example, while two transmitters and four receivers are not absolutely necessary to maintain communications, the extra equipment is a safety factor. When two transmitters are used, they form an overall system with a reliability greater than that of a system with either of the transmitters alone. In addition, the defects in one transmitter can be recognized and repaired while the other transmitter continues to operate satisfactorily. It is assumed that the good transmitter will not fail while the faulty transmitter is being repaired. With spare backup utilities, such as power-generating equipment, the possibility of long outage time is reduced.

Manmade noise. Manmade noise at tropospheric scatter frequencies is usually of some consequence and must be considered in the design and location of troposcatter systems. Usually, the cheapest and simplest solution is to locate the system away from vehicular traffic, aircraft, machinery, electrified fences, power lines, and other manmade interference sources.

Troposcatter losses. Loss in "scatter" transmission depends largely on the scattering angle (fig. 2-2). For this reason, sites are located at elevated terminal locations with no obstructions in the direction of the other terminal. Typical scatter losses range from 150 to 250 dB.

We define scatter loss as the additional loss in free space over and above the loss in LOS transmission. Scatter loss is subject to various types of fading or time variations. *Fast fading* is caused mainly by multipath effects, and it may happen as often as 20 times per second on short paths. Multipath is a condition in which radio waves arrive at a receiving point at slightly different times because they travel over paths that differ appreciably in length. Because of the relative amplitude and phase differences of these two signals, the received signal is canceled at the receiver. *Slow fading*, which occurs daily, is superimposed on the fast fading and is caused by changes in the refractive index of the atmosphere. Seasonal changes can vary the signal level at the receive terminal from 10 to 15 dB between a summer day and a winter night on short paths. The seasonal variations on a 400-mile path are about half this amount because of the more stable conditions of temperature and humidity at the higher scattering elevations. In general, scatter losses are reduced in the daytime hours of summer. The poorest scatter propagation periods are at night during winter. Transmission is better over water than over land, but is no better over frozen water than over land.

Strength of the received signal. Another factor that must be considered when the system is engineered and installed is the received signal strength. The tropospheric scatter system must have a certain amount of signal in order to function. As we have already learned, however, this signal may be very weak. The amount of received signal strength is determined by the:

- Transmitter output power.
- Transmitter antenna gain.
- Receiver antenna gain.
- Scatter loss.

007. Transmitters and receivers used in troposcatter communications

Equipment Used. The equipment used to get reliable transmission and reception of tropospheric scatter signals differs somewhat from the equipment used in conventional LOS systems because the scattering of the UHF-SHF waves results in weak, but very persistent, signals far beyond the horizon. The transmitters must be able to produce large RF power outputs at frequencies in the UHF-SHF range. The nominal power outputs of tropospheric scatter transmitting equipment are 1, 10, 50, or 75 kilowatts. These high-power transmitters are used with high-gain antennae with gains up to 44 dB. The transmitters are air cooled and liquid cooled, except for the 1-kW transmitter, which is air cooled only.

The FM receiver must be highly sensitive because of the very weak signals normally encountered in scatter systems, and it must amplify without introducing appreciable noise into the system. Parametric amplifiers and tunnel diode amplifiers do these things in operational systems. The parametric amplifier is a high-gain, low-noise preamplifier connected between the antenna and the input of the FM receiver. Tunnel diode amplifiers, which are used in some troposcatter receivers, have the same function as the parametric amplifiers and are positioned the same electrically.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

005. The effect the troposphere has on transmitted energy and the effect of scatter angle

1. What effect does the troposphere have on transmitted energy?

2. Scatter depends on turbulences in the troposphere. What geographic area and season of the year provides the best scatter?

3. For best reception, should the scatter angle be as small or as large as possible?

4. What is the usual frequency range of tropo equipment?

5. What type of modulation is used in tropo equipment?

006. Factors that affect reliability and how the received signal strength is determined

1. Name three factors that affect reliability.

2. How can the effect of equipment failure and manmade noise be reduced?

3. Explain the difference between fast and slow fading.

4. List four factors that determine the strength of the received signal.

007. Transmitters and receivers used in troposcatter communications

1. State one requirement of troposcatter transmitters.

2. List two requirements of troposcatter receivers.

2-2. Transmission

The tropospheric scatter exciter, power amplifier, and associated cooling equipment make up a tropospheric scatter transmitter. The Air Force uses two basic types of equipment. The first is designed primarily for fixed service, although there are mobile configurations of this equipment. Fixed equipment is available in 1-kW, 50-kW, and 75-kW power output configurations. The second type of tropospheric scatter set is characterized by its all-transistorized or solid-state circuitry and its mobility. The only exceptions to its all-solid-state composition are a traveling-wave tube and a power klystron.

008. Sections of the exciter

Exciter Block Analysis. Figure 2-3 illustrates the radio transmitter section (exciter) of the solid-state tropospheric scatter set. Figure 2-4 is a block diagram of the exciter. Here the multichannel and teletypewriter data from the multiplexing equipment is applied to the modulation amplifier. This data is carried over 12, 72, 132, or 252 voice channels that extend in frequency up to 1,052 kHz. The signals are distributed over the input band this way:

- An orderwire signal (250 Hz to 12 kHz).
- An LF baseband signal (12 to 60 kHz).
- An HF baseband signal (64 to 1,052 kHz).

The modulation amplifier amplifies the incoming baseband signals to their correct amplitudes before they are applied to the modulators. A 60-kHz pilot tone is also generated in the modulation amplifier to monitor the transmitting and distant receiving functions. The HF baseband signals (64 to 1,052 kHz) are fed to the HF modulator, and the LF baseband signals (12 to 60 kHz), with the 250-Hz to 12-kHz orderwire added, are fed to the LF modulator. Both baseband signals contain the 60-kHz pilot tone.

In the LF modulator, the LF baseband signals phase modulate a carrier frequency, which is held stable throughout the modulation process. After modulation, the signals are amplified and multiplied before they are applied to the HF modulator.

In the HF modulator, the LF modulator output (an FM signal) is heterodyned with the HF baseband signals. The output of the HF modulator is multiplied to produce the FM frequency (70 MHz) that is applied to the mixer section.

In the converter section, the FM frequency is mixed with a locally generated carrier frequency to produce the transmitter frequency. The output of the converter section is fed to the power output section, where it is amplified to a level suitable to drive a high-power klystron amplifier.

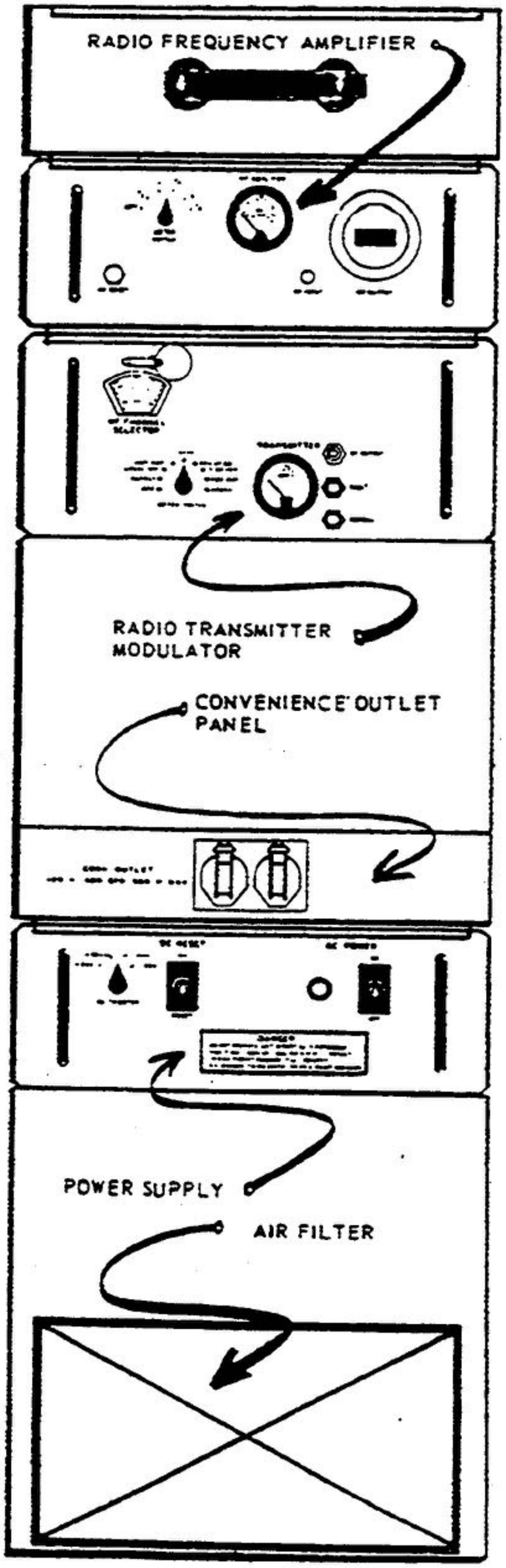


Figure 2-3. Mobile radio transmitter.

009. The klystron power amplifier

The klystron power amplifier receives its driving power from the exciter. The cavity-tube boosts the low-power frequency-modulated driving signal to a frequency-modulated high-power signal. The klystron amplifiers used for this contain from three to five cavities, depending on the power output and the type of equipment in use. The equipment may or may not have an associated dummy load and heat exchanger.

Functional Sections. In the conventional electron tube, electron emission is controlled by a control grid, which varies the current that flows from the cathode to the plate. This process is called *current density modulation*. However, three problems arise at UHF frequencies:

(1) Electron tube transit time.

(2) Interelectrode capacitance.

(3) Limitation of voltage and power-handling capabilities.

These problems have been overcome by *velocity modulation*, which doesn't depend on varying the emission from a cathode. Instead, it varies the speed of the electrons in the beam. This method is the basic principle on which the klystrons in troposcatter transmitters operate. The klystron tube can be divided into three functional sections: the electron gun, the RF section, and the collector section.

Electron gun. The electron gun (fig. 2-5) is the source of the electron beam. It has a filament, a cathode, focusing electrodes, and a modulating anode. The beam is a fast-moving stream of electrons expelled from the cathode. The electrons are held together by the focusing electrode, which operates at cathode potential, or negative with respect to the cathode. This charge applied to the focusing electrode causes the electrons to converge on the axis of the tube.

The entire beam flows through a hole in the modulating anode to the first section of the drift tube. In this application, the modulating anode is grounded through a 10KΩ resistor (fig. 2-6). This feature prevents damage to the tube if arcing occurs in the electron gun section. When arcing occurs, a large current flows to the anode. When this current flows through the 10KΩ resistor, it develops a negative bias that cuts off the beam current until the arcing stops.

RF section. When the beam enters the input cavity (fig. 2-6), the number of electrons is constant, but their velocity is changed because the excitation of the input cavity is changed by the signal to be amplified. If an electron reaches the cavity at gap A when the RF voltage is at zero, its speed is unaffected. However, the speed of any electron reaching gap A when the voltage is positive will be accelerated, while the speed of the electrons reaching the gap when the voltage is negative will be reduced. If the electrons that were accelerated travel long enough, they eventually catch up with those that were slowed down shortly before on a previous negative half-cycle. Thus, velocity modulation becomes density modulation.

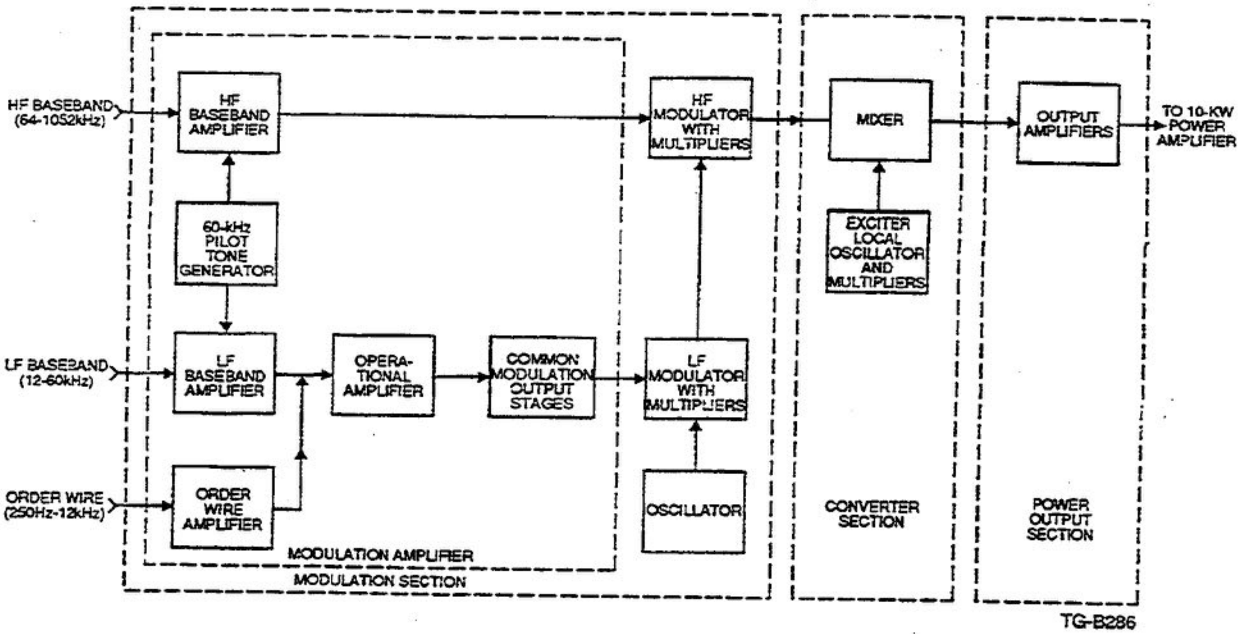


Figure 2-4. Exciter block diagram.

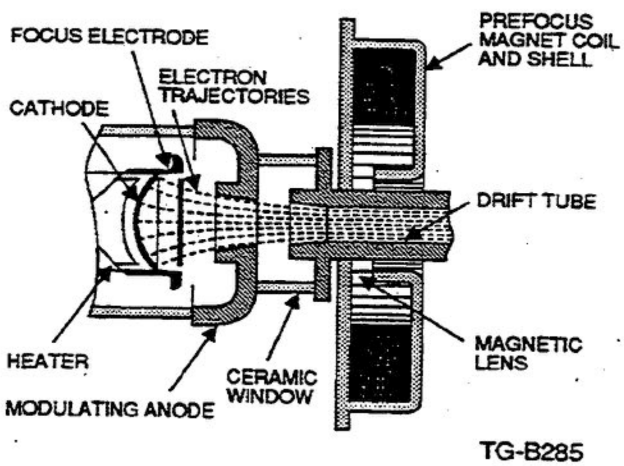


Figure 2-5. Electron gun.

The RF section is made up of the drift tube and the four resonant cavities that surround it at intervals along its length. The drift tube is a round, interrupted tube with a length almost 20 times its diameter. There are four interruptions, or gaps, along the length of the drift tube, so arranged that the sides of the drift tube protrude into the cavity wall. These opposing high-voltage points are surrounded by ceramic windows, and these drift-tube tips become capacitance-loading elements when the cavity is excited. The external demountable tuning boxes (resonant cavities) are assembled around the ceramic sections.

As the electrons pass through the remaining cavities, the bunching becomes more pronounced. As the bunches pass through the output cavity, oscillations are set up in the cavity in much the same way that pulses of current excite the plate-tank circuit of a class C amplifier. Since the power delivered to the output cavity is greater than the power delivered to the input cavity, amplification results. The power output is transferred to the antenna through a directional coupler by the output coupling loop in the output cavity.

Collector section. The klystron's collector section (fig. 2-6) consists of one electrode, the collector. About 30 percent of the beam energy is absorbed by the collector. It gathers the electrons and passes them out of the klystron into an external circuit leading to the positive terminal of the beam power supply.

010. Functions of the heat exchanger and dummy load

Heat Exchanger Operation. A heat exchanger cools and circulates the liquid solution that removes the heat from the klystron. The dummy load allows the klystron amplifier to be tuned and tested without being connected to an antenna. You can see in figure 2-7 that the heat exchanger operates much like the cooling system of an automobile. Assume that the coolant is at normal room temperature, and you start the unit. The coolant will bypass the heat transfer coils because the thermostatic bypass valve will be closed, closing off the part of the line that goes to the heat transfer coils. As the heat from the drift tube heats the coolant, the thermostatic bypass opens. The coolant flows through the heat transfer coils, where it is cooled by circulated air before it returns to the klystron drift tube. The alarm circuits within the heat exchanger monitor the temperature and level of the coolant. Besides its primary function of cooling the klystron, the heat exchanger can be

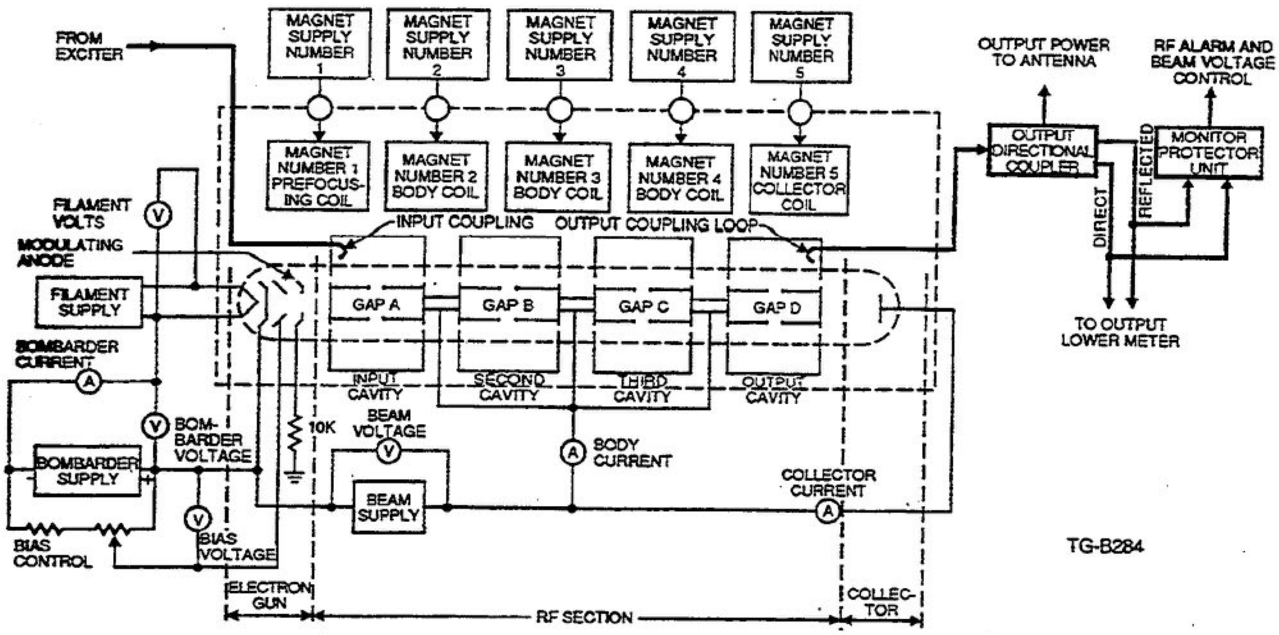


Figure 2-6. Typical four-cavity klystron.

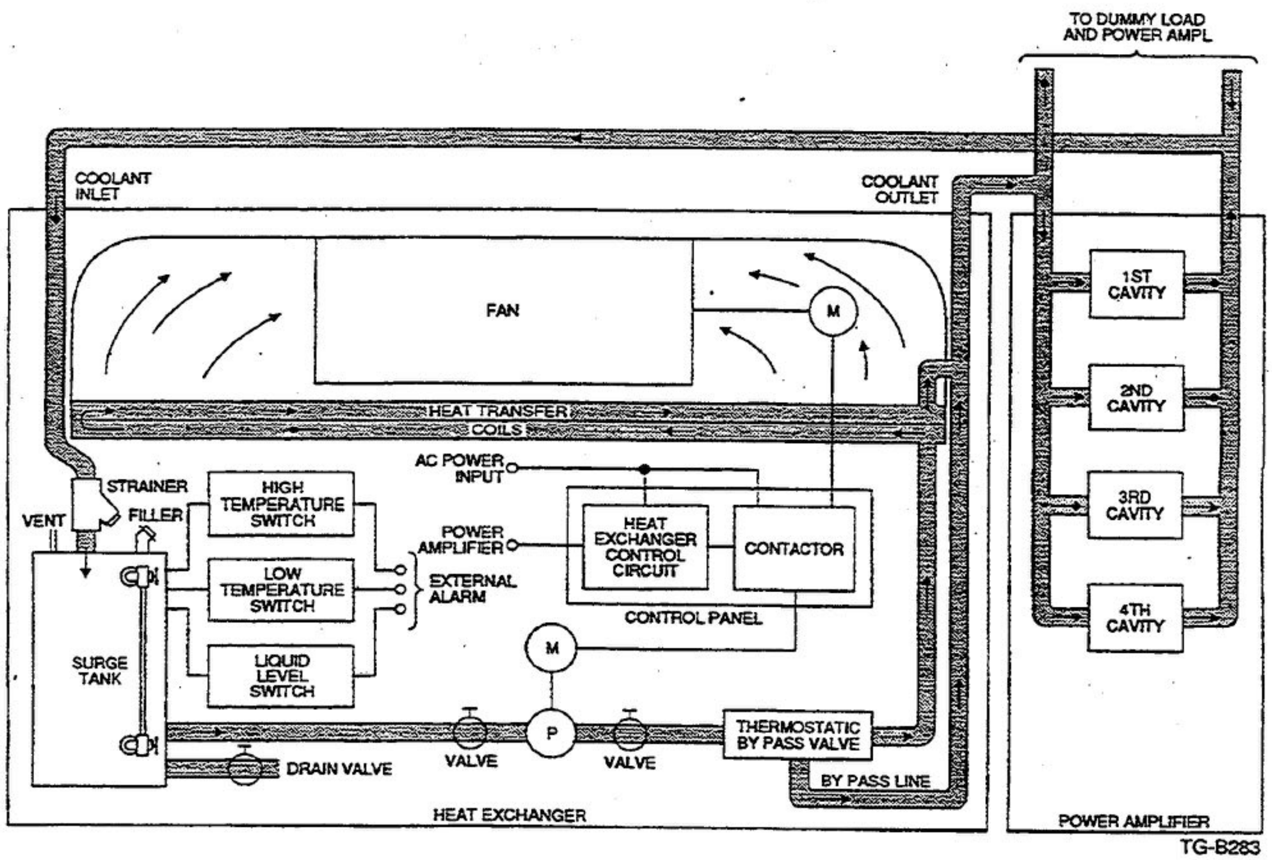


Figure 2-7. Heat exchanger, simplified coolant flow.

used to calibrate a dummy load. The 2-kW klystron is air-cooled and contains no heat exchanger. It is protected from overheating by a high-temperature interlock that activates when the klystron collector reaches about 270°C. This temperature-sensitive switch is embedded in the klystron collector structure and is an integral part of the klystron.

Dummy Load Operation. A dummy load in a troposcatter system allows the 10-kW klystron amplifier to be tuned and tested without being connected to an antenna. In many systems, a 10-kW amplifier is used to drive a 50-kW amplifier. Here, the dummy load can be used as an RF wattmeter to measure the RF power output of the 10-kW amplifier. When the proper RF power output is measured (registered) by this dummy load, the 10-kW amplifier is connected to the input of the 50-kW amplifier. The RF wattmeter works as a closed system's flow calorimeter. Water or another calorimetric fluid is circulated continuously by a pump in the heat exchanger (fig. 2-8). The thermopile senses the temperature of the coolant as it enters the dummy load and again as it returns to the heat exchanger. The difference in temperature is noted on the power meter.

The meter is calibrated by passing the coolant through the heater. For example, assume that the flowrator measures the rate of flow as 1 gallon per minute (gpm) and you calibrate the meter to read 2 kW. Close the valve going to the heater, open the valve to the waterload, and let the coolant flow through it. Turn on the 10-kW amplifier, and when the flowrator reads 5 gpm and the RF power meter reads 2 kW, you know that the output of the amplifier is 10 kW. In the 2-kW tropospheric scatter set, the dummy load is a part of the circulator in the antenna system and can be connected to the circulator through a small section of flexible waveguide. It is mounted in the airstream of the klystron cooling system.

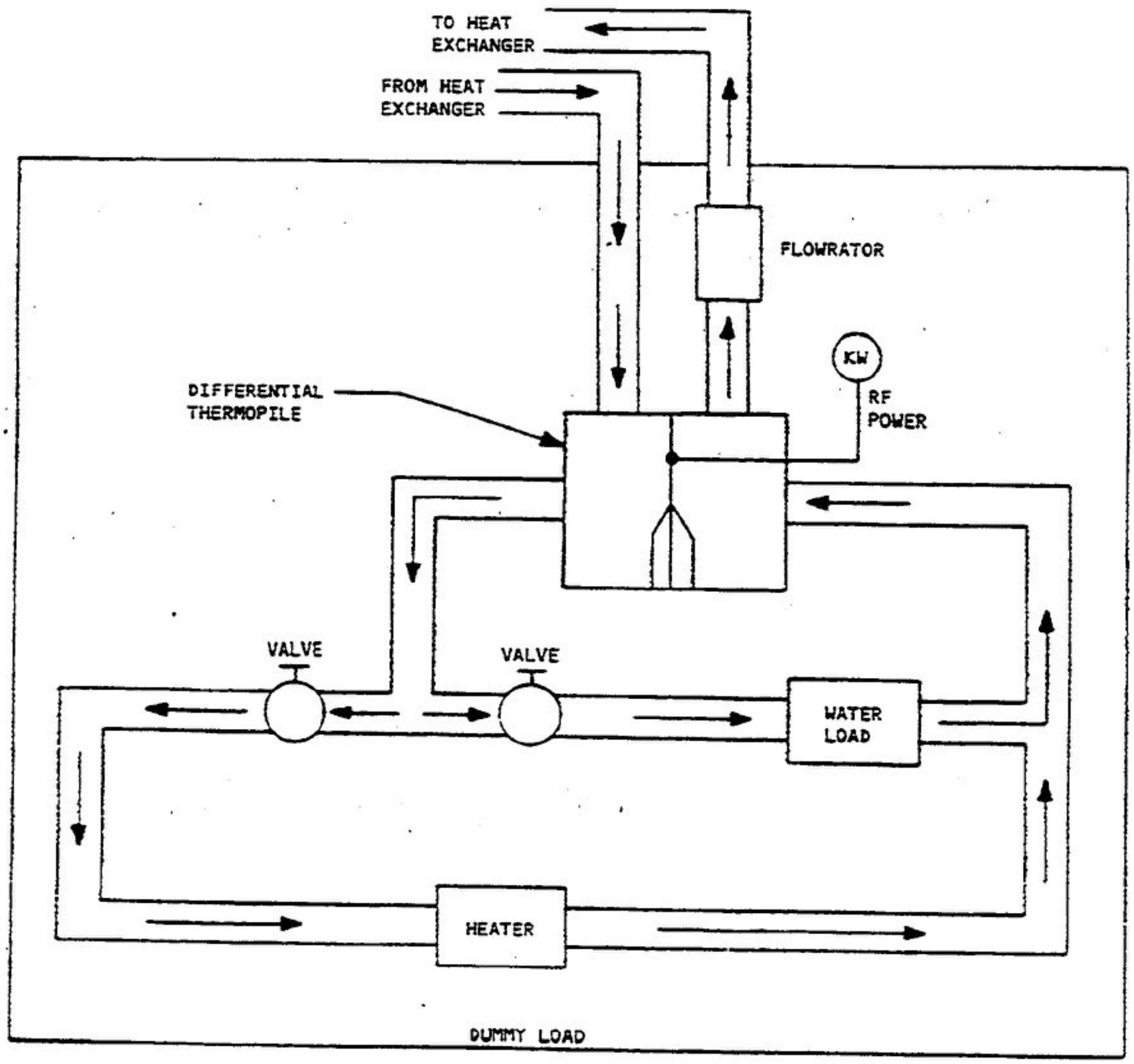


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Figure 2-8. Dummy load, simplified coolant flow.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

008. Sections of the exciter

1. What does the modulation amplifier do?

2. Which component produces the transmit frequency?

3. What does the power output section do?

009. The klystron power amplifier

1. State the purpose of the following sections of a klystron power amplifier:
   a. Electron gun section.
   b. RF section.
   c. Collector section.

010. Functions of the heat exchanger and dummy load

1. Give two functions of the heat exchanger.

2. What is the purpose of the dummy load?

3. What does the reading indicate on the RF wattmeter of the heat exchanger?

2-3. Reception

You should recall that the transmitter signal is attenuated by a considerable amount before it reaches the receiving antenna. In some applications, this attenuation is greater than 180 dB. To receive the signal and maintain communications reliability, the receiving apparatus must be highly sensitive. By using various sizes of parabolic or billboard reflective antennae, you get an initial gain of 40 to 50 dB. Thus, the receiving equipment must supply the remaining gain needed for reliable communications. Satisfactory operation is possible with some FPTS receivers (without preamplifiers) although the input signal level is as low as 5 microvolts.

011. Receiver panels

Block Diagram Analysis. The block diagram in figure 2-9 is a simplified arrangement of a fixed FPTS receiving system. The signals received by the antenna are applied to the respective parametric amplifier panels by styroflex (low-loss, high-frequency) transmission cable. Parametric amplifiers are used as RF preamplifiers in the fixed troposcatter receivers. In the parametric amplifier, the signal is converted from the 755- to 985-MHz transmission frequency to a 70-MHz intermediate frequency. The 70-MHz IF signal is applied (by coaxial cable) to the IF amplifier panel. After amplification, the 70-MHz signal is applied to the demodulator panel's discriminator circuit, which extracts the intelligence from it. The 70-MHz signal is also applied to the threshold extension panel (sometimes called a signal enhancer), where its bandwidth is reduced. This reduces the noise applied to the panel's discriminator circuit. The output of the threshold extension panel's discriminator (intelligence signal) is applied to a transfer stage along with the intelligence signals from the demodulator panel.

The transfer stage (which is part of the threshold extension panel) operates when the output signal from the noise amplifier panel is increased. Since the noise level is used to effect the transfer, the intelligence is automatically selected from the demodulator panel during low-noise conditions and from the threshold extension panel during high-noise conditions. The intelligence selected from the transfer stage is applied to the combiner panel. In the combiner panel, the baseband, orderwire, and pilot-tone signal groups are separated. The baseband and orderwire signal groups are then combined with the corresponding intelligence signals from the diversity receiving unit.

IF Amplification. The received RF signal is routed to the parametric amplifier panel. The parametric amplifier provides the low-noise amplification and converts the RF signal frequency to a 70-MHz intermediate frequency (IF). The 70-MHz IF must be amplified with extreme care to prevent distortion. Noise generation must be minimized, and the amplifier circuitry must be capable of uniform response. The number of channels a tropospheric scatter receiving system can handle and still be reliable is determined by the system path length, transmitter output power, antenna size, and tropospheric conditions. In applications where only a small number of channels are needed, it is advisable to reduce the bandwidth of the IF amplifiers, which increases the gain of the IF amplifiers.

If, for example, the circuit must handle 240 channels of intelligence, the bandwidth must be very broad. The power

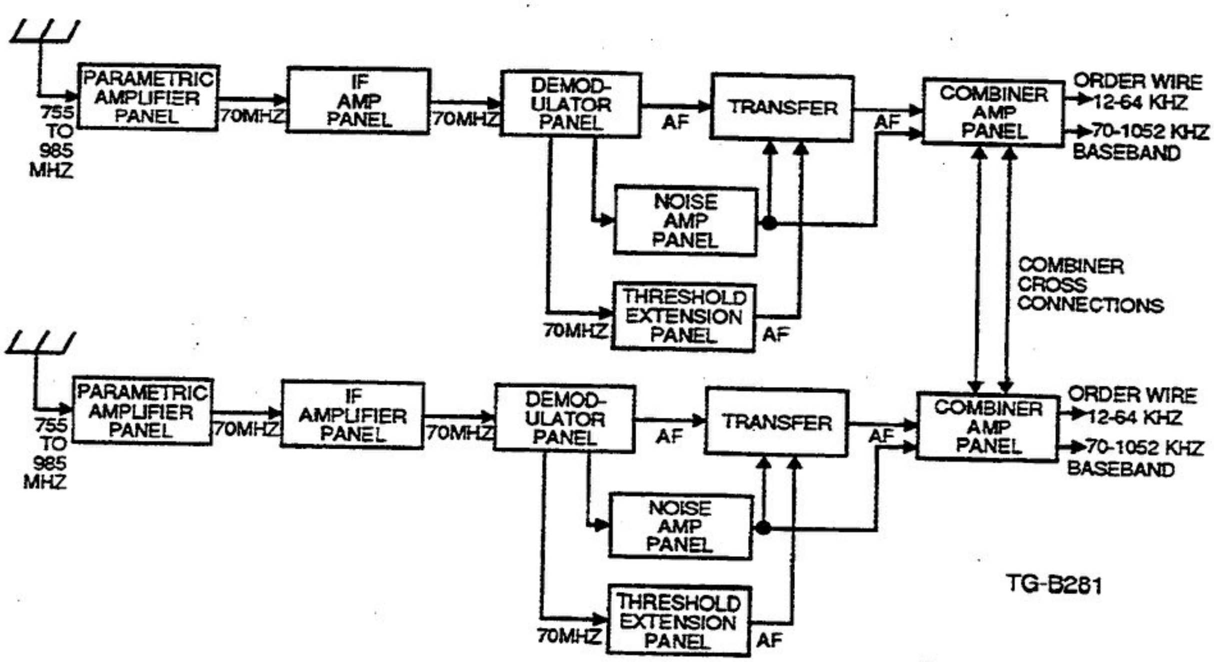

Figure 2-9. FPTS receiving system block diagram.

available for amplification must be distributed equally among these channels for uniform amplification (a flat response). An amplifier capable of delivering 24 watts of power would therefore provide 0.1 watt of power for each channel.

Assume now that the circuit must amplify only 12 channels. The bandwidth can be narrowed and the circuit's selectivity increased. When the bandwidth is decreased, less noise is allowed to pass through to the amplifier and the power available for amplification (using the same 24 watts available) is distributed at 2 watts per channel. This, in effect, provides a gain of about 10 dB.

Figure 2-10 shows the response curves (frequency versus gain) of four typical IF amplifier panels, capable of handling 12, 72, 120, and 240 channels of intelligence. Note the amount of change in the bandwidth and the gain increase. The dots on the curves (3 dB below maximum signal level) are the half-power points.

Demodulation. To understand how tropospheric scatter signals are received, you must remember that frequency modulation was used during the signal transmission. A discriminator circuit converts the intelligence contained in the 70-MHz IF into baseband frequencies. Figure 2-11 is a simplified block diagram of a typical demodulation panel. The IF amplifier's 70-MHz signal is applied to the demodulator panel through the delay equalizer cable. This signal is applied to both the extension amplifier and the first of a series of compressor amplifiers. The compressor amplifiers supply low gain to high-amplitude signals and supply high gain to low-amplitude signals. A difference in signal amplitude can cause distortion in the discriminator circuit. The extension amplifier provides a source of signal pick-off for the threshold extension panel and provides isolation between panel units.

After the amplitude of the signals has been partially compensated for in the compressor amplifiers, the signals are amplified and then passed to the clipper amplifiers to get a

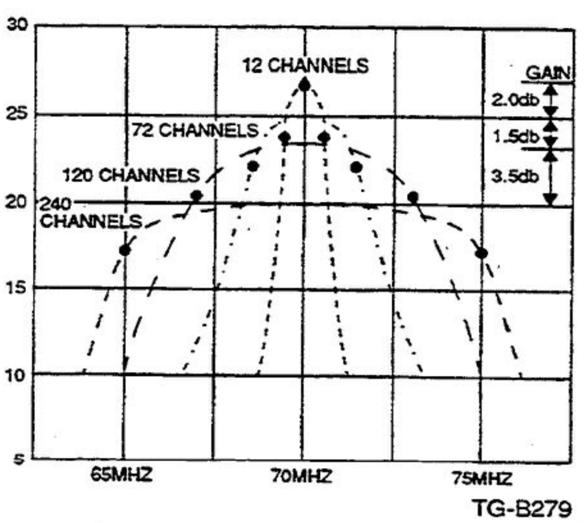

Figure 2-10. Response curve of four IF amplifiers.

more uniform amplitude level. The signal is then amplified by an IF amplifier and a series of driver amplifiers to ensure a sufficient power level for proper discriminator action. The discriminator input circuitry changes the frequency modulated signals into amplitude variations that are proportional to the frequency deviations corresponding to the original modulating signals at the transmitter. The intelligence signals are coupled from the discriminator and applied to a wideband amplifier (fig. 2-11) that's capable of uniform response between 250 Hz and 1,052 kHz. The output of the last wideband amplifier is applied to the transfer stage in the threshold extension panel and to the noise-amplifier panel.

Threshold Extension. The threshold extension panel is used when the input level of the receiver is below the normal threshold (the minimum input signal level at which the detected output signal is discernible from the noise). If the fixed receiver's input level decreases to within 3 dB of the normal threshold, the threshold extension panel is coupled into the circuit automatically, as far as the receiver combiner is concerned. During normal operation the combiner receives its input from the demodulator panel.

You can understand the threshold extension panel process better if you follow the simplified block diagram in figure 2-12. Mainly, the threshold extension panel lets the receiver function below the normal signal threshold. To do this requires three sets of external signals—a 70-MHz signal from the extension amplifier of the demodulator panel, the intelligence signals from the demodulator panel's wideband amplifier, and a transfer control potential from the noise amplifier panel. In addition to these external signals, the threshold extension panel must provide within its own circuitry an FM signal with a center or rest frequency of 100.5 MHz.

Two signals, the 70-MHz input signal and the reactance modulator's 100.5-MHz signal, are applied to the mixer stage. This heterodyning produces signal frequencies of 170.5 MHz and 30.5 MHz. The 30.5-MHz signal is applied to the limiter stages through selected filters and then on to the FM detector or discriminator, but this is only the beginning of the process. The signals from the discriminator circuit are also coupled to the reactance modulator, making the reactance-modulator frequency deviate. The amount of deviation depends on the signal amplitude, or feedback level. For example, in one typical threshold extension panel, 6 dB of feedback reduces the original deviation by half. That is, if the deviation is ±1.2 MHz and if 6 dB of feedback is used, the deviation is reduced to 600 kHz. A reduction in deviation causes a decrease in bandwidth. As you already know, reducing the bandwidth causes a corresponding reduction in noise. In a nutshell, what we have done by reducing the noise is to allow the receiver to discern the same low-amplitude intelligence from the noise.

Signal Combining. The combiner section of the fixed troposcatter receiver has a fourfold function. First, it separates

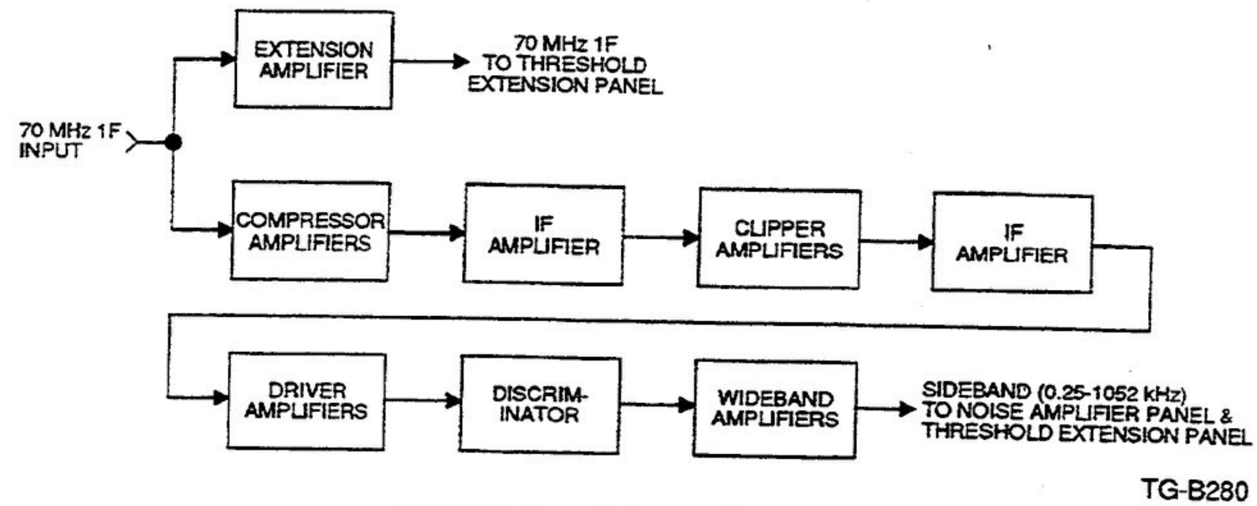

Figure 2-11. Demodulation panel, block diagram.

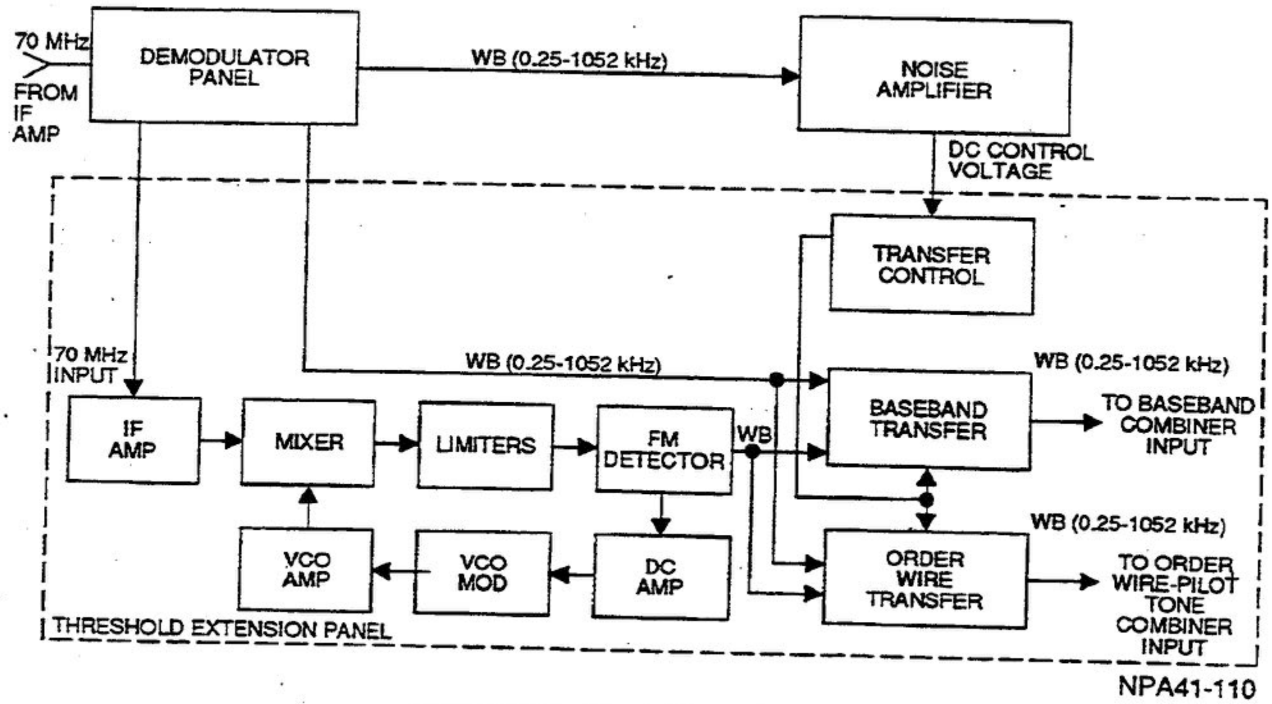

Figure 2-12. Fixed threshold extension panel.

the intelligence signals into three groups—baseband, orderwire, and pilot tone. Second, it parallels the baseband signals of all associated diversity combiners. Third, it parallels the orderwire signals of all associated diversity combiners. Fourth, it operates the pilot tone alarm circuits and applies the pilot tone signal to the noise amplifier. The signals from the transfer stage of the threshold extension panel are applied to both a baseband combiner stage and a cathode follower stage. In the baseband combiner circuit, the output signals of all the associated diversity combiners are applied to the cathode circuit.

012. Delay equalization and the result of improper equalization

Delay Equalization. In UHF systems that use diversity receiving equipment, it's necessary to compensate for any differences in the transmission line lengths. If the varying lengths of the transmission line aren't compensated for, the time delay between units can increase intermodulation distortion. The delay equalizer effectively simulates the ideal situation, where all input transmission lines are of equal length. The required time delay is provided by a length of coaxial transmission cable that varies with each installation's particular requirement. These cables usually follow the IF amplifiers to take advantage of the lower signal attenuation at the intermediate frequencies. Also, because of the higher signal levels at the IF, the signal-to-noise ratio is not disturbed. The delay equalizers aren't shown in figure 2-9, but schematically they would be represented by a straight line.

In mobile configurations, delay equalizers aren't needed because the equipment is arranged in a compact, self-contained layout for ease of transportation. Since this layout is the same for all installations, the input transmission line lengths can be calculated and taken into account in the design of the receivers, eliminating the requirement for delay equalizers.

013. Function of the orderwire

Orderwire Circuit. The output of the dual-baseband combiner is applied to a low-pass filter that passes only the orderwire signals (0.3 to 3 kHz) to the orderwire circuit (fig. 2-13). The orderwire provides party-line communications for operating and maintenance personnel between all radio sites and all alarm monitors. Since a system can be either a single-link or a multiple-link type, facilities for orderwire repeating are within the orderwire circuitry.

Since the orderwire channel is separate from and independent of the multiplex channel, it is useful in setting up and aligning new sites as well as in maintaining and troubleshooting. Instructions to the radio-relay repairman can be relayed after the system is operational. The device that makes the orderwire circuit so versatile is the four-way, four-wire bridge.

The four-way, four-wire bridge provides four-way bidirectional routing for the orderwire signal with high isolation from the return path. The circuit consists of a multiple resistive bridge with an isolation transformer in four input-output terminals. The forward loss is 15 dB from any input terminal to the three corresponding output terminals. For example, with 0-dBm input at S in (South in), the outputs at E out (east out), W out (west out), and N out (north out) would be -15 dBm. Isolation in the return direction is a minimum of 60 dB or, in this example, with an input of 0 dBm at S in, the return signal at S out would be 60 dBm or less. The frequency response is .4 dBm from 300 Hz to 3 kHz.

Through the use of the four-way, four-wire hybrid, signals can arrive from four possible sources and be routed to three

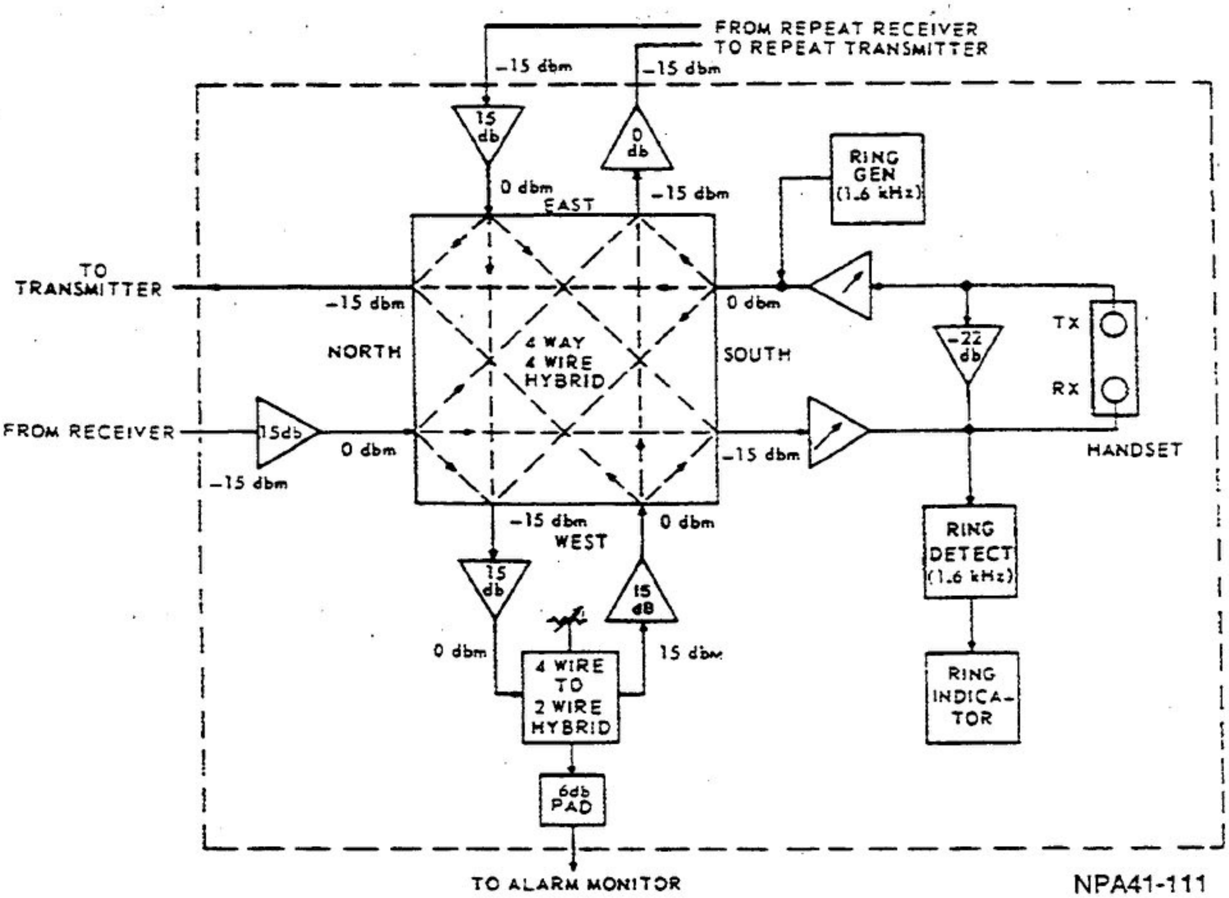

Figure 2-13. Orderwire circuit, block diagram.

possible directions. A pair of send terminals and a pair of receive terminals are used for the local handset. Another set of send and receive terminals are connected to the four-wire side of a two-wire, four-wire hybrid; the two-wire line terminates at the alarm monitor. The third set of send and receive terminals is connected to the radio transmitter and receiver, respectively. The fourth set of terminals is connected to the orderwire circuits of the other repeater radio set when a repeater station is used. In terminal operation, the repeater terminals are terminated resistively.

In addition to this orderwire signal routing, the orderwire circuitry contains a signaling facility. An oscillator provides the signaling tone when a ring switch is actuated. The ring signal is applied to the four-way, four-wire hybrid in parallel with the local handset input, and the signaling tone is routed in the same way as the orderwire signal to provide a ringing tone.

A ring tone detector and amplifier provides a voltage level great enough to energize visual and audio indicators when a signaling tone is received. The ring tone detector is bridged across the receiver circuit of the local handset. A ring tone generated anywhere in the system, except at the local signaling generator, is received and detected. Since the ring tone signal falls within the bandwidth of the orderwire, a guard circuit is provided in the detector circuit so that the detector is sensitive only to the ring tone and is unaffected by speech.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

011. Receiver panels

1. State the purpose of these panels:
   a. Parametric amplifier panel.
   b. IF amplifier panel.
   c. Demodulator panel.
   d. Threshold extension panel.
   e. Combiner panel.

2. What is the relationship between the number of channels, the bandwidth, and gain?

3. Why should the bandwidth be adjusted according to channel capacity?

4. What is the function of the compressor amplifiers?

5. What is the function of the clipper amplifiers?

6. What does the threshold extension panel do?

7. Explain briefly how the threshold extension panel operates.

8. What are the four operations of the signal combiner?

9. Where does the baseband combiner stage and a cathode follower stage get its signal from?

012. Delay equalization and the result of improper equalization

1. Why is delay equalization sometimes used in troposcatter receivers?

2. What can happen if receivers are improperly equalized?

013. Function of the orderwire

1. What function does the orderwire provide?

2. What device makes the orderwire circuit so versatile?

3. What is the function of the four-way, four-wire bridge as it applies to orderwire circuits?

2-4. Antenna Operation

In this section, we discuss the antenna system used in tropospheric scatter communications and how a tropospheric scatter transmitting and receiving system operates. The antenna system used in tropospheric scatter equipment is separated into three major groups—the antenna, the waveguide, and the bandpass filter and duplexer. The antenna system radiates and receives RF energy simultaneously.

014. Function of the feedhorn, waveguides, and duplexer

Feedhorn. The antenna (fig. 2-14) consists of a parabolic reflector (not shown) and a dual-polarized feedhorn. The reflector, center fed by the feedhorn, reflects RF energy from the feedhorn and projects it in a narrow beam toward the distant station through the troposphere. At the same time, the

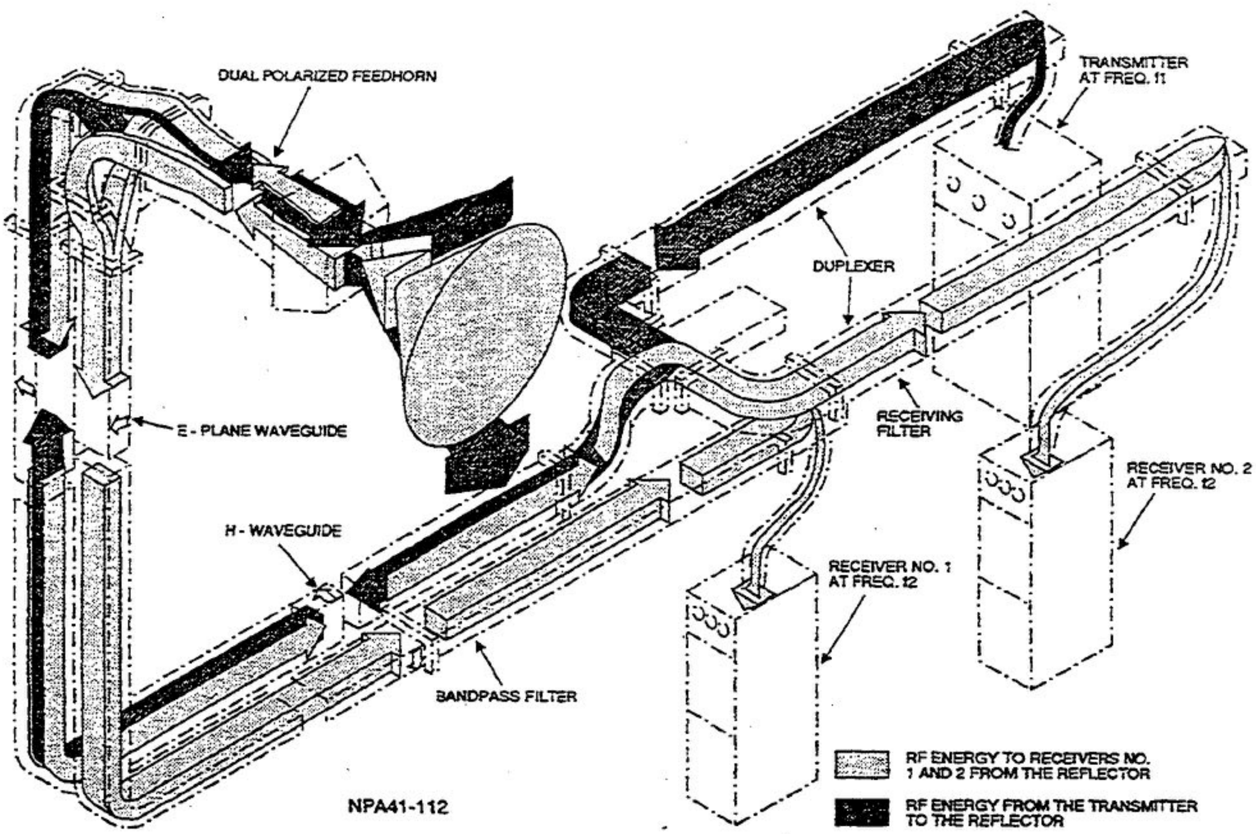

Figure 2-14. Antenna system.

parabolic reflector gathers the RF energy from the distant station and focuses it into the feedhorn for signal reception.

The dual-polarized feedhorn is made up of the basic horn with an H-plane bifurcation (separation) and an E-plane bifurcation, with a waveguide bend in each plane leading into the horn. Four channels feed into the horn opening. The top and bottom channels are H-plane feeds and are used for transmission and reception. The two side channels are E-plane feeds and are used for reception only, as shown in figure 2-14. The distant station in this link is receiving on the E- and H-plane and transmitting only on the E-plane.

An important function of the feedhorn is to terminate the coaxial line and waveguide so that the standing-wave ratio (SWR) is near unit in the line or guide. This requirement is satisfied by impedance changing devices mounted in or near the feedhorn. The elements most commonly used are screws or rods of a definite size, properly spaced in the guide or feedhorn for a good match. Generally, three screws are spaced a quarter wavelength apart. When the tuning screw extends less than a free-space quarter wavelength into the waveguide, it introduces capacitance into the waveguide. When the tuning screw is more than a free-space quarter wavelength, it introduces inductance into the waveguide. Inductive tuning is not generally used because of the possibility of voltage breakdown. The tuning screws are placed in the waveguide parallel to the electric field and are adjusted for a minimum standing-wave ratio.

Waveguide Sections. The waveguide sections of the antenna system couple the RF energy, after coaxial transition, from the power amplifier to the antenna. They also couple RF energy to the receiver from the antenna. Waveguides are used principally at frequencies in the microwave regions and propagate several different types of electromagnetic waves. The waveguide used in tropospheric scatter-type equipment is characterized by the propagation of electromagnetic waves in the form of transverse-electric (TE) waves; that is, the electric vector is always perpendicular to the direction of propagation. The type of propagation used by the waveguide is designated by $TE_{0,1}$. The subscripts indicate the number of half-cycle variations of the intensity of the electric field along the width and height dimensions, respectively, of the waveguide. The waveguide width is at least one-half the free-space wavelength at the operating frequency. This width causes the waveguide to operate in the $TE_{0,1}$ mode. The height, which is not critical, is usually about one-half of the width dimension.

Duplexer and Bandpass Filter. The duplexer in a tropospheric scatter transmitting and receiving system is a network that lets a powerful transmitter and a sensitive receiver use the same antenna system simultaneously. Figure 2-15 shows an equivalent circuit of the duplexer. Bandpass

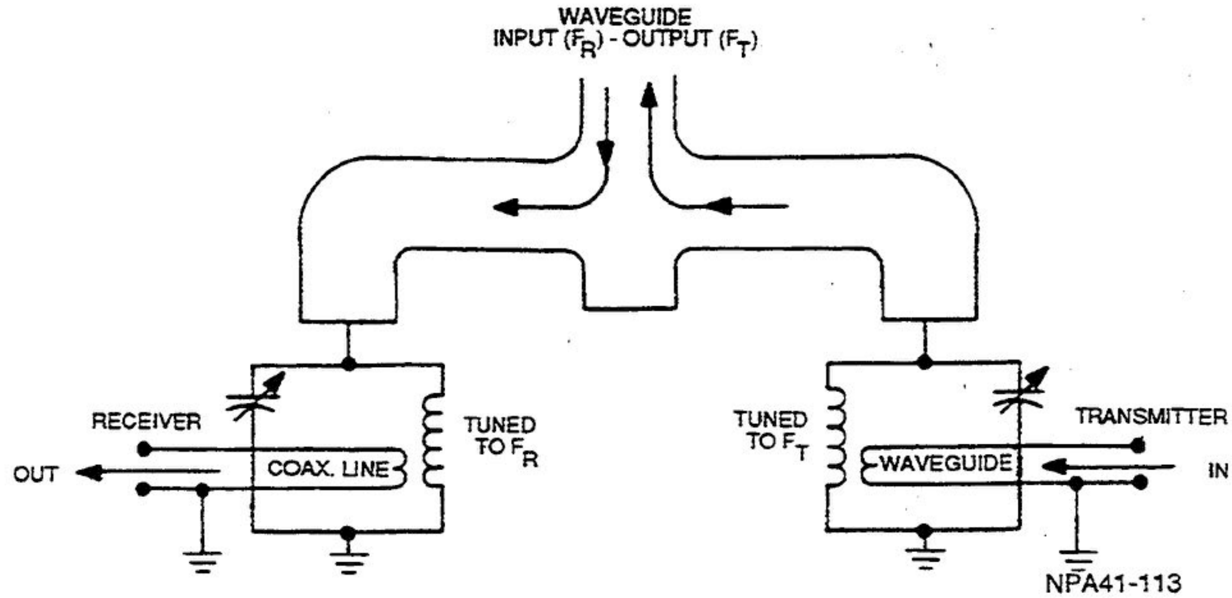

Figure 2-15. Equivalent electrical circuit of duplexer.

filters are represented by parallel-resonant circuits that are tuned to the resonant frequencies of the transmitter and receiver, respectively.

One of the characteristics of the parallel-resonant circuit is its high impedance to the resonant frequency and its low impedance to frequencies off resonance. To see what factors influence a parallel-resonant circuit's discrimination against frequencies off resonance, you must consider the Q of the resonant tank itself. The term *tank*, as used here, refers to the connection of the inductive and capacitive branches of a parallel-resonant circuit.

Assume that the transmitter in figure 2-15 is operating at 800 MHz and the high-Q parallel circuit in that side of the duplexer is tuned to that frequency. The receiver is receiving on an assigned frequency of 920 MHz, and the parallel-resonant tank in that side of the duplexer is tuned to that frequency.

The transmitter output readily passes through the filter on the transmit side of the duplexer since it is tuned to that frequency. However, on the receive side of the duplexer, the bandpass filter is detuned from that frequency and acts as a short circuit to the transmit frequency. Therefore, no voltage is developed across its resonant tank circuit, and none of the transmitted signal is coupled into the receiver. A similar effect takes place with the receive signal. The bandpass filter is a single receive filter (fig. 2-14). It acts as a straight-line filter and operates like the bandpass filters of the duplexer.

015. Types of diversity used in troposcatter systems

Diversity Techniques. In diversity reception, more than one reception source is provided. Thus, if the signal fades at one source, it can be obtained from another. The three diversity techniques used in tropospheric scatter systems are space diversity, frequency diversity, and polarization diversity.

Space diversity. In space diversity, the signal from a single transmitter is received by two receiving antennae spaced several hundred wavelengths apart. The two received signals are combined and the resultant signal presents a signal-to-noise ratio at least as good as, and often better than, the stronger of the two component signals. System reliability is high because simultaneous fading at both antennae is extremely rare.

Frequency diversity. In frequency diversity, the same intelligence is sent simultaneously from two transmitters tuned to different frequencies. The intelligence is input to two receivers operating from a single antenna. If the two frequencies are separated sufficiently, frequency-selective fading, deliberate jamming, and interference are minimized.

Frequency diversity is especially applicable to tropospheric scatter systems because any transmitter in a system is designed to operate on a specific center frequency. This operating frequency is factory-adjusted, and the filters for the operation are factory-installed. Whereas, in HF transmitters, the adjustment is very simple to make, changing the operating frequency of a particular satellite transmitter is quite involved.

If the strength of one receive signal fluctuates at the receive end, outage time results, but if another transmitter sends the same intelligence over another operating frequency, the communications link will remain operational.

Polarization diversity. Polarization diversity requires two transmitters sending simultaneously on the same frequency. One transmits the intelligence vertically polarized, while the other transmits a horizontally polarized wave. At the receiving end, one antenna receives the horizontally polarized signal and another one receives the vertically polarized signal. This mode provides multiple-signal sources and minimizes polarization changes over long distances (which occurs quite rapidly at high frequencies).

Quadruple diversity. To get the higher reliability that is required of some tropospheric scatter systems, you use a combination of diversity techniques (FO 1) called *quadruple diversity reception*. in which the RF equipment is duplicated. The operating frequencies of the four transmitters are separated by at least 12 MHz. Power amplifier #1 transmits frequency F_1, horizontally polarized, while the output of power amplifier #2 is verticality polarized. At the distant end, both antennae receive both horizontally and vertically polarized signals. Receivers #6 and #8 receive frequency F_1, while receivers #5 and #7 receive frequency F_2 from the vertically polarized antennae.

The receivers demodulate the signals and feed them to the combiners, where each receiver's signal-to-noise ratio is combined with the others. If the signal-to-noise ratio of any one receiver reaches the point where it doesn't contribute appreciably to the system, the combiner is removed from the system electronically.

Beyond quadruple diversity, the law of diminishing returns applies—that is, the expense of additional receivers isn't justified by the rise in signal-to-noise ratio. That's why you don't use higher levels of diversity. The quadruple diversity system has approached the reliability of direct wire carrier systems. Another advantage is that the multiple equipment (FO 1) can be switched by SW1 through SW4. If one exciter fails, the other exciter can be used to drive both power amplifiers. Switches are shown in the foldout, but in actual application, the switching is done automatically by relays. If either power amplifier fails, you lose frequency and polarization diversity capability in one direction only; you're still capable of space diversity unless the other power amplifier fails while the faulty amplifier is being repaired.

Another quadruple diversity technique that requires the same amount of equipment as shown in foldout 1 uses all of the individual diversity receiving techniques of frequency diversity. The two power amplifiers are operated on the same frequency and may be driven by one exciter. This system combines polarization and space diversity.

016. Types of tropospheric scatter systems

Typical Tropospheric Scatter System Operation. Three stations are common in a tropospheric scatter communications system—terminal stations, through repeater stations, and drop repeater stations. Figure 2-16 shows a typical tropospheric scatter system. The stations are designated from A to H and are spaced at least 100 to 400 miles apart. Stations that span shorter distances use microwave. Each station has a service channel for an orderwire. The orderwire channel always bypasses any multiplex equipment, and blocking circuits only let one station report trouble at any one time.

Terminal station. The terminal stations are A, C, G, and H. Communications may originate at any terminal station and be relayed to other stations in the line. The information may or may not be taken from other types of communications systems, such as landlines, high-frequency radio, and radar systems. Each tropospheric scatter transmitter at the terminal station transmits its original information in one direction only to the adjacent station. Also, the troposcatter receiving equipment receives simultaneously in only one direction at the terminal station. Multiplex equipment is necessary at the terminal station.

Through repeater station. Through repeater stations D and F are stations where no traffic is to be dropped off. These stations must be able to receive and transmit in two directions. Theoretically, this can be done in several ways, but it's not always practical. The first technique involves reamplifying the received carrier directly and retransmitting. This isn't practical because it may take amplification in the order of 150 dB at a high radio frequency. The second technique involves heterodyning the received frequency down to some relatively low-radio frequency (IF), amplifying it, and then mixing it to increase the frequency to the desired output frequency. In this technique, the orderwire signals are not extracted and combiners would have to be developed to operate at a radio frequency; otherwise, only switch-type diversity could be used. The third technique is the only practical method. It involves reducing the received signals down to the baseband frequencies, then applying them directly to the modulator. The orderwire signals and the pilot tone are extracted for use at the repeater station, after which they're applied to the modulator for retransmission. The repeater station requires the same basic equipment as the terminal station, except that the through repeater station doesn't require multiplex equipment.

Drop repeater station. For the drop repeater stations, B and E, incoming traffic has to be demultiplexed, and additional traffic reinserted (by multiplexing) to be retransmitted in either or all directions. For example, at station B traffic control could-be flowing in six directions simultaneously.

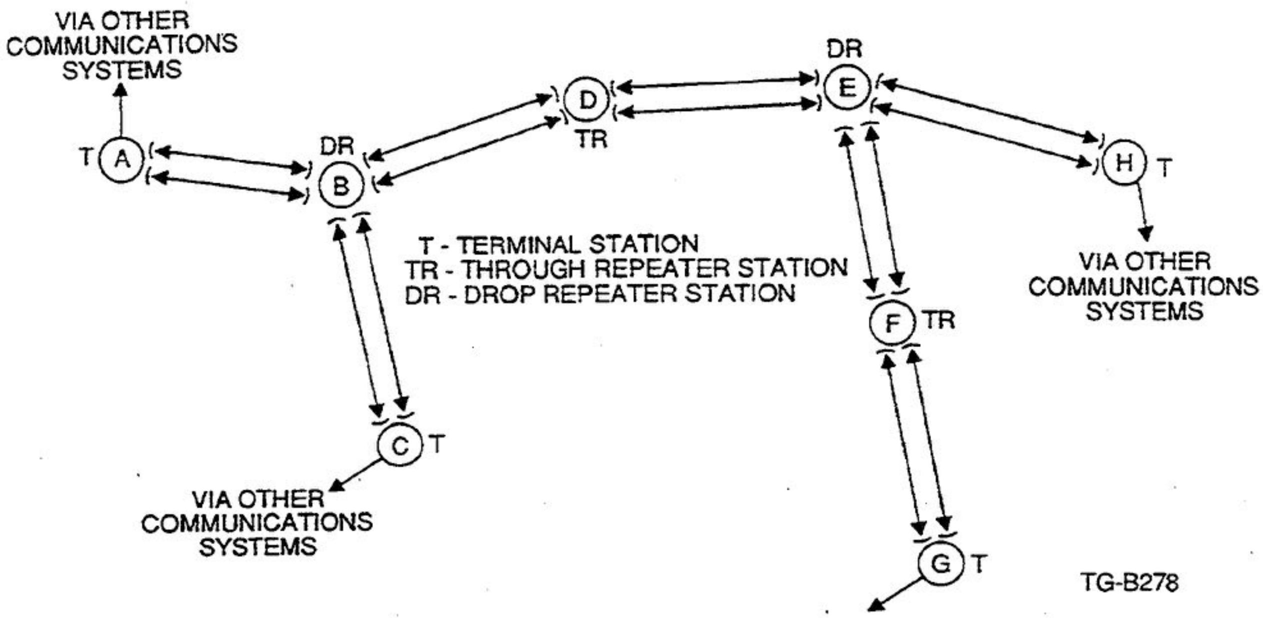

Figure 2-16. Operation of tropospheric scatter stations.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

014. Function of the feedhorn, waveguides, and duplexer

1. What is the function of the feedhorn?

2. How do you get minimum SWR?

3. What is the purpose of a waveguide?

4. What is the principal frequency range for using waveguides?

5. What factors determine waveguide dimensions?

6. Define duplexing.

7. What is the principle involved in the duplexer's operation?

015. Types of diversity used in troposcatter systems

1. What three types of diversity are used in troposcatter systems?
2. Describe space diversity application.
3. Explain frequency diversity.
4. What types of inherent communications difficulties are improved using frequency diversity?
5. How many transmit frequencies are used in polarization diversity?
6. What is the difference between the two antennae used in polarization diversity?
7. Why is quadruple diversity used in a communication system?
8. How many receivers are used in a typical quadruple diversity system?
9. What happens to a receiver in a quadruple diversity system that does not contribute to the overall signal-to-noise ratio of a combiners output?
10. If one power amplifier fails in a quadruple diversity system, what diversity techniques are lost?

016. Types of tropospheric scatter systems

1. Give the characteristics of terminal stations.
2. Give the characteristics of through repeater stations.
3. Give the characteristics of drop repeater stations.

ANSWERS TO SELF-TEST QUESTIONS

005

1. The changing dielectric constant causes the electromagnetic energy to scatter.
2. Tropics in the summer.
3. Small.
4. 350 to 8,000 MHz.
5. Frequency modulation (FM)

006

1. Atmospheric conditions, equipment failures, and manmade noise.
2. The effect of equipment failure can be reduced by using multiple transmitters and receivers. The effects of manmade noise can be reduced by locating the system away from manmade interference sources.
3. Fast fading results when the radio waves arrive at the receiving point at different times because they traveled different path lengths. This causes a rapid increase and decrease in signal strength. Slow fading results from seasonal changes and causes a slow increase or decrease in signal strength.
4. Transmitter output power, transmitter antenna gain, receiver antenna gain, and scatter loss.

007

1. Capable of producing large RF power outputs at frequencies in the UHF-SHF range.
2. Must be highly sensitive and must amplify without introducing appreciable noise into the system.

008

1. Amplifies the incoming baseband signals to the correct amplitude before they are applied to the modulators.
2. Convertor section.
3. Amplifies the convertor output to a suitable level to drive a high-power klystron amplifier.

009

1. a. Provides the electron beam.
   b. Forms the electrons into bunches.
   c. Gathers the electrons and returns them to the power supply.

010

1. To cool the klystron and calibrate the dummy load.
2. To allow the klystron amplifier to be tuned and tested without being connected to an antenna.
3. The difference in the temperature of the coolant as it enters the dummy load and when it returns to the heat exchanger.

011

1. a. Preamplifies the receive signal and converts it to a 70-MHz IF.
   b. Amplifies the IF signal.
   c. Extracts the intelligence from the 70-MHz IF.
   d. Reduces the bandwidth of the signal (reduces noise).
   e. Separates the baseband, orderwire, and pilot-tone signal groups and then combines them with their respective groups from another receiver.
2. The more channels there are, the greater the bandwidth has to be and less gain per channel is achieved.
3. To provide for maximum gain.
4. To supply low gain to high-amplitude signals and high gain to low-amplitude signals.
5. To clip the high-amplitude signals to achieve a more uniform level.
6. Permits the receiver to function below normal signal threshold.
7. The bandwidth of the signal is reduced by deviating it less. This reduces the noise level so that the receiver can pick out the weak intelligence signal.
8. Separates the intelligence into baseband, orderwire, and pilot tone; parallels all baseband signals; parallels all orderwire signals; and operates the pilot-alarm circuits and applies the pilot tone to the noise amplifier.
9. The output of the transfer stage of the threshold extension panel.

012

1. To compensate for varying input transmission line lengths.
2. Intermodulation distortion can increase.

013

1. Party-line communications for operating and maintenance personnel between all radio sites and all alarms monitors.
2. A four-way, four-wire bridge.
3. It provides four-way bidirectional routing for the orderwire signal with high isolation from the return path.

014

1. To terminate the coaxial line and waveguide so that the standing wave ratio (SWR) is near unity.
2. By mounting tuning screws in the waveguide and tuning them for minimum SWR.
3. It is used to couple RF energy from a transmit power amplifier to an antenna or from an antenna to a receiver.
4. Microwave frequency range.
5. Waveguide width should be at least one-half the free space wavelength of the operation frequency. Waveguide height is not critical but is usually about one-half the width.
6. This network lets a powerful transmitter and a sensitive receiver use the same antenna system simultaneously.
7. The duplexer acts as a parallel resonant circuit and operates on the principle that a high-Q parallel resonant circuit will pass only a small band of frequencies; therefore, with a large frequency separation between transmit and receive, neither signal will be felt by the other device.

015

1. Space, frequency, and polarization diversity.
2. In space diversity, one transmitted signal is received by two receiving antennae spaced several hundred wavelengths apart.
3. Two transmitters tuned to different frequencies transmit to a distant terminal simultaneously. At the receive terminal, a single antenna receives the two frequencies and applies them to two receivers tuned to the different frequencies.
4. Frequency selective fading, deliberate frequency jamming, and interference.
5. One.
6. One is horizontally polarized, while the other is vertically polarized.
7. To get a higher system reliability than a single diversity method provides.
8. Four.
9. It is electrically removed from the system.
10. Frequency and polarization in one direction.

016

1. They transmit and receive in one direction only and must have multiplex equipment
2. They transmit and receive in two directions and do not require multiplex equipment.
3. They transmit and receive in at least two directions and must have multiplex equipment.

Do the Unit Review Exercises (URE) before going to the next unit. ➡

UNIT REVIEW EXERCISES

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

8. (005) The amount of bending of a tropospheric scatter wave beam towards Earth is determined by the troposphere's

   a. index of reflection
   b. dielectric constant.
   c. proximity to high-altitude land masses.
   d. common volume.

9. (005) In a tropospheric scatter transmission system, as the scatter angle increases, the received power

   a. decreases rapidly.
   b. increases rapidly.
   c. is not affected.
   d. is lost instantly.

10. (005) Operational tropospheric scatter communications systems use what type of modulation for transmission?

    a. Pulse-code modulation.
    b. Amplitude modulation.
    c. Phase modulation.
    d. Frequency modulation.

11. (006) Stellar noise on a tropo system is generally masked by the effects of

    a. atmospheric noise.
    b. frequency modulation.
    c. equipment reliability.
    d. received signal strength.

12. (006) Fast fading in tropospheric scatter transmission is due mainly to

    a. impulse noise.
    b. multipath effects.
    c. transmitter output power.
    d. seasonal changes of the atmosphere.

13. (007) What is the main difference between the line-of-sight transmitter and the tropospheric scatter transmitter?

    a. The tropospheric scatter transmitter produces a more powerful RF signal.
    b. The line-of-sight transmitter produces a more powerful RF signal.
    c. The line-of-sight transmitter is designed to work better in the UHF-SHF range.
    d. The tropospheric scatter transmitter produces a wider bandwidth.

14. (007) Because of very weak signals *normally* encountered in tropospheric scatter systems, the receiver must be

    a. liquid cooled.
    b. highly reliable.
    c. highly sensitive.
    d. highly selective.

15. (008) In the exciter block of troposcatter transmission, the high-frequency (HF) baseband occupies the range of frequencies from

    a. 250 to 12 kHz.
    b. 64 to 1,052 kHz.
    c. 60 to 108 kHz.
    d. 12 to 60 kHz.

16. (009) Which section of a klystron power amplifier is the source of the electron beam?

    a. Generator section.
    b. RF section.
    c. Electron gun section
    d. Collector section.

17. (010) The heat exchanger's alarm circuits primary function in a forward propagation tropospheric scatter (FPTS) transmitter system is to

    a. protect the klystron from overheating.
    b. monitor the thermostatic bypass valve operation.
    c. monitor the temperature and coolant level.
    d. protect from overheating by high-temperature interlocks.

18. (011) In a forward propagation tropospheric scatter (FPTS) system, as you increase the number of channels, the

a. bandwidth decreases, gain increases.
b. bandwidth increases, gain increases.
c. bandwidth decreases, gain decreases.
d. bandwidth increases, gain decreases.

19. (011) In an FPTS receiver system, the input frequency signal to the demodulator panel is

a. 250 MHz to 1,052 kHz.
b. 755 to 985 MHz.
c. 100.5 MHz.
d. 70 MHz.

20. (011) When the signal deviation is reduced in the FM detector of the FPTS receiver threshold extension panel

a. the input level decreases by 3 dB.
b. the input level increases by 3 dB.
c. the bandwidth decreases and reduces signal noise.
d. the center frequency of 100.5 MHz will increase in amplitude.

21. (011) Baseband and orderwire signals of associated diversity combiners in an FPTS receiver are

a. applied to the threshold extension panel.
b. amplified according to noise content,
c. converted to a 70 MHz IF.
d. paralleled.

22. (012) Delay equalization is sometimes used in tropospheric scatter receivers to

a. reduce phase jitter and intermodulation distortion.
b. compensate for varying lengths of input transmission lines.
c. reduce the amount of noise input to the IF receiver panel.
d. compensate for amplitude losses in the input transmission lines.

23. (012) If varying lengths of transmission lines are not compensated for, the time delay between units can produce an increased amount of

a. intermodulation distortion.
b. capacitive reactance.
c. line imbalance.
d. attenuation.

24. (013) In tropospheric scatter orderwire circuitry, how much loss will there be from an input terminal to any of the three corresponding output terminals?

a. 3 dB.
b. 6 dB.
c. 15 dB.
d. 70 dB.

25. (014) In a tropospheric scatter antenna system, how many channels feed into the feedhorn?

a. Two
b. Four.
c. Six.
d. Eight.

26. (014) What is the primary frequency range for using waveguides?

a. Low-frequency (LF) band.
b. High-frequency (HF) band,
c. Microwave-frequency (VHF-UHF) band.
d. Extremely high radio frequencies (EHF) band.

27. (014) What network on a tropospheric scatter system lets a transmitter and a receiver use the same antenna system simultaneously?

a. Feedhorn.
b. Waveguide.
c. Combiner.
d. Duplexer.

28. (014) An important component in correct operation of a forward propagation tropospheric scatter (FPTS) duplexer as a straight-line filter is the

a. waveguide.
b. tuning screw.
c. TE subscript.
d. bandpass filter.

29. (015) In a tropospheric scatter system, a signal transmitted from a single transmitter and received by two receiving antennae several hundred wavelengths apart is called

a. frequency diversity reception.
b. polarization diversity reception.
c. space diversity reception.
d. quadruple diversity reception.

30. (015) In forward propagation tropospheric scatter (FPTS) systems, when the same intelligence is sent over two transmitters tuned to different frequencies, it is called

    a. polarization diversity.
    b. frequency diversity.
    c. quadruple diversity.
    d. space diversity.

31. (015) In forward propagation tropospheric scatter (FPTS) transmission systems, a station using quadruple diversity combines which reception techniques?

    a. Horizontal and vertical diversity.
    b. Vertical, horizontal and frequency diversity.
    c. Frequency, vertical and polarization diversity.
    d. Polarization, frequency and space diversity.

32. (016) A tropospheric scatter terminal station broadcasts information

    a. in one direction only.
    b. that has been encrypted only.
    c. only on the orderwire circuit.
    d. in two directions simultaneously.

33. (016) A tropospheric scatter, through repeater station requires the same basic equipment as the terminal station except it does *not* require

    a. a transmitter
    b. a receiver
    c. a modulator
    d. a multiplexer

Please read the topic page for Unit 3 and continue. ➡

STUDENT WORK SPACE

MICROWAVE

Page

Two frequently used methods of multiplexing signals into one composite signal are the frequency-division method and the time-division method. Regardless of the multiplexing method used, the wide bandwidth of the composite signal requires the use of a wideband transmission system.

Two wideband systems in use today are tropospheric scatter and line-of-sight (LOS). In this unit, we discuss LOS principles, expand on the propagation principles and their specific effect on LOS systems, and cover antenna and equipment configurations and system operation.

3-1. Propagation

A communications system is made up of links, or components. The quality of a system can be no better than its weakest component. Therefore, equipment is designed, built, and maintained to the highest possible standards. The factors we have no control over are weather, climate, and terrain. These factors have an effect on radio-wave propagation. You must have a basic knowledge of how these factors affect communications systems and what may be done to compensate for them. Knowledge of the effect of weather may save many hours of troubleshooting if you are able to determine whether a loss of receive signal level (RSL) is due to weather conditions or equipment malfunction.

Electromagnetic energy radiated from an antenna forms a spherically expanding wave front that travels at a speed of 186,000 miles per second in free space (or vacuum) where there are no free electrons or ions present. The speed of a radio wave is determined by the density of the medium through which it travels. In the atmosphere, the speed of a propagated wave is almost as great as its speed in free space, but in medium or greater density, a wave travels much slower.

017. Major propagation paths and their associated radio system

Propagation Paths. Recall from Unit 1 that, in general, radio waves travel by three major propagation paths—*ground waves, sky waves* and *space waves* (fig. 3-1). At microwave frequencies, a ground wave is attenuated within a few feet of the transmitting antenna, while most sky waves travel through the atmosphere into outer space.

Ground waves are used for communications at lower frequencies, but not at microwave frequencies. Sky waves are very weak at microwave frequencies and are useful only in "scatter" radio systems. Direct waves, also referred to as space waves, travel through the atmosphere near the earth's surface and are the most efficient means of achieving LOS communications at microwave frequencies.

Microwave propagation. Microwave propagation is accomplished by focusing microwave energy into a narrow beam through the use of high-gain parabolic antennae. A beam of microwave energy has many of the characteristics of a beam of light. Therefore, as with a light beam, a microwave beam may be reflected, refracted, and/or diffracted as it travels between a transmitting and receiving antenna. Because of this, microwave propagation are affected by weather, climate, and terrain. These factors cause a propagated wave to reflect and bend as it travels through the atmosphere. Since microwave energy is focused into a narrow beam for transmission, reflecting or bending can cause the propagated signal to completely miss the receiving antenna. This results in a loss or fading of RSL.

018. Reflection, refraction, and diffraction

Reflection. Reflection causes a radio wave to change direction of travel (fig. 3-2). Maximum reflection of a radio wave takes place when it strikes a surface such as water or earth. Some reflection also occurs when a radio wave passes through the boundary of two atmospheric layers that differ in density.

Reflected radio waves can cause wide variations of RSL in microwave transmissions by causing the RF energy to miss the receive antenna entirely or by alternately aiding and opposing the space wave at the receive antenna. Since the path length of a reflected wave is usually longer than the direct path followed by the space wave, reflected energy and a space wave arrive at a receiving antenna with a phase relation that may be anywhere between 0 and 180°. If a reflected wave and a space wave arrive at a receive antenna exactly 180° out-of-phase, partial or total cancellation will take place (depending on their amplitudes), causing a decrease in RSL. This condition is called *multipath fade*. In microwave communications reflection is generally undesirable.

Weather conditions can cause the points of reflection to change in a propagation path so that reflected waves and space waves pass in and out-of-phase at the receiving antenna. This results in wide variations in signal level due to the aiding and opposing of the two signals at the receive antenna.

Refraction. Refraction can be defined as the bending of radio waves or light waves as they travel at an angle from one

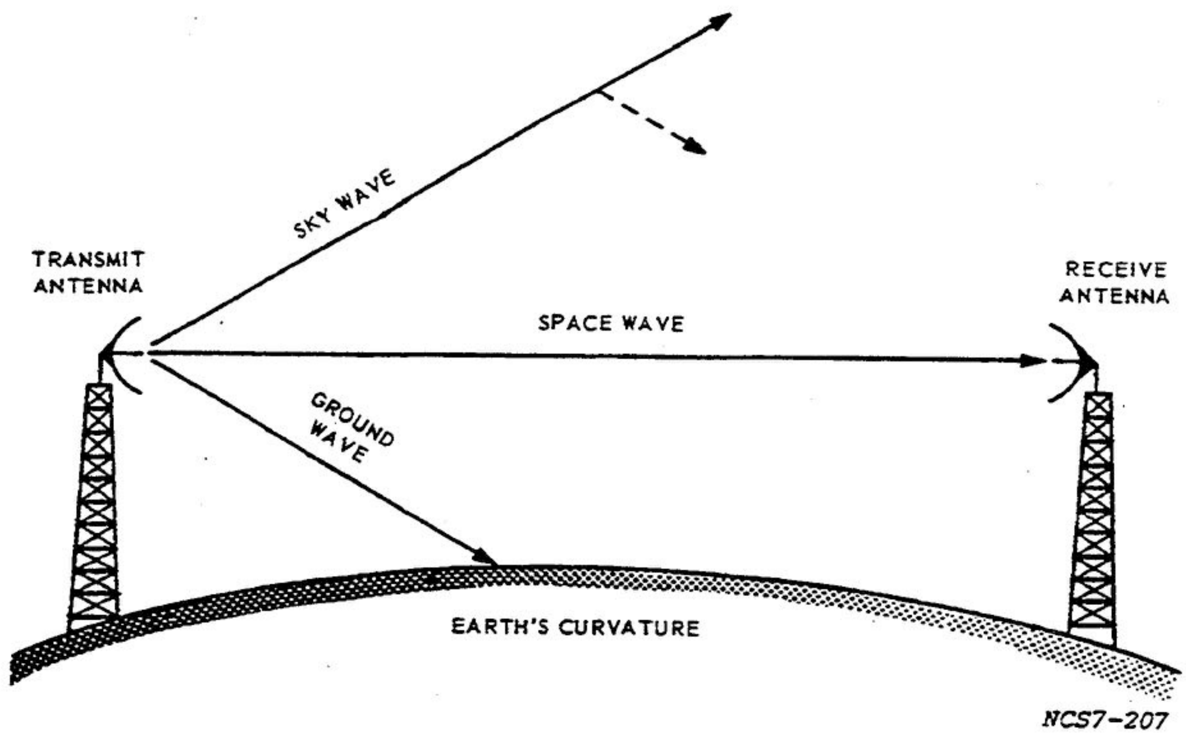

Figure 3-1. Three major propagation paths.

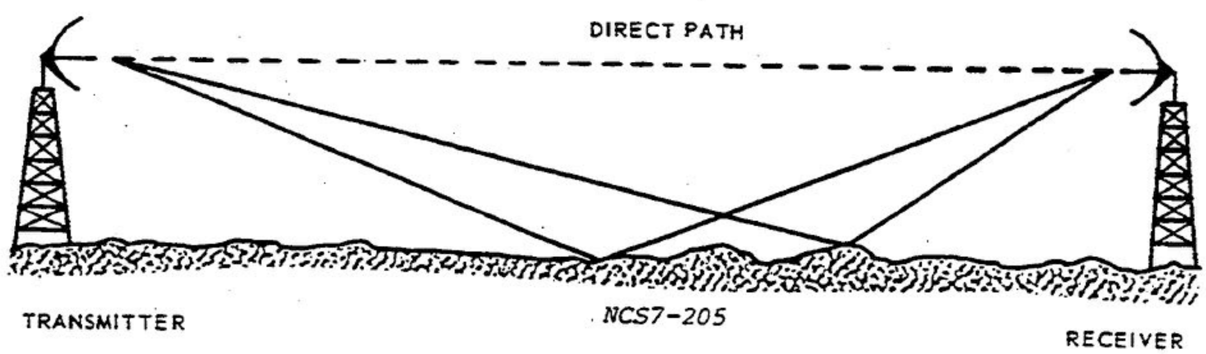

Figure 3-2. Reflected wave.

medium to another with a different density. An example of refraction is shown in figure 3-3. As the upper portion of the wave enters the less dense medium, it speeds up, while the lower portion of the wave is still traveling at a slower speed in the more dense medium. As a result, the wave is refracted or bent. It is important to understand that the refraction would be in the opposite direction if the wave traveled from a less to a more dense medium.

When a radio wave is propagated parallel to the earth's surface, it constantly expands so that the upper portion of the wave is in thinner atmosphere and travels faster than the lower portion of the wave. This causes the wave to gradually bend downward following the curvature of the earth. One factor affecting the amount of radio-wave refraction in the atmosphere is the change in the refractive index of the air as altitude increases. Refractive index is the ratio of radio wave velocity in free space to its velocity in a specified medium.

$$\text{Refractive Index} = \frac{\text{speed of a wave in free space}}{\text{speed of a wave in a medium}}$$

The refractive index of air depends on atmospheric pressure, moisture, and temperature. These atmospheric properties normally decrease as altitude increases causing the atmosphere becomes less dense at higher altitudes. Since the speed of a propagated wave increases as the propagation medium becomes less dense, it is evident from the above formula that the refractive index will normally decrease as altitude increases.

Another factor affecting the amount of atmospheric refraction is the frequency of the electromagnetic wave.

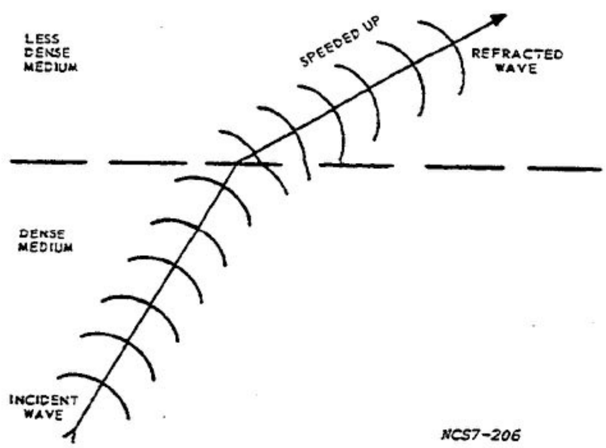

Figure 3-3. Wave refraction.

Through practical experience, it has been discovered that atmospheric refraction varies inversely with frequency. Since the frequency of a microwave signal is high, 1,000 MHz and up, the direct transmission distance for microwave radio is often considered to be LOS or to optical horizon. This is not true in actual practice because the range of microwave communication often extends considerably beyond the optical horizon to a point called the radio horizon (fig. 3-4).

The radio horizon is a point on the earth's surface where propagated radio waves become tangent to the earth. The extended range of microwave communications, as compared to an optical path, is the result of atmospheric refraction, varying inversely with a change in frequency. Through a given propagation path, microwave energy is refracted more than light energy. This causes microwaves to follow the curvature of the earth to a greater degree than light and to travel beyond the optical horizon. Under normal atmospheric conditions, where the density of the atmosphere gradually decreases with an increase in altitude, the microwave LOS communications distance extends approximately 15 percent farther than the optical horizon and approximately 33 percent farther than the true horizon (fig. 3-4).

The effective increase in distance to the radio horizon is much the same as the result of hypothetically reducing the earth's curvature or increasing the earth's radius. A microwave propagation path can be treated as a straight line if the earth's radius is multiplied by a constant (K). The distance to the radio horizon is approximately 33 percent greater than the distance to the true horizon. This, in terms of the constant (K), means that $K = 4/3$.

Up to this point, we have discussed refraction with respect to a standard atmosphere where air pressure, temperature, and humidity decrease linearly with increasing altitude. You will find that standard atmospheric conditions seldom occur over the entire length of a propagation path for a full day, week, or year. For example, standard atmospheric conditions may occur for 80 percent of a given period. During the remaining 20 percent, the propagation characteristics may be such that K is less or greater than 4/3, its value for a standard atmosphere. In the early morning hours of late summer and early fall, the atmospheric conditions may be such that K decreases considerably in value. The effect of this is to decrease the distance of the radio horizon.

Occasionally, a temperature or humidity inversion occurs when the thicker air is on top instead of the bottom, as it usually is. Instead of bending forward, the radio wave is bent upwards, causing inverse beam bending. The area of inversion will be relatively thin and can be viewed as a duct, or layer, of special air. The wave will tend to bounce back and forth between the edges of this layer and can, as a result of this ducting, be bent away from the intended destination.

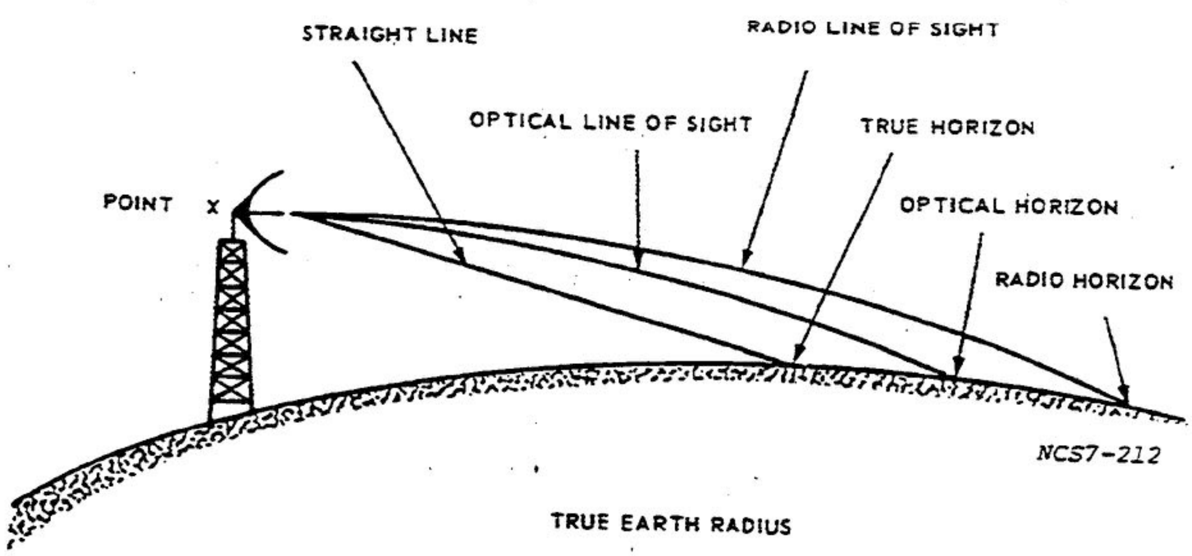

Figure 3-4. Radio and optical horizons.

Since we can't control the weather, you can understand that microwave LOS radio systems must be designed to overcome signal fading caused by changes in the atmosphere's refractive characteristics. We discuss ways to overcome fading later in this text.

Diffraction. Diffraction is the downward bending of radio waves as they graze the earth's surface or the top of an obstruction in a propagation path (fig. 3-5). Diffraction is sometimes referred to as knife-edge effect since radio waves are bent as they pass over the top edge of obstacles in a propagation path. Ordinarily, diffraction causes no great difficulties in microwave communications since it can usually be avoided by planning the radio routes.

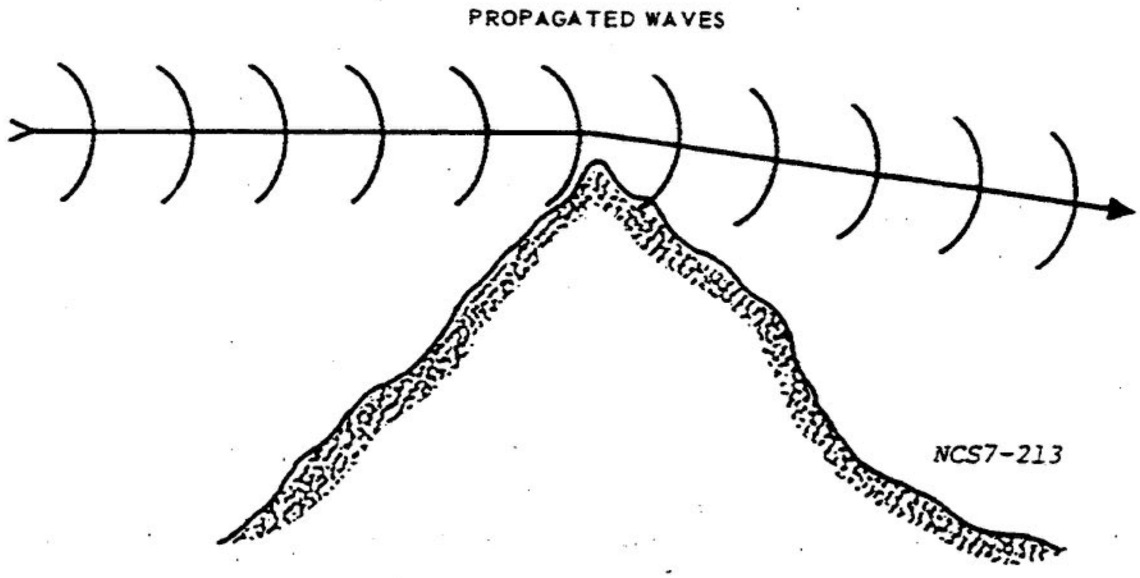

Figure 3-5. Diffraction.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

017. Major propagation paths and their associated radio system

1. Name three major propagation paths and identify the radio system used with each path.

2. Name Three factors that affect microwave propagation.

018. Reflection, refraction, and diffraction

1. What happens if a space wave and a reflected wave arrive at a receive antenna 180° out-of-phase?

2. What happens when reflected waves and space waves pass in and out-of-phase at the receiving antenna?

3. In a standard atmosphere, how much farther is the radio horizon than the true horizon?

4. It is the early morning hours of late summer, and the atmospheric conditions are such that K has decreased considerably in value. What is the effect on the radio horizon?

5. As the atmosphere becomes less dense, what is the effect on the speed of the propagated wave?

6. State the effect on a line-of-sight receiver signal level when the constant varies.

7. What is diffraction?

3-2. Basic Microwave Equipment Operation

Many models of microwave equipment are in use throughout the Air Force. Some of this equipment is of military design and some is commercially designed equipment that has been adopted for use in certain military applications. You may encounter equipment manufactured by well-known companies such as Lenkurt Electric, Philco-Ford, Radio Corporation of America, General Electric, California Radio, Motorola, and others. In addition, the Air Force operates several foreign-made models of microwave in overseas areas. Here we only describe a basic microwave system consisting of the transmitters, receivers, waveguides, and antennae.

019. Characteristics of microwave equipment

Equipment Similarities. The design of the various models of microwave equipment varies, but (among others) you'll these find basic similarities:

a. Klystrons - Used extensively for generating the microwave RF signal (at frequencies above 6,000 MHz) in the transmitter. They are used as local oscillators in microwave receivers.

b. Waveguides - Used for transmission lines in many microwave systems, especially those operating above 3,000 MHz.

c. Antennae - Most microwave systems use highly directional, paraboloid reflector antennae or paraboloid reflector and plane reflector antennae in combination.

d. Microwave receivers - Most microwave receivers are similar in design (i.e., they require a large number of IF amplifiers and the same type of discriminator).

We stress basic microwave equipment in this discussion, but we also use techniques developed by the Lenkurt Electric Company to give our discussion continuity and to give you a broad understanding of microwave techniques.

Receivers and Transmitters. You'll see many different configurations of transmitters and receivers. In any configuration, the transmitter must be compatible with the receiver in frequency, modulation technique, pilot frequencies, and bandwidth.

Multiplexers. You may also see different types of multiplexers used in the same system. The basic characteristics for voice-frequency multiplexers that must be compatible are: frequency translation, pilot frequencies, channel capability, and method of multiplexing. By channel capability, we don't mean that a terminal with a 600-channel multiplexer can't transmit to a relay with a 120-channel multiplexer—it can. On the other hand, the terminal has the capability of 10 supergroups (60 channels per supergroup), and if you tried to put information on supergroup 3, the 120-channel relay couldn't receive it.

Recall how the multiplexed frequencies were translated. The method of multiplexing used is either frequency or time division multiplexing. Concerning data or telegraph-type multiplexers, signals must be transmitted and received the same way. For example, if a space is transmitted high, then it must be received high. You should remember that most multiplex sets have a sense switch that will reverse the polarity of the signal. In addition, the speed of the transmitter and receiver must agree.

020. Microwave transmitters and receivers used with frequency-division multiplexing (FDM)

Microwave Transmitters. By definition, microwaves are radio frequencies with wavelengths short enough to exhibit some of the properties of light. There's no exact frequency at which this happens, but it's generally agreed that it happens around 1,000 MHz. Using microwaves in a communications system presents both advantages and disadvantages. One disadvantage is that microwaves, like light waves, travel in a nearly straight line, limiting transmission to line of sight. Another disadvantage is that circuit design becomes quite critical. On the other hand, microwaves let us use highly directional antenna systems. Since microwave transmissions are LOS, transmitting power can be very low (1 to 5 watts), except for tropospheric scatter systems. Therefore, there's usually no requirement for extensive power amplification circuits. There are some cases when microwave signals are transmitted at a relatively high-power level. This is the case when there's no clear path between the two microwave terminals or in tropospheric scatter systems.

according to MIL-STD-188-313, all new microwave and LOS subsystems must be designed to operate in a frequency range from 4 to 13 GHz. The bandwidth is from 5 to 15 MHz, and the IF is 70 MHz. The deviation is ±7 MHz. Power output must be ±37 dBm (5 watts). You'll find microwave transmitters that don't meet these specifications, but with the introduction of TDM/PCM, you'll see new transmitters that exceed them. For example, the AN/FRC-155(V) to AN/FRC-160(V) can transmit 600 channels with an IF bandwidth of 25 MHz.

Microwave Receivers. Compatible microwave receivers have the same bandwidth, frequency range, and IF frequency as the transmitter. Microwave receivers must be able to receive weak signals because of the transmitter's low-power output. At VHF frequencies, it's possible to increase receiver sensitivity by using RF amplifiers. Amplification of low-level microwave signals hasn't been practical except by using parametric amplifiers. Microwave (LOS) receivers don't provide amplification at the received signal frequency. Microwave receivers are FM superheterodyne receivers with enough IF amplification stages to boost the first detector (mixer) output signal to the desired level. In these receivers, the noise generated in the input circuits (first detector and first two IF stages) is the factor that limits the receiver's signal-to-noise ratio. Normally, a signal-to-noise ratio of 15 dB is considered satisfactory for reliable reception.

021. Components and characteristics of a waveguide

Waveguides. One of the characteristics of electromagnetic waves is that they can be confined in and propagated along hollow metal tubes that are circular or rectangular in cross section. A rectangular tube is generally the most practical because of its wide frequency range and ability to maintain wave polarization. The power loss in a waveguide is about one-third the loss in a comparable air-insulated coaxial line and very small compared to the loss in a flexible coaxial cable with solid insulation (rubber, plastic, etc.). Waveguides can be rigid or flexible, and they have an infinite life as long as they're free of corrosion or dents.

One factor limits the use of waveguides. This is the physical dimension required for propagation at given frequencies. The lowest frequency a waveguide can transmit is determined by its width. The wavelength at this lowest frequency, or cutoff frequency, is twice the width of the waveguide. This means that a waveguide designed to transmit a 30-MHz signal must be at least 17 feet wide. Needless to say, this is impractical. At 2,000 MHz, however, one-half wavelength is about 3 inches and at 6,000 MHz only 1 inch. Waveguides can be built economically to handle these frequency ranges, and they lend themselves to convenient equipment arrangements.

The waveguide's characteristic impedance is similar to that of a two-wire transmission line. Therefore, the waveguide must be terminated by an impedance equal to its own to prevent reflected waves. The voltage standing-wave ratio (VSWR) is an important parameter in dealing with waveguides. The value of VSWR determines whether or not the waveguide is correctly terminated in its characteristic impedance. The optimum VSWR is 1:1, indicating that the load completely absorbs all of the energy in the incident wave.

022. How antennae work

Antenna. An efficient antenna system is a vital part of any successful radio system. This is particularly true of LOS, where the low power output and the high propagation losses combine to make highly directive antennae necessary. The antenna system's efficiency depends on how much of the transmitted energy can be retrieved by the receiving antenna, and the amount of this received energy depends on the characteristics of both antennae.

An antenna system includes all the equipment necessary to radiate the signal of a transmitting set and to intercept incoming signals and feed them to the receiver. There are four types of devices, but you won't find them all at every installation.

(1) Antenna - Includes parabolic reflectors, feedhorns for waveguide or feed dipoles for coaxial line, and any necessary mechanical mounting.

(2) Feed system - Is the waveguide or coaxial line connecting the antenna to the transmitter and receiver.

(3) Branching networks - Used to divide the signals when you're transmitting and receiving on the same antenna system or to connect more than one transmitter to an antenna. Duplexers are one type of branching network that lets a transmitter and receiver use the same antenna.

(4) Circulators and isolators - Have the property of acting differently on signals passing through them in opposite directions. Waveguide circulators are used to couple two or three pieces of microwave equipment to a single antenna. Such an arrangement is useful when diverse equipment is used or when you add microwave equipment to existing equipment to increase channel capacity.

Paraboloid Antenna. In LOS microwave communications, the most common antenna consists of a waveguide feed device and a paraboloid reflector or dish (fig. 3-6), often called a paraboloid antenna. The radiation principle of a paraboloid antenna is like the radiation characteristics of a flashlight reflector. That is, RF energy is fed to a paraboloid dish that reflects the energy to a distant station. The feed device is located at the focal point of the reflector. This gives maximum directivity to the transmitted signal and allows received signals to be reflected from the paraboloid dish into the feed device.

The paraboloid antenna is especially desirable for microwave communications because it concentrates the RF energy into a narrow, unidirectional beam. This results in a high antenna gain compared to an isotropic radiator, which is a theoretical antenna that radiates in all directions (omnidirectional radiation). A paraboloid antenna's gain depends on the diameter of the dish and the frequency of the RF signal. If either the diameter or the frequency is increased, the antenna gain also increases. You can calculate a paraboloid reflector's approximate gain with this formula:

$$G_{dB} = 20LogD_{ft} + 20LogF_{MHz} - 52.6$$

Where:

G_{dB} = Gain in decibels
F_{MHz} = Frequency in MHz
D_{ft} = Diameter of the parabolic reflector in feet

The diameter of paraboloid antennae commonly used with LOS radio are 4, 6, 8, or 10 feet. These antenna sizes provide gains of roughly 30 to 40 dB.

Most of the energy radiated from a paraboloid antenna is confined to a small cone of a nearly circular cross section. The width of the cone or beam is the number of degrees between the points on either side of the maximum radiation direction where the power drops to one-half maximum. These are called the 3-dB, or half-power, points on the radiation pattern. You can calculate the approximate beamwidth, but it's of little use to the working tech controller. Since the paraboloid antenna's directivity varies inversely with its beam width, it varies directly with the dish diameter and the frequency. That is, if either the diameter of the dish or the frequency increases, the directivity will also increase. It should be clear by now that the paraboloid antenna's radiated energy is more concentrated in a desired direction as the beamwidth decreases. Thus, the antenna gain will increase as the radiated beam becomes narrower.

Paraboloid antenna feed devices. The most common type of feed device used to radiate towards a paraboloid antenna is the feedhorn (horn antenna). Several types of horns are shown in figure 3-7. A feedhorn has two functions. It is shaped and positioned at the focus of the parabola so that the RF energy is directed at the reflector. It also provides the proper terminating impedance for the transmission line, which is usually a waveguide. The two general types of feed devices are known as rear- and front-feed devices. A front-feed is formed by bending the waveguide so that the radiating horn faces the reflector (fig. 3-8,A). A rear feed, also known as a Cutler or double-slot rear feed, has a folded horn design (fig. 3-8,B). The waveguide is, in effect, split into halves, with each half terminating in a slot that faces the reflector. A

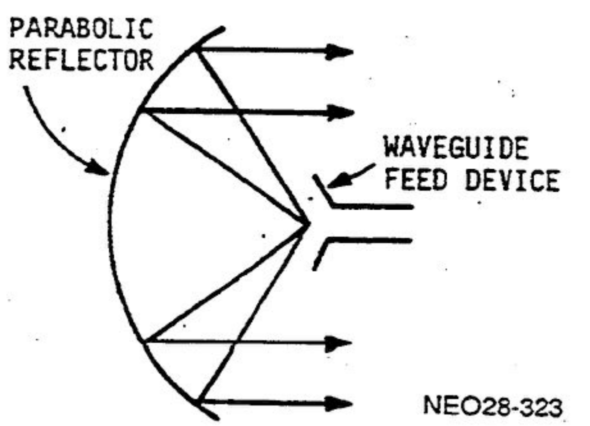

Figure 3-6. Radiation characteristics of a paraboloid antenna.

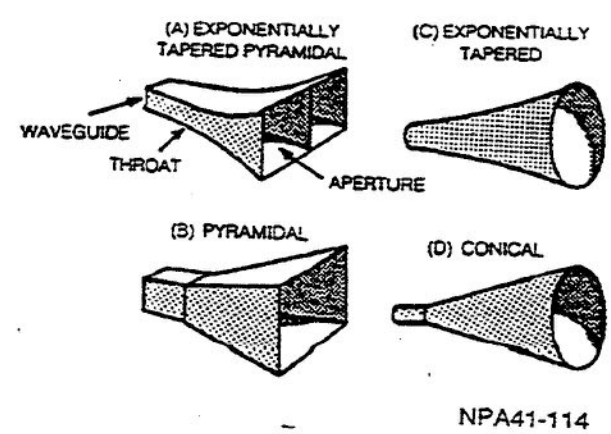

Figure 3-7. Horn types.

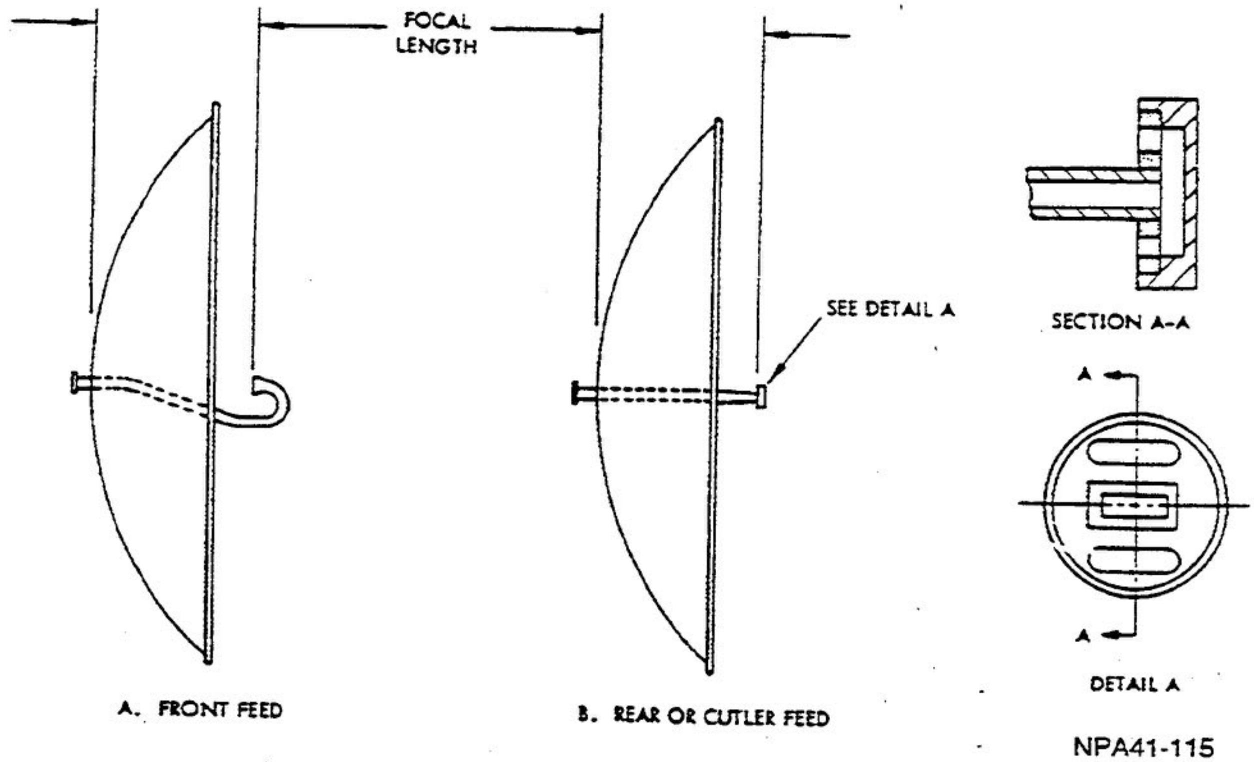

Figure 3-8. Antenna feed devices.

rear-feed device is the most common method of feeding paraboloid reflectors used with LOS radio. Both front and rear feeds are usually sealed at the orifice by a sheet of mica so that the waveguide can be pressurized. If the inside of a waveguide corrodes, severe signal attenuation will result.

Although feed devices are necessary to illuminate a paraboloid antenna, they have the disadvantage of aperture blockage. Since a feed device is positioned in front of the paraboloid dish, it will block some of the reflected energy. Some RF energy will be reflected back into the feed device. This causes signal attenuation due to standing waves. Some aperture blockage is caused by the rear-feed method, but the signal loss is small compared to the loss caused by the front-fed method.

Cornucopia antenna. The cornucopia antenna overcomes aperture blockage. It's basically a horn-reflector combination consisting of a paraboloid section mounted behind a horn aperture (fig. 3-9). The paraboloid section is positioned so that a received signal entering the horn aperture will be reflected to the bottom of the horn, where a coaxial cable or waveguide is connected. Energy entering the bottom of the horn from a transmitter will be reflected out of the aperture toward a distant station. Although the cornucopia antenna eliminates aperture blockage, it is heavy and expensive compared to a conventional paraboloid reflector.

Plane reflectors (periscope antenna). An antenna system for LOS radio will often consist of more than a paraboloid dish and a feed device. For locations where the antenna's effective height must be more than about 50 feet, the antenna can be mounted on a shelter, roof, or similar platform. The antenna is directed upward toward a plane reflector, which is mounted on a tower and directs the radiated energy toward the next station (fig. 3-10). Using the antenna and plane reflector combination saves money because it eliminates long runs of waveguide so that pressurizing systems aren't required and maintenance is simplified.

A microwave transmitter radiates only a small amount of power—usually 1 to 5 watts. The power must be concentrated into a narrow beam directed toward the receiving

Figure 3-9. Cornucopia antenna.

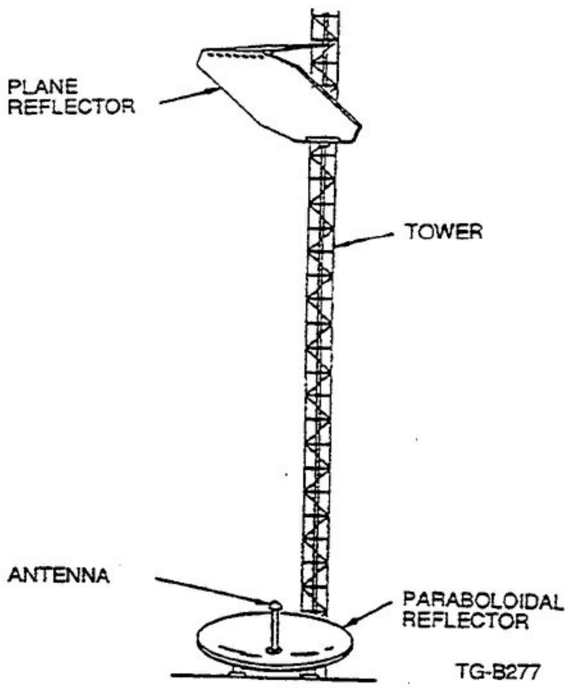

Figure 3-10. Typical plane reflector installation (periscope).

antenna. Both antennae must be highly directional to ensure that as much of the transmitted energy as possible reaches the receiving antenna. This directional property of the antenna is very important to the efficiency of the system. The directional property is measured in terms of gain. Antenna gain results from the directivity of the antenna and is used as a figure of merit for the antenna. It is usually defined as the ratio of the maximum radiation intensity in the same direction from an isotropic radiator. (An isotropic radiator is an "ideal antenna" that radiates equally in all directions; it can't be realized in practice, but it serves as a convenient performance reference.) An example would be the sun.

Antenna gain increases the effective power of a transmission just as surely as does amplifier gain. A distant observer located along the beam would receive as much signal power from an antenna with a gain of 30 dB and a transmitter power of 1 watt, as he or she would from an isotropic radiator at the same distance with an output of 1,000 watts. The effectiveness of the transmission is similarly increased by the gain of the receive antenna. In fact, all of the properties of an antenna are the same whether it is used for transmission or for receiving.

Closely related to the gain of an antenna is its beamwidth, usually defined as the angle between the "half-power points," the point where the radiated power is 3 dB down from maximum. The beamwidth may be specified both vertically and horizontally to describe the beam shape in three dimensions. One of the most attractive properties of microwaves is that they follow many of the rules of optics. For this reason, shaped reflectors may be used where a high-gain antenna is required. The most popular reflector is the parabolic.

023. Types of diversity used to overcome the effects of fading

As we said earlier, reflection and refraction over a microwave path can cause fading due to multipath conditions, ducting, and/or inverse beam bending. If any of these propagation phenomena are severe enough, fading will cause the received signal to fall below threshold. There are several methods used to overcome the effects of fading. One method is to increase the transmit power. The objection to this method is that it may cause interference between other stations using the same frequency. Other methods are shorter distance between relay stations and larger antennae. Each method has merit but can be costly. A more practical approach to the problem is to use some form of diversity operation. Through practical experience, three types of diversity have been found useful for overcoming the effects of fading—space diversity, frequency diversity, and polarization diversity.

Space Diversity. Space diversity takes advantage of the fact that simultaneous fading is not likely to occur over two well-separated propagation paths. In a space diversity system, only one signal is transmitted, but it is received by two or more antennae and their associated receivers. The receiving antennae should be spaced at least 50 wavelengths apart (generally vertically), but a common receive antenna spacing is 100 or more wavelengths. In diversity reception, the outputs of the two or more receivers are automatically combined or selected to get a single signal. Figure 3-11 shows two space diversity microwave stations where combiners give one output signal from the two received signals. Space diversity conserves the frequency spectrum, since only one transmitting frequency is used. This type of diversity usually overcomes multipath fade that's due to direct reflections from the earth or other objects. This type of diversity gives a 3-dB improvement in signal-to-noise ratio over a nondiversity system.

A major disadvantage of space diversity is cost, since more than one antenna is required. If a single tower is used, it must be stronger than one designed for a single antenna, and it needs to be higher to get the required receive antenna separation. The basic configuration of space diversity is one transmitter and two receivers with separate antennae on the receive side. A hot standby transmitter may be required to protect against equipment failures. Remember, in the hot standby configuration, a transmitter is in the standby position until the online transmitter fails, and then the standby transmitter automatically switches to the online position.

Frequency Diversity. Frequency diversity uses the principle that two different microwave frequencies fade independently of each other even though they travel the same propagation path. In a frequency diversity system, two different microwave frequencies, modulated by the same intelligence or baseband, are transmitted and received. Consequently, this type of diversity requires at least two transmitters and two receivers at each station (fig. 3-12). As in the

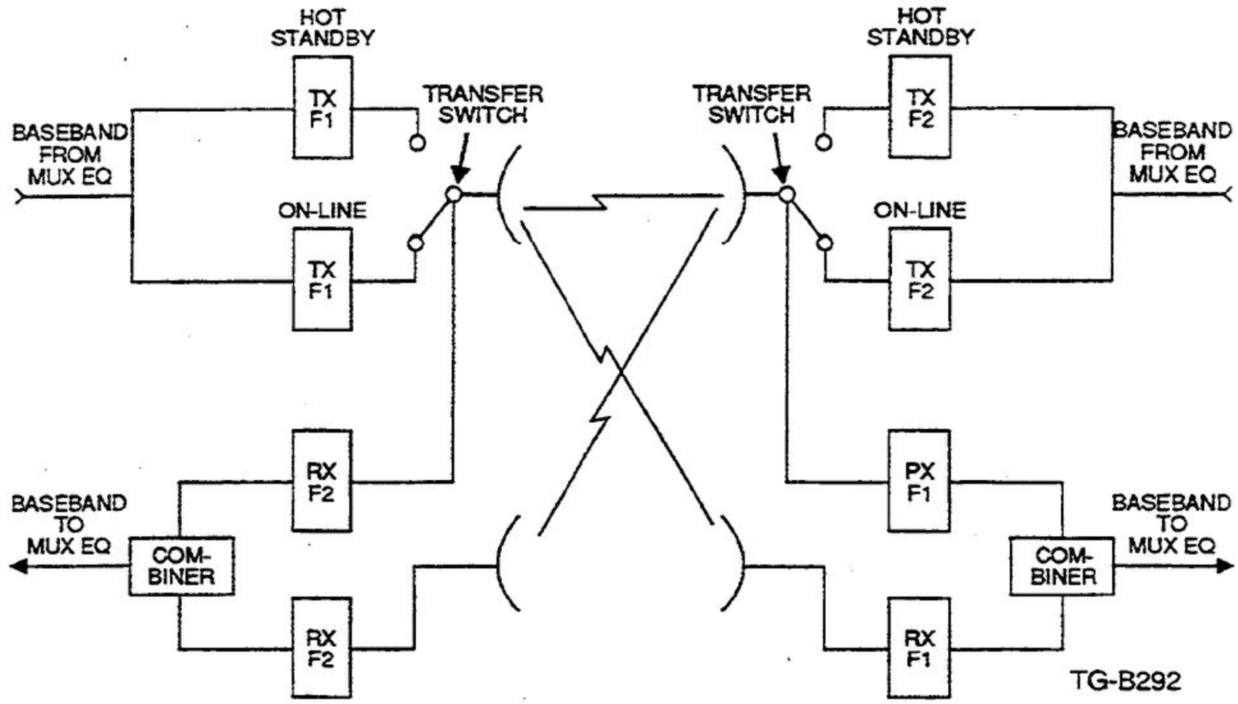

Figure 3-11. Space diversity with hot standby.

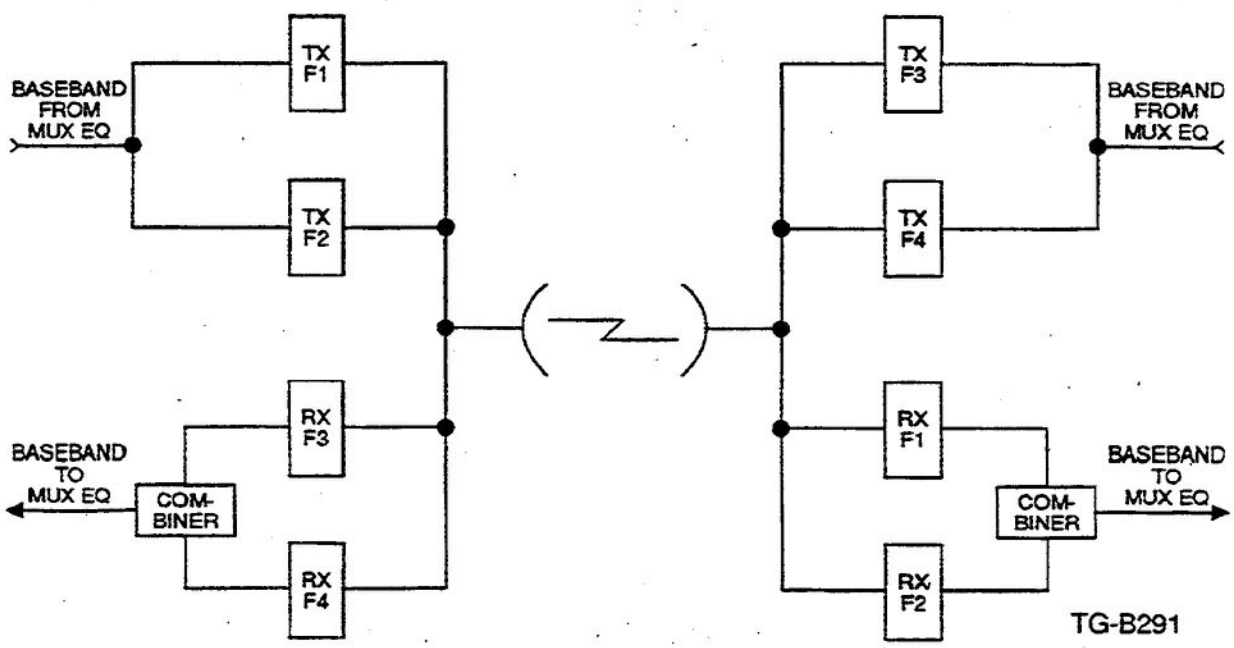

Figure 3-12. Frequency diversity.

case of space diversity, the output of the two receivers is automatically combined or selected to obtain a better signal and reject the faded transmission.

Most frequency diversity systems use frequencies separated by 2 to 3 percent. A separation of 5 percent is considered ideal, but it's usually hard to get because of frequency allocations. A 6-GHz signal requires a second signal 300 MHz above or below the 6-GHz signal. Frequency diversity is usually more economical than space diversity when the costs of providing equal reliabilities are compared for the two systems. Comparing figures 3-11 and 3-12, you can see that the major difference is that space diversity (hot standby) requires an additional antenna at each site. Frequency diversity also provides a backup in equipment since it has two complete electrical paths. If a transmitter fails, the other keeps working, and the system is still usable. This is also an advantage in maintenance because maintenance can be done on one transmitter or its corresponding receiver without an affecting the other end.

Another type of frequency diversity is crossband diversity. Instead of 5 percent separation, the signals are in entirely different allocations. For example, one transmitter may be operating at 6 GHz and the other at 12 GHz. One of the definite advantages of crossband frequency diversity is that it offers protection from rain attenuation, while space diversity and in-band frequency diversity don't. Frequency diversity is believed to be somewhat superior to space diversity with respect to overcoming multipath fading as long as the frequencies are separated by 5 percent or more. Another advantage of frequency diversity is that it requires only the same number of towers, antennae, and waveguides as nondiversity. Frequency allocation is the major disadvantage of frequency diversity; it's often hard to get the required number of frequencies with the proper separation.

Polarization Diversity. In polarization diversity, the same signal frequency is radiated simultaneously in two different planes—horizontal and vertical. Remember, from basic electronic theory, that horizontal polarization is the condition in which the E field is parallel to the earth and vertical polarization is the condition in which the E field is perpendicular to the earth. This type of diversity requires two antennae, two receivers, and two transmitters (fig. 3-13).

Polarization diversity is effective in radio systems where propagation is largely by sky wave. This method generally provides no advantage in LOS microwave systems using frequency division multiplex (FDM). Pulse code modulation (PCM) has introduced this method to the microwave system. Because PCM transmission over microwave radio is less sensitive to interference than FDM transmission, both horizontal and vertical polarization of the same radio frequency can be used for two independent PCM systems over the same path in most propagation conditions, thereby doubling the route capacity. Typically, the value of cross-polarized discrimination (XPD) of a carefully aligned antenna system provides a 25 to 30 dB polarization advantage on a single hop. This means that the vertically polarized signal is attenuated 25 to 30 dB from the horizontally polarized signal (or vice versa). While this separation is unacceptable for transmission of FDM signals, it has an insignificant effect on the transmission of digital signals except near the receiver threshold. Both the horizontal and vertical polarization transmission of a single radio frequency can therefore be used for digital transmission. Thus, two signals from different radios occupying the same RF frequency assignment, but representing two different digital systems, can be transmitted over the same antenna and the same path (fig. 3-14). Through the use of polarization diversity (Lenkurt's name for this type of polarization is *cross polarization*), the digital transmission channel capacity over 2-GHz radio using a 48-channel digital multiplexer can be increased to 96 channels per radio frequency.

Quadruple Diversity. Quadruple diversity is a combination of frequency and space diversity or space and polarization diversity. In many cases, it is not possible to obtain two frequency allocations; therefore, a combination of space and polarization diversity is usually used. Figure 3-15 shows the equipment requirements for quadruple diversity. This configuration has four reception paths and is used where the propagated waves are subject to severe and frequent fading. Quadruple diversity achieves a 6-dB improvement in signal-to-noise ratio over a nondiversity system. The major disadvantage of this system is the cost of the additional equipment.

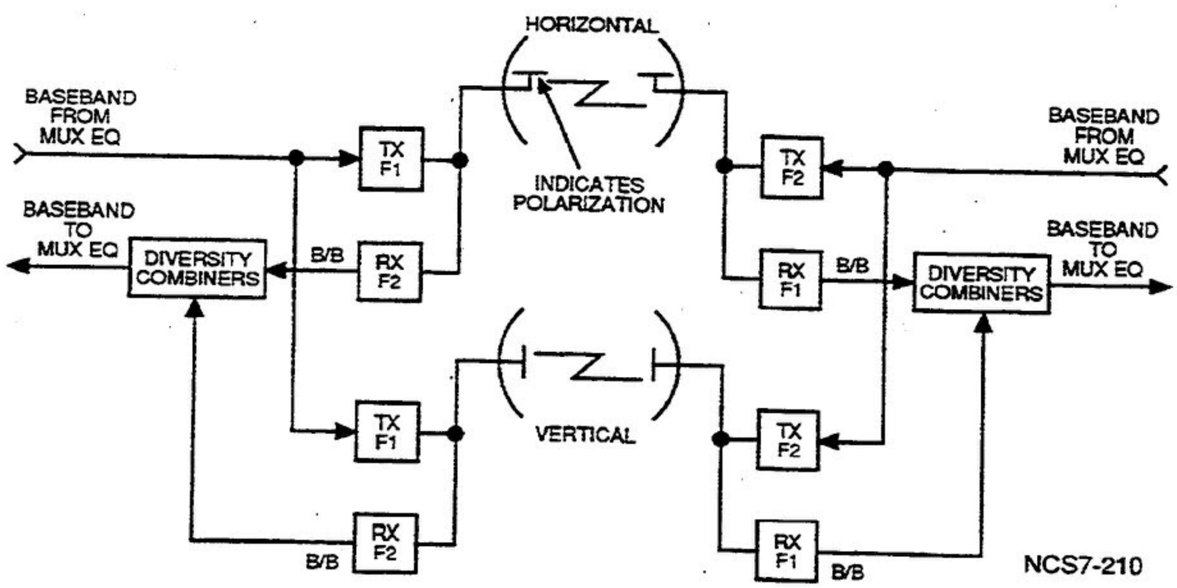

Figure 3-13. Polarization diversity (FDM).

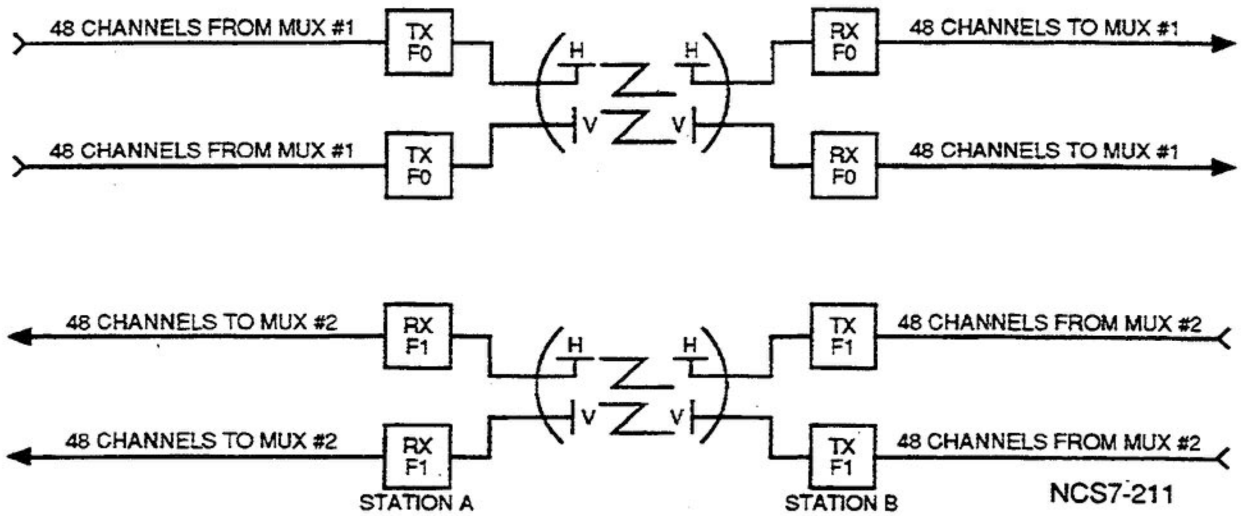

Figure 3-14. Polarization diversity (TDM).

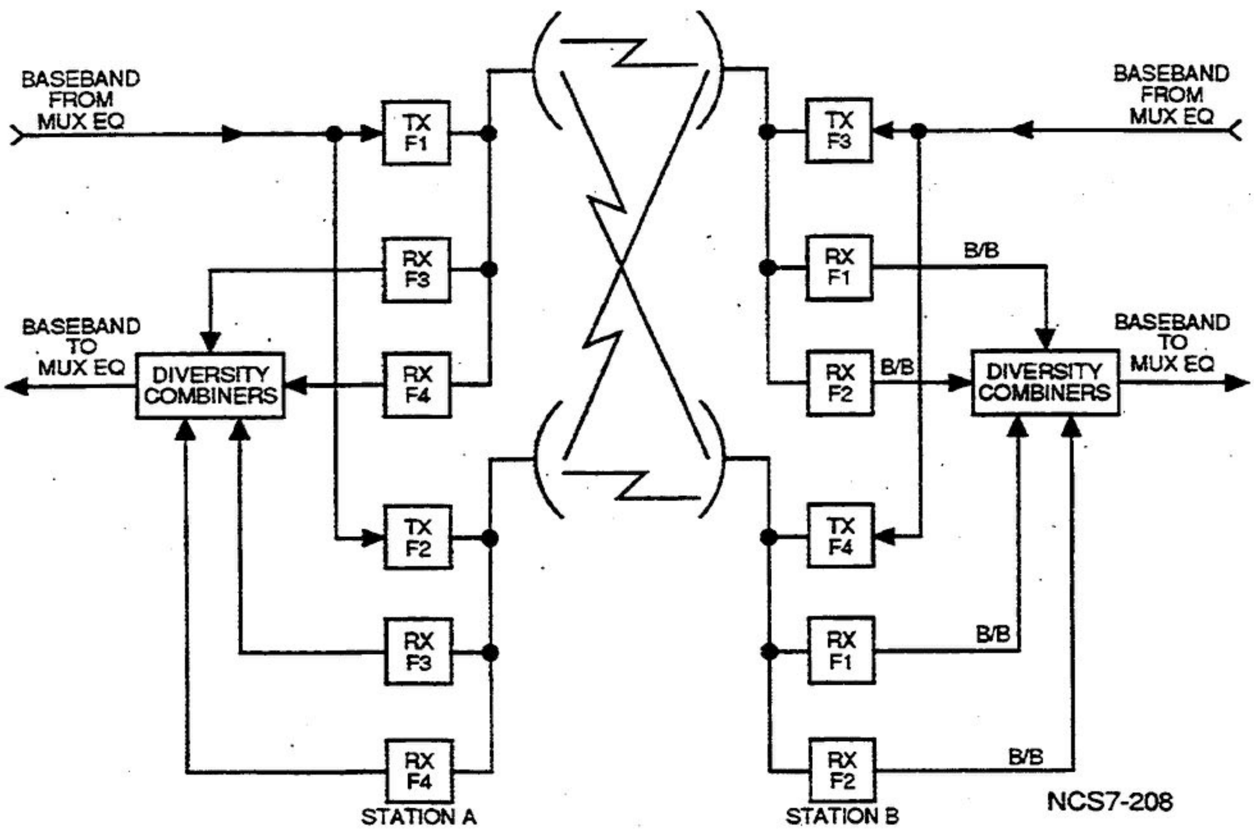

Figure 3-15. Quadruple diversity (frequency and space).

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

019. Characteristics of microwave equipment

1. Name the type of device used extensively as local oscillators in microwave receivers.

2. Name the type of transmission line used in microwave systems operation above 3,000 MHz.

3. Name two similarities in design of many microwave receivers.

4. Name one characteristic of microwave antennae that is similar to all microwave systems.

5. List four characteristics of transmitters and receivers that must be compatible.

6. List four characteristics of voice multiplexers that must be compatible.

7. List characteristics of data multiplexers that must be compatible.

020. Microwave transmitters and receivers used with frequency-division multiplexing (FDM)

1. According to MIL-STD-188-313, what is the frequency range of microwave transmitters used with FDM?

2. What is the specified power output of microwave transmitters used with FDM?

3. What is the specified IF frequency of transmitters used with FDM?

4. Identify each true statement and explain why the others are false.

a. Microwave receivers usually have a bandwidth 1.5 MHz less than the distant end transmitter.

b. Microwave receivers should have the same IF frequency as the distant end transmitter.

c. Because of the low transmit power of microwave transmitters, microwave receivers must use either RF or parametric amplifiers.

d. Microwave receivers are basically FM superheterodyne receivers.

021. Components and characteristics of a waveguide

1. Identify each true statement and explain why others are false:

a. A waveguide has 3 dB more power loss than a comparable air-insulated coaxial line.

b. The lowest frequency a waveguide can transmit is determined by its width.

c. A waveguide must be terminated by an impedance equal to two times its characteristic impedance to prevent reflected waves.

d. A VSWR of 1:1 indicates that the load reflects all of the energy in the incident wave.

022. How antennae work

1. Match the antenna terms and parameters (column A) to their definitions or descriptive phrases (column B). Some column B items may be used more than once or not at all.

Column A

___ (1) Antenna gain.
___ (2) Isotropic radiator.
___ (3) Beamwidth.
___ (4) Parabolic.
___ (5) Directional property.

Column B

a. Most popular type of microwave reflector.
b. Measurement in terms of gain.
c. Radiates equally in all directions.
d. Ratio of the maximum radiation intensity in a given direction to the maximum radiation intensity in the same direction from an isotropic radiator.
e. The angle between the "half-power points,"
f. Follows the rules of optics.
g. Front-to-back ratio.

023. Types of diversity used to overcome the effects of fading

1. List at least one advantage of space diversity.

2. List at least one disadvantage of space diversity.

3. List two advantages of frequency diversity.

4. List one disadvantage of frequency diversity.

5. Define polarization diversity.

6. What prompted the development of this type of diversity?

7. Explain quadruple diversity.

8. List two combinations that may be used for quadruple diversity.

3-3. Equipment Configurations and System Operation

As you saw in the last section, microwave equipment can be configured in many different ways. A relay site can consist of a minimum of two transmitters, two receivers, two antennae, and the necessary power equipment. There are sites with a combination of microwave and tropospheric scatter. Some have audio breakouts, some are through group, some have diversity systems, and some don't. The main point is that the equipment must suit the situation.

024. What is a repeater?

A repeater is basically a transmitter and receiver combination that receives, amplifies, and retransmits a microwave signal. You must remember that these stations may receive on microwave or LOS and retransmit on tropo or vice versa. Since radio and multiplex equipment are the major sources of noise or signal distortion in a microwave system, the number of repeaters in a system is limited.

A repeater must be capable of two functions—amplification and frequency translation. Gain is the fundamental function, but frequency translation is necessary so that the signal is retransmitted at a frequency different from the received frequency. Frequency translation provides frequency isolation between hops so that interference between the repeaters is held to a minimum. Microwave repeater stations are classified according to the lowest frequency to which the received RF is translated before it is amplified and converted up for retransmission. The different types of repeaters are RF heterodyne, IF heterodyne, baseband, and audio.

The use of repeater stations in a system is determined by such factors as the distance to be covered, the effective range of the equipment, the terrain, and the need to drop or insert signals along the system. Theoretically, you can use as many repeater stations as necessary to establish communications between terminals. There's a practical system limit of about eight hops (a hop is the radio path from one station to the next) because of the noise and distortion inherent in each hop. This is true with systems using FDM, but in a system using TDM/PCM with regeneration, tests run with systems up to 15 hops show very little distortion.

RF Heterodyne. The RF heterodyne repeater is simple with respect to equipment requirements, but it's not used widely because microwave frequencies are hard to amplify without introducing large amounts of distortion. The problems associated with filters, limiting, automatic gain control, and delay distortion also add to the cost and make this type of repeater undesirable (fig 3-16).

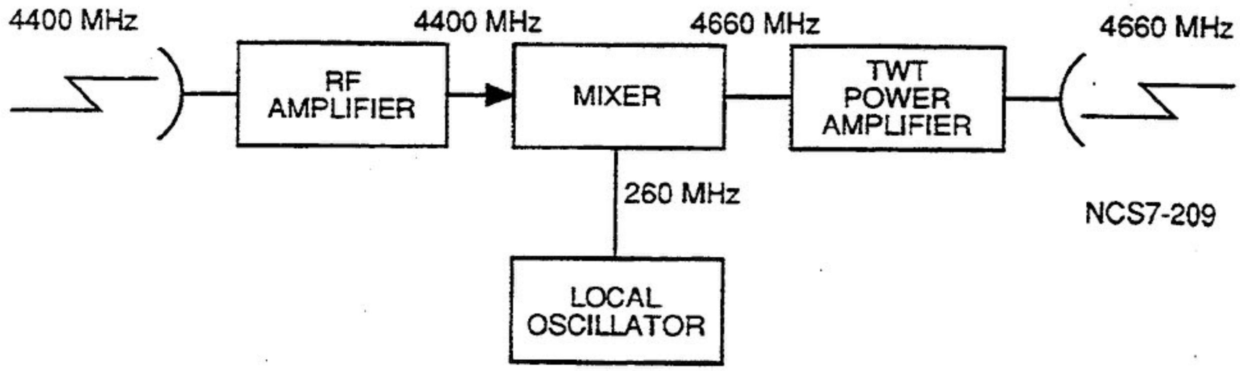

Figure 3-16. RF heterodyne repeater.

IF Heterodyne. In an IF heterodyne repeater, the received signal is translated to an intermediate frequency, normally 70 MHz, at which most of the amplification is done. After the IF signal is amplified, it is then converted up to SHF for retransmission. Figure 3-17 shows the major units required for frequency translation and amplification in a simplex IF heterodyne repeater. The IF heterodyne repeater does most of the amplification at the IF frequency, so it causes less distortion than the RF heterodyne repeater.

Baseband. The baseband repeater is basically a back-to-back connection of two microwave radios. (Remember that these can be LOS, tropo, or a combination of the two.) The baseband output of a receiver is fed directly into the baseband amplifiers of a transmitter. Figure 3-18 shows the major units contained in a simplex baseband repeater. The baseband repeater has several advantages over the heterodyne repeaters. The most notable is its capability for dropout operations. Because the full baseband is present at a baseband repeater site, it's easy to drop and insert channels of information by using filters, thus providing telephone or teletype communications to local customers.

Audio. An audio repeater is essentially two terminal stations connected back to back. In its simplest form, the output from a radio receiver is applied to the transmitter in a second radio through multiplexing equipment. Figure 3-19 shows the basic equipment that makes up an audio repeater. Since each audio channel is available in an audio repeater, it's easy to get dropout operation.

Passive. At this point we must mention a device that's not a pure repeater or pure antenna configuration. The passive repeater is used in radio relay to direct the propagated beam of energy around or over some obstacle that can't be moved. The two types of passive repeaters are plane reflectors and back-to-back parabolic antennae. If two radio stations are so located that the radio beam can be bounced off a reflector to the receiving station, the plane reflector is sufficient for repeating. We use two back-to-back parabolic antennae where a high ridge blocks a microwave beam, or where a plane reflector can't reflect the signal to a receiver. This type of passive repeater consists of two parabolic antennae, one facing each radio station, connected together by a coaxial cable or waveguide.

The passive repeater has several advantages over an active repeater, which amplifies the signal. The biggest advantages are low cost and high reliability. Passive repeaters are very seldom used, however, because they provide no amplification. In fact, the passive repeater causes signal attenuation because a reflector or parabola intercepts only part of the radio beam. In the case of two parabolic antennas connected back to back, the waveguide or coaxial cable will cause signal attenuation.

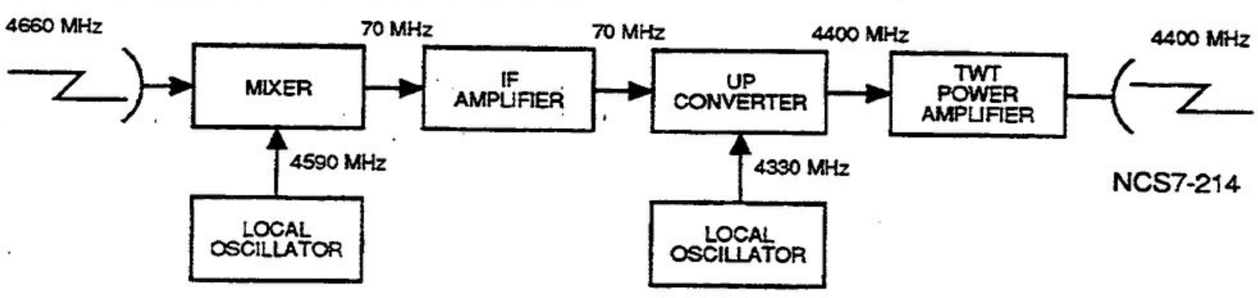

Figure 3-17. IF heterodyne repeater.

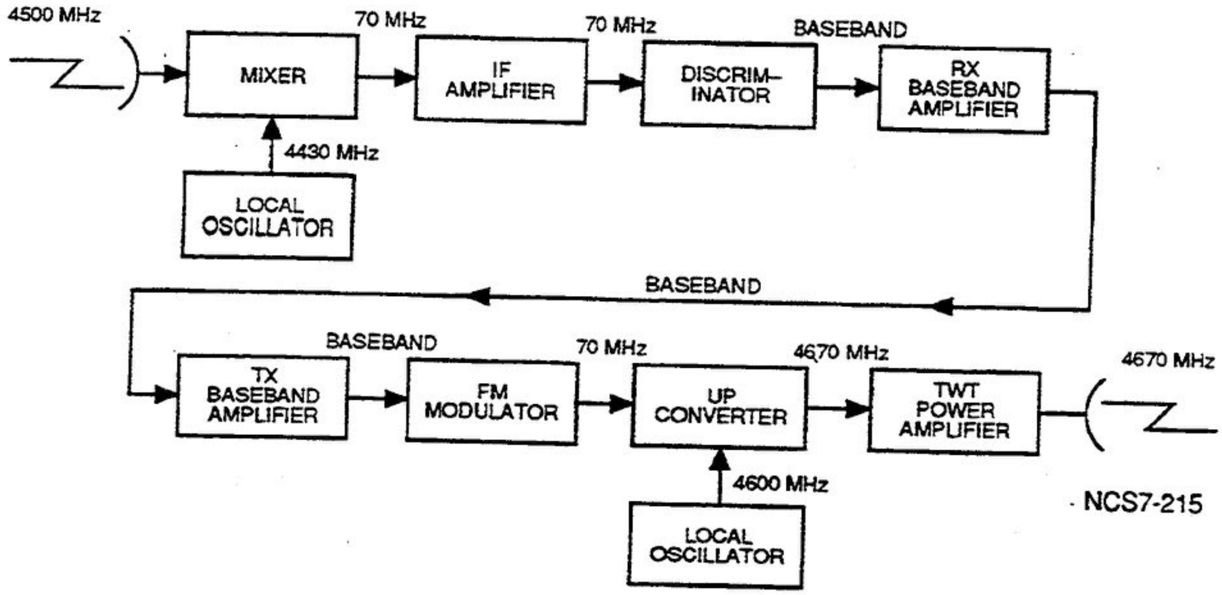

Figure 3-18. Baseband repeater.

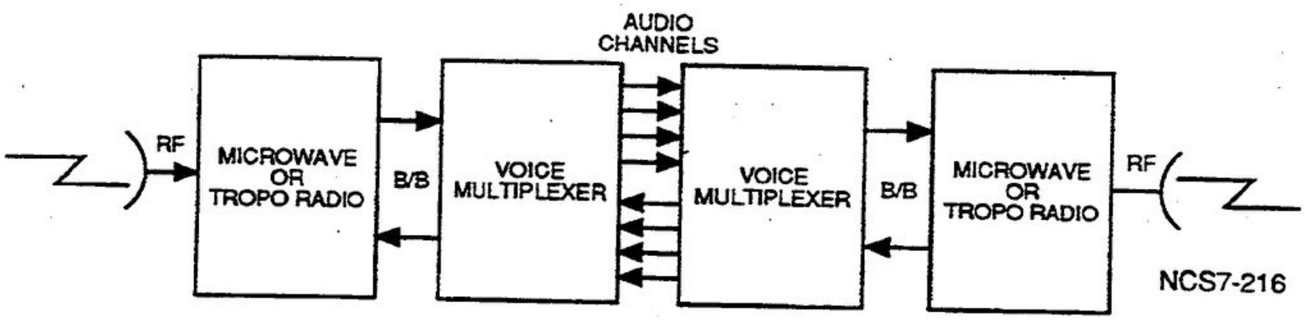

Figure 3-19. Audio repeater.

025. The theory of microwave system operation

There are several definitions of microwave, but we use the one preferred by DCA—"An extremely short electromagnetic wave; a wave less than 10 meters, or especially less than 1 meter in length." A 1-meter wavelength is about 300 MHz, so all frequencies above that are considered to be microwaves.

General Theory. Frequencies up to 450 MHz are generally for private use and small capacity links, such as intersite, where not more than 48 VF channels are required. Frequencies in the 700-to-10,000-MHz range are most commonly used in the DCS because of the large channel capacity and the favorable propagation characteristics. Frequencies in the 10,000-to-15,000-MHz range are susceptible to some distortion from elements such as rain, fog, and snow. These frequencies are suitable only for relatively short distances, and they may be affected to some extent by the natural elements we have just mentioned. Frequencies above 20,000 MHz are very susceptible to the natural elements and are quickly absorbed by any adverse conditions in the transmission path.

The average distance that microwave may be used is 25 to 30 miles. Where a longer distance is needed, the signal must be relayed one or more times by repeater stations, depending on the distance and terrain to be covered. Repeater stations are like terminal stations except that they don't normally have the signal broken down beyond the IF stage. They're sometimes unmanned and are controlled from the connecting terminal station by various control and alarm circuits between the stations. In these cases, when a failure of a component is detected, backup equipment is automatically put into service, and an alarm notifies the connected terminal station. Repair is then made to the faulty component by a maintenance worker from the terminal station.

026. Similarities and differences between typical LOS and tropospheric scatter systems

Power Requirements. Microwave operation is very similar to tropospheric scatter operation in that the principles of the transmitters, receivers, antennas, and reception are almost identical. The main differences between the two systems are the power outputs, channel capacity, and distance or length of path covered. The short distances between terminals in microwave operation let you use very low-power transmitters as compared to tropo transmitters. At the present, microwave transmitters are limited to 2 watts maximum power output, but 1 watt is normally sufficient for most systems. Power outputs must be limited in microwave transmissions to keep some of the radiated signal from going beyond the receiving terminal and interfering with the signal from a repeater station or other microwave system.

Channel Capacity. Microwave, like tropospheric scatter operation, operates in the super-high-frequency (SHF) range. Since the SHF spectrum is relatively uncrowded, you can operate on practically unlimited bandwidths. You must keep in mind that power requirements are directly proportional to bandwidth. The wider the bandwidth, the greater the power required to transmit it. Because of the way LOS operates, losses in microwave transmissions are negligible compared to tropospheric scatter. This means that you can operate on much wider bandwidths, even with the limited power output. Microwave systems providing up to 600-VF channels are in use throughout the DCS, and commercial companies are working with 1,800- and even 2,400-channel systems. Here we'll stick to the 600-channel systems, since those will be the most common for quite some time.

We've discussed the principles of microwave and tropospheric scatter transmission and reception and have briefly discussed some similarities of the two. These two systems are so similar that in some instances entire tropospheric scatter systems were used for LOS operations merely by reducing the transmitter power output and positioning the antennas for LOS operation. Transmitters in both systems use FM, waveguides, klystrons, and parabolic antennas. (Microwave antennas are, of course, much smaller, being either 8 or 10 feet in diameter.) Reception and demodulation are the same in both systems, except that microwave doesn't normally use parametric amplification.

Multiplexing. Another area in which tropospheric scatter and microwave systems are similar is the multiplexing equipment used to combine the VF channels. The VF multiplexing equipment used for both systems is, in most cases, capable of expansion from 60 channels to 600 channels (in 60-channel increments) through the use of supergroup modulators. By limiting the number of supergroup modulators used, the multiplexing terminal used for LOS operation can also be used for tropospheric scatter operation. Normally, tropospheric scatter systems are limited to four supergroup modulators plus the 12-VF channel LF baseband for a total of 252-VF channel capability. However, some tropo systems perform satisfactorily when the LF baseband is eliminated and another supergroup modulator is added, thereby extending the system capability to 300-VF channels.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

024. What is a repeater?

1. List four different types of repeaters.

2. Define a basic repeater.

3. To which type of repeater does each of these descriptions refer?

   a. Not widely used because of the difficulty in amplifying microwave frequencies.

   b. Able to drop channels by the use of filters.

   c. Has greater loss than other repeaters.

   d. Received signal is translated to an IF frequency.

   e. Able to drop and insert channels using multiplexer (AF) equipment.

025. The theory of microwave system operation

1. Why are frequencies above 20,000 MHz not used in microwave transmission?

2. What is the average distance that microwave may be used?

026. Similarities and differences between typical LOS and tropospheric scatter systems

1. What are thqe major differences between microwave and tropospheric scatter system operations?

2. Maximum power output on microwave transmitters should not exceed how many watts?

3. What are some of the similarities between microwave and tropospheric scatter systems?

4. How do antenna configurations differ between microwave and troposcatter systems?

5. What is the channel capacity of most DCS microwave communications links?

6. How may VF multiplexing capabilities be expanded?

7. In a 252-VF channel tropo system, what is the result of eliminating the LF baseband and adding a supergroup modulator?

ANSWERS TO SELF-TEST QUESTIONS

017

1. (1) Ground waves (path); low frequency (system), (2) sky waves (path); scatter (tropo) (system); (3) space waves (path); line-of-site (LOS) (system).
2. Reflection, refraction, and diffraction.

018

1. The RSL decreases because of partial or total cancellation.
2. The RSL varies due to the aiding and opposing of the two signals.
3. 1/3, or 33 percent.
4. The distance to the radio horizon will decrease.
5. Speed will increase.
6. As the constant varies, the distance the signal travels to the radio horizon varies. This causes fading. (The signal level decreases and increases as the constant varies.)
7. Diffraction is the downward bending of radio waves as they graze the surface of an obstruction. Sometimes the term "knife-edge effect' is used to define diffraction.

019

1. Klystron.
2. Waveguide.
3. Large number of IF amplifiers and the same type of discriminator.
4. Highly directional, paraboloid reflector or paraboloid reflector, and plane reflector in combination.
5. Frequency, modulation technique, pilot frequencies, and bandwidth.
6. Frequency translation, pilot frequencies, channel capability, and method of multiplexing.
7. Signals must be transmitted and received the same way, and the speed must be the same.

020

1. 4 to 13 GHz.
2. +37 dBm (5 watts).
3. 70 MHz.
4. a. False, the receiver should have the same bandwidth as the transmitter.
   b. True.
   c. False, microwave receivers used in line-of-sight use IF amplifiers to boost the output of the first detector (mixer).
   d. True.

021

1. a. False, waveguides have about 1/3 the loss—not two times.
   b. True, the cutoff frequency is two times the width.
   c. False, the waveguide must be terminated by an impedance equal to its characteristic impedance.
   d. False, 1:1 indicates that the load has absorbed all of the energy in the incident wave.

022

1. (1) d; (2) c; (3) e; (4) a; (5) b.

023

1. Conserves the frequency spectrum; gives a 3-dB gain over nondiversity.
2. Cost of additional equipment.
3. Cheaper than space diversity; provides a backup.
4. Frequency allocation because of the required number of different frequencies necessary for the proper channel separation.
5. Polarization diversity is the method by which the same signal frequency is radiated simultaneously in the horizontal and vertical plan.
6. Introduction of pulse code modulation (PCM).
7. Quadruple diversity is a combination of frequency and space or space and polarization diversity. Another explanation is a system with four receive paths.
8. Frequency and space, space and polarization; or frequency, space, and polarization.

024

1. RF heterodyne, base band, and audio.
2. Basically, a repeater is a combination of equipment that receives, amplifies, and retransmits a microwave signal.
3. a. RF heterodyne.
   b. Passive.
   c. Audio.
   d. Baseband.
   e. IF.

025

1. They are very susceptible to the natural elements and may be absorbed quickly.
2. 25 to 30 miles.

026

1. Power output, channel capacity, and length of path.
2. 2 watts.
3. They both use FM, waveguides, klystrons, and parabolic antennae.
4. Microwave antennae are smaller in diameter.
5. 600-VF channels.
6. By using supergroup modulators.
7. Channel capacity is increased to 300 channels.

Do the Unit Review Exercises (URE) before going to the next unit. →

UNIT REVIEW EXERCISE

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

34. (017) Why are ground waves *not* used for microwave radio systems?

    a. Equipment used to generate ground waves isn't cost efficient.
    b. Ground waves work better at higher frequencies.
    c. Ground waves are attenuated within a few feet of the transmitting antenna.
    d. Ground waves can't be propagated in a beam narrow enough for microwave.

35. (017) A microwave radio system uses which of these propagation paths?

    a. Space waves.
    b. Ground waves.
    c. Earth waves.
    d. Skywaves.

36. (018) In a microwave line-of-sight (LOS) transmission system, a reflected wave and a space wave that arrive at the receive antenna 180° out-of-phase will cause a

    a. single-hop fade.
    b. cancellation fade.
    c. multipath fade.
    d. phase relationship fade.

37. (018) In a microwave/LOS system, the downward bending of radio waves as they graze the surface of the earth or the top of an obstruction is

    a. reflection.
    b. refraction.
    c. diffraction.
    d. dioptric.

38. (019) In a microwave transmitter, what device is used to generate the microwave radio frequency (RF) signal?

    a. Feedhorn.
    b. Klystron.
    c. fier.
    d. Master oscillator.

39. (019) In a microwave system, what serves as the transmission path line between the M/W radio and the antenna?

    a. Feedhorn.
    b. Klystron.
    c. Waveguide.
    d. Pilot frequencies.

40. (020) In most instances, microwave line-of-sight (LOS) equipment can be operated at relatively

    a. few locations.
    b. high-power output.
    c. low-power output.
    d. the same power output as most FPTS equipment.

41. (020) According to MIL-STD-188-313, what is the frequency range of microwave transmitters using frequency- division multiple (FDM) subsystems?

    a. 4 to 13 GHz,
    b. 5 to 15 MHz.
    c. 7 to 8 GHz.
    d. 3,000 to 6,000 MHz.

42. (020) Compatible microwave receivers should have the same intermediate frequency, range, and

    a. signal-to-noise ratio.
    b. parametric amplifier.
    c. bandwidth.
    d. multiplex.

43. (021) The lowest frequency a waveguide can transmit is determined by its

    a. composition.
    b. flexibility.
    c. curvature.
    d. width.

44. (021) In a microwave waveguide, the voltage standing-wave ratio is 1:1 and correctly is terminated when the load

    a. has less than 3 dB power loss.
    b. has more than 3 dB power loss.
    c. reflects all of the energy in the incident wave.
    d. absorbs all of the energy in the incident wave.

45. (022) What is the normal radiated power range of a microwave transmitter?

    a. 1 to 5 watts.
    b. 5 to 10 watts.
    c. 10 to 20 watts.
    d. 20 to 50 watts.

46. (022) Microwave transmission effectiveness can be increased by increasing the

    a. antenna angle.
    b. antenna gain.
    c. waveguide width.
    d. front-to-back ratio.

47. (023) Space diversity in microwave communication systems usually will overcome the effects of

    a. digital transmission facilities.
    b. multiple receive antennas.
    c. multipath fading.
    d. equipment failure.

48. (023) Space diversity has a major disadvantage of

    a. cost of the antennae.
    b. needing a wide frequency spectrum.
    c. a common receive antenna.
    d. a 3-dB loss in the signal-to-noise ratio.

49. (023) In polarization diversity, the same signal frequency is radiated simultaneously

    a. isotropically.
    b. in the same plane.
    c. at different angles.
    d. in two different planes.

50. (023) A major advantage of using quadruple diversity in microwave transmission systems is

    a. improved signal-to-noise ratio.
    b. ease of maintenance.
    c. less transmitters.
    d. less receivers.

51. (023) The major disadvantage of quadruple diversity reception on microwave systems is

    a. cost.
    b. reliability.
    c. equipment malfunction.
    d. susceptibility to interference.

52. (024) The fundamental function of a microwave repeater is

    a. frequency translation.
    b. frequency isolation.
    c. multiplexing.
    d. gain.

53. (024) Which of these repeaters would be used in a radio relay station to connect two microwave radios back to back?

    a. Passive.
    b. Baseband.
    c. IF heterodyne.
    d. RF heterodyne.

54. (024) Which of these repeaters would be used in radio relay to direct a propagated beam of energy around or over some obstacle that cannot be moved?

    a. Passive.
    b. Baseband.
    c. IF heterodyne.
    d. RF heterodyne.

55. (025) What frequency range is most commonly used for microwave systems in the DCS because of the large channel capacity and the favorable propagation characteristics?

    a. Up to 450 MHz.
    b. 700 to 10,000 MHz.
    c. 10,000 to 15,000 MHz.
    d. 20,000 or higher.

56. (025) When communications are necessary beyond a general microwave's normal range,

    a. repeater stations may be used.
    b. multiple receivers are used.
    c. power output is increased.
    d. antennae are enlarged.

57. (026) Line-of-sight and tropospheric scatter systems can usually use the same system components except for the

    a. multiplexers.
    b. waveguides.
    c. klystrons.
    d. antennas.

58. (026) Multiplexing terminals used in LOS operations can be used in tropospheric scatter systems by

    a. using only voice circuits.
    b. using only data circuits.
    c. limiting the number of supergroup modulators used.
    d. limiting channel capacity to 600.

59. (026) How many supergroup modulators are used in a normal tropospheric scatter system?

    a. One.
    b. Two.
    c. Three.
    d. Four.

Please read the topic page for Unit 4 and continue. ➡

STUDENT WORK SPACE

HIGH FREQUENCY (HF)

Since Marconi invented the radio, the world has watched electronic communication emerge from its infancy, pass through its childhood, and enter the adult state. Before World War II, development of long-distance communications was slow, but the war established a need for rapid, dependable communications that had not been met by the end of the war. Research and development continued at a furious pace that has resulted in effective worldwide communications.

Despite the technical advances in communications in the past few years, high-frequency (HF) radio-one of our first means of long-distance communication-still fulfills an important function and is still a very good means of communications in the DCS. Although it is gradually being replaced, where possible, by tropospheric scatter, microwave/LOS, cable, and satellites, we can expect to find HF in use for a number of years to come.

4-1. Principles of HF

In the early days of radio, mathematical physicists reasoned that it would be impossible to receive radio signals at very great distances because of the attenuation resulting from the absorption of the energy by the earth. When it was found experimentally that signals could be received across the Atlantic Ocean, the work of the physicists was questioned. Their ideas were correct concerning the problem of propagation of ground waves around a curved earth surrounded by free space. Obviously, some other means of propagation had to exist. The experimental evidence of trans-Atlantic communication proved only that the assumption of an earth surrounded by nothing but free space was unjustifiable in this connection. It was then suggested by Heaviside, an English scientist, and Kennelly, an American, that the earth actually is surrounded by an electrified layer, which acts as a reflector and prevents the escape of the wave into free space by bending it back toward the earth. Such a layer also could form the source of the electric currents in the upper atmosphere, which had been suggested as the cause of changes in the earth's magnetic field during magnetic storms. Later, when it was shown that not only one but several such layers actually do exist and that these layers consist of ionized gases of the atmosphere, the name ionosphere was suggested for the region in which the layers were found. A detailed analysis of what happens to electromagnetic waves as they enter the ionosphere is beyond the scope of this course, but we'll look at some practical effects of the relationship between electromagnetic waves and the ionosphere.

027. HF characteristics and terms

Remember from Unit 1 that, when energy is radiated from an antenna, two basic waves are present—ground waves and sky waves (fig. 4-1). Sky waves are the primary waves used to transmit HF. The operation of HF is such that the ionosphere and the radiation of radio waves are closely related. Let's see just how they're related.

Sky Waves. When transmitted waves leave an antenna, strike the ionosphere, and are refracted back to earth, they're classified as sky waves. Refraction is similar to reflection except that refracted waves lose part of their energy when they strike the atmosphere. As an example, imagine using a flashlight to represent an HF transmitting antenna. The light beam represents the transmitted radio wave, and a mirror placed on a ceiling illustrates the ionosphere. If you shine the flashlight against the mirror, the light rays are refracted back to a spot on the floor. If you vary the angle at which the light strikes the mirror, the spot on the floor will change position. You can also change the position of the spot by lowering the mirror or by raising the flashlight.

Now let's relate and compare those variations in light refraction to the position and angle of an HF antenna to the atmosphere. As a transmit HF antenna is varied in relation to the atmosphere, the refracted waves change angle and return position. Also, suppose that we had been using a mirror of inferior quality and we replace it with a mirror of high quality. The intensity of the light beam reflected would greatly increase. By comparison, as the ionosphere intensity increases, the intensity of the refracted wave also increases, and as the transmit angle increases, the distance from the transmit antenna to the return point increases.

Ionospheric Variations. The ionosphere is composed of gaseous layers that are highly susceptible to ionization. The sun is the primary source of ionization since it showers those layers with radiation particles and cosmic rays. Scientists have found that the ionosphere is composed of four layers, designated as D, E, F1, and F2. Note in figure 4-2 the relationship of each layer to the earth's surface. Note that layer D is 45 miles from the earth's surface and is least affected by ionization. Since layers E and F are more highly affected, they deserve more attention.

The density of the E layer reaches maximum ionization at noon and then becomes almost nonexistent at night. During daylight hours, this layer makes HF communications possible for distances up to 1,500 miles. For greater distances, the HF waves must be refracted off the F layer. The F layer is actually a single layer at night, but splits into

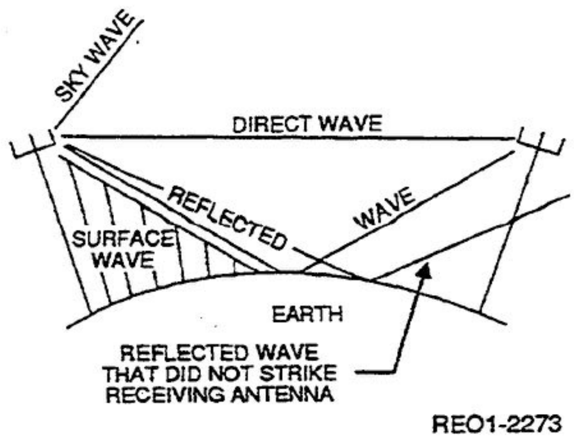

Figure 4-1. Ground-wave and sky-wave radiation.

F1 and F2 layers during the day. The F2 layer is the highest and most highly ionized; thus, it is the most useful for long-distance HF communications.

Waveguide. Remember our experiment with the flashlight? The distance from where the light was transmitted to the point where it struck the floor is known as skip distance. This phenomenon is important to radio communications. Look at figure 4-3 to see how we can increase or decrease the skip distance of HF waves by using different ionospheric layers and different antenna angles.

Cyclic Variations. Cyclic variations in the ionosphere occur as 27-day sunspot variations, seasonal variations, or 11-year sunspot variations. The 27-day sunspot variations correspond to the sun's rotation time and recur as disturbances or ionospheric storms. Seasonal variations cause the F2 layer to rise in summer and lower in winter. The density of the F2 layer also changes with the season. The 11-year sunspot variations cause the F1 and F2 layers to increase in height and density every 11.1 years. During these periods higher HF frequencies can be used.

Noncyclic Variations. Sporadic E-layer variations are a result of ionized clouds or patches that lie near or slightly above the E layer. These patches come and go, and they're found at day or night. They can be used for communication—especially within the normal skip zone. Sometimes they're also used for good long-distance communications. Noncyclic variations may also occur as sudden ionospheric disturbances. Sometimes the receivers seem to suddenly go dead or be totally interrupted. The signal and even static is eliminated. Intense solar activity may cause all the layers to increase in density for periods of a few minutes to hours. If the D layer increases in density, it may absorb all but the lowest frequencies. This condition means that lower frequencies must be used for long-distance HF communications.

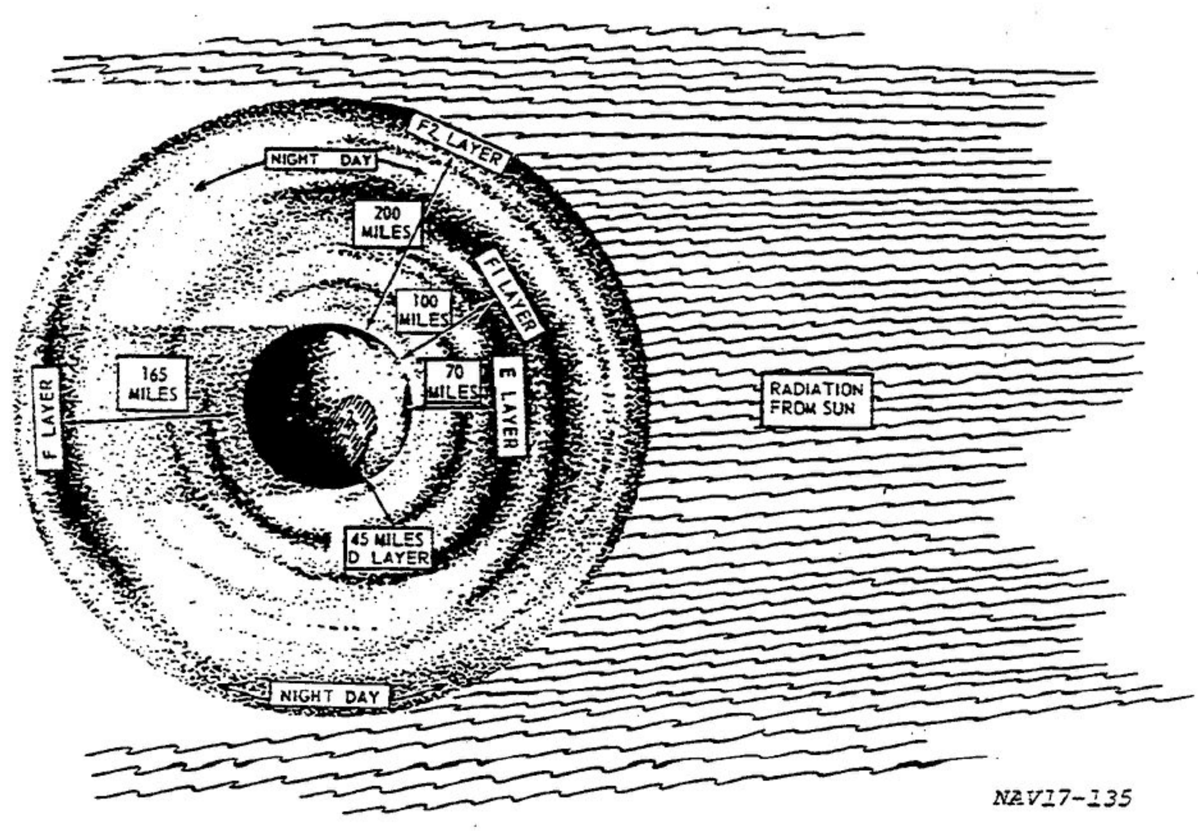

Figure 4-2. Ionospheric layers.

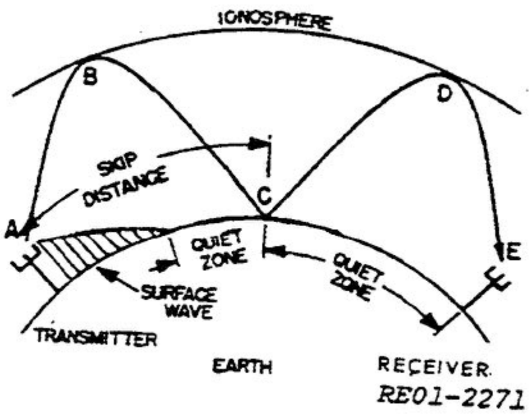

Figure 4-3. Sky-wave refraction.

028. How do ionized layers of the atmosphere affect radio frequencies?

Critical Frequency. In addition to the height, the main ionosphere characteristic that controls long-distance radio transmission is each layer's ionization density. The higher the frequency, the greater the density of ionization required to reflect waves back to earth. In other words, the shorter the length of the waves, the denser or more closely compacted the medium must be to refract them. Therefore, the upper layers, which are the most highly ionized, reflect the higher frequencies, whereas the D layer, which is the least ionized, reflects only lower frequencies—usually none above about 500 kHz. Thus, at any given time, for each layer, there is a value of highest frequency, called the *critical frequency*, at which waves sent vertically upward are reflected directly back to earth. Waves of frequencies higher than the critical frequency pass on through the ionized layer and are not reflected back to earth unless they are reflected from an upper layer. Waves of frequencies lower than the critical frequency are reflected back to earth unless they are absorbed by or have been reflected from a lower layer.

Figure 4-4 shows waves of different frequencies radiated vertically into the ionosphere. Two of these signals are returned directly to the earth and the third passes through both layers and is not returned. Each of the returned waves is at the critical frequency for its layer—that is, the highest frequency that is returned. All frequencies below the critical frequency are returned in the same manner. The unreturned signal is at

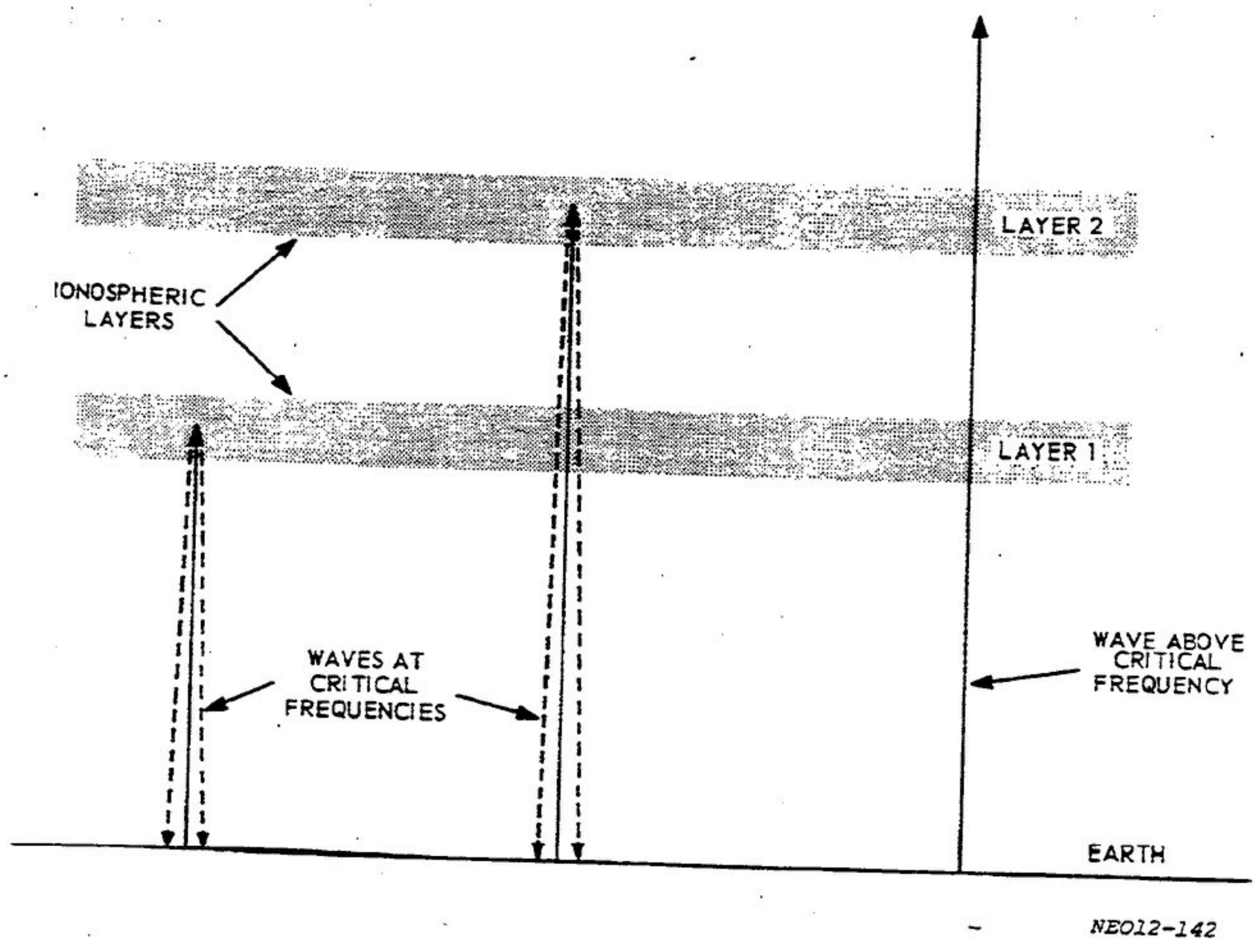

Figure 4-4. Critical frequencies.

a frequency above the critical frequency for either layer and, therefore, passes through to outer space.

This phenomenon can be understood in terms of the combined refractive and reflective effects of ionization on an electromagnetic wave. When a ray, or train of waves, enters an ionospheric layer, it is slowed down as soon as it starts to penetrate the layer. This process of refraction is much like the refraction of light passing from air to water. When the signal enters the ionosphere at a 90° angle, there's no bending of the wave—the whole wavefront is slowed down uniformly. The higher the signal's frequency, the deeper it must penetrate the layer before it surrenders all of its energy. Remember, however, that an ionization layer is most dense near its center, and that the wave will pass on through if this center density can't absorb all of the energy. The surrendered energy is reradiated by the layer directly downward to the area of transmission. By analogy, this effect is like tossing tennis balls vertically upward to a wire screen. If the openings in the screen are smaller than the diameter of the ball, all of those thrown are reflected back almost as effectively as though the screen were a solid piece of metal. If you threw golf balls at the same screen, most of them would pass through the screen and not be reflected. Thus, we may conclude that (like frequency in respect to ionization) for a given screen, there is a critical diameter of ball which will be reflected back; any smaller ball will pass on through.

029. Characteristics of the critical angle in HF communications

Critical Angle. Determining a critical frequency by vertical propagation is useful because it marks a boundary condition. Electromagnetic waves used in radio communications, however, are generally incident at some oblique angle to the ionosphere. These waves are refracted by the ionosphere and may or may not be returned to the earth. Obviously, any frequency at or below the critical frequency will be returned to the earth, but frequencies above the critical frequency also will be returned if they're propagated at certain angles of incidence. Consider the analogy of the screen and the tennis balls. If the critical diameter for a given screen is the diameter of a tennis ball, most of the golf balls thrown obliquely at the screen will hit the wire mesh at an angle and be reflected downward, even though they would pass through easily if they were thrown vertically. Thus, for this screen, there is a certain angle of incidence at which most of the golf balls would be reflected downward. In electromagnetic wave propagation, the same conditions prevail. At angles of incidence near the vertical, a given frequency passes on through the ionosphere, but as the angle lessens, a point is reached at which the wave is reflected back to earth. This angle is called the *critical angle*. The point at which the wave returns is a minimum distance, called the *skip distance;* at smaller angles of incidence, the wave returns at greater and greater distances.

A similar optical phenomenon (fig. 4-5) helps to explain the concept of critical angle. If a beam of light passes from a dense medium (water) to one of less density (air) at right angles to the boundary between them, it passes through with no change in direction. As the angle of incidence becomes smaller than 90°, the beam is only slightly reflected back into the water, most of the light being refracted, or bent, in the air. The amount of bending increases as the angle grows smaller, but at the critical angle, no light is refracted by the air, all of it being reflected back into the water. At angles smaller than the critical angle, the light beam is reflected back at greater and greater distances from the source. At this point, we should note that this optical phenomenon can't be applied strictly to radio waves since there are no sharp boundaries between the dense ionization of the layer and the air above it. The wave is both bent and reflected and, therefore, in propagation work the terms refraction and reflection tend to be used interchangeably.

Figure 4-6 shows the popular explanation of the return of radio waves as a phenomenon in refraction alone. Suppose a train of wavefronts is propagated from A so that it enters the ionosphere at an angle Θ, Greek theta. As each wavefront enters the ionosphere, the upper part of the wavefront feels the effect of lowered index of refraction first. Therefore, the upper part of each wavefront has an increased phase velocity so that the entire wavefront, as it enters the ionosphere, wheels about like a column of soldiers obeying the command, "column right." Since the central parts of the ionosphere have a greater ion density, the bending effect on the upper part of the wavefront is greatest; the wheeling process continues and the waves are directed back toward the earth at point B.

Virtual Height. The oversimplified curved path shown in figure 4-7 also helps to make clear the notion of virtual height

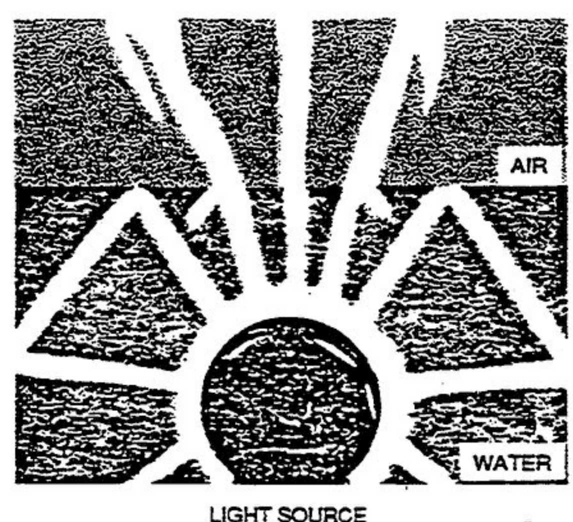

Figure 4-5. Critical angle of light beam.

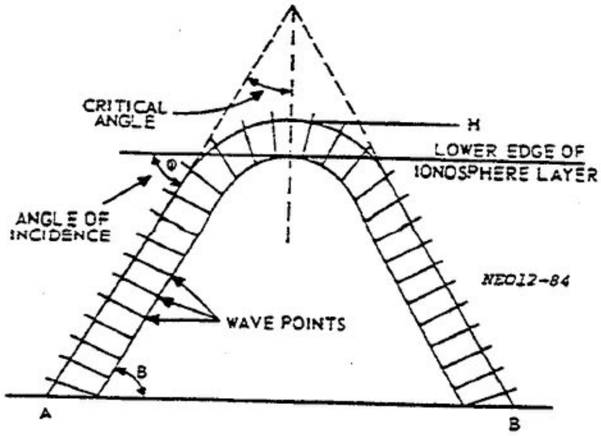

Figure 4-6. Idealized refraction of radio wave.

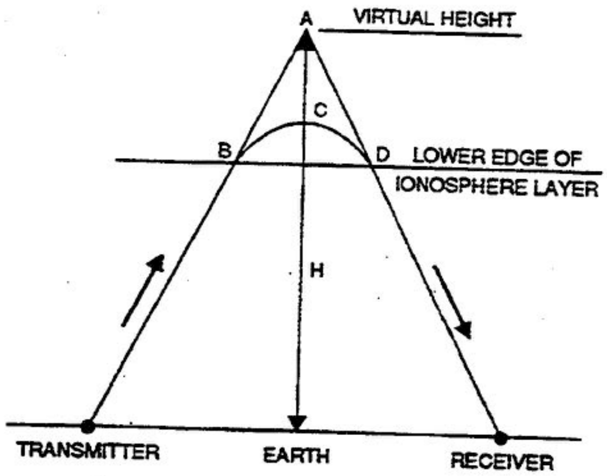

Figure 4-7. Virtual height of ionospheric layer.

of an ionospheric layer. In following the curved path of figure 4-7, the time of transmission of the radio wave along the actual path (BCD) in the ionized layer is considered to be the same as would be required for transmission along path BAD if there were no ionized particles present and a perfect reflecting surface at A instead. The height, H, from the earth to the intersection of the two projected straight parts of the path is called the *virtual height* of the layer. Note that this virtual height is considerably greater than the actual layer height. However, it is a convenient and an important quantity in measurements and applications involving ionospheric reflections to determine critical frequencies.

030. Causes of regular and irregular variations of the ionosphere

The existence of the ionosphere depends on radiations from the sun. Because of this, the movements of the earth about the sun or changes in solar activity that increase or decrease its radiation will cause variations in the ionosphere's conformation. These variations include those that are more or less regular and, therefore, can be predicted in advance, and the irregular variations that result from abnormal solar behavior. For purposes of discussion, we can divide the regular variations into four classes—the diurnal or daily variation, the seasonal, the 11-year, and the 27-day. For convenience, table 4-1 lists the regular variations together with the resulting effects on the ionosphere and on radio communications and suggested ways to compensate for these effects.

Diurnal. We've discussed most of the diurnal variations and their effects on the ionosphere layers. Note in table 4-1 that you can compensate for the resulting variations in the skip distance by using higher medium frequencies during the daytime and lower medium frequencies at night. This is true because the ion density of the F2 layer is greater during the daytime and reflects radio waves of higher frequency than the F layer reflects during the night. The higher frequency waves suffer less absorption in passing through the D region, whereas at night the disappearance of the D region lets you use lower frequencies.

Another diurnal variation that must be considered in HF communications is those links that are transmitted from east to west. In these long-distance links, the ion density changes very rapidly with changes from day to night and night to day. For example, with one communications station in daylight and another in darkness, the absorption of transmitted frequencies accelerates until the day-to-night transition is complete for both stations. We talk more about absorption of radio waves in lessons 055 and 056.

Seasonal. As the sun's apparent position moves from one hemisphere to the other with corresponding changes in season, the maximum ion density in the D, E, and F1 layers shifts accordingly, each being relatively greater during the summer. The F2 layer, however, doesn't follow this pattern in seasonal shift. In most localities, the F2 ion density is greatest in winter and least in summer, which is quite the reverse of what might be expected from simple theory. Figure 4-8 shows graphs of the relative ion densities of all the layers as seasonal shifts occur. Note that in the winter the ion density of the F2 layer rises to a sharp peak at about noon and assumes a much higher density than in summer. Also note that the separation of the F1 and F2 layers is not so well defined in summer since the height of the F2 layer is relatively less during that season.

Eleven-Year. Since 1851 we've known that sunspot activity varies according to an 11-year cycle. Shortly after the discovery of this phenomenon, a method was devised for measuring the relative intensity of sunspot activity, and, by means of this method, the alternations from maximum to minimum have been followed closely throughout the years. Briefly, the method entails the so-called Walf sunspot number, a number derived for each day by multiplying by 10

TABLE 4-1
REGULAR VARIATIONS OF THE IONOSPHERE

Type Of Variation	Effect On Ionosphere	Effect On Communications	Methods of Compensation
Diurnal (varies with hour of day)	F Layer: Height and density decrease at night, increase after dawn. During day, layer splits into - (1) F1 Layer: Density follows vertical angle of the sun: (2) F2 Layer: Height increases until midday,density increases until later in the day. E Layer: Height approximately constant, density follows the vertical angle of the sun. Practically nonexistant at night. D Layer: Appears after dawn, density follows the vertical angle of the sun, disappears at night.	Skip distance varies in 1 to 30 MHz range. Absorption increases during the day.	Use higher frequencies during day and lower frequencies during night.
Seasonal	F2 Layer: Vertical height increases greatly in summer, decreases in winter. Ionization densitypeaks earlier and reaches higher value in winter. Minimum predawn density reaches lower value in winter.	MUF's generally reach higher midday values in winter but maintain high values later into afternoon in summer.Predawn dip in MUF's reaches lower value in winter. Less absorption encountered in winter	Provide greater spread between nightime and daytime frequencies in winter than in summer.
11-year sunspot	F1, E, and D Layers: Reach lower maximum density in winter months.		
11-year sunspot cycle	Layer density increases and decreases in accord with sunspot activity. Minimum 1944 and 1955. Maximum 1959 and 1970	Higher critical frequency during years of maximum activity. MUF variation: Sunspot max: 8-42 MHz, Sunspot min:4-22 MHz.	Provide for higher operating frequencies to be used during periods of sunspot max and lower frequencies during min.
27-day sunspot	Recurrence of SIDs and ionospheric storms at 27-day intervals. Disturbed conditions frequently may be identified with particularly active sunspots whose radiation is directed towards the earth every 27 days as the sun rotates.	See effects of SIDs and ionospheric storms in table 4-2.	See compensation for SIDs and ionospheric storms in table 4-2.

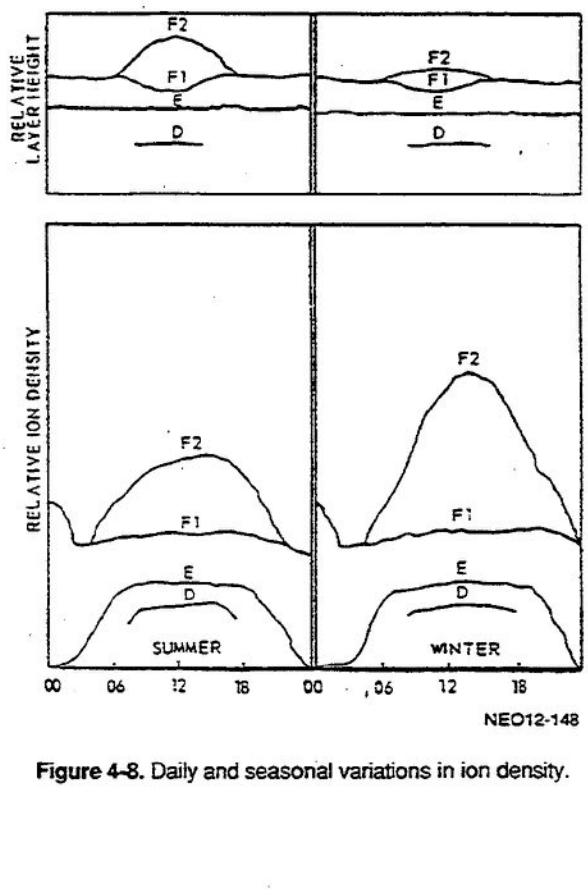

Figure 4-8. Daily and seasonal variations in ion density.

the number of distinct visible sunspot groups and adding the number of individual spots observable in the groups. For months at a time, the visible surface of the sun may be devoid of spots, so that sunspot number is zero. This often happens during times of sunspot minimum. At other times, the mean annual sunspot number has been known to rise as high as 140, with daily values running into the hundreds. These conditions occur at the maximum of the sunspot cycle. Although the time from minimum to minimum is variable, it averages around 11 years. Also, the height of the maxima and the depth of the minimum vary from cycle to cycle. The increased activity at the time of sunspot maximum is reflected in an increase in ion density of all the ionosphere layers, resulting in higher critical frequencies for the E, F1, and F2 layers and higher absorption in the D region. This lets us use higher frequencies for communication over long distances at times of sunspot minima. The increased absorption in the D region, which has the greatest effect on the lower frequencies, requires that higher frequencies be used. However, the overall effect is an improvement in propagation conditions during sunspot maxima as the critical frequencies are raised more than the absorption limits.

Twenty-seven Day. Another cycle caused by sunspot activity is the 27-day variation from the sun's rotation on its axis. As the number of sunspots changes from day to day with solar rotation, formation of new spots, or disappearance of old ones on the visible part of the sun, absorption by the D region also changes. Similar changes occur in the E-layer critical frequency. These variations cover a wide geographic range; they aren't observed at one station and not observed at others. Although day-to-day fluctuations in F2 layer critical frequencies are greater than for any other layer, they aren't generally worldwide. Because of the variability of the F2 layer, we can't predict its critical frequencies precisely for individual days. We can outline seasonal and long-term trends and geographic distribution accurately in advance. In selecting frequencies for long-distance communication, we have to allow for these fluctuations.

Irregular Variations. In addition to the more or less regular variations in the characteristics of ionosphere, a number of singular, transient effects, though unpredictable, have important bearing on propagation phenomena. Some of the more prevalent of these effects are sporadic E, sudden ionospheric disturbance (Dellinger fade), ionospheric storms, and scattered reflections. These variations are listed in table 4-2 along with their effects on the ionosphere and on radio communication and suggestions for compensating for them.

Sporadic E. The sporadic E, also known as the sporadic E layer, is an ionized cloud that appears at indefinite intervals and at a slightly greater height than the normal E layer. The nature and cause of this abnormal layer are as yet unknown. Sometimes the sporadic E consists of an extremely efficient radiating surface that reflects so much of the energy radiated from a transmitting antenna, even at 10 to 15 MHz, that reflections from the other layers of the ionosphere are blanked out completely. At other times, the sporadic E may be so thin that, although its presence can be verified by sounding, reflections from the upper layers can easily be received through it. The sporadic E layer may occur during the day or night. It occurs often enough that, from 25 to 50 percent of the time, long-distance propagation at frequencies up to 15 MHz is possible in middle latitudes. Occurrence of sporadic E is not usually simultaneous at all stations. In general, tropical stations exhibit less sporadic E than stations in higher latitudes.

Sudden ionospheric disturbance or Dellinger fade. The most startling of all the irregularities of the ionosphere and of radio wave transmission is the sudden type of disturbance manifested by a radio fadeout. This disturbance, abbreviated SID and sometimes called the Dellinger fade, comes without warning and may prevail for a few minutes or for several hours. All stations lying wholly or in part on the sunward side of the earth are affected, and at the onset of SID, receiving station operators are inclined to believe that their radio sets have suddenly gone dead. Examination of the sun during these effects has revealed that, in all cases where reliable solar data was available, the appearance of

TABLE 4-2

IRREGULAR VARIATIONS OF THE IONOSPHERE

Type Of Variation	Effect On Ionosphere	Effect On Communications	Methods of Compensation
Sporadic E Layer	Clouds of abnormal ionization occurin in the E layer or slightly above for a large portion of time each month result in abnormally high critical frequencies. Usually spotty in geographic extent and time.	Excellent transmission within normal skip distance. Occasionally, long distance communications on frequencies of 60 MHz or higher are possible.	Frequency may have to be lowered to maintain short skip communications. At times long distance communications on abnormally high frequencies are possible.
Sudden Ionospheric Disturbance SID	Unusual amount of ultraviolet radiation from solar flare results in abnormally high ionization in all layers. Ionization increase occurs with great suddenness throughout day light portion of the earth.	Normal frequencies above 1 or 1.5 MHz are rendered useless because of the high absorption in the abnormally ionized D layer. Frequencies considerably higher than normal will survive this absorption for short hops. Low frequencies may not penetrate the D layer and thus may be transmitted for long distances.	Raise working frequency above normal for short hop transmission. Lower frequency below normal for long hop transmission.
Ionospheric Storm	Usually accompanies magnetic disturbance occuring about 18 hours after SIDs. Probably both are due to abnormal partical radiation. Upper ionosphere expands and diffuses, critical frequencies below normal, and virtual hights above normal. Severest effects toward magnetic poles, decreasing towards equator. Few minutes to several hours in duration; effects disappear gradually in few days	Limits number of usable high frequencies.	Use frequencies lowe than normal, particularly in high latitude circuits.
Scatter Reflections	The ionospheric layers are not smooth. Irregularities in density and in height are normal.	Because of the irregularities in the ionosphere, the electric field at the receiver consists of several fields arriving from slightly different directions with varying phase relaationships. The result is fading of the signal resulting from cancellation and reinforcement.	Fading of short duration. No compensation required.

ionospheric disturbance was coincidental with the onset of a bright solar eruption (fig. 4-9), and its duration was the same as that of the eruption. Such an eruption causes a sudden abnormal increase in the ionization of the D region, frequently with simultaneous disturbances in terrestrial magnetism and earth currents. Such increases in D region ionization usually result in total absorption (in this region) of all frequencies above 1,000 kHz.

Ionospheric storms. An ionospheric storm is a disturbance in the ionosphere during which critical frequencies, layer heights, and absorption vary greatly from normal. These storms may last for periods of varying intensity (from several hours to several days) and usually cover the entire earth. High-frequency sky-wave transmission above approximately 1,500 kHz then shows low intensity and is subject to flutter fading. During the first few hours of severe ionospheric storms, the ionosphere is turbulent, stratification is destroyed, and radio-wave propagation is erratic. During the later stages of severe storms and during the whole period of more moderate storms, the upper part of the ionosphere is expanded and diffused. The critical frequencies are much lower than normal because of a decrease in ion density, and the virtual heights of the layers much greater so that the maximum usable frequencies are much lower than normal. It is often necessary to lower the working frequency to maintain communication during one of these storms. There's also increased absorption of radio waves during the storm. Ionospheric storms are most severe at the higher latitudes and decrease in intensity toward the equator. These storms probably are caused by abnormal particle radiation from the

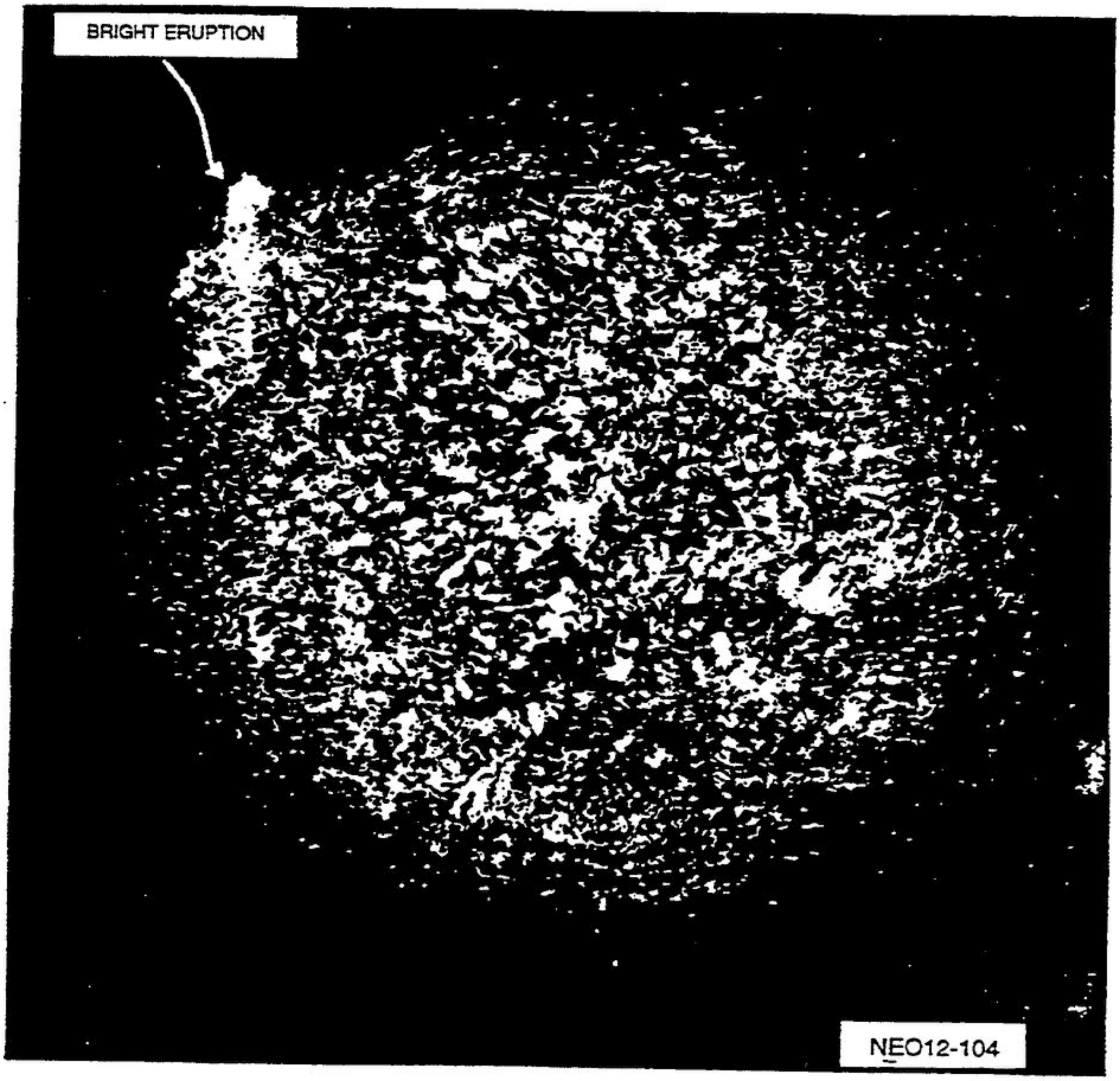

Figure 4-9. Bright solar eruption.

sun and are likely to occur during periods of great solar activity. The storms are most likely to start about 2 days after an active sunspot group crosses the center of the sun's disk.

Scattered reflections. An irregular reflection from the ionosphere occurs at all seasons and is prevalent both day and night. The ionosphere layers are irregular. We have previously mentioned the presence of ionized clouds or scattering patches at E-layer heights. You get irregular reflections from these because of the rapid change of ionization with height. A radio wave can reflect from either the top or bottom of one of these scattering clouds, and these reflections make possible the reception of signals within the normal skip zones and at frequencies much higher than those well receivable from the regular layers. The reflections may cause signal distortion and contribute to so-called flutter fading. Signals received from such reflections either may arrive from all directions or, if the transmitter operates with a highly directional antenna, may appear to come from the direction in which the antenna is pointed. The field intensity at the receiving station may be the sum of the components of several contributing radio waves of varying phase relations. Figure 4-10 shows the effect of just two of these scattered signal components arriving at a receiving station by different paths, the one by reflection from the lower surface

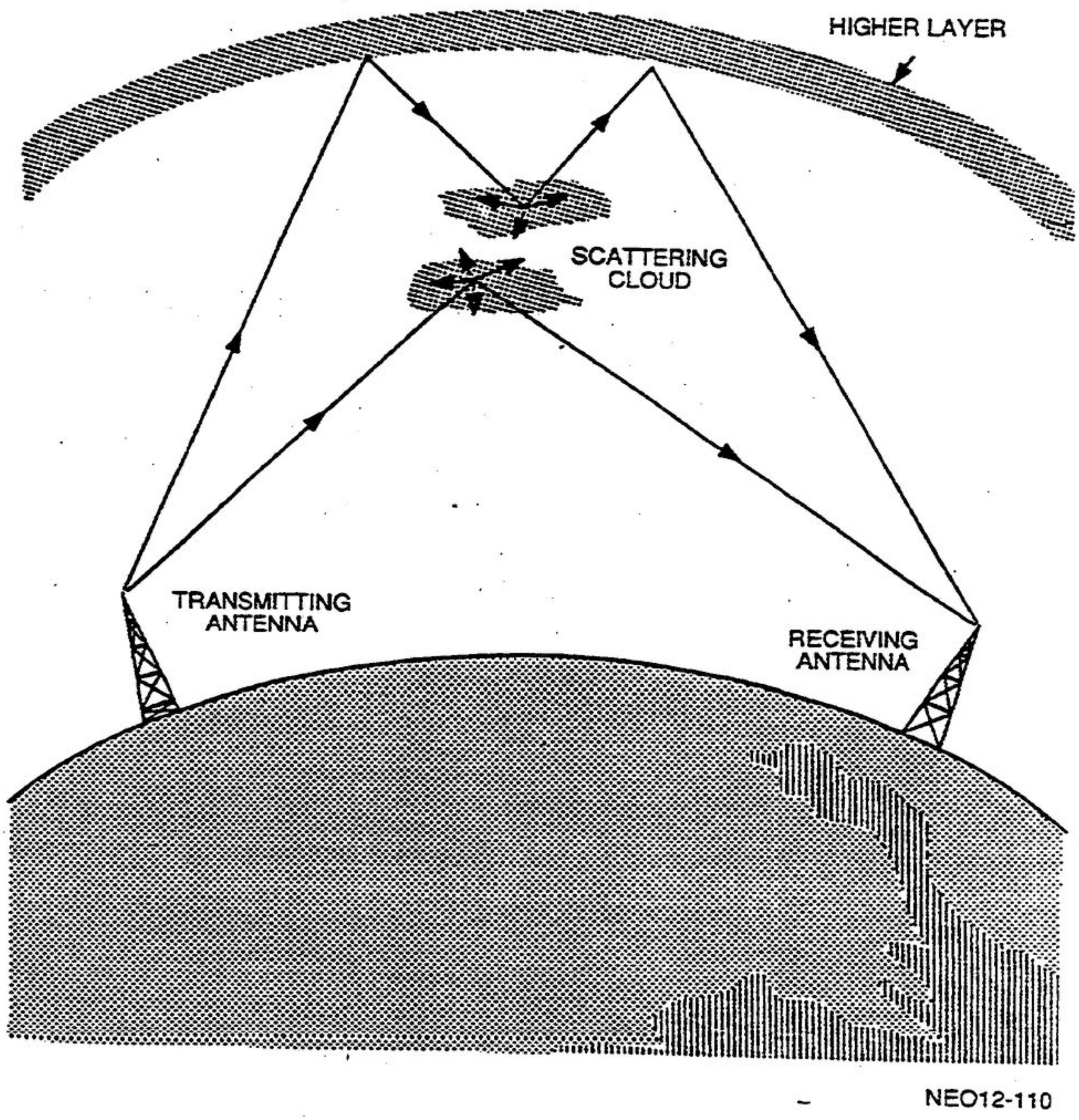

Figure 4-10. Scattering of signal components of radio waves.

of the scattering cloud of ionization and the other after rereflection from the top of this same cloud. It is obvious that, with respect to the latter signal component, there will be a time lag that either will cancel part of the signal reflected directly from the bottom surface of the scattering cloud and thus cause fading or will augment this signal depending on the phase relations of the two components at the receiving station.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

027. HF Characteristics and terms

1. Match the item in column A with the proper definition or description in column B by placing the correct letter in the space provided. Items in column B may be used once, more than once, or not at all.

Column A

___ (1) Refraction.
___ (2) Number of ionospheric layers.
___ (3) Layer D.
___ (4) Layer E.
___ (5) Layer F1.
___ (6) Layer F2.
___ (7) Skip distance.
___ (8) Cyclic variations.

Column B

a. Similar to reflection.
b. Four.
c. 70 miles from earth.
d. 45 miles from earth.
e. 100 miles from earth.
f. Seasonal and sunspot variations.
g. Highest and most highly ionized.
h. Varies with ionospheric density and antenna angle.
i. Ionized clouds.
j. Static noises.
k. 6 miles from earth.

028. How do ionized layers of the atmosphere affect radio frequencies?

1. What is the principal ionospheric characteristic that controls long-distance radio transmissions?

2. What is the meaning of critical frequency?

3. What happens to frequencies higher and lower than the critical frequency?

029. Characteristics of the critical angle in HF communications

1. What is meant by the term *critical angle?*

2. What effect does critical angle have on HF communication?

3. What is meant by the term *virtual height?*

4. How does virtual height compare to actual height of an ionospheric layer? Why?

030. Causes of regular and irregular variations of the ionosphere

1. Match the description of an ionospheric variation in column A with the types of regular variations in column B. Items in column B may be used more than once.

Column A

___(1) The complete disappearance of the D region.
___(2) Results from the sun's rotation on its axis.
___(3) Higher medium frequencies may be used during the day.
___(4) Ion density is greater in the summer.
___(5) Occurs with variations in sunspot activity.
___(6) Occurs when the sun moves from one hemisphere to another.

Column B

a. Diurnal.
b. Seasonal.
c. 11-year.
d. 27- day.

2. What is sporadic E?

3. What is a SID?

4. What effect do ionospheric storms have on radio-wave propagation?

5. What condition has occurred when a rapid change in the ionization causes irregularities in the ionospheric layers?

4-2. Propagation

Heinrich Hertz, in 1887, demonstrated that electromagnetic energy could be senqt out into space in the form of radio waves. We know, of course, that there's an induction field about any wire carrying an electric current. Another field, called the radiation field, becomes detached from the wire and travels through space to make radio communication possible.

031. How to compute wavelengths when velocity and frequency are known

Calculating Wavelength. People often illustrate waves radiating into space by comparing them to the waves formed by dropping a stone on the smooth surface of a pond. Although the analogy is not exact, it does serve a useful purpose in linking radio wave propagation with this well-known physical action. Figure 4-11 shows such an event taking place,

Figure 4-11. Formation of waves in water.

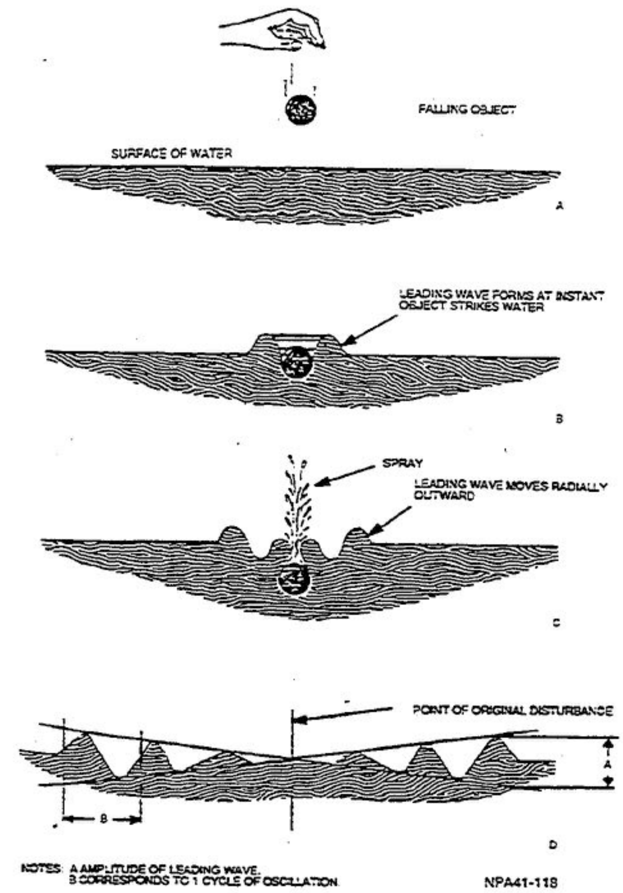

Figure 4-12. How a falling stone imparts wave motion to a wave surface.

the waves appearing to be a series of regularly alternating crests and hollows moving radially outward in all directions from the point of disturbance on the surface of the water.

Figure 4-12 presents a graphical analysis of this action, showing how the stone imparts its energy to the water surface. Part A shows the falling stone just an instant before it strikes the water. Its energy has been derived from the gravitational pull exerted on it by the earth, and the amount of this energy depends not only on the weight of the stone but on the height from which it has been dropped. B shows the action taking place at the instant the stone strikes the surface, pushing the water around it upward and outward, thereby imparting an initial velocity to the mass of water at this point of contact. In C the stone has sunk deeper into the water, which closes over it violently, causing some spray, while the leading wave has moved radially outward because of its initial velocity. An instant later (D), the stone has sunk out of sight, leaving the water agitated. Here the leading wave has continued to move outward and is followed by a series of waves of gradu- ally diminishing amplitude. Meanwhile, the agitation in the immediate vicinity of the original point of contact gradually subsides. Note that the leading wave has amplitude and wavelength (D) corresponding to one complete cycle.

Of course this isn't completely comparable with electromagnetic radiation, since a dropped stone doesn't impart continuous wave motion to the water surface, but a motion we call damped oscillation. Suppose, though, that we attached a string to the stone of figure 4-13 to control its upward and downward motion from above. Before the event shown in figure 4-12,C, takes place, the stone is pulled sharply upward after its initial fall to the position shown in figure 4-12,A, and then lowered again to position shown in figure 4-12,B. These upward and downward motions reinforce the diminishing amplitude of the succeeding waves and, if the timing and the downward force of the stone are exactly right, waves of constant amplitude continue to travel outward from the disturbing source at a velocity, V, determined by the product of the frequency, f, of the downward motion (those that impart energy to the medium) multiplied by the measured wavelength, W, is used for the length of waves). Thus, V=Wf. If you know the frequency and the velocity of propagation, you can determine the wavelength:

$$\lambda = \frac{V}{f}$$

Like light and radiant heat, radio waves are a form of radiant energy propagated through space at nearly 300,000,000 meters (186,000 miles) per second. Thus, a wave alternating at a frequency of 1,000,000 Hz has a wavelength of approximately 982 feet. Since:

$$\lambda = 0.186 \text{ mile}$$

Converting to feet:

$$\lambda = 0.186 \times 5280$$
$$\lambda = 982 \text{ feet}$$

Then,

$$1/2 \text{ wavelength of } \frac{\lambda}{2} = 982 \div 2 = 491 \text{ feet}$$

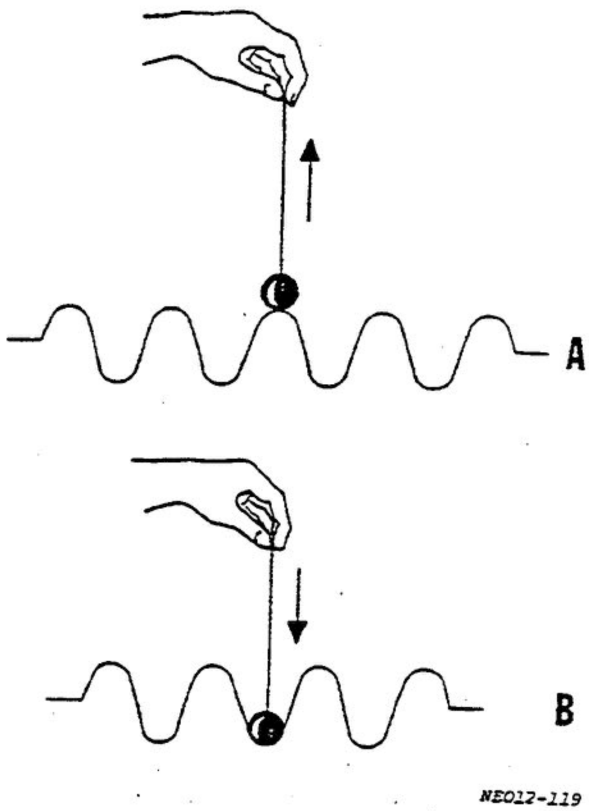

Figure 4-13. Formation of continuous waves in water.

032. Characteristics of propagation

Free-Space Propagation. The same type of wave action we just discussed takes place at the antenna of a radio transmitter, the medium in this case being the free space about the antenna instead of a water surface, and the disturbing source a fluctuating induction field in place of a moving stone. The wavelength formula holds for this wave motion and for all types of wave motion, whether it be of water waves, sound waves in air, or light and electromagnetic waves in free space. However, the term *free space* is used to denote the unobstructed medium through which radio waves travel. Free space implies that the source (transmitter and antenna in the case of radio waves) is surrounded by nothing except ordinary air or vacuum. The presence of trees, hills, lakes, or other aspects of the local terrain modifies (in each case) the effective radiation of an electromagnetic wave. And, although the surface of the earth, or the air near its surface, is not considered to be free space, the formula still holds true.

Sky-Wave Propagation. There are two principal ways radio waves travel from a transmitter to a receiver—ground waves that travel directly from the transmitter to the receiver and sky waves that travel up to the electrically conducting layers of the earth's atmosphere (the ionosphere) and are reflected back by them to the earth. Since long-distance radio transmission takes place mainly by sky waves, we'll spend the rest of this lesson discussing sky waves.

Sky-wave propagation refers to radio transmissions that use ionospheric reflections to provide signal paths between transmitters and receivers. Sky-wave transmission, being by far the most important method for long-distance radio communication, presents many problems that can be solved adequately only through complete understanding of the principles. A typical question in sky-wave propagation is whether the ionosphere will support (reflect) a radio wave of a particular frequency and whether the received signal will be strong enough at the receiver to be heard above the noise level present at the receiver. The answer can be given only after considering the particular path the radio wave will take in traveling from transmitter to receiver, whether the frequency of the radio wave lies between the limits determined by the maximum usable frequency and the lowest useful high frequency for the particular signal path, and the signal's field strength at the receiver (received signal strength).

033. What affects radio waves in free space?

Radio Wave Characteristics. Figure 4-14 illustrates some of the many possible paths of radio waves from a transmitter to a receiver as transmitted by reflection from an electrically conducting layer of the ionosphere. Note that some of the components of the entire wavefront, which in this case are assumed to be of too high a frequency for reflection by the ionized layer, pass on through and are lost in outside space, unless they happen to be reflected from some higher layer that has a greater degree of ion density. Other components of the wave, which are assumed to be of the correct frequency for reflection from the ionosphere layer, are returned to earth. These components of the wave provide communications. Note also that the *skip distance* is that distance from the transmitter at which the ion density of the layer will just support reflection. The *skip zone* and its relation to the ground wave are shown in figure 4-15. When the skip distance becomes less than the inner limit of the skip zone, both the sky wave and the ground wave may have nearly the same field intensity but a random relative phase. When this occurs, the field of the sky wave successively reinforces and cancels that of the ground wave, causing severe *fading* of the signal. Note the distinction between the terms *skip distance* and *skip zone*. For each frequency (greater than the critical frequency) at which reflection from an ionosphere layer takes place, there is a skip distance that depends only on the frequency and the state of ionization. The skip zone, on the other hand, depends on the extent of the ground-wave range and disappears entirely if the ground-wave range equals or exceeds the skip distance.

Sky-wave modes. The distance at which the wave returns to the earth depends on the height of the ionized layer and how much the paths bends while traversing the layer. The latter depends on the frequency of the wave as compared to the ion density of the layer required to refract or bend the wave. When it returns to the earth's surface, part of the energy enters the earth and is rapidly dissipated. Part is reflected back into the ionosphere where it may be reflected downward again at a still greater distance from the transmitter. This means of travel, in hops, by alternate reflections from the ionosphere and from the surface of the earth, may continue, enabling transmission to be received at long distances from the transmitter. Figure 4-16 illustrates this means of travel for paths involving one and two reflections from the ionosphere (single- and double-hop modes). Figure 4-17 further illustrates this means of travel and reflection from different layers, with the layers represented by lines for simplicity. It also relates the heights of the various ionized layers to actual distances along the earth's surface.

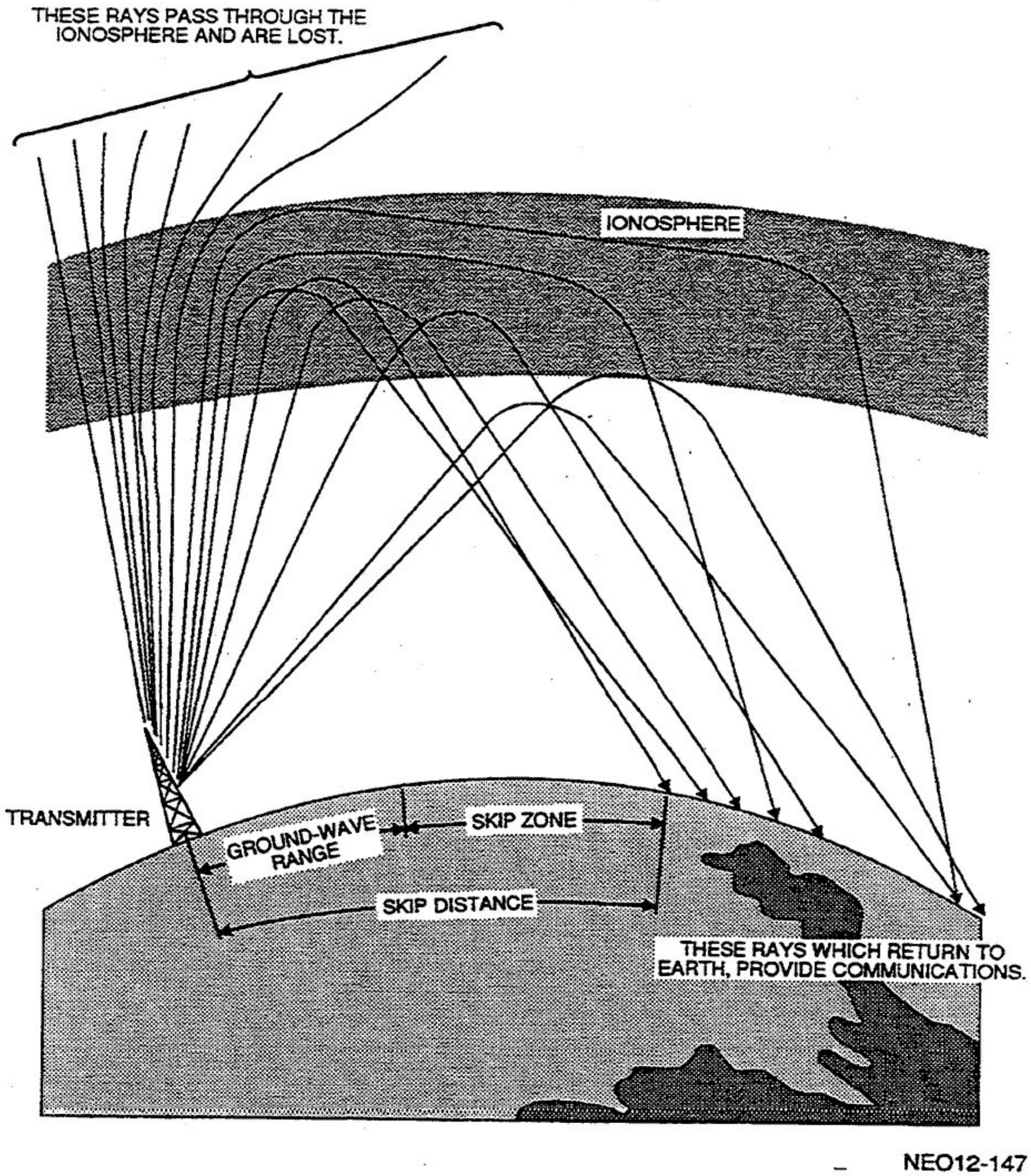

Figure 4-14. Variations sky-wave transmission paths.

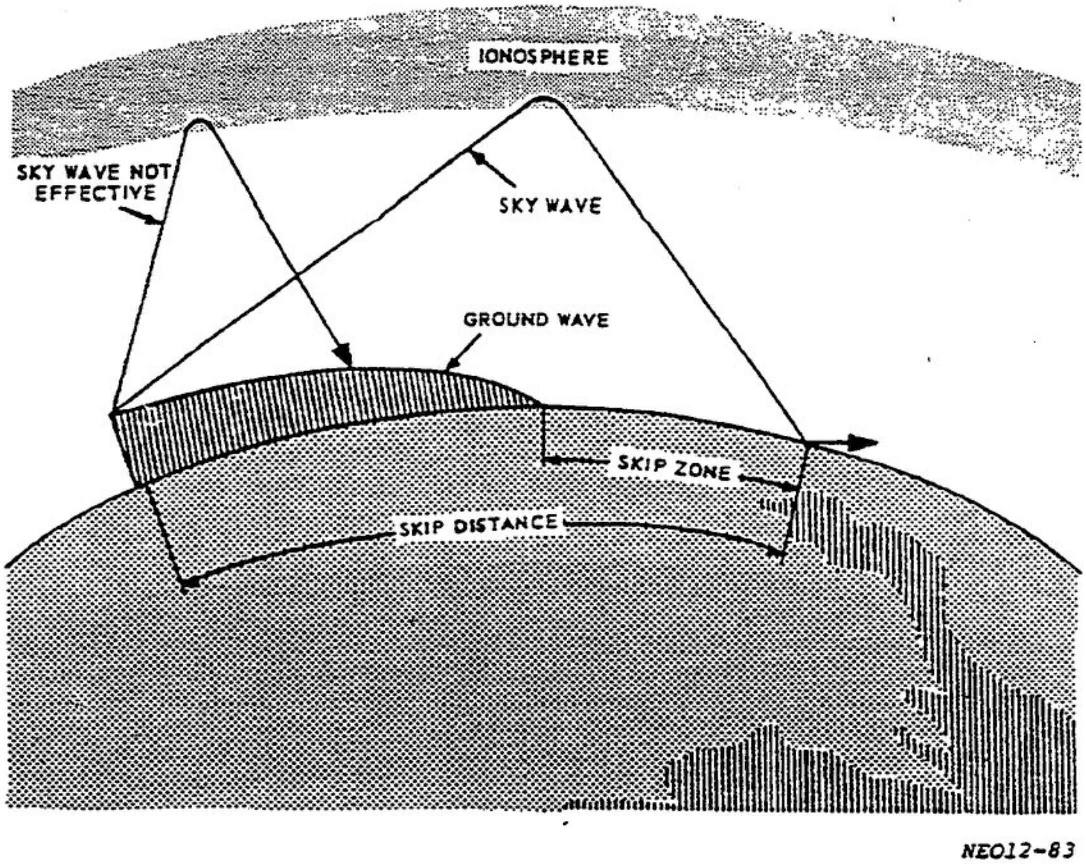

Figure 4-15. Skip zone.

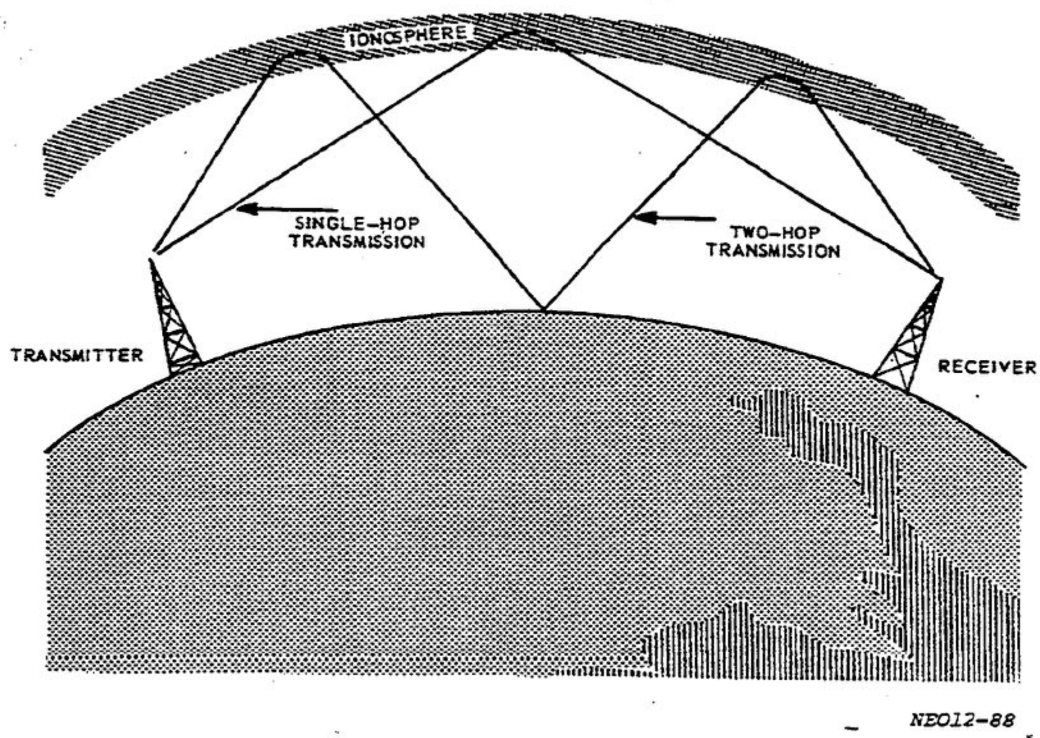

Figure 4-16. Modes of sky-wave transmission.

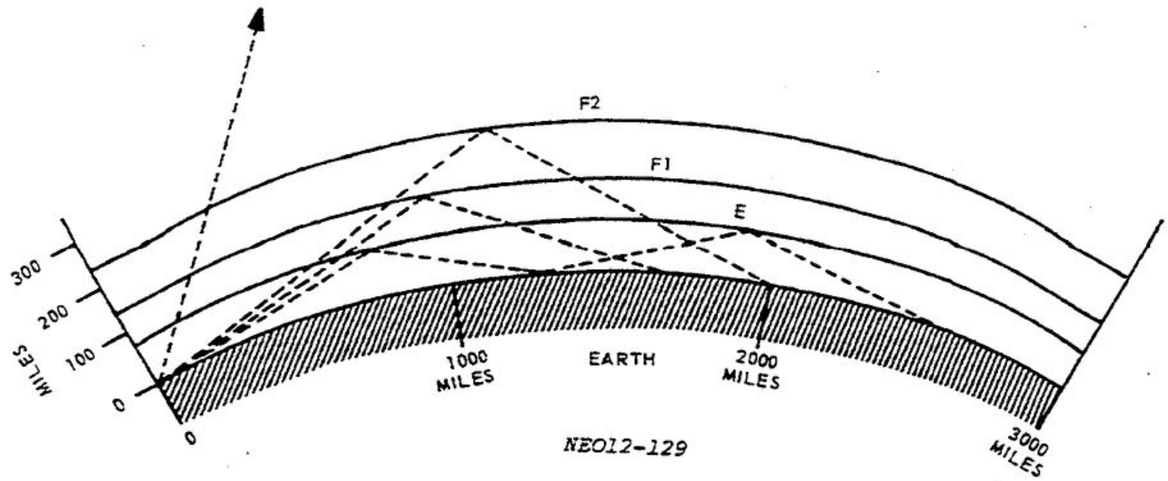

Figure 4-17. Relating reflected waves to distance.

Frequency. As we saw in discussing the ionosphere, the higher the frequency of a wave, the less it is refracted by a given ion density. Thus, if the angle of incidence of the wave with the ionosphere is fixed and the frequency increased, the minimum distance between the transmitter and the point of return of the wave to the earth increases slightly. Figure 4-18 shows three separate waves of different frequencies entering at the same angle an ionospheric layer of a given density. Here the 100-MHz wave is not refracted enough by the ionosphere and is not returned. The 5- and 20-MHz waves are returned, but the 20-MHz wave, being refracted less than the 5-MHz wave, returns at a greater distance.

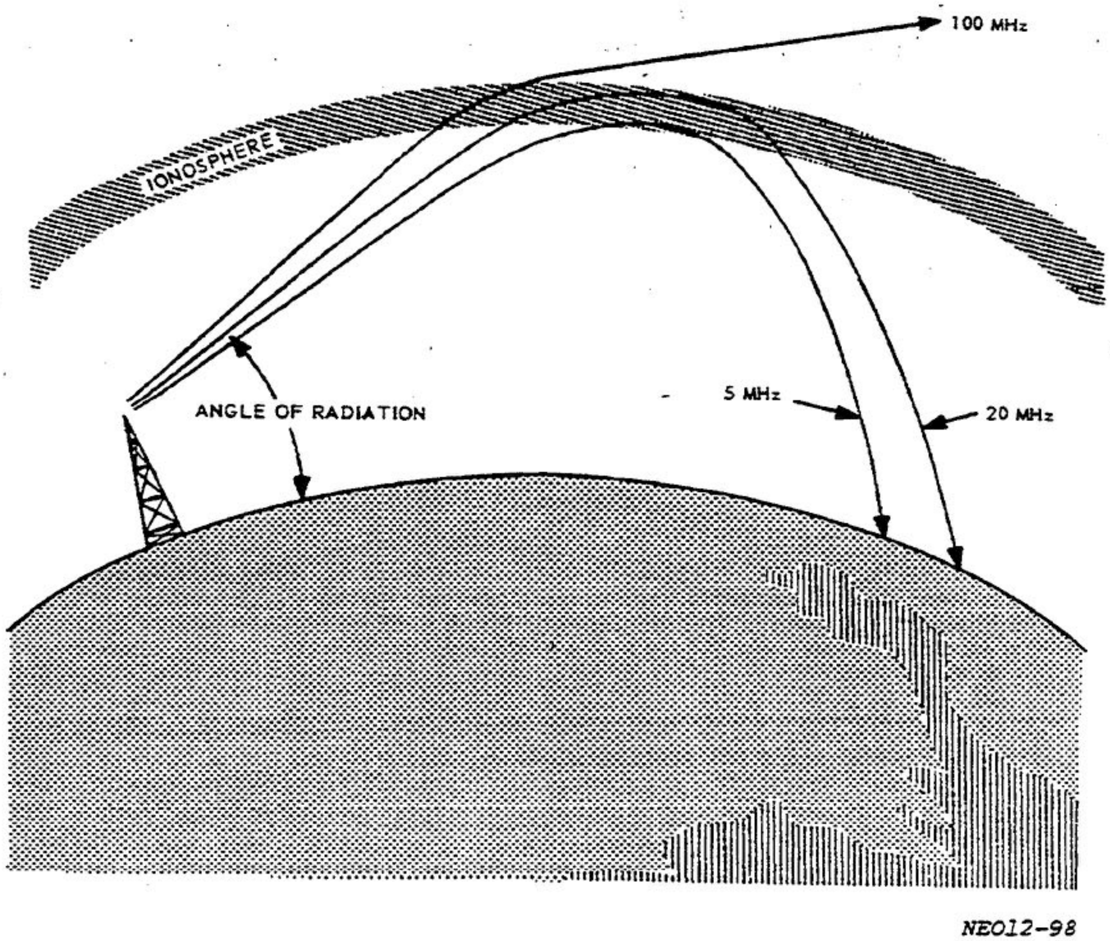

Figure 4-18. Frequency vs distance for returned waves.

Incident angles. For a radio wave of a particular frequency and for an ionized layer of a particular density of ionization, there is an angle of incidence, called the critical angle, at which the wave is reflected and returns to earth near its minimum or skip distance. The critical angle of a given wave sometimes is defined as the angle at which the wave is propagated horizontally within the ionospheric layer and, therefore, does not return to earth. These two definitions are actually the same since the angle at which the wave first returns and the angle at which it just does not return are the same. Also, the critical angle is measured (for purposes of calculation) between the wave path at incidence with the ionosphere and a line extended from the ionosphere to the center of the earth.

Figure 4-19 shows a given wave at various angles of incidence with the ionosphere and its resultant variation in refraction or reflection. Note that, at angles of incidence larger than the critical angle, the wave is not sufficiently refracted in the ionosphere and escapes into space. As the angle of incidence decreases below the critical angle, the wave returns to earth at *decreasing* distances from the transmitter until a point of minimum distance, the skip distance, is reached. Then, as the angle of incidence continues to decrease, the distance between the transmitter and the point at which the wave returns *increases* and continues to increase for smaller angles of incidence. Also, any high-angle wave that returns beyond the skip distance is attenuated greatly, and the skip distance remains as the point at which the wave first is returned in strength to the earth.

This irregular variation of the return distance with regular variation of the incident angle results from the fact that the ionosphere acts principally as a refracting medium for the larger angles of incidence. If the angle of radiation of the transmitted wave can be controlled, the smaller angles of radiation will result in greater distance of communication. Figure 4-20 shows sky waves of a fixed frequency propagated at the critical angle and at various smaller angles. Note that the smaller the radiated angle, the greater the distance at which the wave is returned to earth.

Don't confuse the critical angle for a given frequency with the critical frequency for a given layer of the ionosphere. The critical frequency is the highest frequency a given density of ionization will return directly to the earth when it is propagated at a vertical angle (at 90° to the ionosphere). Although a vertically propagated frequency higher than the critical frequency does not return to the earth, it is possible that this same frequency propagated at a different angle will return. In other words, frequencies higher than the critical frequency may be used if the angle of incidence is less than 90°. Figure 4-21 illustrates this relationship between the angle of incidence and the use of frequencies higher than the critical frequency for communication.

034. How to determine the best operating frequency

Maximum Usable Frequency (MUF). For any given ionized layer of fixed height and ion density, and for a transmitting antenna with a fixed angle of radiation, there is a frequency (higher than any other) that will return to the earth at a given distance. This is the maximum usable frequency for that distance. Moreover, it is always higher than the critical frequency because the angle of incidence is less than

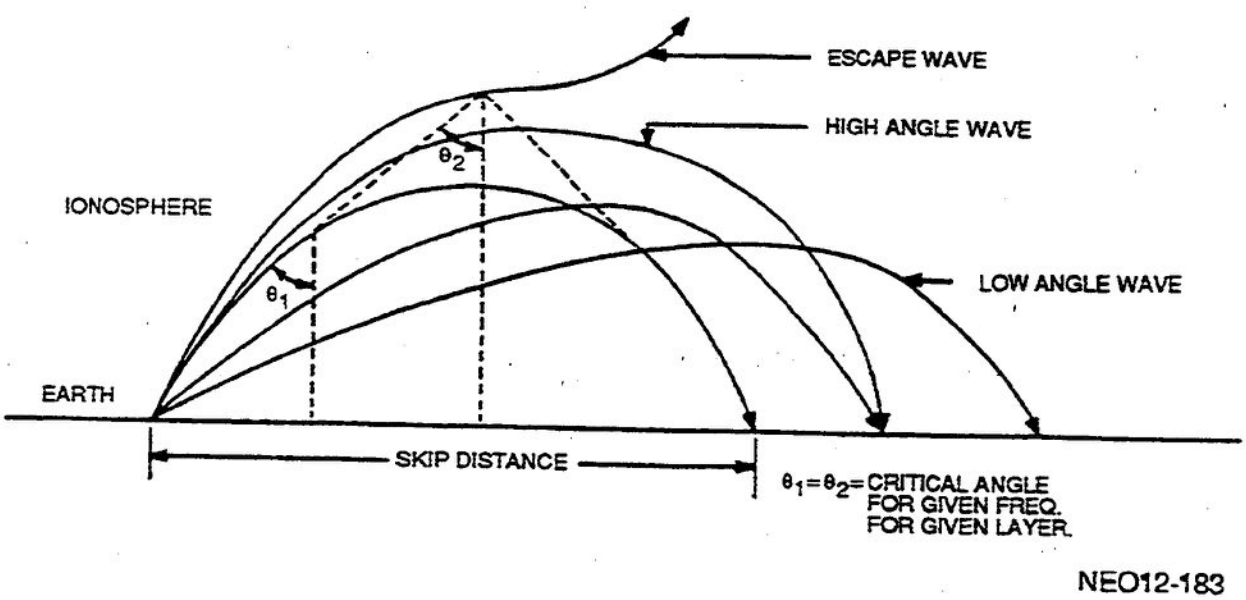

Figure 4-19. Incident wave paths for a plane earth and a plane ionosphere for a fixed frequency.

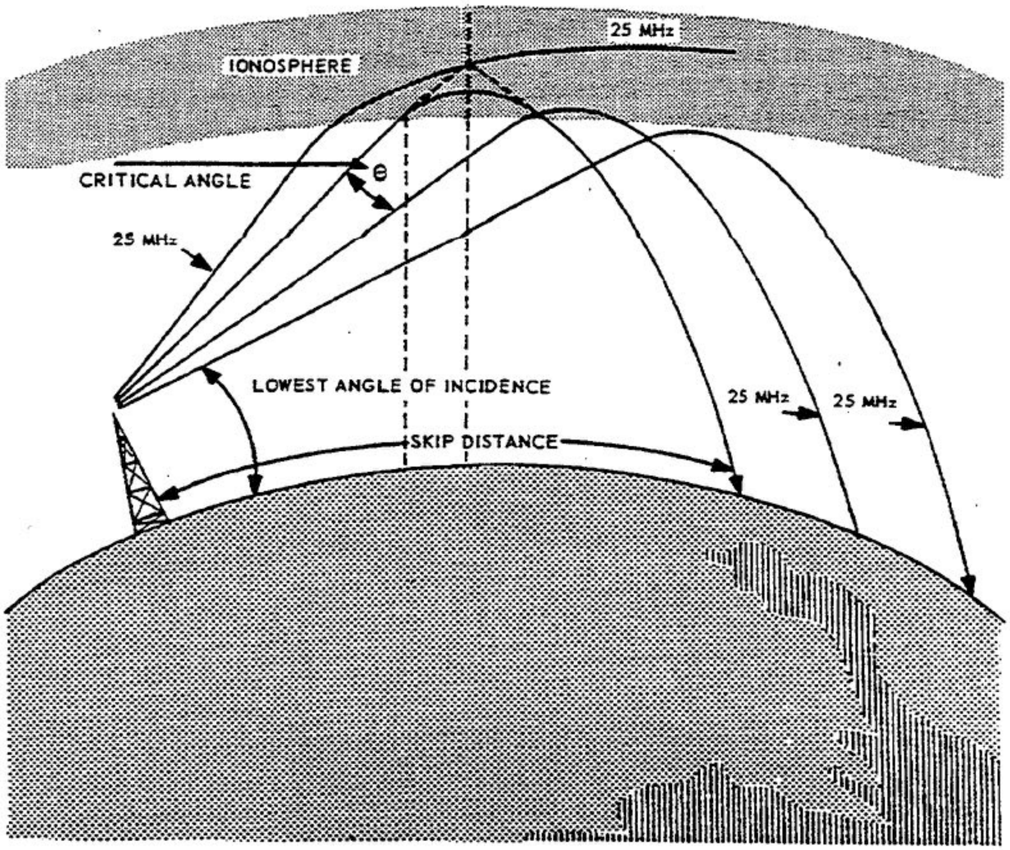

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Figure 4-20. High-frequency wave at various angles.

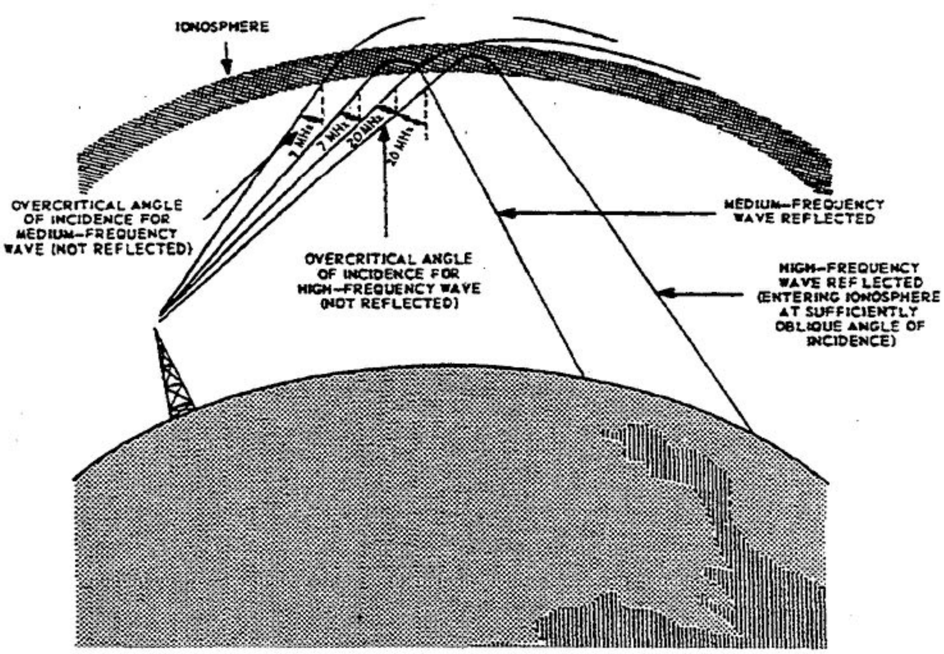

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Figure 4-21. Relation of angle to usable frequency.

90°. Thus, for any given great circle distance along the earth, there is a maximum usable frequency—the highest frequency that will be reflected from a given layer of the ionosphere and will return to the earth at the great circle distance. If the distance between transmitter and receiver increases, the maximum usable frequency increases. In other words, the greater the transmission distance, the higher the maximum usable frequency.

In selecting the proper operating frequency for sky waves that travel along a fixed radio path, the maximum usable frequency is perhaps the most important factor to consider. If the operating frequency is above the maximum usable frequency, the wave is said to escape, since it then will not be reflected by the ionosphere layer but will pass on through. On the other hand, if the operating frequency is decreased below the maximum usable frequency in the daytime, the wave becomes increasingly attenuated. In the HF range, the lower the frequency the more wave energy is lost through ionospheric absorption. Hence it's usually desirable for transmission frequency to be as near the MUF as possible. There's a direct relationship between the MUF and the condition of the ionosphere, time, and angle of radiation, as shown in figure 4-22. Thus, you can predict mean values of maximum usable frequency for propagation over any path

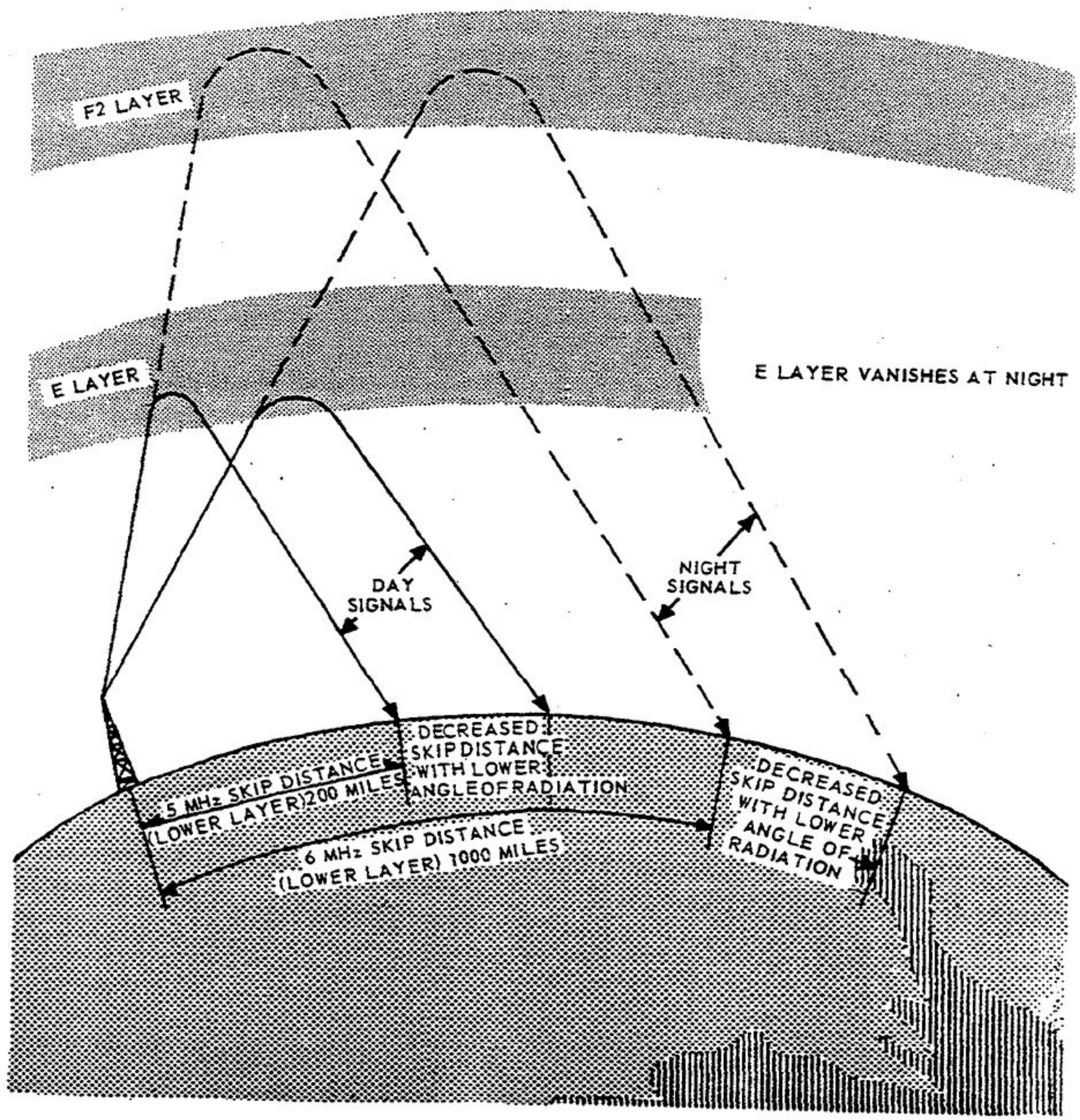


Figure 4-22. Relationship of distance, time, angle, and frequency.

for any time in any future month. Since the solution entails using world contour charts and complicated procedures, it's beyond the scope of this course.

If the density of the ionosphere is such that the maximum usable frequency is near the critical frequency, the wave is excessively retarded in the ionized layer and, because of the effects of the earth's magnetic field, splits into two components known as the *ordinary wave* and the *extraordinary wave*. These components, shown in figure 4-23, are usually of different polarization and phase. The critical frequency for the extraordinary wave is higher than that for the ordinary wave, the difference varying with the intensity of the earth's magnetic field, which changes with geographic position. Since the critical frequency for the ordinary wave is lower than that for the extraordinary wave, a layer of given ion density bends the ordinary wave less than it does the extraordinary wave. From another point of view, the ordinary wave, which obeys the laws of simple refrac- tion, must penetrate a greater distance into the layer than the extraordinary wave, which responds to both refraction and reflection. Figure 4-23 shows these two waves in conjunction with the MUF. This effect is important only for F layer transmission, causing interference fading. The extraordinary wave does not affect radio reception.

Lowest Usable Frequency (LUF). Ions in the upper atmosphere not only cause bending and the return to earth of a radio wave of sufficiently low frequency, but also cause part of the wave energy to be absorbed. The collisions of electrons with neighboring molecules of air reduce the intensity of the radio wave below that resulting from the normal spreading of the wavefront as it travels out from the transmitter. This absorption process is also important in ionospheric radio transmission. During the day absorption takes place mainly in the D region of the ionosphere. Electron densities in this region are considerably less than in the higher regions, but increased atmospheric density increases

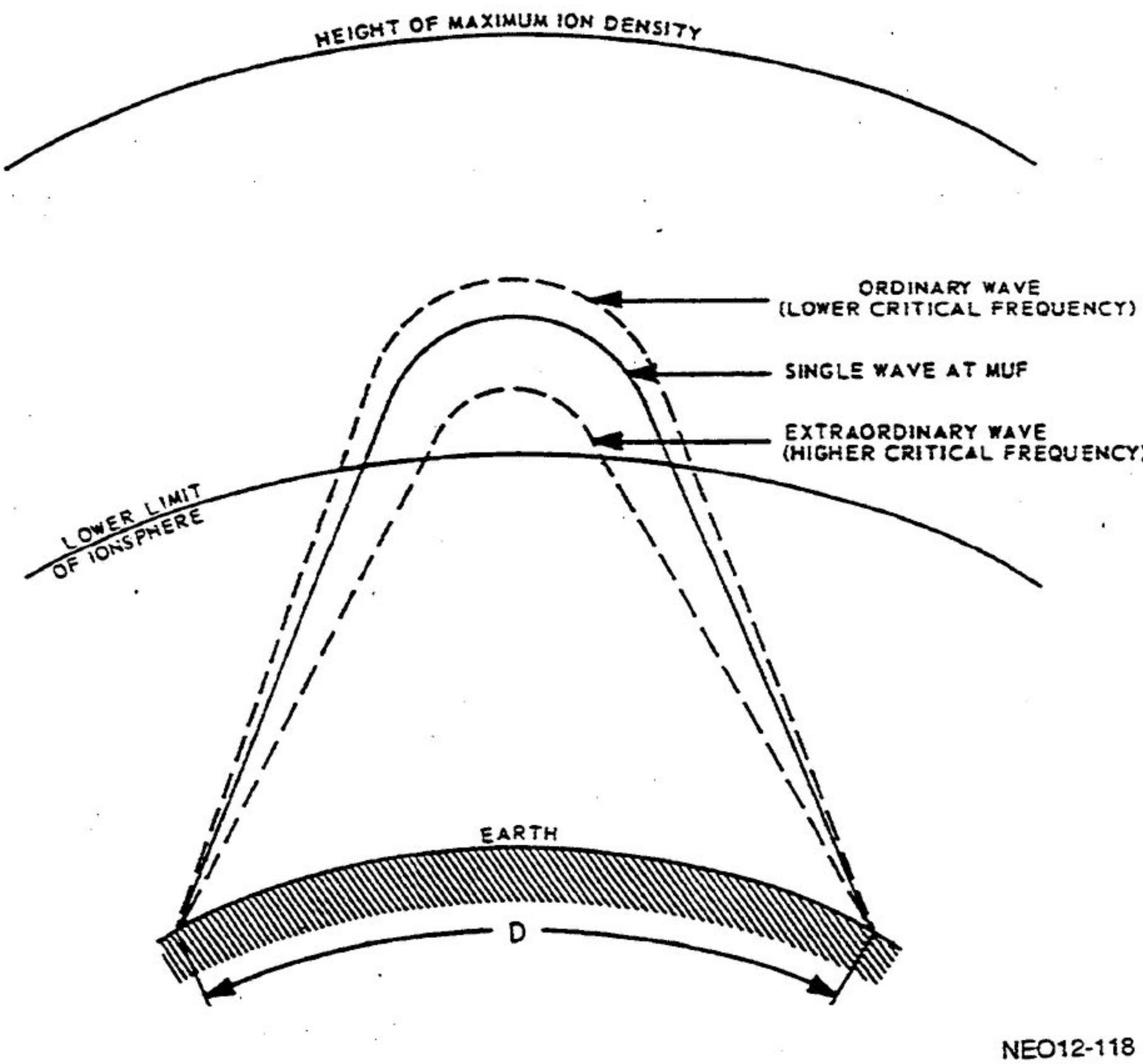


Figure 4-23. Ordinary and extraordinary waves.

the number of collisions between electrons and molecules of air and more than compensates for the scarcity of electrons. During the night ionization and absorption in the D region become negligible. However, there is some absorption for frequencies near the MUF of the F2 layer because waves at these frequencies are retarded long enough for appreciable energy loss to take place in spite of the relatively small number of collisions. Such absorption is called *deviative* absorption because it occurs in conjunction with retardation, which bends the waves. Absorption that takes place even though the wave is not appreciably retarded is called *nondeviative* absorption. The absorption in the D region is largely nondeviative.

At certain transmission frequencies, radio waves penetrating into the ionosphere, primarily in the D region and in the lower part of the E region, lose some of their energy by absorption. Generally speaking, the higher the frequency used, up to the MUF, the less the total absorption will be and the more satisfactory the level of communication will be. Absorption is maximum for frequencies of about 500 kHz to 2 MHz in the daytime, and it decreases for both higher and lower frequencies at night. Thus, for frequencies above about 1 MHz, the strength of the received sky waves will, in the daytime, increase with frequency (corresponding to decreasing absorption). Finally, a frequency will be reached for any given sky-wave path where the strength of the received signal just overrides the noise level. This frequency is called the LUF. Frequencies lower than the LUF are absorbed to such an extent that they are too weak for useful communication. However, the LUF depends on the power of the transmitter as well as on the distance concerned. At night, the noise level increases with decreasing frequency so that, as the frequency is lowered, the signals become weaker with respect to the noise and the LUF eventually is reached. Thus, the *lowest usable frequency* may apply to either day or night transmission.

Summary of Variable Frequency. Assuming constant ionospheric conditions, a constant distance, and single-hop transmission:

a. Frequencies considerably below the MUF will be attenuated greatly by nondeviative absorption.

b. Frequencies somewhat below the MUF will be reflected as ordinary and extraordinary waves, either or both of which may be attenuated greatly by deviative absorption.

c. Frequencies near the MUF will be reflected as ordinary and extraordinary waves, both of fair strength.

d. Frequencies at the MUF will be received in the greatest possible strength as one wave.

e. Frequencies above the MUF will escape and not be received, except as scattered waves.

Summary for Variable Distance. Assuming constant ionospheric conditions, a fixed frequency, and single-hop transmission, it can be said that:

a. At short distances, a wave will skip and not be received except, of course, as a ground wave.

b. At just a certain distance, called the skip distance, the wave will be received as one wave and at its greatest strength.

c. At a greater distance, a wave will still be received but as an ordinary and extraordinary waves, with resultant facing because of random polarization.

d. At still greater distances, the ordinary and extraordinary waves will be received, but either or both will be attenuated considerably by deviative absorption.

e. At even greater distances, the wave will be attenuated greatly by both deviative and nondeviative absorption.

NOTE: Radio waves of fixed radiation angle are receivable at distances greater than the skip distance, but as this distance is increased appreciably, increased attenuation results.

Frequency of Optimum Traffic (FOT). The MUF could be used for stable communications except that it doesn't have a safety factor to take care of small unpredictable changes in the ionosphere. For example, a variation in the height of the layer would cause the point of contact the returning wave makes with the ground to sweep back and forth. Because of these rapid changes, a receiver placed at the extreme edge of the zone in which the sky waves strike the earth could not be depended on for reliable communication. To ensure that the receiving point will always be within the sweep of the returned wave, a frequency slightly lower than the monthly median value of the MUF is selected. This effectively locates the receiving point just inside the edge of the receiving zone. This lower frequency was formerly called the optimum working frequency (OWF), but is now more commonly called the *frequency of optimum traffic*. The FOT is 85 percent of the monthly median value of the MUF.

For any given transmission path, frequencies above the FOT cannot be relied on for constant communication. Therefore, frequencies below the FOT are selected. These frequencies fall into a band between the FOT and the LUF. The LUF is the frequency at which the received signal just exceeds the required signal for successful communications. A number of factors establish the LUF, and determining it is usually the most difficult problem in frequency prediction and selection.

Ionospheric absorption. As a signal passes through the D layer, some of its energy is absorbed. This effect is most noticeable in the auroral zone. Ionospheric absorption may be determined by the use of published contour charts in radio-wave propagation manuals.

Noise. Atmospheric or manmade noise in the vicinity of the receiving point is an important factor in determining the LUF. Most atmospheric noise is generated in and propagated from the tropical zones.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

031. How to compute wavelengths when velocity and frequency are known

1. What is the formula for determining wavelength when velocity and frequency are known?
2. Velocity is 186,000 miles per second. Frequency is 5 MHz. Calculate the wavelength, lambda (λ).

032. Characteristics of propagation

1. Explain the term *free space*.
2. What are some factors that can alter the radiation of waves in free space?
3. What is sky-wave propagation?
4. What factors must be considered in propagating electromagnetic waves through the ionosphere?

033. What affects radio waves in free space?

1. What effect does the degree of ion density of an ionospheric layer have on radio wave propagation?
2. Can an electromagnetic wave be reflected by the ionosphere more than once? Why?
3. What effect does increasing the frequency of a transmitted wave have on the ionosphere?
4. What should be done if a wave is not being refracted by the ionosphere?
5. What is the difference between the critical frequency and the critical angle?

034. How to determine the best operating frequency

1. How does maximum usable frequency relate to ionospheric propagation?

2. What effect does transmission distance have on MUF?

3. What is the relationship between ionospheric layer density and MUF?

4. Explain lowest usable frequency.

5. Name two variables that must be considered when determining the LUF.

6. When transmitting frequencies above the MUF, what type of reception can be expected?

7. Assuming the frequency and the ionosphere are constant, at what distance will signal strength be at its greatest?

8. What is the relationship between MUF and FOT?

9. What condition prevents the use of the maximum usable frequency at all times for high-frequency operation?

10. Why is the FOT always lower than the MUF?

11. What band of frequencies are relied on for ionospheric propagation?

4-3. Antennae

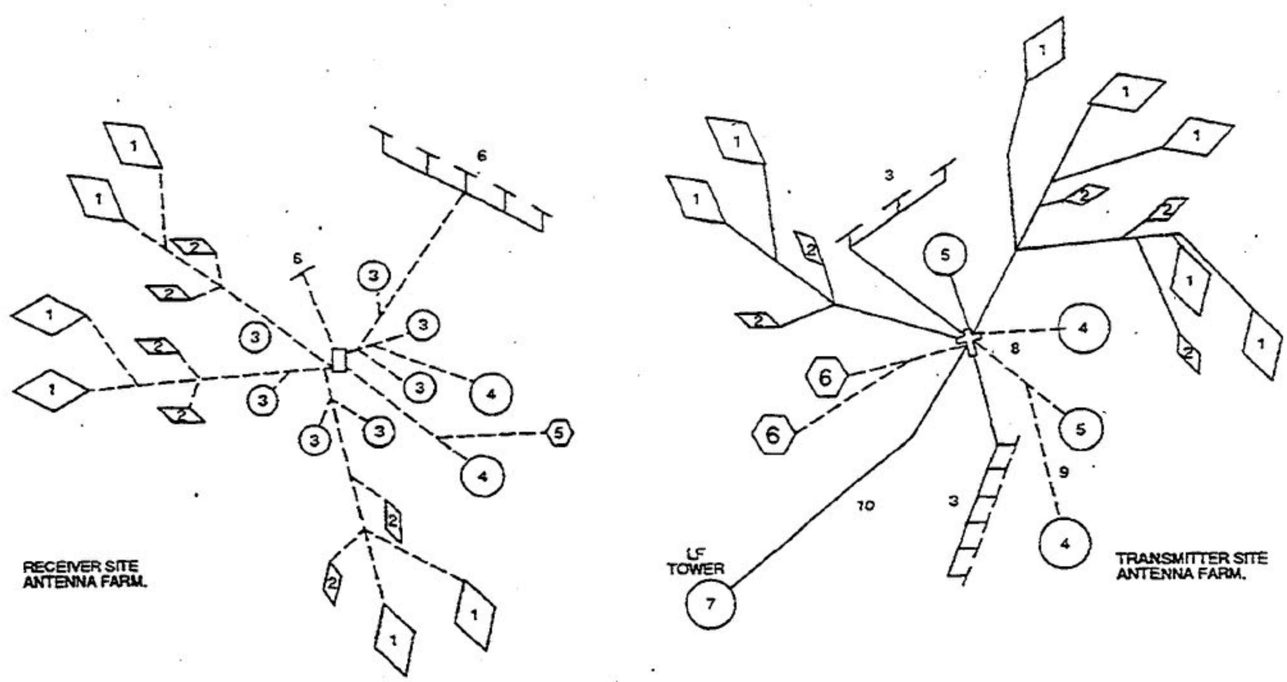
Since the technical controller normally exercises greater control over the selection of receiving antennae than transmitting antennae, we base our discussion on receiving antennae. As a general rule, a receiving antenna is the same type as that used by the distant-end transmitting station. Each remote site maintains its own antenna farm, the receiver sites being considerably larger than the transmitter sites due to the widespread use of space diversity. Figure 4-24 illustrates both transmitter and receiver site antenna farms. Since the various types and variations number in the hundreds, we discuss only the more commonly used types.

035. Radiation characteristics of common antennae

Doublet. A doublet antenna, also known as a dipole, consists of two elements, normally comprising a total of one-half wavelength in relation to its operating frequency. Conductors from a two-wire transmission line connect to the elements, one wire to each. An insulator separates the two elements. A doublet antenna is usually installed parallel to the ground and attached with insulators to masts as high as 35 feet. It radiates mainly from the center, on both sides, at right angles to the direction of the wire. If the antenna runs north and south, it will send out the strongest signal to the east and west. A doublet can be used for both receiving and transmitting, as can most types of antennae.

For many reasons, the doublet has long been the workhorse of the communications field. Its physical length is easily calculated, and it is easily erected, especially when it is to be used for high frequencies. The greatest directivity is broadside-perpendicular to the antenna. Figure 4-25 illustrates a typical doublet antenna. Note that figure 4-25.A, shows the antenna as being center fed and figure 4-25.B, shows it as being end fed. Also, note that both elements of part A total one-half wavelength while the longer element of part B is cut to one-half wavelength. Energy radiated from the short element of an end-fed doublet is negligible.

Long-Wire Antenna. A long-wire antenna (fig. 4-26.A) is any single-element radiator that is one or more wavelengths and radiates more power in the directions off the



1. DIVERSITY RHOMBIC ANTENNAS, MEDIUM FREQUENCY
2. DIVERSITY RHOMBIC ANTENNAS, HIGH FREQUENCY
3. DISCONE ANTENNAS, GROUND-TO-AIR
4. ROTATABLE LOG PERIODIC ANTENNA, GROUND-TO-AIR BACKUP
5. CONICAL MONOPOLE, GROUND-TO-AIR
6. HALF-WAVE ANTENNAS

1. RHOMBIC ANTENNA, MEDIUM FREQUENCY
2. RHOMBIC ANTENNA, HIGH FREQUENCY
3. HALF-WAVE ANTENNAS
4. INVERTED DISCONE ANTENNA
5. ROTATABLE LOG PERIODIC ANTENNA
6. CONICAL MONOPOLE ANTENNA
7. LOW FREQUENCY TOWER
8. EQUIPMENT BUILDING
9. UNDERGROUND COAX
10. OPEN-WIRE TRANSMISSION LINE

TG-B276

Figure 4-24. Transmitter and receiver site antenna farms.

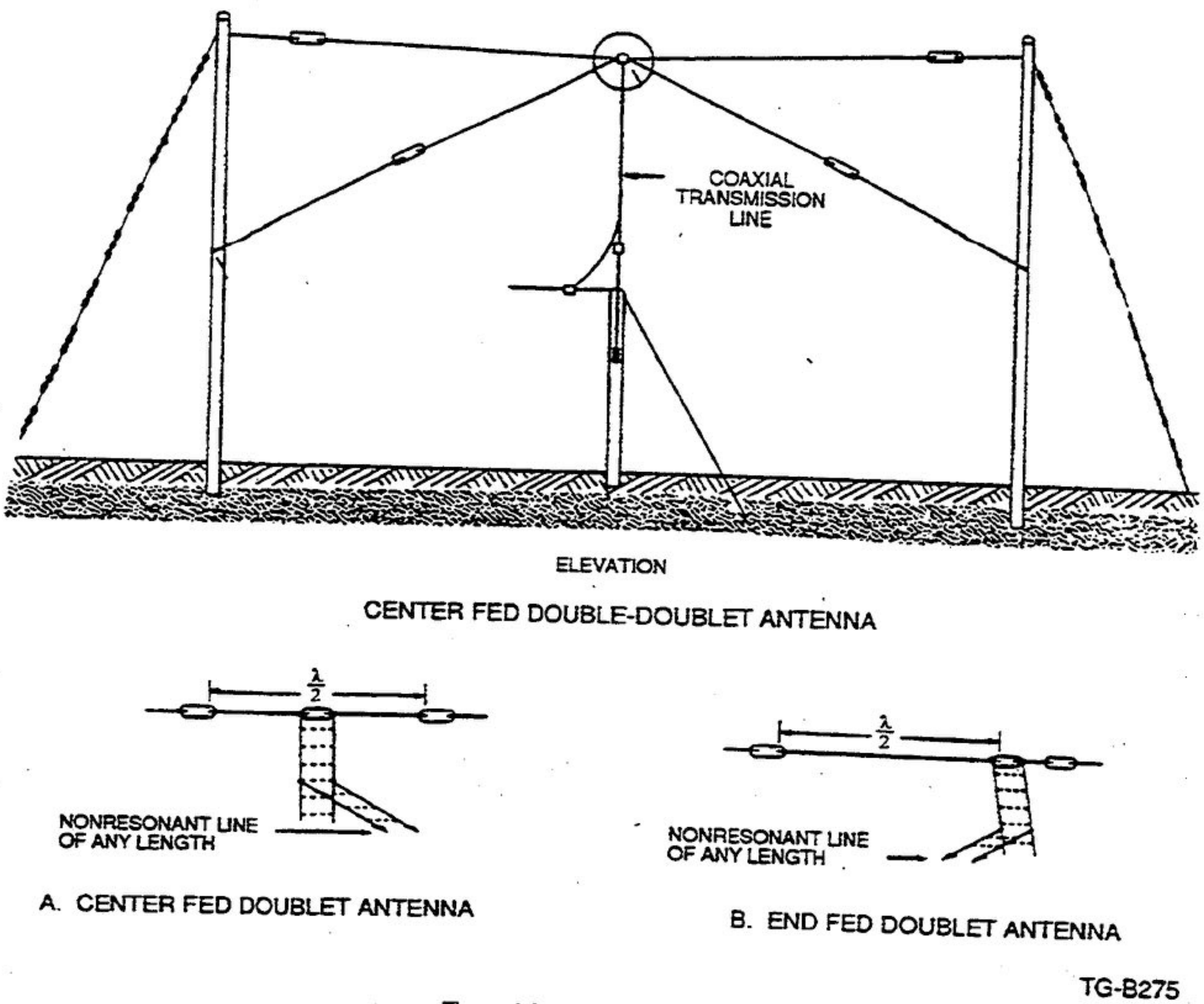


Figure 4-25. Doublet antennae.

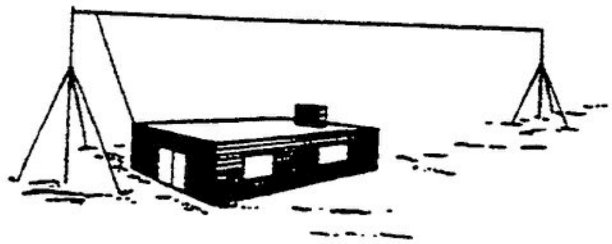
ends than a half-wave antenna radiates broadside. The directional pattern of a long-wire antenna consists of a number of lobes radiating at an angle from the axis of the wire. Increasing the length of the antenna reduces the angle that the major lobes make with the axis and increases the power in the major lobes. Figure 4-26,B, shows the effect of antenna length on the angle of the radiation lobes. Terminating a long-wire antenna in a resistance equal to the antenna's characteristic impedance gives a pattern that's unidirectional toward the terminated end.

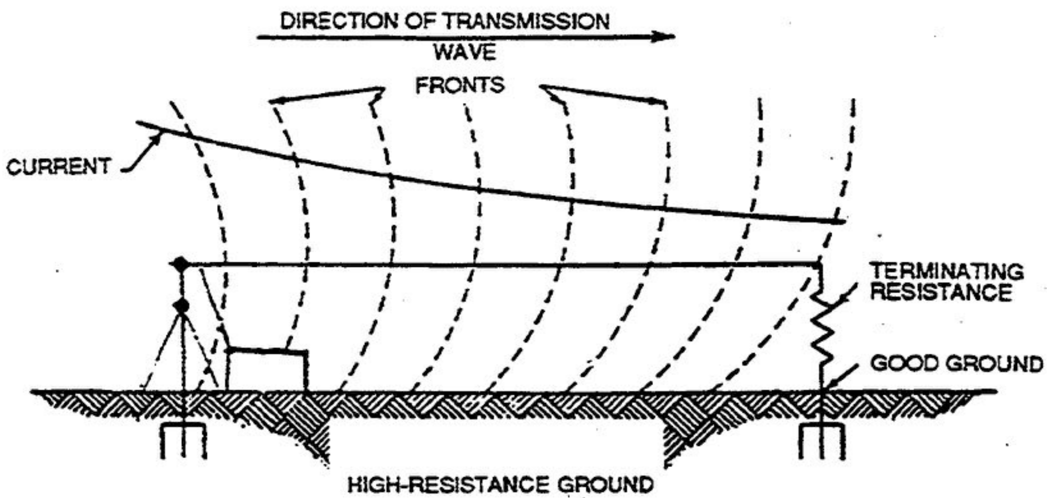
A long-wire antenna has many applications. It is used in fixed point-to-point, air-to-ground, and tactical point-to-point communications. It can be tuned to any frequency in the HF range by an antenna tuning unit, but it must be retuned for each frequency. A long-wire antenna's gain is variable, depending on length, but it is normally about 3 dB.

Sloping-V Antenna. This type antenna (fig. 4-27) is nothing more than two long-wire antennae arranged in the form of a V and fed 180° out of phase. The major lobes of radiation from each leg of the V add along a line bisecting the apex angle—the angle between the legs—and tend to cancel in other directions. Figure 4-27 also depicts the individual patterns of each leg and the combination of the legs to form the bidirectional major lobes. Lobes of the radiation patterns on each leg are numbered to refresh your memory of how individual radiations add vectorally to produce the resultant directivity pattern. As with long-wire antenna, sloping-V antenna can be made practically unidirectional by terminating the two ends of a V with resistors, as shown in figure 4-27.

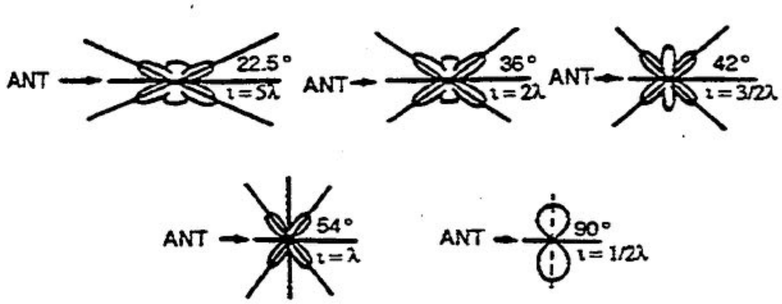
A sloping-V antenna has a bandwidth of 3 or 4 to 1. In other words, if a V is designed to operate at a low frequency of 4 MHz, its upper limit is three to four times the lowest operating frequency, or 12 to 16 MHz. It is primarily used for fixed and tactical point-to-point communications. Its gain, as compared to a doublet antenna, is up to 12 dB, with an 8-db gain being normal.

Rhombic Antenna. This antenna is also a member of the long-wire family of antennae. It consists of four legs, each several wavelengths long, in the shape of a rhombus or a diamond. The legs are of equal length, and the radiation lobes of each leg reinforce those of the other legs. Figure 4-28 shows a basic rhombic antenna, and figures 4-28,A and B,





A. LONG-WIRE WAVE ANTENNA



B. LONG-WIRE ANTENNA RADIATION PATTERNS.

TG-B290

Figure 4-26. Long-wire antenna.

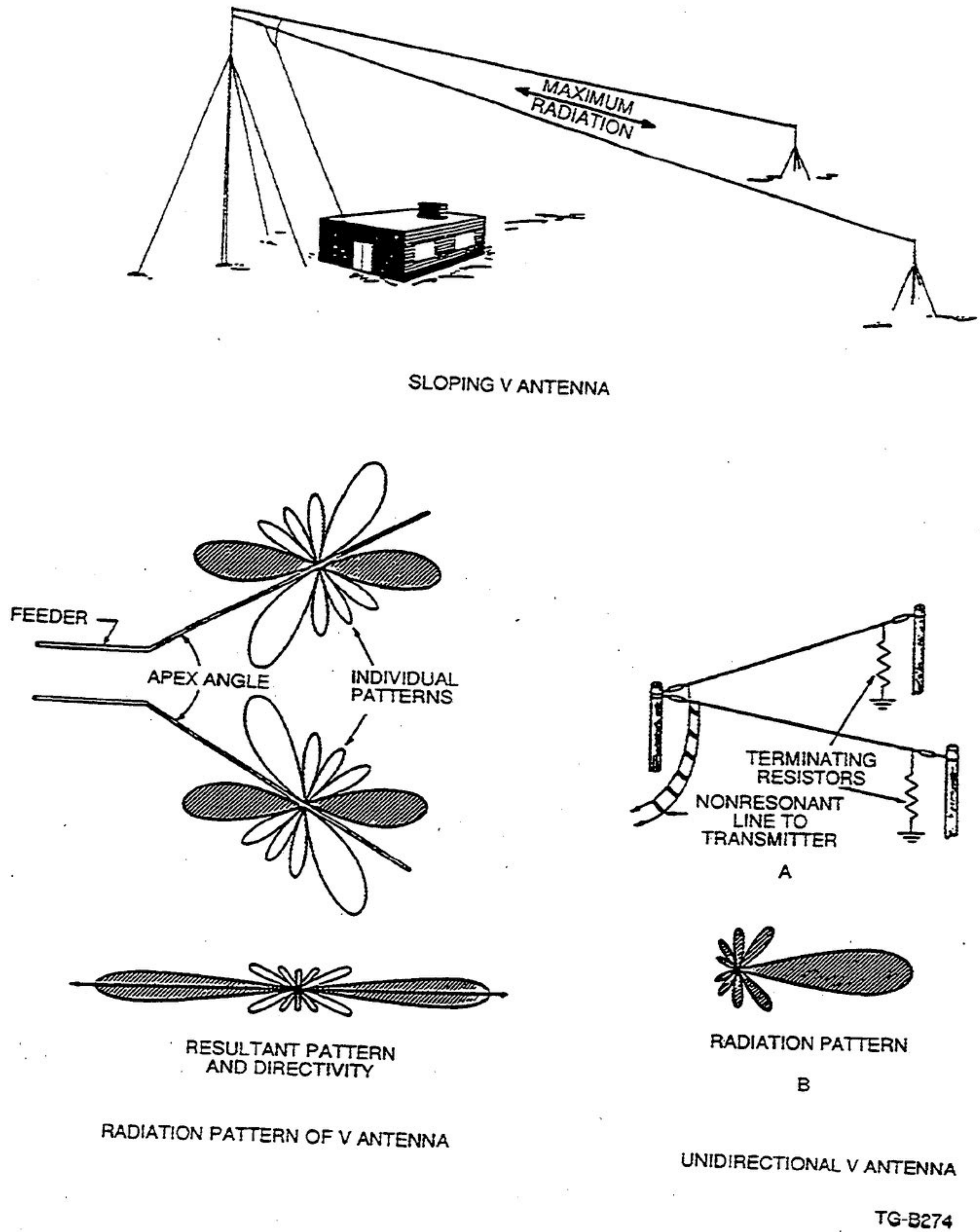


Figure 4-27. Sloping-V antenna.

show a terminated rhombic, the individual radiation patterns of each leg, and the resultant radiation pattern.

The rhombic antenna is widely used in DCS for numerous reasons. They are highly directional, can be used over a wide range of frequencies, respond to extremely long-distance sky-wave signals, and are particularly sensitive to weak signals. Its greatest disadvantage is its size. Each leg of the antenna is normally several wavelengths long in order to obtain the required gain, resulting in legs of several hundred feet. As shown in figure 4-28,C, a rhombic antenna 800 feet long and 300 feet wide is not uncommon.

Rhombic antennae are used primarily for long-haul, point-to-point communications. It has a bandwidth of about 4 to 1, and the gain of a rhombic with legs of 4 to 5 wavelengths is over 40 times that of a half-wave dipole. About one-half of this amount of gain can be realized by using legs of only two wavelengths.

Discone Antenna. A discone antenna, in its basic form, is a disc mounted horizontally above a cone. The cone and disc may be constructed of a solid sheet of metal but, more often, are simulated by a series of rods or wires, as shown in figure 4-29. The discone is used frequently as the antenna for a multichannel, ground-air, backup transmitter. It is well suited for this since it is nondirectional and can be used over the entire ground-air frequency range. Its gain is slightly less than that of a dipole.

036. Array-type antennae

Arrays. One means of attaining increased antenna gain and directivity is by use of a *multielement array*. A long wire, regardless of its length, is looked on as a single-radiating or -receiving element. The array is a combination of elements that, considered separately, could be an individual antenna. These elements act together or on each other to produce a given radiation pattern. Various factors influence the choice of methods used to produce high directivity. Although a long-wire antenna is often preferred where reception or transmission on more than one frequency is required and where gain or directivity requirements are moderate, the more exact phasing and determination of element lengths in the array make for a more regular radiation pattern. Since fewer minor lobes are developed, the available power is concentrated in the major lobe or lobes; therefore, there is greater gain and sharper directivity in the favored direction. In a given available space, the elements of an array can be arranged so as to provide greater gain than a long-wire antenna confined to the same space.

Arrays have been previously described with respect to their radiation patterns and the types of elements they are composed of. It is useful, however, to identify them by the physical placement of elements and the direction of radiation with respect to these elements. Generally speaking, the term

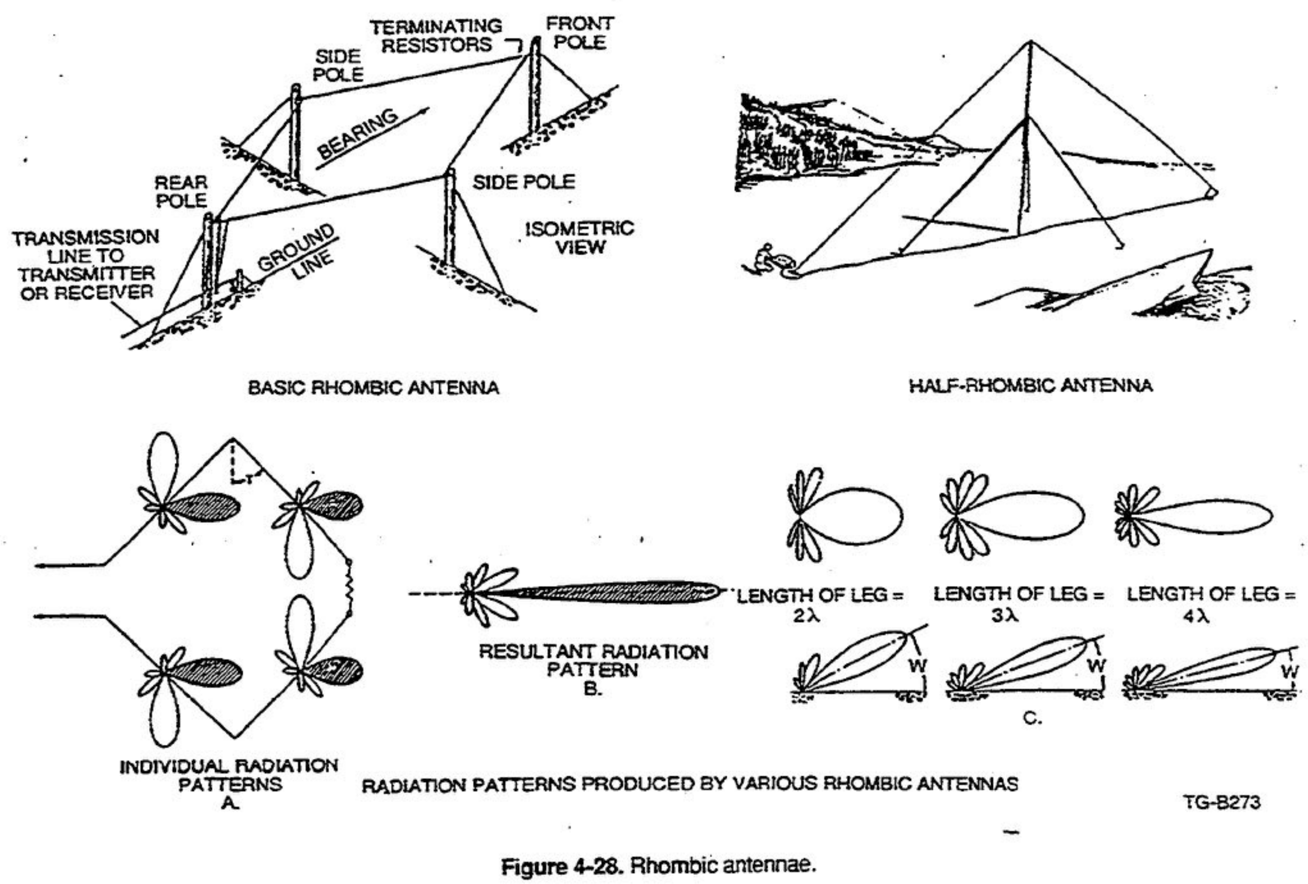


Figure 4-28. Rhombic antennae.

broadside array designates any array in which the direction of maximum radiation is perpendicular to the plane containing the elements. In practice, however, this term is confined to arrays in which the elements themselves are also broadside or parallel with respect to each other. This type of array resembles a ladder, either upright or lying on one side, depending on whether it was polarized horizontally or vertically.

A *collinear array* is one in which all the elements lie in the same straight line. The direction of propagation is broadside to the array. In an *end-fire array*, the principal direction of radiation is along the plane of the array itself. Sometimes a method is used incorporating characteristics of more than one of these three types of arrays. For instance, some of the elements may be collinear and others may be parallel. Such an arrangement is often referred to as a *combination array* or an *array of arrays;* however, since maximum radiation is at right angles to the plane of the array, the term *broadside array* can still be used.

Other arrays have only one driven element, the nondriven (parasitic) elements being used as directors and reflectors. Perhaps the simplest of the latter type is the parasitic multielement *Yagi* antenna. Professor Yagi of Japan discovered that a dipole's directivity and gain increase when it is placed next to another element of slightly different size. If the second element is shorter, as shown in figure 4-30,A, the energy of the driven element is drawn to it, and if longer, as shown in figure 4-30,B, the energy of the driven element is forced away.

By using a combination of longer (reflecting) elements behind the driven element and shorter (directing) elements in front of the driven elements, as shown in figure 4-30,C, the energy of the antenna is concentrated in the forward lobe, resulting in increased directivity and gain. You can see this increase in directivity and gain in the radiated pattern shown in figure 4-30,B, which shows little energy being radiated from the rear of the antenna, whereas the polar diagram (radiation pattern) in figure 4-30,A, shows considerable energy being radiated toward the rear. There are many applications where array-type antennae are beneficial, especially in long transmission shots. Again, this is because of the antenna's gain and directivity. Some of the different variations of array antennae and their radiation patterns are illustrated in figure 4-31.

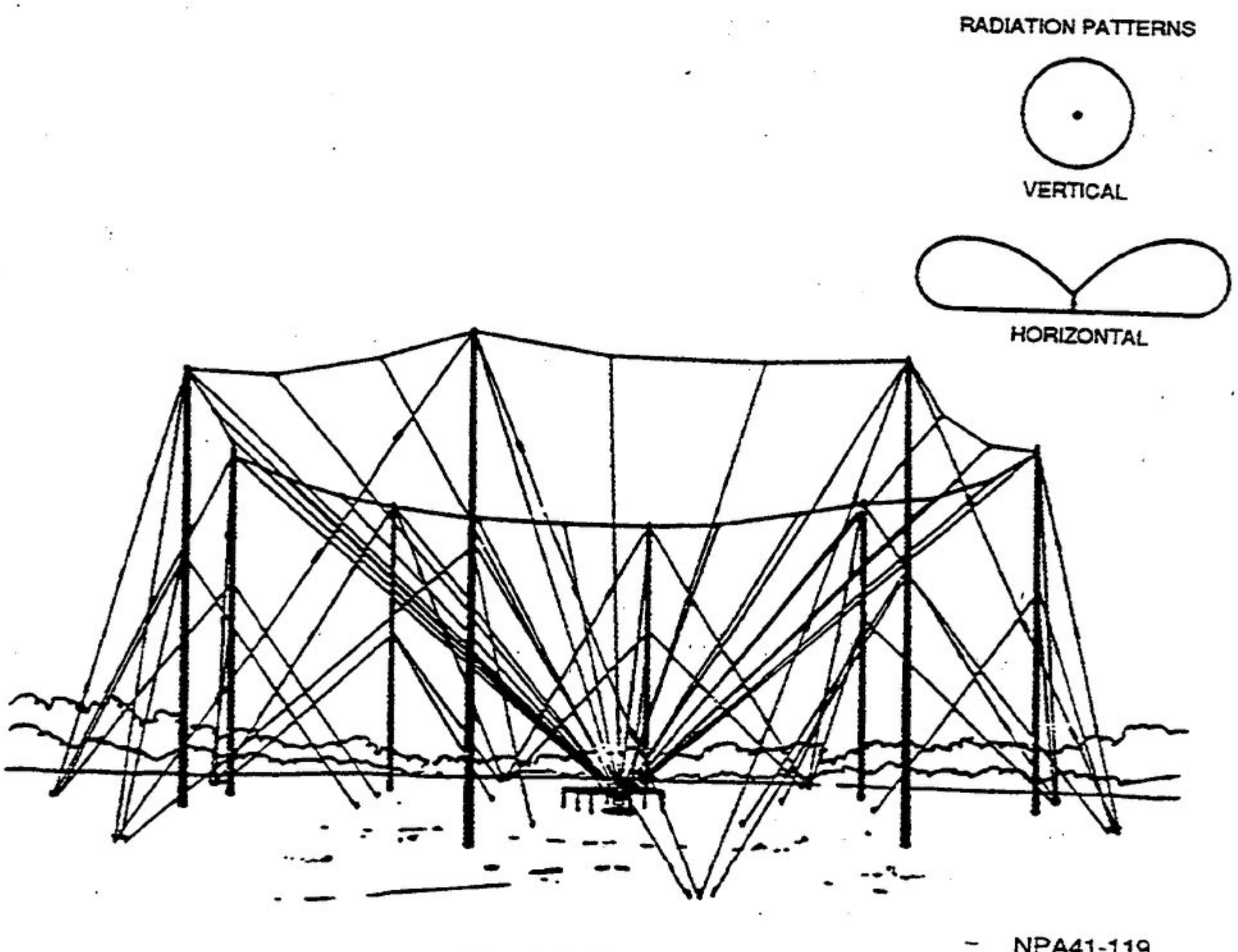


Figure 4-29. Discone antenna.

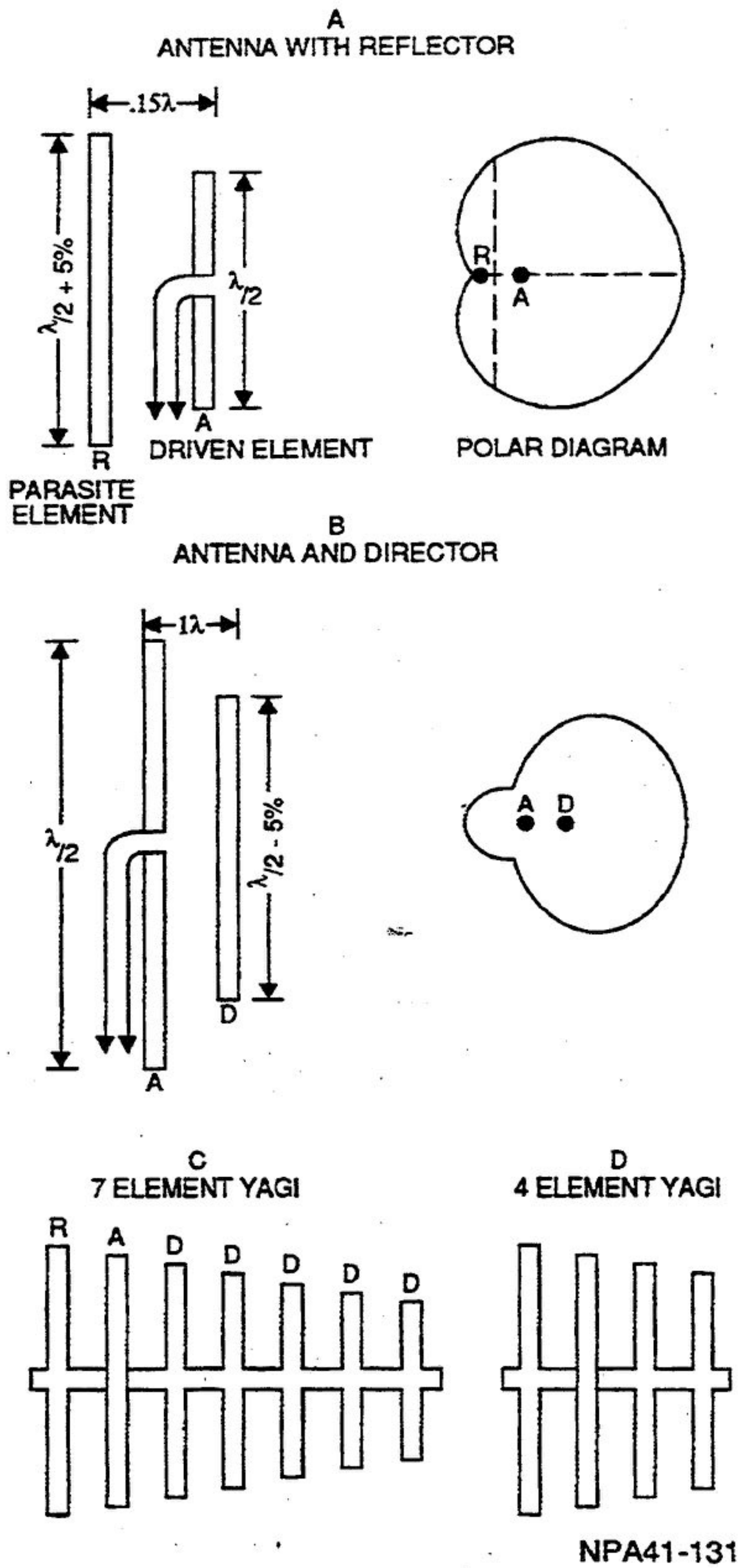


Figure 4-30. Parasitic antennae.

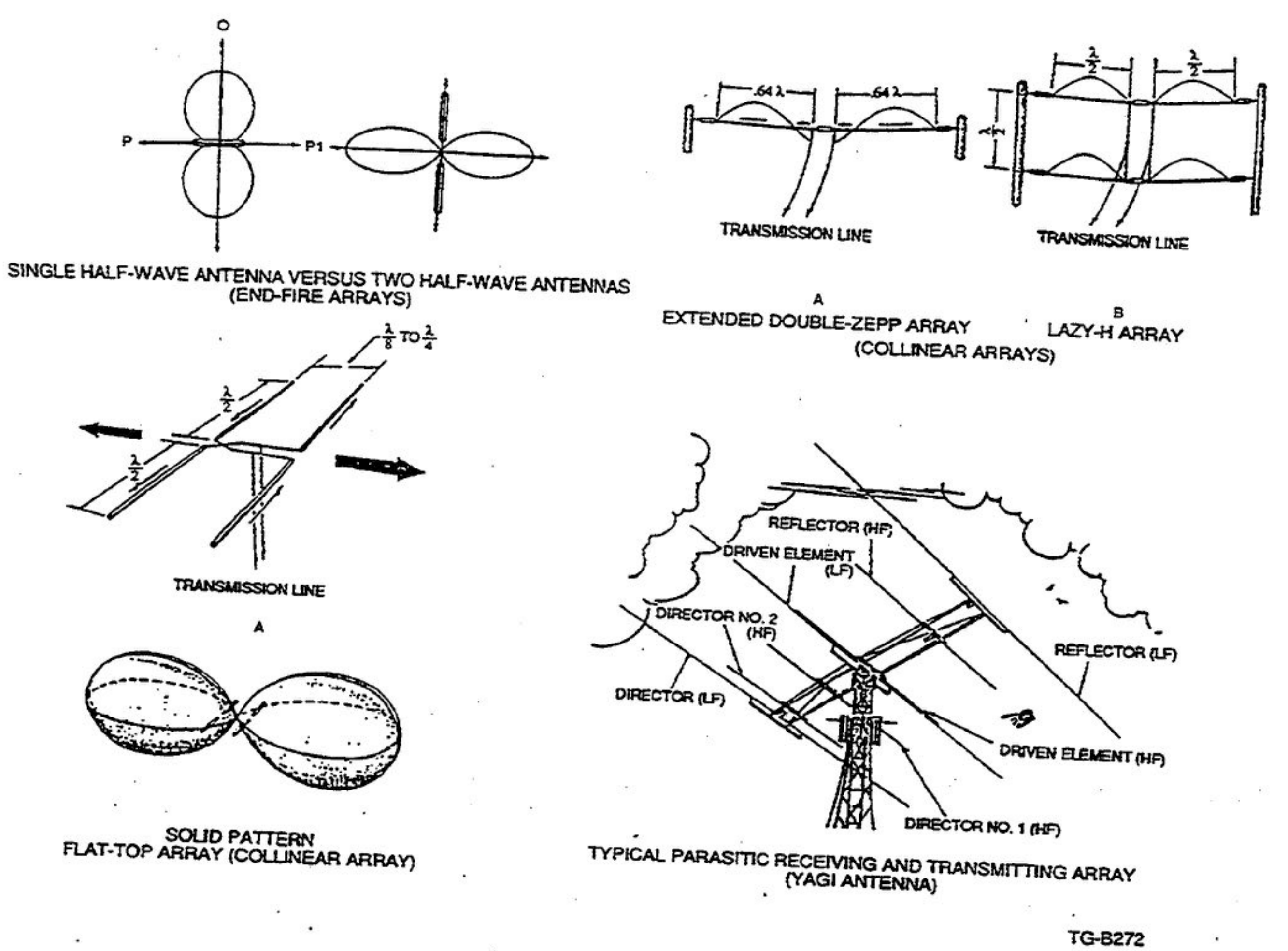


Figure 4-31. Arrays.

037. The log periodic antenna (LPA)

The log periodic antenna gets its name from the logarithmic spacing and proportion of its elements. The outstanding feature of the LPA is its RF bandwidth, or the range of frequencies within which the antenna functions efficiently. This can be as much as 10 to 1. Virtually any two RF limits can be chosen for an operating bandpass, but it's not desirable to expand the RF limits beyond what is absolutely necessary. Such bandwidth restriction is required because the lower radio frequencies that have a fairly long wavelength in the VHF band would make the antenna very large and difficult to construct. Normal gain for a log periodic antenna is 6 to 8 dB throughout its RF bandwidth.

In addition to the LPAs we cover here, there are many other types—the spiral, the helical, and the helical/spiral, to mention but a few. Most of these are special application antennae, used for telemetry, feeding parabolic antenna, and when a very wide bandwidth is needed.

The *planar log periodic antenna* (fig. 4-32) is basically a configuration of parallel in-plane dipole elements constructed along a common axis. It is a 360° rotatable antenna and has much the same appearance as a Yagi.

The *log periodic V antenna* differs from the planar only in that its dipole elements are formed into a V, making an angle of about 80° (fig. 4-33). It has a relatively high gain—as much as 20 dB—across its entire bandwidth. Its two largest side lobes are usually very intense (0 to 6 dB down with respect to the major lobe), so the RF bandwidth is generally limited to an octave—a bandwidth where the upper frequency limit is twice the lower frequency limit. The LPA V can be designed for use in the HF, VHF, or UHF bands.

The *spear point log periodic antenna* (fig. 4-34) is an example of a nonplanar antenna; its elements aren't all in the same plane. Although it has better directional characteristics than the regular planar, this advantage is offset by the fact that it is cumbersome to handle and much harder to fix in a rotatable position if used at very high frequencies. It is small enough and can be used at the higher microwave frequencies as a feed element for a parabolic reflector antenna instead of a conventional dipole.

The *vertical monopole antenna* (fig. 4-35) is one of the most used general-purpose log periodic antennae. It offers

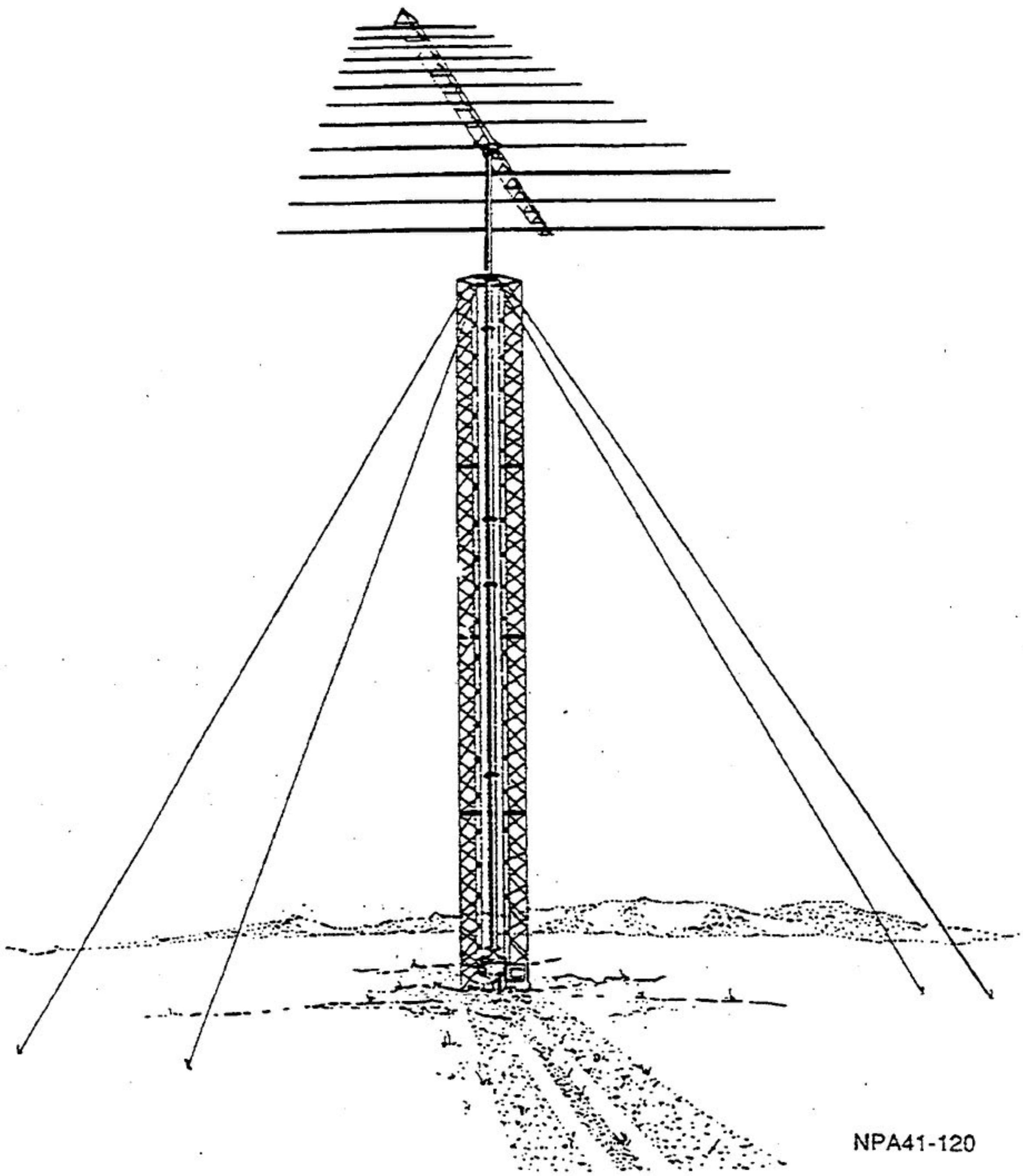


Figure 4-32. Planer log periodic antenna.

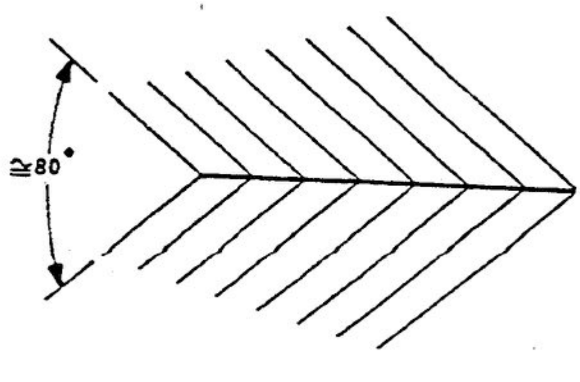


Figure 4-33. Log periodic V array.

omnidirectional coverage over a wide band. It is normally constructed with a central structure of either steel pipe or welded angle iron. It may be designed to cover almost any bandwidth from a 4-to-1 range to a 10-to-1 broadband coverage. Since the vertical monopole does not provide a good elevation pattern, multimode radiators are added. The radiators are arranged so that they will operate in more than one manner. The center of the conductors are farther from the monopole than from the ends. This causes the antenna to act more or less like the sloping-V antenna, giving the effect of low-angle radiation. A ground screen of as many as 60 copper wires arranged in a circular pattern may be used with the monopole to improve its efficiency. Since all vertical monopole antennae are omnidirectional, they are particularly useful for air-ground and ship-to-ship communications.

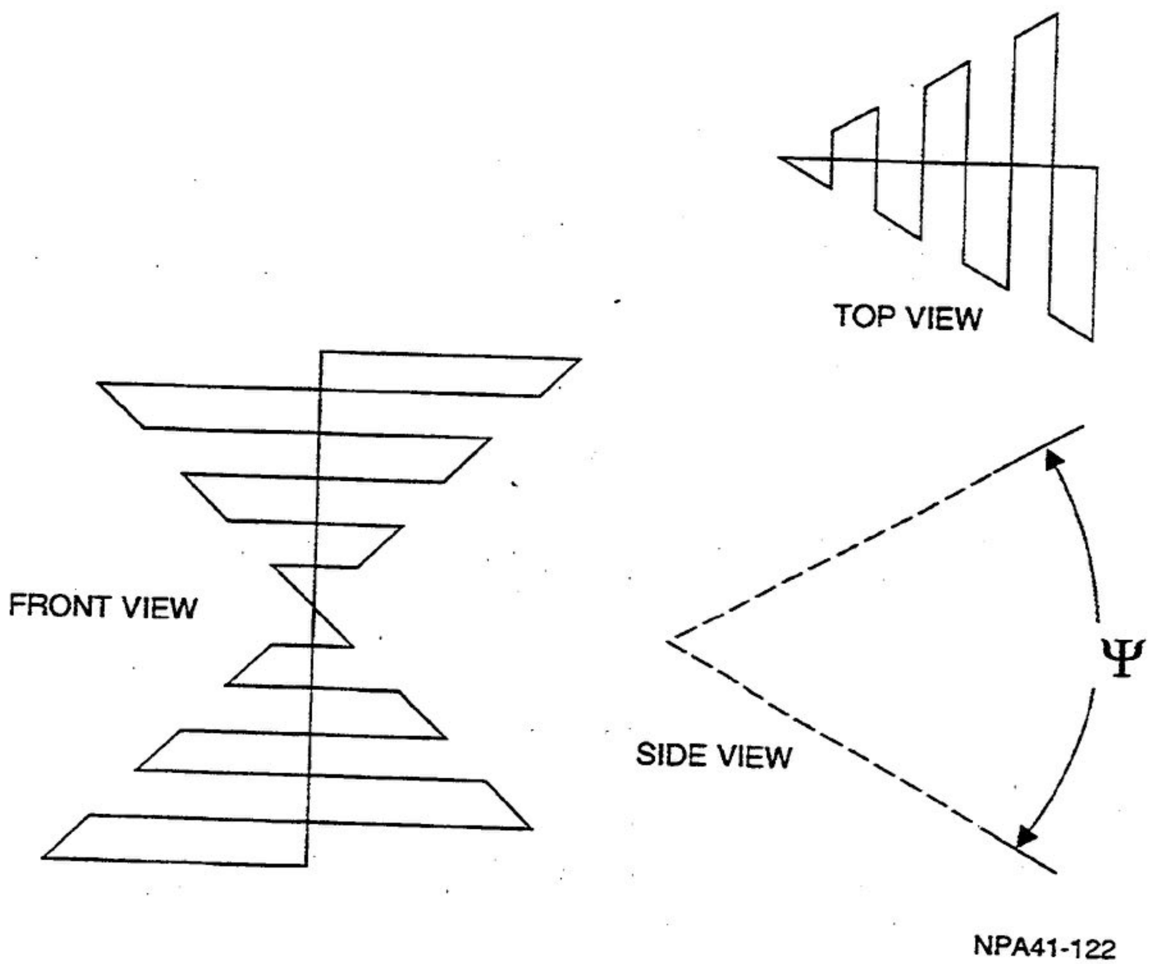


Figure 4-34. Nonplanar log periodic spear.

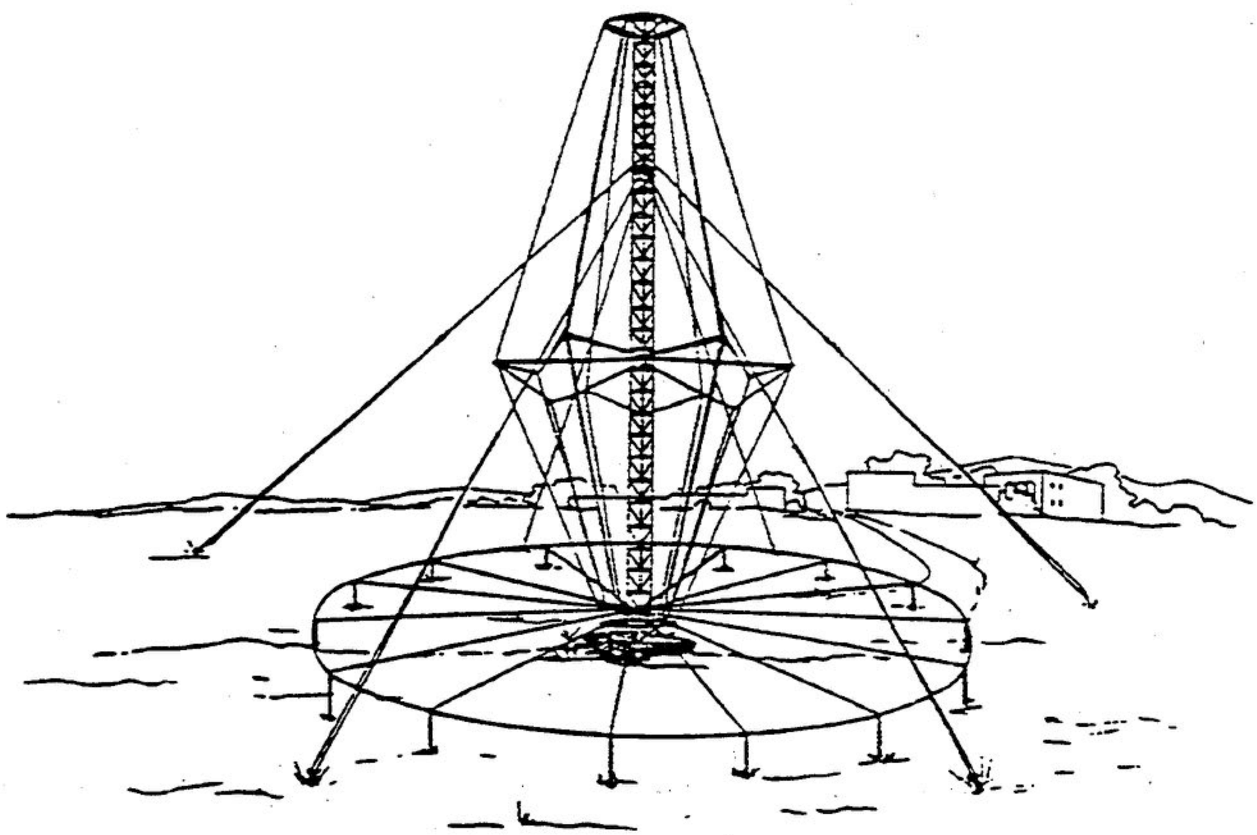


Figure 4-35. Log periodic monopole antenna.

038. How to connect transmitters or receivers to an antenna

Transmission Lines. The connection between an antenna and a receiver is called a feeder, feed-in, feed line, lead-in, waveguide, or transmission line. Except for the waveguide, all of the terms are used interchangeably when referring to a transmission line. Figure 4-36 illustrates several types of transmission lines, and figure 4-37 shows the construction of coaxial cable.

A coaxial line (coax) is a conductor within a conductor. The inner conductor is separated from the outer by an insulator such as polyethylene or teflon. It is normally used when low radiation is desired. While the impedance can vary according to the manufacturer, the most common are the 52- and 72-ohm lines. Normally, each of the receiver site transmission lines is terminated at an antenna multicoupler. The multicoupler is a broadband RF amplifier that amplifies and distributes the signal to several outputs, allowing one antenna to be used for several receivers. Most antenna couplers can accept RF signals within a range of 2 to 20 MHz. The receivers may be tuned to the same frequency or to different frequencies, as long as the selected frequency is within the bandwidth of the antenna and coupler. Various types of cable systems are covered in more depth later.

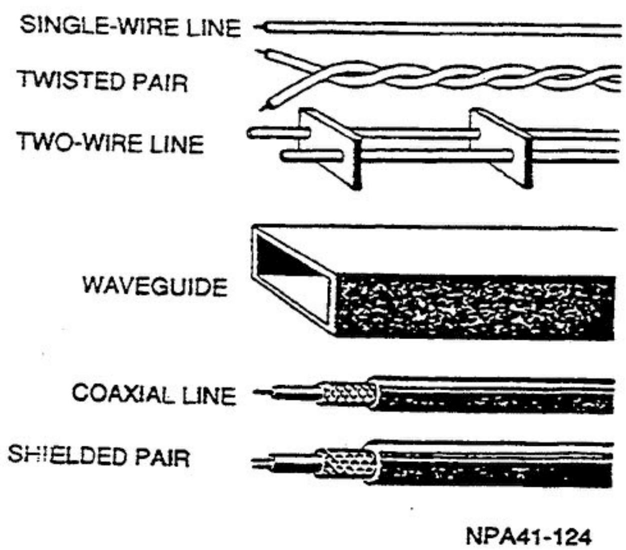


Figure 4-36. Transmission lines.

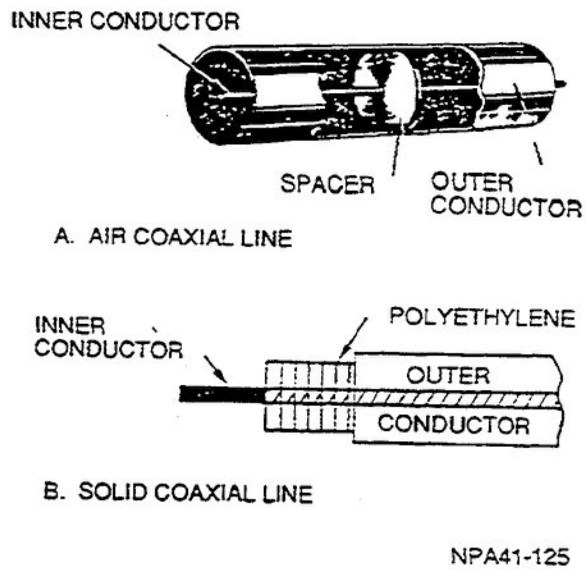


Figure 4-37. Coaxial line construction.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

035. Radiation characteristics of common antennae

1. What is a doublet antenna?

2. What radiation characteristics are typical of a doublet antenna?

3. What are some of the applications of long-wire antennae?

4. Having two major radiating lobes makes the sloping V what type of antenna?

5. What effect does terminating the two ends of a sloping-V antenna have on its radiation pattern?

6. What are the primary uses of the sloping-V antenna and what is its frequency range?

7. How a is rhombic antenna constructed?

8. What is the typical pattern of radiation of a rhombic antenna? Why is this an advantage or disadvantage?

9. What typical radiation pattern can be expected from a discone antenna and what are its primary uses?

036. Array-type antennae

1. How does an array antenna operate?

2. What characteristics of array antennae make them desirable to use?

037. The log periodic antenna

1. Match the characteristic of a log periodic antenna in column A with the specific antenna it describes in column B.

Column A

___ (1) This antenna is nonplanar.
___ (2) Parallel in-plane elements are constructed along a common axis.
___ (3) Consists of a central structure with multimode radiators normally added.
___ (4) Dipole elements are formed into a V.
___ (5) Two-side lobes are very intense in radiated power.
___ (6) Easily rotatable in a 360° pattern.

Column B

a. Planar log periodic.
b. Log periodic V.
c. Spear-point log periodic.
d. Vertical monopole.

2. What is the normal gain for a LPA?

038. How to connect transmitters or receivers to an antenna

1. What method is used to couple transmitters/receivers with the antenna system?

2. What is the purpose of the antenna multicoupler?

4-4. Equipment Configuration

In HF transmission, AM is normally used to impress the signal on the carrier. When all three components of the AM wave (upper sideband, lower sideband, and carrier) are transmitted, it is known as double-sideband (DSB) transmission. However, the carrier component is steady and conveys no intelligence. Each of the two sidebands carries all of the intelligence of the signal. In many cases, you get greater efficiency by transmitting only one sideband; the other sideband and the carrier are suppressed. This is called single-sideband (SSB) transmission. SSB takes more equipment than DSB transmission, but it has several advantages. Its signal bandwidth is only about half as wide as that transmitted in DSB operation. Since the high-frequency spectrum is already overcrowded, this factor is important. Also, the signal-to-noise ratio for a given transmitter power is better in SSB operation since the full available power can be concentrated in one sideband instead of among two sidebands and the carrier. The improvement in signal-to-noise ratio can be as much as 9 dB if the transmitters radiate the same peak power in both cases. SSB transmission is used extensively by DCS aeronautical stations. In point-to-point communications, an adaptation of these principles, called independent sideband (ISB), is often used.

039. The ISB transmitter

Many types of ISB transmitters are used in the DCS. Selection is based on the power output required, frequency stability, and frequency range. The carrier wave in ISB is lost radiated power, since it does not carry intelligence. For economical operation, the carrier wave is suppressed partially or entirely, depending on the characteristics of the equipment used. Two types of transmitters—stabilized and nonstabilized—are in common use. The main difference is that the stabilized type uses an accurate frequency generator (frequency synthesizer) in conjunction with the ISB transmitter on both the *send* and *receive* sides of the circuit to maintain an operating frequency that's virtually drift free, allowing complete suppression of the carrier. A nonstabilized circuit, on the other hand, requires transmission of at least part of the carrier to let the receiver's automatic frequency control (AFC) "lock on" to the signal and compensate for drift. Carrier suppression is done at the transmitter in 10-dB steps, with up to 40-dB suppression available. Normal carrier suppression for a nonstabilized transmitter is 20 dB. Figure 4-38 illustrates the GA-11038 ISB transmitter. Notice the frequency generator at the lower left. You'll find that, except for the frequency generator, this unit operates much the same as other types in use.

Independent sideband transmissions have two sidebands, but, unlike DSB, each sideband carries different intelligence. One sideband is modulated by one source and the other sideband by another, giving the same transmission capability as two SSB transmissions. This means that an ISB circuit provides at least two audio channels for the controller's use.

The ISB transmitters used in the DCS provide two 6-kHz transmission slots, each of which will accept two 3-kHz signals, providing a total of four VF paths or channels. The two 3-kHz paths are fed into a multiplexer, where they are combined into a single 6-kHz signal, which is then transmitted on one sideband. Two additional 3-kHz paths undergo the same process and make up the other sideband. The combining is done by passing one of the signals through the muxer without alteration and then heterodyning the other to a frequency 3 kHz higher, with the result that instead of two signals falling within the 0- to 3-kHz band, you have one signal in the 0- to 3-kHz band and one in the 3- to 6-kHz band. Figure 4-39 shows that the A (or upper sideband) is broken down into two paths—the A1 and the A2. Similarly, the B (or lower sideband) is broken down into the B1 and B2 paths. The term *direct* is given to the A1 and B1 paths since they are not multiplexed before they go into the sideband transmitter. The A2 and B2 paths are referred to as translated, since they are heterodyned to a higher frequency band.

040. ISB subsystems and channel allocations

ISB System, Send Side. Figure 4-40 illustrates a conventional ISB system, send side. Teletype signals are received from various users and fed into the telegraph terminal equipment (VFCT), where they are multiplexed into a single voice-frequency tone group. The tone group (tones) is then fed into the VF multiplex equipment. Three additional voice-frequency bands are fed into the VF multiplex equipment, and the output is transmitted by microwave or cable to the transmitter site, where the process is reversed—and the received signal is broken down into the original four paths. Two of the paths are fed into muxer A and the remaining two into muxer B. The 6-kHz outputs of the muxers are then fed into the ISB transmitter, which transmits one as the upper sideband and the other as the lower sideband of a 12-kHz-wide HF radio signal. The telegraph terminal tones are normally placed in the A1 path and the remaining paths are used for telephone, facsimile, data, or any other source requiring a 3-kHz transmission path. Figure 4-40 is valid for both stabilized and nonstabilized operation.

Reception. As you might expect, reception of an ISB signal is merely a reversal of transmission. While the equipment in a stabilized circuit differs from that in a nonstabilized circuit, both methods use space diversity and follow the same general principles.

General theory. In a nonstabilized circuit, two antennae, separated by two or more wavelengths, feed two receivers. Each receiver, in turn, feeds the signal to an ISB converter

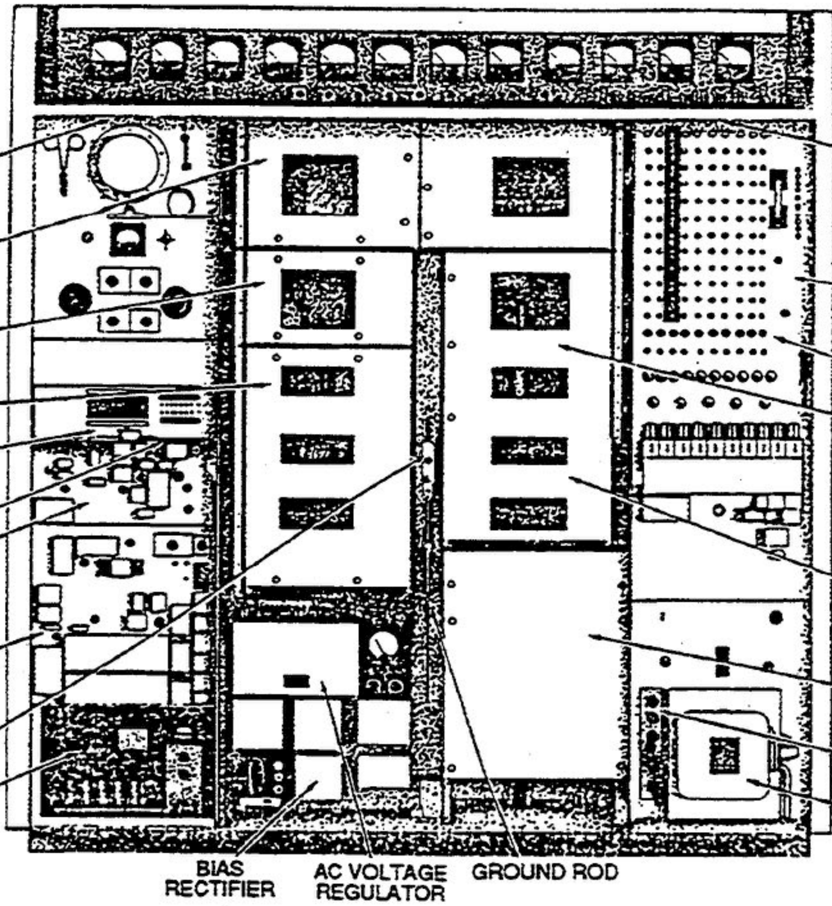


Figure 4-38. Radio transmitter GA-11038.

that separates the upper sideband from the lower sideband. The upper and lower sidebands are then fed into a demuxer that passes the frequencies from 0 to 3 kHz (A1 or B1 paths) and lowers the part of the sideband between 3 and 6 kHz to the 0- to 3-kHz range. The two 3-kHz bands are then fed individually into the intersite VF multiplex equipment. The operation is much the same in the stabilized circuit.

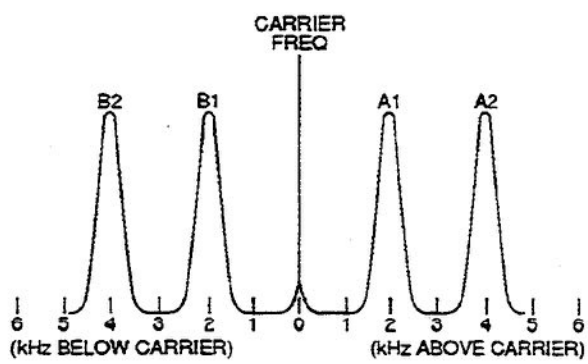
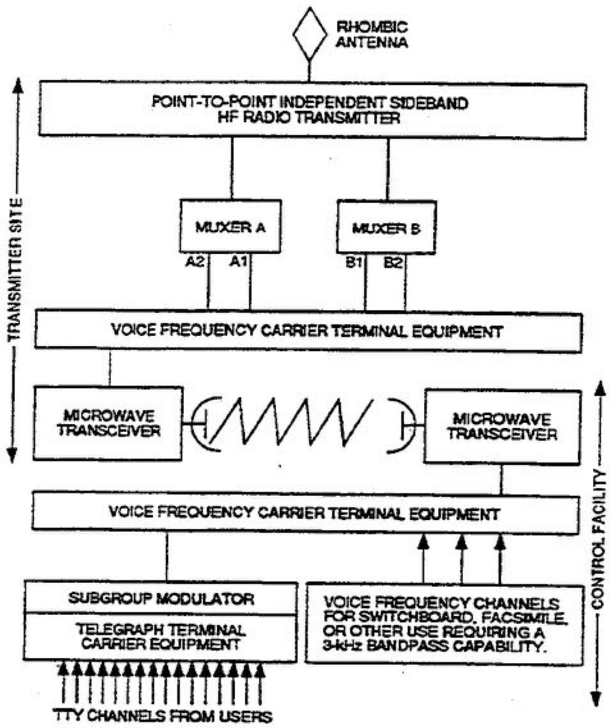


Figure 4-39. ISB signal.

HC-150 receivers. A typical receiver is the HC-150, which can monitor any one of up to 10 pretuned channels between 2 and 28 MHz. Figure 4-41 shows the receiver set up with a five-channel capability. Each channel has four front ends, two for normal upper and lower sideband reception and two for diversity upper and lower sideband reception. Normal or diversity reception is selected within the receiver automatically. A single-frequency synthesizer provides two frequencies to the mixer associated with the channel in use. The mixer combines the two frequencies and produces an injection frequency, which is fed to the front ends of the channel to determine the operating frequency. The demodulator drawer converts the intermediate frequency (IF) output signals of the front ends into four 3-kHz signals, which are fed directly into the VF multiplex equipment. As selection of normal or diversity paths is made automatically in the front ends, only one set of tones is sent to the control facility.

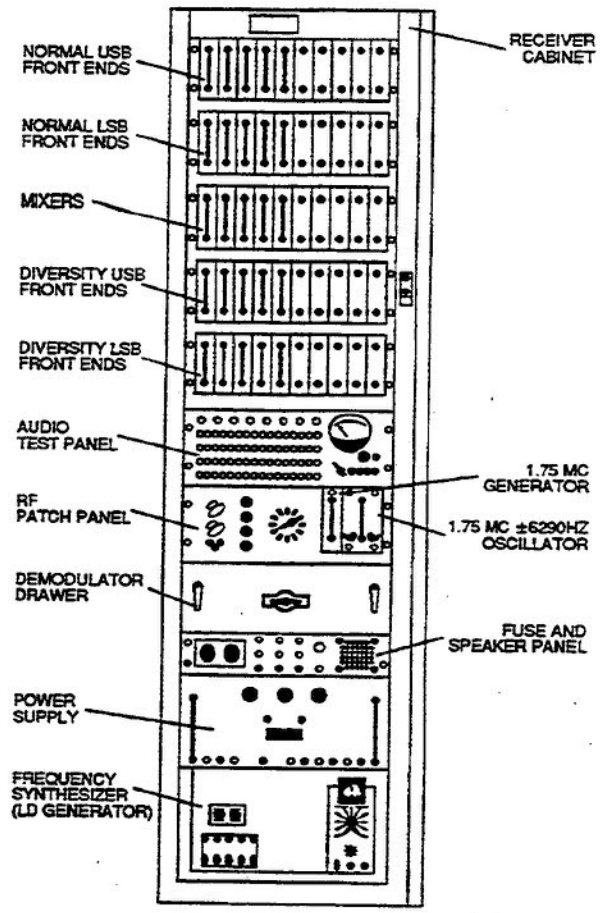
ISB System, Receive Side. A conventional nonstabilized ISB receive system is shown in figure 4-42. Again, space diversity is used, the signal being received by two receivers at the same time. The signal goes from the receivers to an ISB



NPA41-133

Figure 4-40. ISB system, send side.

converter, which breaks it down into upper and lower sidebands. Each of the resulting signals is then fed into a demuxer, which further breaks the signal down into four 3-kHz paths. The four paths of the normal circuit are sent via the intersite equipment to the control facility. Notice that only the A1 path of the diversity signal is transmitted to the control facility. Remember that the telegraph terminal carrier equipment has provisions for selecting the better of two input signals. The equipment used on the three VF channels lacks this capability, so these three channels of the diversity path are normally blocked at the receiver site and only the path carrying the telegraph terminal tones is fed into the VF multiplex equipment. Figure 4-43 shows a stabilized circuit



NPA41-132

Figure 4-41. Radio receiver, model HC-150.

using the HC-150 receiver. The receiver performs the functions of both the normal and diversity receivers, their associated ISB converters, and the demuxers used in a nonstabilized circuit. Remember, since normal or diversity signals are selected automatically in the front ends of the receiver, only one set of tones is sent to the control facility.

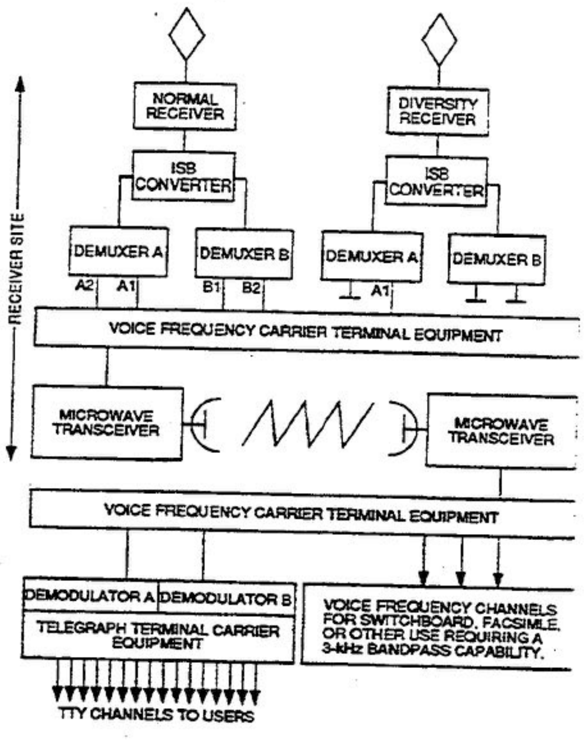


Figure 4-42. ISB system, receive side.

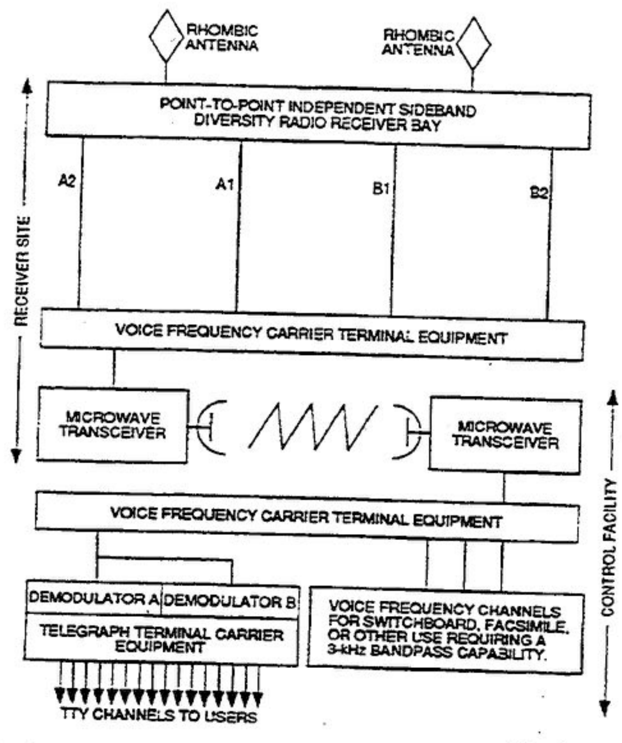


Figure 4-43. ISB system, stabilize receiver.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

039. The ISB transmitter

1. What is the bandwidth capacity of an ISB transmitter?

2. What characteristics must be considered in selecting an ISB transmitter?

040. ISB subsystems and channel allocations

1. What channels are VFCT tones, telephones, facsimile, and data normally allocated?

2. How is a received signal demultiplexed in an ISB received system?

3. What steps are required between reception of an HF signal and its transfer to tech control?

4-5. System Operation

As in any communications system, there are certain factors to consider in operating a point-to-point HF system. As a technical controller, you will find yourself heavily involved in many factors, possibly including siting and antenna considerations if you are in a tactical environment, or eliminating problems that plague all communications systems such as noise and interference. In this section, we will concentrate on such factors as noise, received signal strength, and antenna gain. These and additional considerations will give you, the technical controller, an insight as to how reliable communications can be derived from the HF spectrum.

041. Sources of noise inherent to HF communications

Noise and Interference. Noise and interference from other communication systems are two factors that limit the useful operating range of all radio equipment. External radio noise (i.e., other than receiver set noise) consists of three types—atmospheric, manmade, and galactic.

Atmospheric noise. Most atmospheric noise originates in thunderstorms. Of the three noise types, this is the most erratic. It consists of short, randomly occurring pulses superimposed on a background of random noise. At a given location, the atmospheric noise is made up of noise from nearby noise centers, such as local thunderstorms, and noise that has been propagated over great distances from one of the principal noise centers, such as the active thunderstorm areas in equatorial Africa, Central America, and the East Indies. The activities of the various noise centers vary with time of day and season, and propagation conditions that transmit the noise also vary. Major thunderstorm centers tend to shift above and below the equator from summer to winter and, even though ionospheric absorption is greater in the summer, increased storm activity seems to predominate. As a result, received noise tends to be highest in the summer and lowest in the winter.

The received noise level also varies inversely with frequency (i.e., decreasing with an increase in frequency). There are variations with geographical location, too, since highest noise levels are encountered in equatorial regions and the lowest levels are in polar regions.

Manmade noise. Manmade noise can arise from any number of sources such as power lines, industrial machines, and ignition systems. The characteristics vary over a wide range of limits. Much of the noise energy from sources of this type is propagated to the receiver over power lines or by ground-wave propagation. In general, the level of manmade noise decreases with increasing frequency. This is due in part to the source spectrum and in part to propagation factors.

Galactic noise. Galactic noise is rather like thermal noise with a Gaussian amplitude-time distribution. The intensity of galactic noise decreases with increasing frequency. The amount of energy impinging on an antenna depends in part upon the part of the sky seen by the antenna lobes. Great noise sources are found in the direction of the constellations Sagittarius and Cassiopeia. Since the galactic noise source is external to the ionosphere, the noise level received depends on ionospheric absorption characteristics and the relationship of the operating frequency to the critical frequency. In arctic regions, where very-low noise from atmospheric and manmade sources is low, at times galactic noise may be the principal external noise source in the HF band. At temperate and tropical latitudes, where critical frequencies are higher and atmosphere noise stronger, galactic noise is usually negligible below 15 or 20 MHz.

Site Noise Evaluation. Optimally, the noise levels at sites chosen for high-frequency receiving terminals should not exceed that caused by atmospheric or galactic noise. You can get the expected values of atmospheric or galactic noise levels in the HF band worldwide for all times of day and seasons of the year from the International Radio Consultative Committee's periodically published reports. While only a noise measurement program can ascertain whether manual or manmade sources are the principal contributors of noise at a given site, a receiver site shouldn't be located near obvious manmade environments such as excessive vehicular traffic, industrial areas, or transmitter sites.

Vehicular traffic. Since this is a major source of radio noise, you should locate receivers where there's a minimum of nearby vehicular traffic. It's especially important that no traffic pass immediately in front of the receiving antennae. A reasonable clearance between a heavily travelled highway and a receiving antenna, in the direction of the main lobe, is probably 3 miles or more. Somewhat shorter distances may be tolerated in other directions as determined by the horizontal pattern of the antennae used.

Industrial areas. Manufacturing areas, areas near powerplants or power substations, medical facilities that use diathermy and x ray, street lighting systems, and high-voltage overhead power lines are examples of environments likely to generate radio noise. This noise may be radiated much the same as radio waves are radiated from antennae, or it may be conducted over an appreciable distance by power lines and radiated by those that pass near the receiving site.

Interference from nearby radio stations. Radio transmitters within several miles of a receiving station can create serious interference due to harmonics, keying transients, parasitic oscillation, or cochannel operation. When receiver sites are in strong radio-frequency fields, cross-modulation products may be generated in receivers, even though transmitter frequencies are greatly different from the normal receiving frequency. Existing and even proposed sources of radio interference must be taken into account in the overall evaluation of a site.

042. Signal degradations inherent to HF communications

Received Signal Strength. You can determine whether the ionosphere will support transmission of sky waves over a given signal path at a certain time by finding the MUF and LUF for this path. If a consistent optimum working frequency can be derived from these factors, radio communication over this signal path is possible. In the downcoming sky wave, you're not dealing with a steady wave of constant amplitude and phase, but one that may fade suddenly and greatly and whose polarization may be changing constantly. It may be composed of not one but many component waves, it's affected by reflection at the ground near the receiver, and it's subject to the variations in height and energy absorption in the ionosphere and to focusing by the ionosphere. These difficulties may be minimized by due regard to certain factors upon which the received signal strength depends—such as transmitter power, antenna gain, transmission-path distance, absorption function of the signal path, and interference losses. It is obvious that the transmitter must supply enough power to provide a field of sufficient strength at the receiver.

Fading. Because of fluctuations in ionospheric conditions, the received intensity of the sky wave isn't constant, but varies with time. The term *fading* refers to relatively rapid variations during a space of minutes, seconds, or even fractions of a second. In general, fading is more sudden on high than on low frequencies. A type of fading known as *selective* fading also can distort radiotelephone signals. In such cases, the fading affects certain frequencies more than others and, therefore, may affect the sidebands and the carrier wave differently. Fading, which is usually a nuisance, may be reduced by several methods, such as automatic volume control, suppressed carrier transmission, and diversity reception.

The many types of fading fall into four principal classes—interference fading, polarization fading, absorption fading, and skip fading. Most of the rapid fading in the input to a receiver is a combination of the first two types; the other two are responsible for slower changes.

Interference fading. Interference fading is phase interference between two or more waves from the same source arriving at the receiver over slightly different paths. If the paths are of different lengths and their relative lengths vary for some reason such as fluctuations in the height of the ionosphere layers, the relative phases of these waves vary with time, causing alternate reinforcement and cancellation of the field intensity. Because of irregularities in the ionosphere, one downcoming sky wave is really the summation of a great number of waves of small intensity and of random relative phases. Thus, the resultant field intensity can vary over wide limits. The root mean square (RMS) value of the fading intensity is equal to the *homogeneous field*, or the steady value of the field that would have existed had the ionosphere not broken the wave up into many components.

Polarization fading. Additional variation in the field intensity affecting the receiving antenna is a result of changes in the state of polarization of the downcoming wave relative to the orientation of the antenna. This variation is called polarization fading. In general, the state of polarization of the downcoming sky wave is changing constantly. This is due mainly to the combination, at random amplitudes and phases, of the two oppositely polarized components—the ordinary and the extraordinary wave. The polarization of the downcoming sky wave is generally elliptical. Elliptical polarization means that, as the wave travels along the signal path, the electric and magnetic fields remain at right angles to each other and to the direction of propagation but rotate about the signal path in more or less corkscrew fashion instead of remaining constantly in either a vertical or a horizontal plane with respect to the path, as does the plane polarized wave. This results in random and constantly changing values of the amplitude and orientation of the electric field with respect to the receiving antenna. The state of polarization of sky waves varies more rapidly the higher the frequency, which accounts in part for the rapid fading on the higher frequencies.

Absorption fading. Absorption fading is caused by short time variations in the amount of energy lost from the wave because of absorption in the ionosphere. In general, the period of this type of fading is much longer than the other two types since the ionospheric absorption usually changes slowly. (The sudden ionospheric disturbance is an extreme case of this type of fading, although it is usually classified as an irregular disturbance rather than as fading.) Somewhat similar to this type of fading, although not caused in the ionosphere but by reflections and absorption in objects close to the receiver, is the type of fading experienced in receiving a signal while moving along in an automobile. The fading out of the signal when the automobile is passing under a bridge or near a heavy steel structure is caused by absorption of the wave's energy by the structure. In these so-called *dead spots*, radio reception is particularly difficult. Also, radiation from wires, fences, and steel structures can cause an interference pattern that is relatively fixed in space and can be noticed when you move the receiving equipment around. Where there are nearby structures that can cause these effects, you must select the receiving site carefully.

Skip fading. Skip fading is observed at places near the limit of the skip distance and is caused by the changing angle of refraction. Near sunrise and sunset, when the ionization density of the ionosphere is changing, the MUF for a given transmission path may fluctuate about the actual operating frequency. When the skip distance moves out past the receiving station (sometimes called going into the skip), the received intensity abruptly drops by a factor of 100 or more and just as abruptly increases again when the skip distance moves in again. This may take place many times before steady conditions for transmission are established.

043. Receive signal strength and noise figures of a system

Required Signal Strength. The minimum radio field intensity necessary for satisfactory reception of an intelligible signal of a particular type in the presence of radio noise is called the *required signal strength* for this type of service. As a propagation factor, the required signal strength is subject to wide variation. It depends on the receiving set, the local noise or static, the type of modulation of the radio wave or, in other words, the type of service, and the grade of service desired (e.g., barely intelligible, high fidelity, etc.). It also varies, with the radio noise, according to the time of day and season.

Noise Figure. For many years, radio engineers were faced with the problem of devising a system for rating a receiver or an amplifier on its merits from the standpoint of low noise. The problem was complicated by the fact that, in addition to the useful output voltage of a generator (the generator, under operating conditions, being an antenna and the useful output voltage being the desired signal voltage), a certain noise voltage is always present. In an antenna, this noise voltage includes that caused by thermal resistor noise and atmospheric and cosmic noise; in a standard voltage generator, this voltage includes only that resulting from thermal resistor noise. Because of the fluctuations of atmospheric and cosmic noise voltages with time, location, and construction and orientation of the antenna, these noise voltages don't offer a constant standard for rating a receiver or an amplifier. However, thermal noise, presenting a readily computed voltage, offers a satisfactory standard against which the noise introduced by a receiver or an amplifier can be rated. Based on this principle, a system of rating a receiver in terms of its noise figure has been devised for this purpose.

a. In a receiving system, the total noise is the sum of the tube noise, the thermal noise in the input circuit, the thermal noise in the output circuit, and the antenna noise. Antenna noise is the induced atmospheric and cosmic noise that appears at the receiver input.

b. The signal-to-noise ratio of an ideal receiving system can be expressed as

$$\text{Signal-to-noise power ratio of ideal system} = \frac{\text{available signal power}}{\text{ideal available noise power}}$$

where the ideal available noise power is the power developed across the antenna resistance by the thermal noise voltage. The available signal power at the receiver input is the power that the signal will develop across an input resistance equivalent to the antenna resistance. Noise figures usually are expressed in terms of power ratios or in dB.

c. You can get the noise figure of an actual receiver from this ratio:

$$\text{Noise figure} = \frac{\text{signal-to-noise power ratio for an ideal receiver}}{\text{signal-to-noise power ratio for an actual receiver}}$$

d. The required signal power at the input of an actual receiver is the required signal power for an ideal receiver multiplied by the receiver noise figure for the same signal-to-noise ratio.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

041. Sources of noise inherent to HF communications

1. What is the primary source of atmospheric noise?

2. Name one method of decreasing the effects of manmade noise (without decreasing the number of sources).

3. The contribution of galactic noise depends on what?

4. What considerations must be made before placing a receiver site?

042. Signal degradations inherent to HF communications

1. What five factors influence received signal strength in an HF system?
2. What is interference fading?
3. What is polarization fading?
4. What is absorption fading?
5. When is skip fading likely to occur?

043. Receive signal strength and noise figures of a system

1. What is required signal strength?
2. What is the purpose of noise figure?
3. How is noise figure calculated?

ANSWERS TO SELF-TEST QUESTIONS

027

1. (1) a; (2) b; (3) d; (4) c; (5) e; (6) g; (7) h; (8) f.

028

1. Ionization density of each ionospheric layer.
2. The higher frequency that can be transmitted into the ionosphere and reflected back toward earth.
3. Frequencies higher than the critical frequency pass through the ionosphere without reflection unless an atmospheric layer above the ionosphere provides reflection. Lower frequencies are reflected back to earth or absorbed by lower layers of the atmosphere.

029

1. The angle of incidence at which most or all of the electromagnetic waves are reflected back to earth.
2. As the critical angle changes, the amount of reflected energy changes.
3. It is the height from earth to the intersection of the two projected straight parts of the path.
4. Virtual height is higher than actual height. Because virtual height is calculated using straight lines directed upward to a point of intersection, from the transmit and receive antennae, the height of the propagating medium is always below this height.

030

1. (1) a; (2) d; (3) a; (4) b; (5) c; (6) b.
2. Sporadic E is an ionized cloud that appears at indefinite intervals and can provide excellent transmission within normal skip distances.
3. SIDs occur during a bright solar eruption that cause a sudden, abnormal increase in the ionization of the D region that results in a radio fadeout.
4. Storms limit the number of usable high frequencies for propagation.
5. Scattered reflections.

031

1. $x = \frac{v}{f}$ of wavelength $= \frac{\text{velocity}}{\text{frequency}}$
2. 196.4 feet.

032

1. An unobstructed medium, either air or a vacuum.
2. Trees, hills, lakes, etc.
3. Types of radio transmission that use ionospheric reflections to provide signal paths between stations.
4. Path, frequency, field strength at the receiver.

033

1. The greater the ion density, the greater the reflection.
2. Yes, the refracted energy from the wave is reflected back into the ionosphere where it can again be reflected downward again at a still greater distance from the transmitter.
3. The higher the frequency of the wave, the less it will be refracted by a layer of a given density.
4. The angle of incidence should be decreased.
5. The critical frequency is the highest frequency that will return to earth when propagated vertically (90°). The critical angle is the angle at which that wave is reflected and returns to earth at its minimum.

034

1. For any given ionized layer at a given density and height and with a fixed angle of radiation, it is the highest frequency that will be returned to earth.
2. The greater the transmission distance, the higher that maximum usable frequency.
3. The more dense an ionospheric layer, the higher the MUF.
4. The frequency that, for any given sky-wave path, will allow the received signal to just override noise.
5. LUF depends on the output power of the transmitter and the distance involved.
6. Frequencies above MUF will escape and not be received, except as scattered waves.
7. At the skip distance.
8. The frequency of optimum traffic occurs at 85 percent of the MUF.
9. The unpredictable changes in the ionosphere.

10. Due to ionospheric variations. A frequency propagated to a changing virtual height, as is the case with the ionosphere, will be reflected back to earth in a sweeping motion. A lower frequency ensures that the receiving station will be in the reflected path.
11. Frequencies below the FOT are used for the most reliable communication.

035

1. The antenna consists of two elements totalling 1/2 wavelength long in relation to its operating frequency. It may be center or end fed.
2. It will radiate at right angles to the direction of the wire.
3. Fixed point-to-point, air-to-ground, and tactical point-to-point communications.
4. Bidirectional.
5. This makes it unidirectional.
6. Fixed and point-to-point, 4 to 16 MHz.
7. The rhombic consists of four legs in the shape of a diamond or rhombus.
8. The radiation lobes of each leg reinforce the others, making it highly directional. Greatest disadvantage is its size.
9. It is nondirectional and is, therefore, used in ground-air communications.

036

1. Shorter elements in succession draw energy away from the driven elements and produce a highly directional radiation pattern.
2. The transmitter energy of the antenna is concentrated in the forward lobe resulting in increased directivity and gain.

037

1. (1) c; (2) a; (3) d; (4) b; (5) b; (6) a.
2. 6 to 8 dB.

038

1. A feeder, feed-in, feed line, lead-in, waveguide, or transmission line.
2. It allows one antenna to serve several receivers.

039

1. 12 kHz.
2. Power output, frequency stability, and frequency range.

040

1. The A1 path is normally used for VFCT tones, the rest for other sources of intelligence.
2. Two receivers feed the signal to an ISB converter to separate upper and lower sidebands. These sidebands are then fed into a demultiplexer.
3. Receivers, ISB, converter, demultiplexer, channel to TCF.

041

1. Thunderstorm.
2. Increase the frequency.
3. Ionospheric absorption and the relationship of operation frequency to critical frequency.
4. The receiver site should be away from vehicular traffic, industry, and other communications sites.

042

1. Transmitter power, antenna gain, path distance, absorption factor of the ionosphere, and interference.
2. Interference fading happens when two or more waves arrive at receiving antennae at different times (out of phase).
3. Results from changes in the state of polarization of the wave relative to the antenna.
4. Occurs from absorption of an electromagnetic wave by the ionosphere.
5. During sunrise and sunset because of rapid changes in the angle of refraction.

043

1. The amount of signal required for satisfactory reception of an intelligible signal.
2. To calculate the noise power present in a receiver
3. $\text{Noise figure} = \dfrac{\text{signal–to–noise ratio for an ideal receiver}}{\text{signal–to–noise power of an actual receiver}}$

Do the Unit Review Exercises (URE) before going to the next unit. ➡

UNIT REVIEW EXERCISES

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

60. (027) The ionospheric layer least affected by ionization is the

   a. D layer.
   b. E layer.
   c. F1 layer.
   d. F2 layer.

61. (028) What effect do the ionized layers of the atmosphere have on higher radio frequencies?

   a. The upper layers will reflect them.
   b. The upper layers will absorb them.
   c. The lower layers will absorb them.
   d. The lower layers will reflect them.

62. (028) In radiating electromagnetic waves vertically into the atmosphere, the highest frequency that will be returned is defined as the

   a. return frequency.
   b. critical frequency.
   c. reflective frequency.
   d. absorption frequency.

63. (029) The *critical angle* is the angle at which

   a. a frequency will no longer return to earth.
   b. the critical frequency will no longer return to earth.
   c. a frequency will return to earth.
   d. the critical frequency will return to earth.

64. (029) In comparison to its *actual* height, an ionospheric layer's virtual height is

   a. greater.
   b. smaller.
   c. the same.
   d. nonexistent.

65. (030) If your HF communications link starts to fade out without warning, you could be experiencing.

   a. an ionospheric storm.
   b. a diurnal variation.
   c. a seasonal ionospheric trend.
   d. a sudden ionospheric disturbance.

66. (030) What ionospheric irregularity is most severe at the higher latitudes?

   a. Sporadic E.
   b. Sudden ionospheric disturbance.
   c. Ionospheric storms.
   d. Scattered reflections.

67. (031) The two variables you must know to compute wavelength are

   a. layer height and velocity of propagation.
   b. velocity of propagation and frequency.
   c. layer height and ion density.
   d. ion density and frequency.

68. (031) When the velocity of a signal calculated by $V = \lambda f$, what is the wavelength, λ, of a 10-MHz signal traveling at 186,000 miles per second?

   a. 98.2 feet.
   b. 982.06 feet.
   c. .0186 feet
   d. 1,860,000 feet.

69. (032) Free space consists of

   a. trees, lakes, and other earth surface terrain.
   b. the air immediately above the earth's surface.
   c. any object that propagates signals.
   d. the unobstructed medium through which radio waves travel.

70. (032) The type of wave propagation that uses ionospheric reflections to provide signal paths between transmitters and receivers is called a

   a. sky wave.
   b. space wave.
   c. direct wave.
   d. ground wave.

71. (033) What happens when the skip distance becomes less than the inner limit of the skip zone?

    a. The angle of incidence will increase.
    b. There will be severe fading of the signal.
    c. The reflected signal will reinforce the ground wave.
    d. There will be a change in polarization.

72. (033) When an HF wave is propagated at a fixed angle and the frequency is increased,

    a. the skip distance increases.
    b. the skip zone decreases.
    c. the signal is absorbed.
    d. the skip zone does not change.

73. (034) In communicating via HF systems, if the transmission distance increases, the maximum usable frequency (MUF) will

    a. depend on the geographic position of the site.
    b. remain the same.
    c. decrease.
    d. increase.

74. (034) What happens to the HF transmission signal when the density of the ionosphere creates a condition where the maximum usable frequency is near the critical frequency?

    a. It is totally absorbed by the ionosphere.
    b. It radiates directly through the ionosphere.
    c. It splits into two new waves with different polarity and phase.
    d. It causes the angle of incidence to decrease.

75. (034) During the daytime, ionospheric absorption of electromagnetic waves occur mainly in the

    a. D region.
    b. E region.
    c. F1 layer.
    d. F2 layer.

76. (034) In ionospheric propagation, frequencies above the calculated MUF probably

    a. are received at great strength.
    b. escape the atmosphere.
    c. are greatly attenuated and returned.
    d. are reflected as ordinary and extraordinary waves.

77. (034) Frequencies that can be relied upon to provide constant communications in the HF range are normally located between the

    a. MUF and LUF.
    b. MUF and FOT.
    c. FOT and LUF.
    d. FOT and OWF.

78. (035) A doublet antenna running east and west radiates its strongest signal to the

    a. east.
    b. west.
    c. east and west.
    d. north and south.

79. (035) Increasing the length of a long-wire antenna

    a. changes direction of transmission.
    b. decreases the power in the major lobes.
    c. increases the power in the major lobes.
    d. increases the angle of the major lobes from the axis.

80. (035) What is the *primary* disadvantage of a rhombic antenna?

    a. Size.
    b. Bandwidth.
    c. Directivity.
    d. Responsive to weak signals.

81. (035) The discone antenna is

    a. directional.
    b. nondirectional.
    c. used in air-to-air communications.
    d. used mainly in point-to-point systems.

82. (036) What are the *main* advantages in using array antennae?

    a. Size and cost.
    b. Directivity and size.
    c. Gain and directivity.
    d. Cost and gain.

83. (036) In array antennae, the available transmission power is concentrated in the

a. minor lobes.
b. major lobes.
c. lobes equally.
d. minor lobes that are produced.

84. (036) A Yagi array antenna uses

a. one driven element.
b. two driven elements.
c. a long-wire design.
d. an omnidirectional system.

85. (037) Which type of log periodic antenna radiates a relatively high gain across the antenna entire bandwidth?

a. V.
b. Planar.
c. Spear point.
d. Vertical monopole.

86. (037) The spear point log periodic antenna is one example of a

a. planar antenna.
b. nonplanar antenna.
c. monopole antenna.
d. long-wire antenna.

87. (038) A coaxial line *normally* is used whenever

a. an extremely small bandwidth is present.
b. a flexible conductor is necessary.
c. low radiation loss is desired.
d. waveguides are unavailable.

88. (039) In an independent sideband (ISB) transmitter, which two sidebands are not multiplexed before going into the sideband transmitter?

a. A1 and A2 paths.
b. B1 and B2 paths.
c. A1 and B1 paths.
d. A2 and B2 paths.

89. (039) For economical independent sideband (ISB) transmitter operation, the carrier wave is

a. amplifier for ensured accuracy.
b. processed with intelligence.
c. suppressed.
d. stabilized.

90. (040) After the upper and lower sidebands of a received HF radio signal have been separated, they are fed into a

a. synthesizer.
b. stabilizer.
c. combiner.
d. demultiplexer.

91. (040) Of the four paths received on the diversity signal independent sideband (ISB) radio system, which is sent to the technical control facility?

a. A1.
b. A2.
c. B1.
d. B2.

92. (041) Power lines, ignition systems, and industrial machinery are sources of

a. atmospheric noise.
b. galactic noise.
c. manmade noise.
d. impulse noise.

93. (041) Receiver sites should be away from

a. communications facilities.
b. excessive vehicular traffic.
c. industrial areas.
d. all of these.

94. (042) Received signal strength in HF radio systems depends on

a. antenna gain.
b. transmitter power.
c. interference losses.
d. all of these.

95. (043) For an HF system with a prescribed length, the required signal strength used as the propagation factor is

    a. dependent on the transmit power.
    b. constant and intelligible.
    c. subject to wide variations.
    d. dependent on receiver sensitivity.

96. (043) Basic noise figure is based on a standard of measuring receiver

    a. fading characteristics.
    b. signal strength.
    c. thermal noise.
    d. static.

Please read the topic page for Unit 5 and continue. ➡

SATELLITE

Page

5-1. Satellite Characteristics and Subsystems

5-2. System Considerations

Radio communications, in one form or another, affect the lives of most of the world's inhabitants. Through radio, the world's population is enlightened and entertained. Radio is a vital tool in promoting international understanding and goodwill, and it's essential to the safety of many people on the ground, in the air, and on the sea. Radio can be a powerful political tool. Our own national security depends on communications. A highly efficient, secure, rapid, and reliable worldwide communications network is the backbone of military operations.

Today the primary means of radio communications for the military are LOS microwave, forward propagation tropospheric scatter (FPTS or tropo), and high frequency (HF). LOS provides high-capacity, reliable communications for about 30 miles; greater distances require relay stations. Tropo can increase the range of high-capacity communications to a maximum of 600 miles. Due to its complexity, tropo is less reliable and harder to set up than LOS. HF radio provides low-capacity communications up to 2,500 miles, but its dependence on ionospheric conditions for propagation makes it the least reliable of the three systems. This limitation, coupled with pressure of near saturation usage of the transmission medium, has caused the military to seek another mode of communications.

The ever-expanding communications requirements of commercial and government agencies, both foreign and domestic, provide constant incentive to explore and exploit every new developments in communications. Communication via satellite is a natural outgrowth of modern technology and the demands for greater capacity and high-quality communications. Relatively recent technical developments have made satellite communications possible. Communications satellites probably won't replace existing communications systems, but they'll offer new ways to satisfy the ever-increasing demand for communications services.

The enlargement of the communications services required by the military was largely due to the compression of time allowed for response to nuclear threat and to the handling and exchange of large volumes of information made possible by computer-controlled automatic data processing systems. The demand for full-time, reliable, long-distance circuits has received special attention by both the civilian and military research and development industry. Improvements have been made in existing systems, but the major problems that affect their reliability or limit their application still prevail. In view of this situation, it's not surprising that the initial and major emphasis in using satellites for communication should be for long-distance circuits.

5-1. Satellite Characteristics and Subsystems

Since the early part of this century, when Marconi developed wireless telegraphy, people have been sending messages through space. Today, the means already exist for communicating as far as the known limits of the solar system. The problems that the space communications engineer is asked to solve aren't involved with generation and propagation of electromagnetic waves, but rather with problems that arise because of the complexity of the system components and the nature of the host vehicle. Such problems are those involved in allowing for the cubage and mass of the equipment in the host vehicle and in generating electrical power in space. This section acquaints you with the characteristics of satellites.

044. Passive and Active satellite systems

Types of Satellites. The first aspect of satellite fundamentals to consider is the type of satellite to be placed in orbit. There are two major categories of satellites—passive and active. As a communications expert, you should be familiar with these categories.

Passive systems. A passive system uses a reflecting surface that can't amplify or retransmit signals. Some of the advantages of a passive system are its inherent reliability and the possibility of being shared by a large number of users operating over a wide range of frequencies. However, a typical passive system, operating between two locations 2,000 miles apart, requires 24 nonsynchronous passive satellites, 100 feet in diameter, in randomly spaced orbits at 3,000 miles altitude for an outage time of 1 percent. Since substantially more satellites are required to provide longer range or wider coverage than that, such satellites don't offer an economical solution for truly global communications. Since a passive satellite merely reflects signals transmitted toward it, there's no "onboard" equipment, and it has no function to perform except to be there. These features give the passive satellite the advantages of economy, simplicity, and reliability.

Active systems. An active satellite is more complex and expensive, with at least a transmitter, a receiver, an amplifier, a power supply, and an antenna on board. Other components are determined by the satellite's purpose and the designer's system specification. Active communications satellites receive signals, translate them in frequency, and amplify and retransmit them. They're like repeater stations in space, letting us use smaller ground terminals that, in turn, enhance the flexibility of military operations. Because of the increased radiated power over that of passive reflectors, the transmission path loss is less and active satellites can be placed in orbit at much higher altitudes.

There are two types of active satellites—delay and real time. A delay satellite has some type of recording device on board. As this type of satellite orbits the earth, certain ground stations "talk" to it. The conversation is stored (or more correctly recorded). When the satellite comes in view of another earth station and on command, the conversation is retransmitted. In contrast, a real-time active satellite receives a message from an earth station and immediately relays the message to another earth station. There's actually a delay of about 0.6 second from earth to satellite and back to earth, but only in telephone conversations does this cause any problem.

Medium-altitude orbit. Continuous global communications coverage from medium altitudes requires from 18 to 24 satellites in orbit. Even then, there would be a switching problem at ground terminals as one satellite passed from view and a new one approached to take its place. The ground terminals would require steerable antennas as well as computing equipment to calculate trajectories and furnish look-angles (acquisition data) for antenna orientation.

Geostationary orbit. Three satellites, at an altitude of 22,300 miles and equally spaced in 24-hour equatorial orbit, appear to remain fixed to an observer on the earth. Such a satellite system provides complete global coverage except for the extreme polar regions. The high altitude of this orbit makes each satellite visible from 40 percent of the earth's surface. Since the satellite appears to be motionless in the sky, service may begin or continue with only one satellite in orbit and functioning. A disadvantage is the time delay that can be experienced in connection with telephoning. The two-way propagation delay through a geostationary satellite is about .6 second—not objectionable if there's no echo. Proper equipment balancing and echo suppression are solving this problem.

045. How propagation affects satellite communications

Propagation. Satellite communications systems experience the same propagation problems as the other systems we've discussed, but a few are unique to satellites. In a system that has ground stations communicating with space vehicles, radio signals from a ground transmitter must pass through the earth's atmosphere, the ionosphere, and through outer space. The return trip to the ground receiver must follow the opposite path. This environment subjects signals to attenuation, refraction, rotation, multipath scattering effects, doppler shift, and noise. Many of these effects are functions of the transmission signal frequency; all of them affect the signal as it appears at the receiver input. Accordingly, ground and space vehicle transmitter, receiver, and antenna designs must take these effects into consideration. Figure 5-1 shows the cumulative effect of some of these factors on the frequency spectrum.

Frequency Spectrum. The earth's atmosphere limits the usable frequencies for satellite systems. The atmospheric radio window includes the frequencies that will pass through the earth's atmosphere—roughly from 100 to 10,000 MHz (MHF to EHF). All frequencies below this range will either be absorbed or reflected by the ionosphere, and those above this range will be absorbed by water vapor and oxygen before they leave the atmosphere. This doesn't rule out eventual use of electromagnetic waves above the radio frequency range, such as infrared and light waves. Selection of specific radio frequencies for communications satellites depends on the demand for maximum traffic capacity, which requires maximum bandwidth. That's why we usually select the upper end of the usable spectrum.

Free space attenuation. Free space attenuation is reduction in amplitude of a radio signal as it travels away from the source through a propagation medium that's free of obstructing, scattering, or reflecting effects. Free space attenuation increases with the square of the distance from the source and the frequency of the transmission signal. This loss can be figured mathematically by using the formula:

$$P_L = 10 \text{ Log } \frac{PT}{Pr}$$

where

P_L = Path Loss
PT = Transmit power
Pr = Receiver power

Free space attenuation is the major factor used in determining total gains and losses in a satellite system. It's not uncommon to have 200 dB of free space attenuation on an earth-terminal-to-satellite link. This should give you an idea of how sensitive the satellite receivers must be.

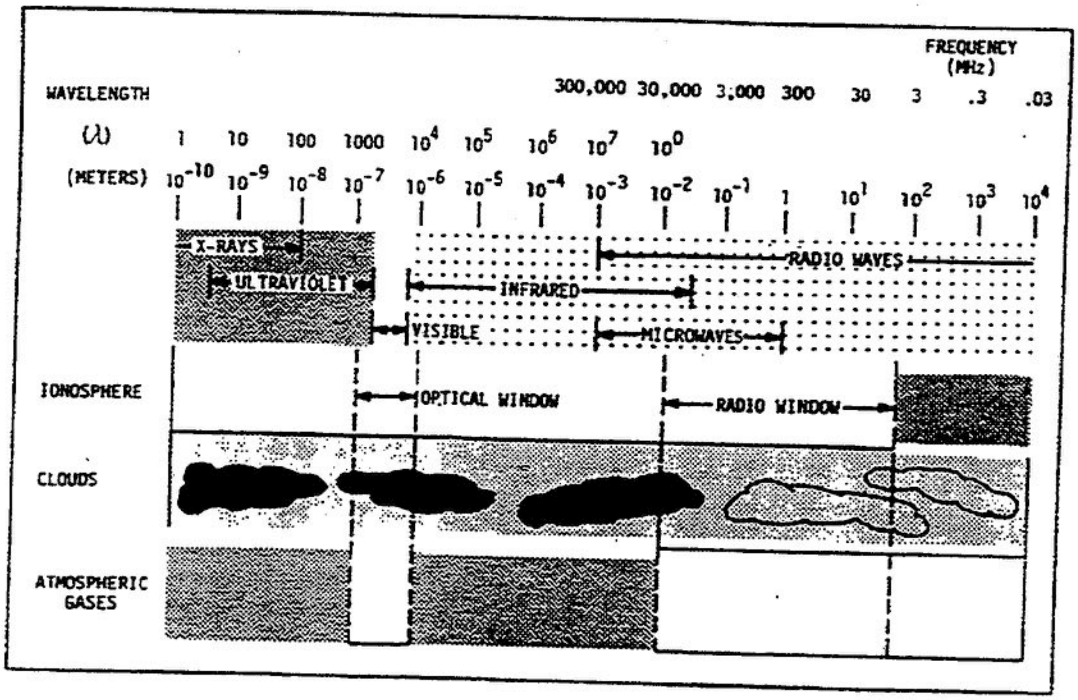


Figure 5-1. Propagation characteristics.

Faraday effect. The Faraday effect is the slow fading caused by the rotation of polarization of radio waves as they pass through the earth's magnetic field. Since the direction of propagation, the magnitude of the earth's magnetic field, and the density of the ionosphere changes constantly, so does the rate of fading. Faraday *rotation* can severely distort all frequencies if the antennae used in the system are not circularly polarized.

To combat the Faraday effect, the transmit signal is rotated 90° from a vertical to a horizontal position. This rotation makes the radio wave travel in a spiral or circular path toward the receive antenna. In satellite systems, transmit signals are usually right-hand circularly polarized and the receive signals left-hand. The directions right and left merely indicate the direction the signal is rotated from vertical.

Doppler effect. A satellite communications system design must take into consideration the shift in signal frequency caused by the satellite's position relative to the transmitting and receiving ground stations. This shift is called Doppler effect. It is similar to the apparent change in pitch of an automobile horn as the automobile approaches, passes by, and continues on its way. In general, since the receiving subsystem must compensate for the shift by providing for sufficient bandwidth or for following the frequency shift, determining the maximum Doppler shift and the rate at which the shift occurs are important design considerations.

Frequency or phase-lock ground receivers are used to overcome the Doppler effect. For wideband satellite communications, a Doppler shift isn't of primary importance. For example, when a satellite is orbiting at 6,000 miles, the one-way maximum Doppler shift will be less than 35 kHz for a frequency of 5,000 MHz. A Doppler shift may, however, distort the RF bandwidth in broadband systems. Narrowband satellite communications systems are even more seriously affected by a Doppler shift.

046. Subsystems used in satellite communications

Before we discuss the various satellite programs the Air Force uses, let's first look at the subsystems that are the backbone of these programs. A satellite serves as a relay station between ground stations, much like an intermediate repeater in a line-of-sight microwave (LOS M/W) link (fig. 5-2). Early communications satellites were passive devices, providing only a reflective surface to redirect radio waves, but most satellites today are active transponders. They receive, amplify, and retransmit signals from ground stations. A satellite link's major advantage is that it is particularly well-suited for long distance communications. A single satellite can provide the link between ground stations separated by thousands of miles that may have otherwise required numerous terrestrial repeaters. The elements that form the Defense Satellite Communications System (DSCS) are the space, earth, and control segments.

Space Segment. The DSCS space segment consists of DSCS II and DSCS III satellites in a constellation configured to provide maximum mission support. The less versatile

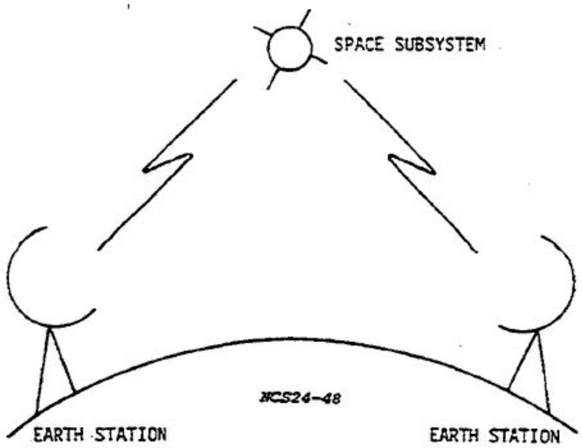


Figure 5-2. Basic satellite communications link.

DSCS II satellites are being replaced by DSCS III satellites that will occupy the same orbital positions and operate in the same frequency bands. The DSCS III is designed for more effective implementation of a worldwide military communications mission. It provides protected communication services and has greater performance capabilities than the phase II system, particularly in the area of antenna flexibility.

Space Subsystems. Unlike microwave repeaters, communications satellites are designed to serve multiple ground stations. Techniques that make this possible are discussed in subsequent sections on multiple access techniques. Figure 5-3 is a block diagram of a typical satellite communications network. In this simple illustration, earth terminal (station) 1 transmits one uplink carrier, which is received by terminal 2. Terminal 2 transmits two carriers, of which one is received by terminal 1 and the other by terminal 3. Terminal 3 transmits three carriers, one to terminal 2 and the other two to terminal 1.

It is apparent from this illustration that satellite networks offer tremendous potential and flexibility. By reconfiguring the ground stations, you can change the network configuration. Normally, all that's required to establish a new link is to retune the ground station receiver to the distant terminal's corresponding downlink frequency. In systems where more than one satellite is used, it is necessary only to redirect the antenna toward the other satellite and adjust the ground station for the appropriate transmit and receive frequencies.

There are, however, many problems associated with satellite networks. They stem mostly from the satellite transponders that provide frequency conversion and retransmission. The power limitations of transponders, coupled with long transmission paths, result in low receive signal levels (RSL) at earth terminals. This complicates the design of earth subsystems and increases costs. Transponder power limitations also limit the number of users satellites can provide service for. As more and more users access the satellite, the amount of transmitter power available to each user is decreased, thus reducing the quality of communications. Since a satellite is inaccessible once it is placed in orbit, transponders must be designed for maintenance-free operation.

Low-noise-receiver front ends and large high-gain antennas are required for high-quality communications.

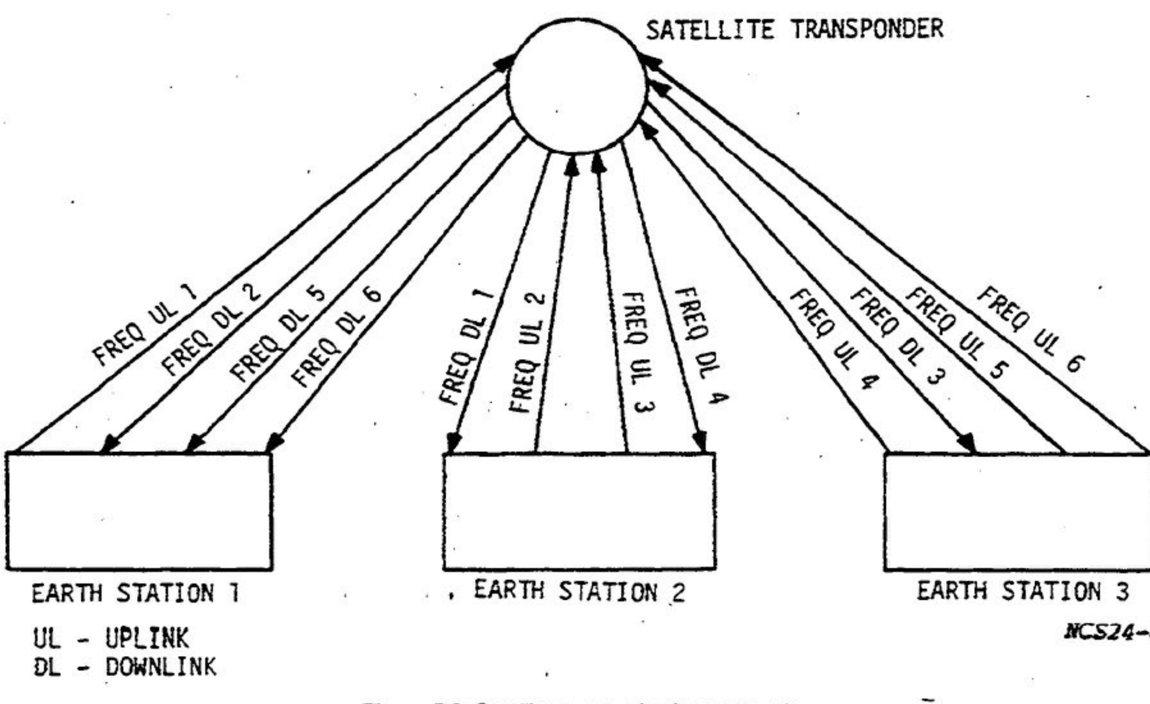


Figure 5-3. Satellite communications network.

Ground station design is further complicated by the fact that satellites are not stationary. This is true even of geostationary satellites, although their movements are minimal. An earth terminal must be able to track or constantly keep its antenna directed toward the satellite. Geostationary satellites require this capability because of the narrow beamwidth of the terminal's antenna. The mechanics and electronics involved with a large tracking antenna greatly increase costs. Finally, the aspect that makes a satellite system desirable can also create problems. The satellites' visibility over large parts of the earth's surface makes them susceptible to jamming by hostile forces.

Figure 5-4 depicts an active satellite system with its subsystems. The space subsystem consists of a satellite antenna array and a transponder. There are many other components that make up this subsystem, but we don't cover them individually.

Antenna. Antennae on space-borne satellites enable them to receive and transmit signals from earth terminals. Older satellites use a variety of antennae ranging from a collinear array, or phased array, to slot antenna. Newer satellites often use a gimballed dish, which resembles a parabolic antenna and provides high gain to transmit radio waves over vast distances. Also used on newer satellites are multibeam antennae, which let ground control terminals adjust the transmit radiation pattern. The radiation pattern for multibeam antennae can be blanked out to deny reception in a nulled area. This radiation pattern resembles a doughnut. The hole in the doughnut representing the nulled area. The control terminal can steer the transmit null, or signal, to anywhere in the coverage area.

Transponder. Satellite transponders receive, amplify, and retransmit signals from earth terminals. Figure 5-5 is a block diagram of three typical types of satellite transponders. The particular type of transponder used is based on bandwidth and gain requirements. Usually, narrow bandwidth requirements are implemented using double-frequency conversion or processing transponders, with the latter providing some improvement against jamming.

Satellite transponders provide one or more RF channels with each channel normally required to receive and relay several simultaneous signals. With few exceptions, communications transponders have saturating nonlinear input-output characteristics that result in intermodulation distortion when two or more signals enter the satellite. The magnitude of the intermodulation products is held to acceptable levels by various means. Bandpass filters channelize the transponder to reduce intermodulation distortion. Judicious selection of uplink frequencies also helps reduce distortion. By selecting frequencies properly, you can make many of the intermodulation products lie outside the transponder's operating bandwidth.

Another way to reduce intermodulation distortion is to operate the transponder at a back-off point below saturation. This reduces the intermodulation radiated power (EIRP). The EIRP is a function of the transponder's amplifier output and the gain of the antenna. A satellite's EIRP bears significantly on the quality of the communications. In a system that is already power constrained, only a few dB less radiated power can severely reduce system capabilities.

In addition to relaying signals between earth stations, satellite transponders usually provide a beacon signal that is

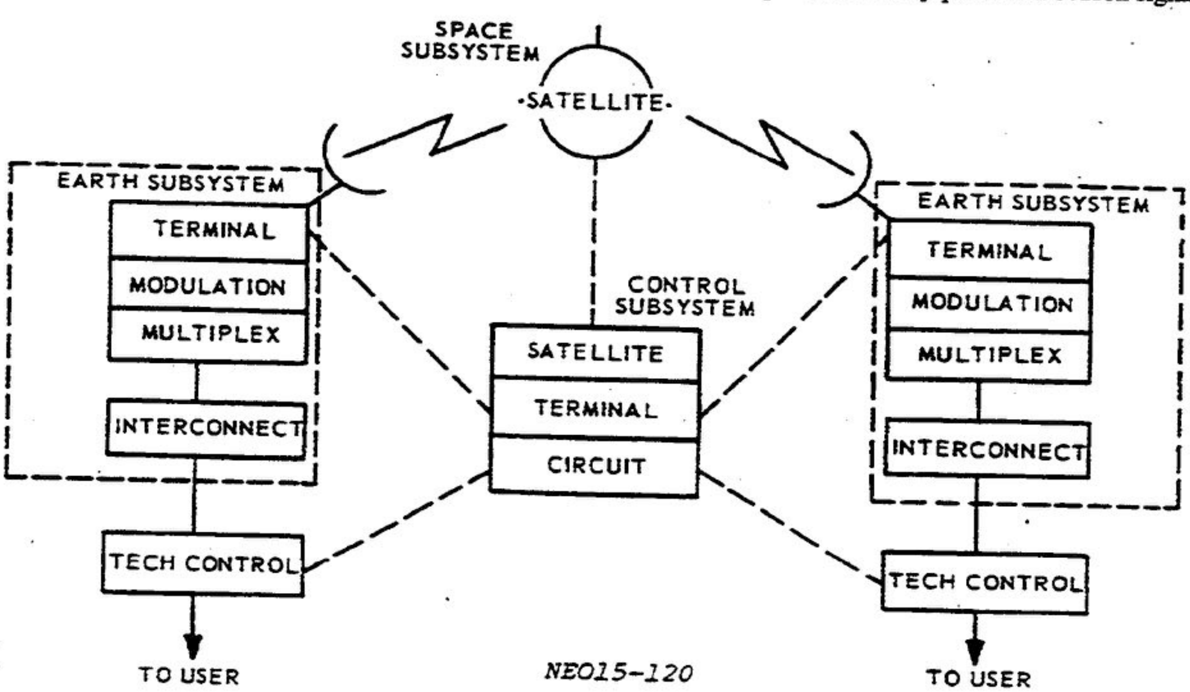


Figure 5-4. Active satellite system block diagram.

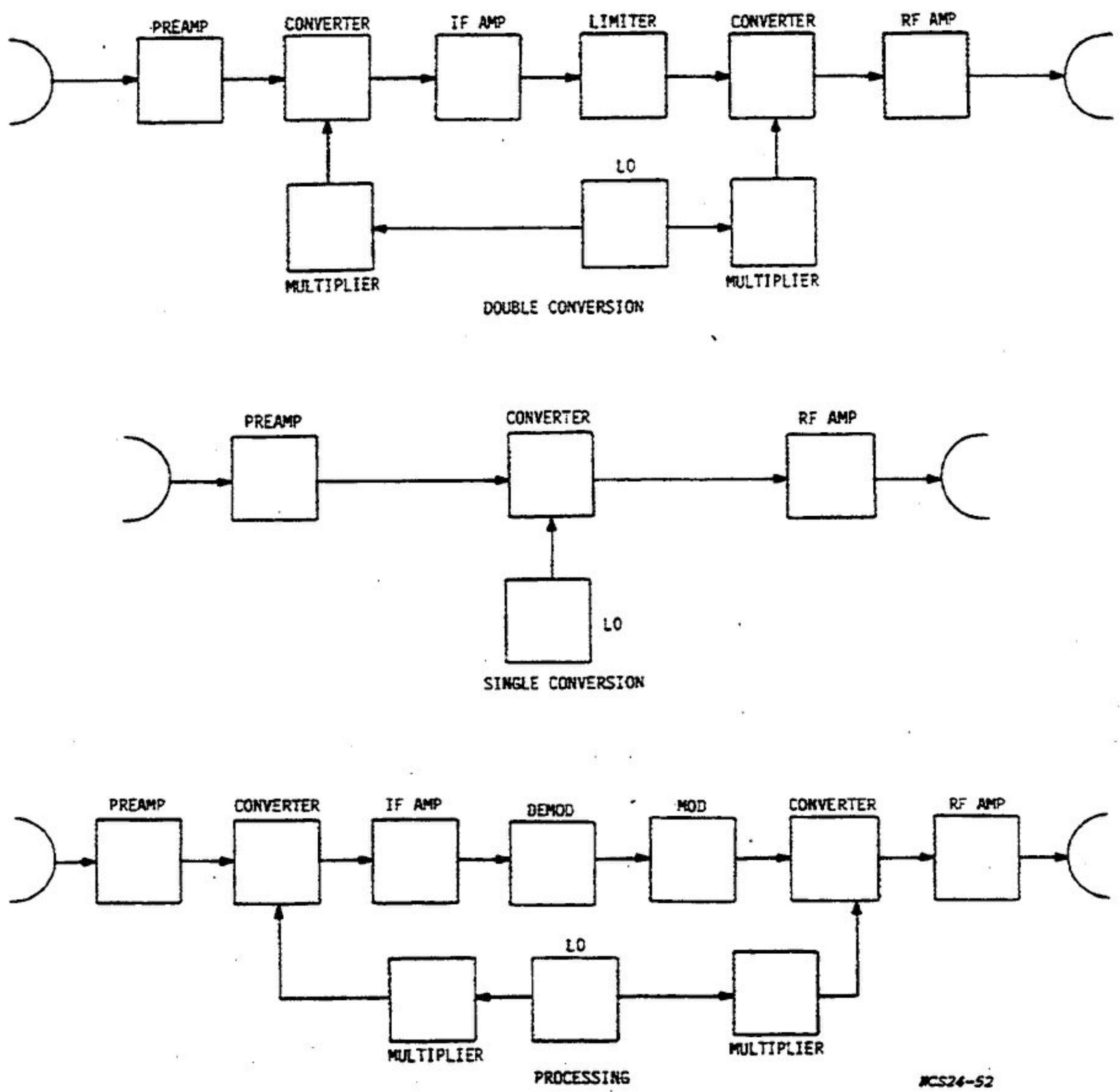


Figure 5-5. Basic satellite transponders.

used for acquisition and tracking by earth terminals. The beacon signal is generated internally or supplied to the satellite by an earth station. Often, the beacon is modulated with telemetry information necessary to perform station-keeping and maintenance functions (switching redundant components in the transponder, orbital correction, repositioning, etc.).

Station keeping is occasional readjustment of a satellite's position to maintain desired orbital characteristics. It's necessary because of disturbing forces that result from gravity irregularities, atmospheric drag, solar radiation, etc. Normally, the satellite is positioned by a system of gas jets that can be controlled via ground station commands.

Earth Segment. DSCS earth segments are a network of earth terminals operating in a multipoint, multicarrier network configuration for each satellite. DSCS earth terminals are categorized as fixed, transportable, and equipment. They are further categorized as DSCS standard heavy, medium, light, and other. Other includes DSCS-GMS, airborne, shipborne, and DTS terminals. Some of these terminals are covered in later lessons.

Earth Terminals. A satellite communications system uses satellites to relay radio signals between earth terminals. As we've said several times, a passive satellite system merely reflects these signals back to the receiving terminals, while an active satellite amplifies the signals and then retransmits them to a receiving terminal or terminals. A typical link involves an active satellite and at least two earth terminals. One terminal transmits to a satellite on the uplink frequency. The satellite amplifies the signal, translates it to the downlink frequency, and then transmits it back to earth where it is picked up by the receiving terminal's antenna (fig. 5-6). It's apparent from this illustration that satellite networks offer tremendous potential and flexibility. By reconfiguring the ground stations, it is readily possible to change the network configuration. Normally, all that's required to establish a new link is to retune the ground station receiver to the distant terminal's corresponding downlink frequency. In systems with more than one satellite, you must redirect the antenna toward the other satellite and adjust the ground station for the appropriate transmit and receive frequencies.

Antenna and tracking components. An earth terminal is like a M/W station in many respects, but there are some notable differences. The earth terminal antenna component must be able to track a moving satellite. Where high-gain requirements dictate large antennae and narrow beam widths, the mechanics and electronics necessary for accurate antenna positioning can get very complex. Tracking errors of less than a tenth of a degree can be disastrous to the quality of the terminal's communications. Signals received at an earth terminal are low level due to long transmission paths and the relatively low transmitter power of satellites. This means that the antenna must provide high signal gain while contributing low noise. The measure of an antenna's noise contribution is normally expressed in terms of antenna noise temperature. For large antennae, noise temperatures of about 30 to 80°K (Kelvin) are common, depending on the antenna elevation angle.

Antenna polarization is also an important consideration. Because satellites are normally used by geographically wide-spread terminals, polarization loss must be independent of the look angle from the ground station to the satellite. Circular polarization has this property and is used in all satellite systems. Losses from polarization mismatches in vertical or horizontal polarization can be as great as 30 dB. The transmitter of a typical earth terminal consists of frequency conversion and amplifier sections. Most DCS terminals have a multiple transmit carrier capability. The AN/FSC-78 earth terminal, for example, can transmit nine separate uplink carriers. The number of transmit carriers possible depends on the RF bandwidth capability of the amplifier sections, the number of frequency converters, and the intermodulation

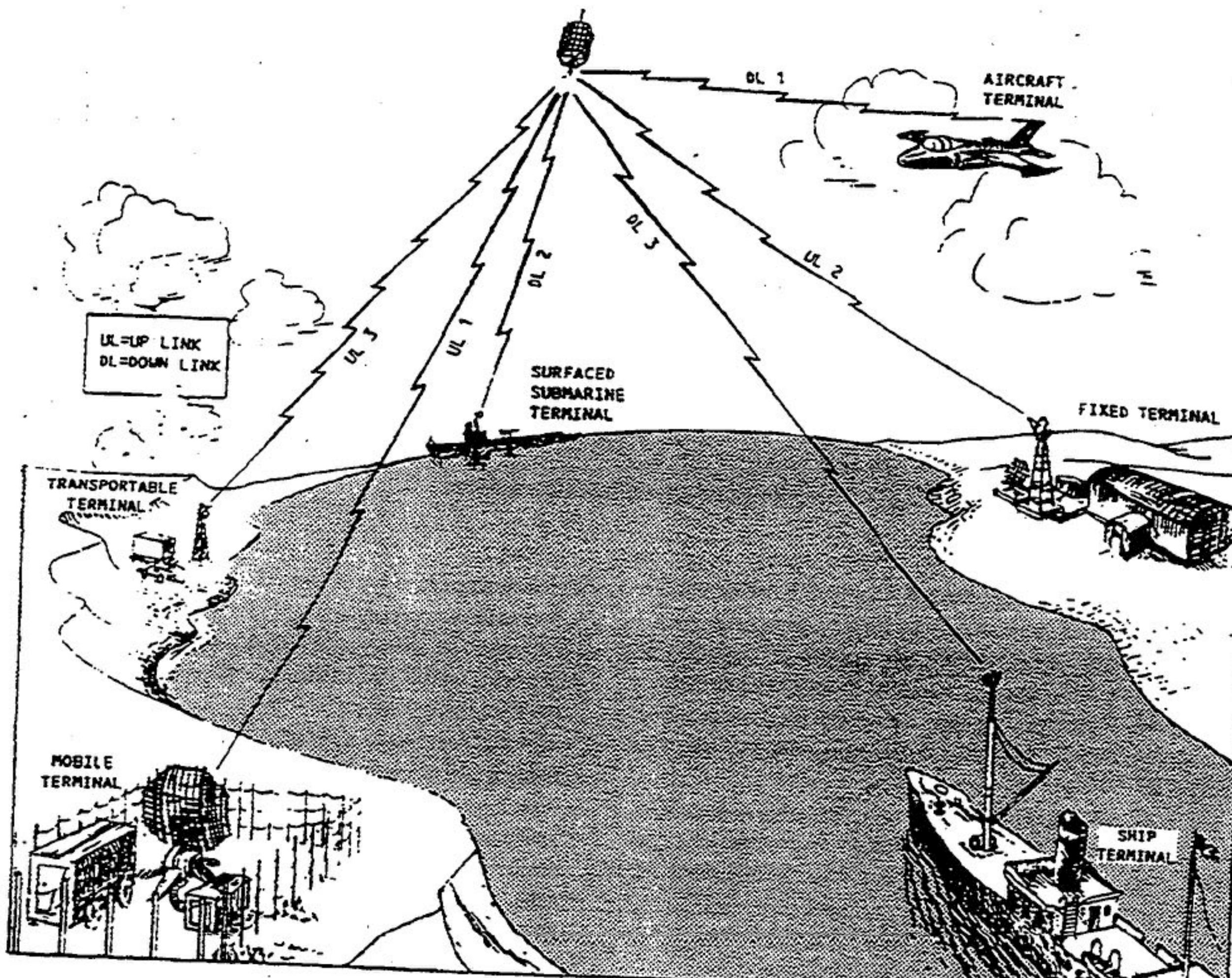


Figure 5-6. Satellite communications system.

distortion products generated as a result of multiple input frequencies.

Figure 5-7 represents a typical DCS earth terminal receive subsystem. Again, the receive subsystem is like a terrestrial M/W receiver, but there are some differences that bear discussion. The RF amplifier in high-quality earth terminal receivers is normally a low-noise device. Typical noise figures range from .5 to 2.0 dB, versus the 8 to 11 dB noise figures for normal terrestrial M/W receivers. A low-noise, front-end amplifier is located as close as possible to the antenna. Normally, the receiver front end is mounted on an antenna pedestal, reducing carrier-to-noise (C/N) degradation from losses between the antenna and the amplifier input.

Control Segment. The Defense Communications Agency (DCA) exercises operational direction of the DSCS through the DCA Operations Control Complex (DOCC). A subsystem of the DOCC, the DSCS Operation Control System (DOCS), consists of a hierarchy of control elements that are responsible for the control of space communications via the DSCS. Using computer facilities, the DOCS provides near real-time control to ensure efficient transponder use and rapid DSCS reconfiguration to meet user requirements. The control concept specifies the major control categories as satellite control, communication, payload control, and satellite communications (SATCOM) network control.

Satellite telemetry, tracking, and control (TT&C) is done by the Air Force Satellite Control Facility (AFSCF) at Onizuka AFS (formerly Sunnyvale), California. The AFSCF uses a network of remote tracking stations to keep satellites in their assigned orbital positions, maintain the prescribed satellite attitude relative to earth, and support the housekeeping functions necessary to ensure optimum operation of the satellites.

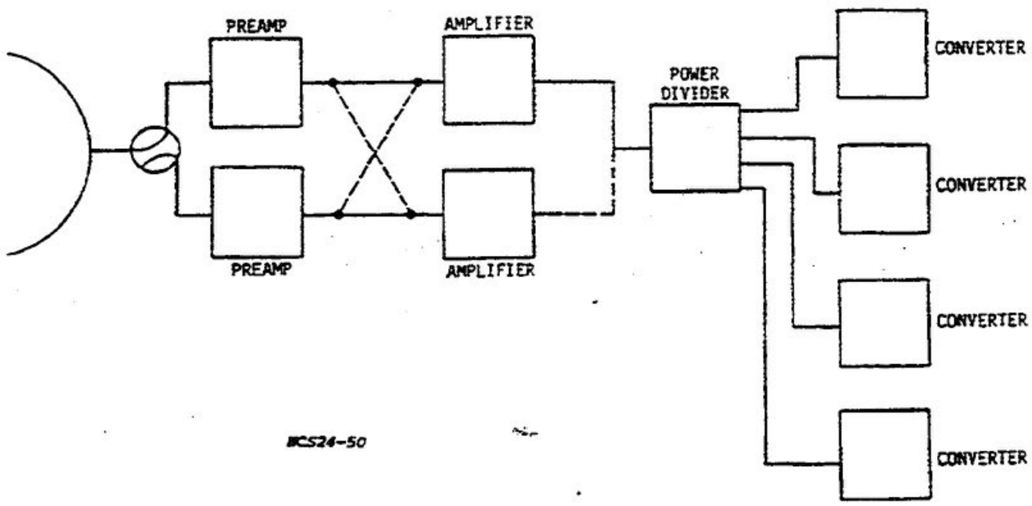


Figure 5-7. Basic earth termincal receiver subsystem.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

044. Passive and active satellite systems

1. Describe a passive satellite.

2. In an active satellite system, what does the satellite do?

3. Which type of satellite orbit requires the fewest satellites for almost global coverage?

045. How propagation affects satellite communications

1. What is free space attenuation?

2. What type of fading is caused by the Faraday effect?

3. Compensation for the Doppler effect is made where?

046. Subsystems used in satellite communications

1. What is required to establish a new link with a distant station?

2. What are the two parts of the space subsystems?

3. What are the three parts of the earth subsystems?

4. How does a satellite earth terminal receiver compare to that of a terrestrial line-of-sight receiver?

5. What are the major control categories of the satellite control segment?

5-2. System Considerations

Our continuous efforts to improve and expand our means of communications can be viewed as an ongoing struggle. Establishing an operational communications system based on satellites in space involves some very familiar factors, but it also introduces new ones we must consider for the first time. We can start by comparing satellite and tropo systems. A tropo system must cope with the meager portion of signal scattered by tropospheric irregularities. This requires a high-power transmitter, highly directional transmitting and receiving antenna, and an ultrasensitive receiver for the system to function. In comparison, a satellite system that deals with the direct path of propagation may seem improper, but due to other (environmental) factors, similar equipment, and special techniques, these systems operate with similar limitations.

Visualize a tropo link, using two repeater stations, that is converted to a satellite system by simply using a satellite to replace the two stations in the middle, as illustrated in figure 5-8. Of course this is an oversimplification, but it does come close to how satellite ground stations function. A tropo link connecting New York and California requires four to six relay stations, while one satellite, in the right position, can satisfy this relay requirement. Also, when this same distance involves stations separated by water, such as Hawaii and California, the long-distance advantage of satellites is fully exploited.

In developing operational tropo systems, a tremendous technological base was established that was directly transferable to communications satellites. The basic systems are the same and differ only in the need for greater expertise in developing a satellite communications system. An advantage of satellites is that one satellite may relay information to

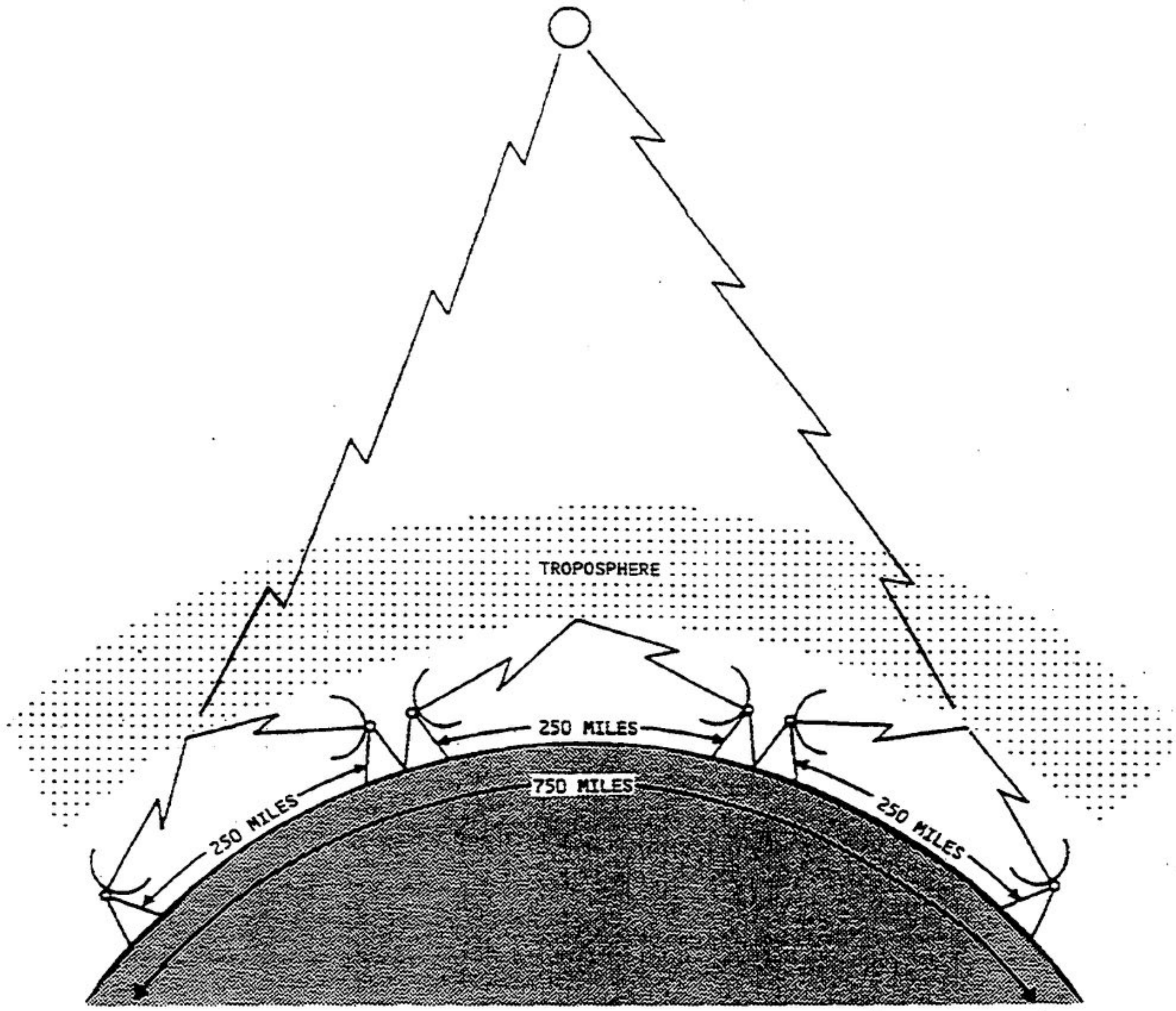


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Figure 5-8. Troposcatter vs satellite communications.

several ground stations. There are several ways to get this multiservice capability. Let's look at some of the system characteristics that determine whether a satellite system is more feasible than one of the other systems we've discussed.

047. Satellite system considerations

Orbits. First, a systems designer must consider the satellite's orbit. To achieve orbit, a satellite must be lifted above the atmosphere and started moving around the earth at the exact speed required to produce a centrifugal force just equal and opposite to the gravitational force at that altitude. Since the earth's gravitational attraction decreases with altitude, high-altitude satellites don't have to circle the earth as fast as low-altitude satellites to stay in orbit or to achieve it.

The basic design of a satellite communications system depends, to a great extent, on the parameters of the satellite's orbit. Traditionally, an orbit is identified by its shape, the inclination of its orbital plane (in relation to the earth's equatorial plane), and the altitude of the orbiting satellite.

All artificial satellite orbits are circular, elliptical, parabolic, or hyperbolic. The initial launch parameters and later deployment techniques determine the orbit. Communications satellite orbits are either elliptical or circular, and deep space probes and rockets have circular orbits.

Orbital Control. The two types of orbital control for satellites are attitude control and station keeping. Attitude control, which is used on practically all satellites, can be implemented about one axis, two axes, or all three axes. The attitude control system used has a great effect on the design of directionally sensitive satellite subsystems, such as antennae for communication and solar cells for prime power generation. Station keeping refers to the maintaining a fixed-satellite position relative to the earth (in the case of a geostationary satellite) or to another satellite (in the case of several satellites spaced along the same nonsynchronous orbit). Station-keeping control is not used for one satellite in a nonsynchronous orbit, but it is normally used in geostationary satellite systems.

Attitude control. Required pointing accuracy, system lifetime, reliability, weight, and cost are some of the factors involved in attitude-control system design. Early satellites, which were designed for long-term operation, were spin stabilized. The more stringent requirements of present space missions demand more precise control. The five types of attitude control systems used are spin stabilization, gravity-gradient, momentum storage, mass expulsion, and mixed systems. They're somewhat complicated to explain, but they're all, in some way, based on the torque forces that affect a satellite's position.

Station keeping. Station keeping keeps the satellite in a desired position in orbit within acceptable limits. For example, a geostationary satellite is given occasional commands that adjust its position so that it stays in a fixed position within a few degrees relative to the earth. Station keeping is necessary to offset the effects of perturbing forces on the satellite's orbit. These forces include solar radiation, atmospheric drag, gravity perturbations from the sun and moon, and gravity perturbations due to the earth's not being quite round. Advantages of station keeping include simplifying acquisition and tracking (with narrow beam earth antenna) and providing a satellite that permits continuous or predictable links between selected earth terminals. A mass expulsion system is used for station keeping and can be integrated with the attitude control system. Certain combinations of gas jets are fired simultaneously for attitude control, and other combinations are fired simultaneously for station keeping. The satellite is allowed to drift slowly between limits imposed by system requirements. Station-keeping function is done periodically, every few weeks or months.

Satellite Ground Tracks. The orbits of all satellites lie in planes that pass through the center of a theoretically spherical earth. Each plane intersects the surface of the earth in a great circle (fig. 5-9). A satellite's ground track is traced by the intersection of the earth's surface and a line between the center of the earth and the satellite. As the space vehicle moves in its orbit, this intersection traces out a path on the ground below. The last important aspect we'll consider is how the ground tracks will communicate and control the satellite itself.

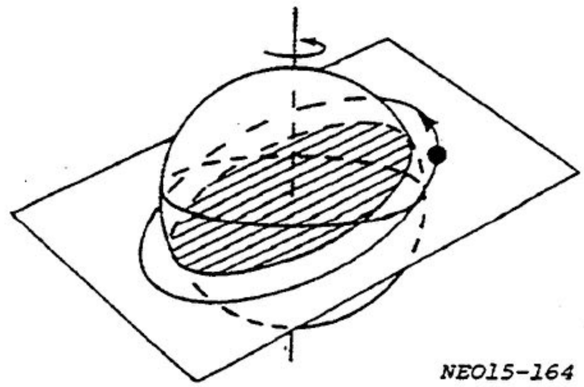


Figure 5-9. Satellite ground track geometry.

048. Multiple-access service and system control used in satellite communications

Frequency-Division Multiple Access. Frequency division multiple access (FDMA) is the most common technique used today and the easiest to implement. In this technique, each uplink carrier is assigned a separate frequency within the transponder's frequency band. The transponder acts like a common amplifier and frequency translator to relay signals back to the earth (fig. 5-10). One of the method's shortcomings is that the power available to retransmit signals must be shared by all users of the satellite. This reduces the power available for each downlink signal. As the number of users accessing the satellite increases, the quality of communications decreases.

Problems also arise from the fact that the traveling-wave tube (TWT) used in most satellite transponders is a hard-limiting device that reaches saturation abruptly. When a hard-limiting device is driven into saturation by multiple input signals, large amplitude intermodulation products are generated. For efficient use a TWT should be operated near saturation. In an FDMA satellite system, this necessitates strict power control over all the satellite's users. Normally, in order to exercise adequate control and keep intermodulation products at acceptable levels, the transmit power from ground stations is monitored and maintained at an equivalent transponder input level that keeps output 1 to 3 dB below TWT saturation. This necessary back-off reduces the transponder's EIRP, thus reducing system capabilities.

Another detrimental characteristic of using transponders with FDMA techniques is signal capture—the tendency of larger signals to suppress weaker ones. Although this does have some limited advantages where jamming protection is required, it can create problems in normal use. FDMA techniques also require careful selection of uplink frequencies to void the generation of unnecessary intermodulation products. By judiciously selecting frequencies, you can make many of the intermodulation products fall outside the transponder's bandpass.

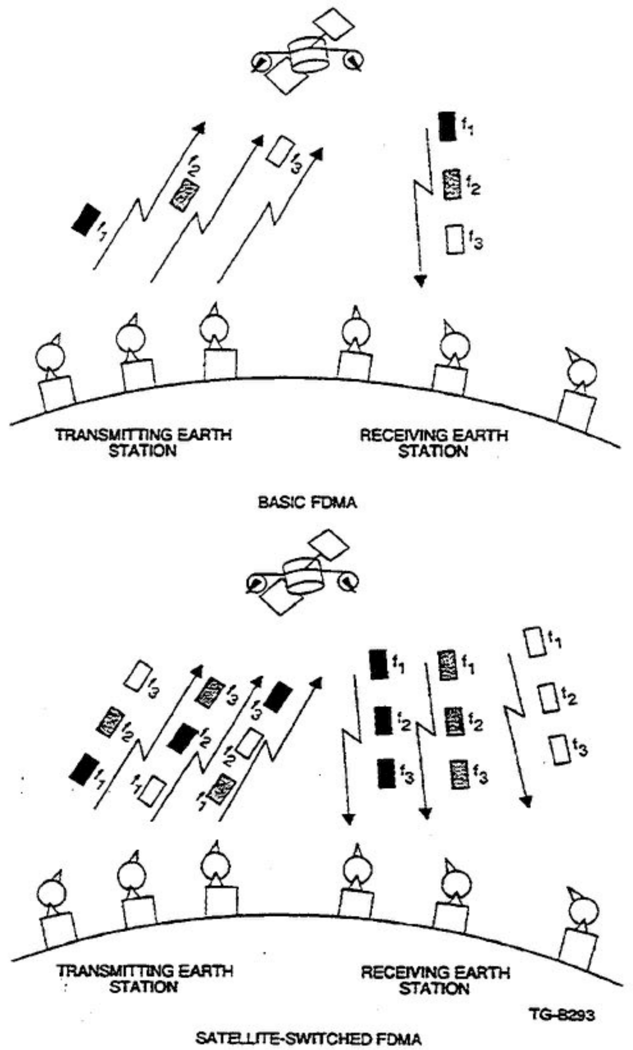


Figure 5-10. FDMA models.

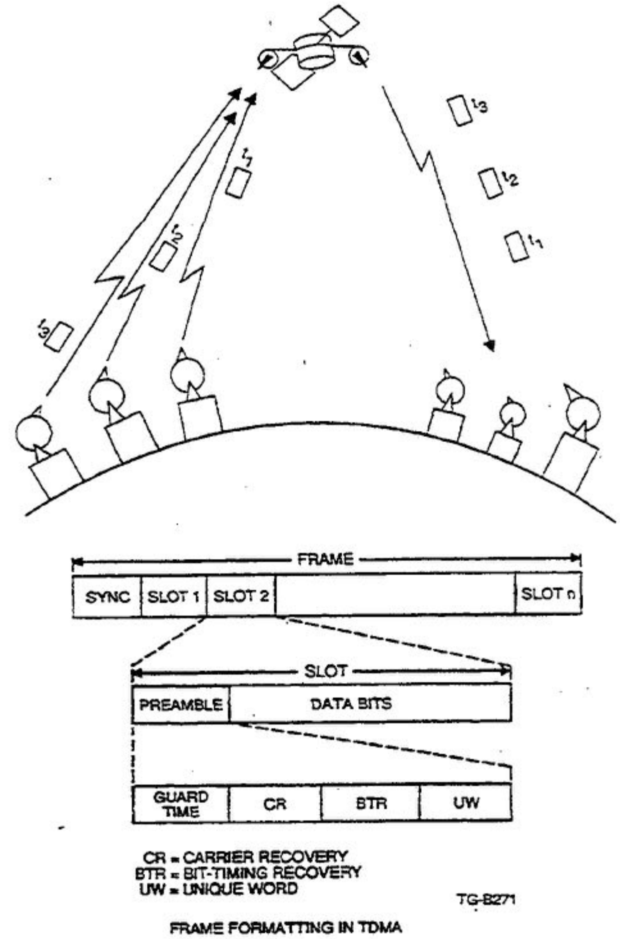


Figure 5-11. TDMA satellite system model.

Time-Division Multiple Access. The most efficient form of multiple access is time-division multiple access (TDMA), in which each earth terminal has exclusive use of the satellite transponder for a specified time interval (fig. 5-11). Assuming that four ground stations are using the satellite, the figure shows that each one has a specific time interval in which to transmit information. Each of the terminals has access to all of the downlink transmission, but processes information only during the interval in which the desired distant terminal is transmitting.

One problem with TDMA is that it requires accurate network timing and all terminals must be in sync with one another. Another problem is that all information must be in digital form; analog information must be digitized before transmission. Since there's no continuous information path between terminals, buffering (storage capability) is also required at the earth stations. Even considering these problems, TDMA is the approach that most future systems will take.

Spread-Spectrum Multiple Access. Spread-spectrum multiple access (SSMA) is like FDMA in that users share satellite power. The difference is that several users occupy the same frequency spectrum in the transponder simultaneously. Each user's carrier is modulated twice at the ground station, first by the information and then by a high-frequency band-spreading signal. The band-spreading signal (usually digital) has the effect of dispersing the power in a carrier over a wide band of frequencies, resulting in a spectrum that appears noise-like (fig. 5-12). The pattern of the spreading signal (the code) is a pseudorandom sequence. An identical code generated at the receiving terminal and synchronized with the transmitting end allows the information signal to be recovered. If different codes that show a low cross-correlation are assigned to different users, then transmissions by several users are possible with only a small amount of interference. This interference does, however, increase with the number of simultaneous users and, therefore, limits the number of ground stations sharing the same transponder. As with FDMA methods, the total power available also restricts the number of users.

System Control. Any communications system requires some sort of system control for optimum performance. This

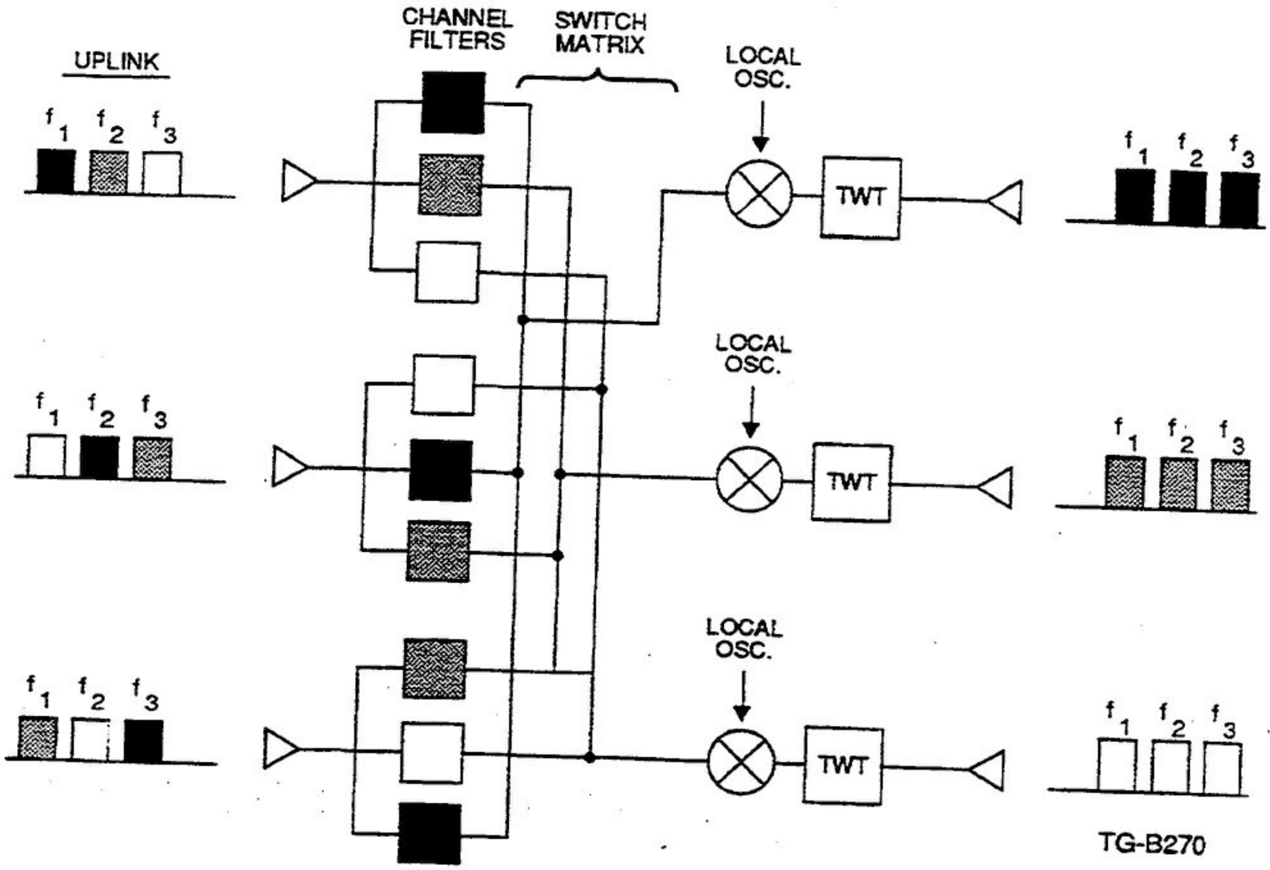


Figure 5-12. SS-FDMA satellite block diagram.

is especially true in satellite systems where several users share a common transponder. The operation of each terminal directly affects all other users in the system. Misaligned or defective equipment at one ground station requires more satellite power, and it can degrade performance for the whole system. Hence within a satellite system, the type of control required can be divided into two categories—satellite control and communications control.

Satellite control includes whatever is done to maintain correct orbital characteristics and optimum transponder performance. Without periodic adjustment of the satellite's position, orbital characteristics would be unpredictable and system planning impossible. Likewise, it's just as important to be able to switch to redundant equipment in case of component failure or to change amplifier gains within the transponder to meet customer demands.

Communications control involves monitoring system performance and future planning. The input signal level to a satellite must be closely monitored to make sure the transponder isn't driven into nonlinear operation. Frequency assignments within the system must be carefully planned to prevent unnecessary interference between users. In TDMA systems, synchronization must be monitored and maintained. Satellite loading and capacity must be judiciously monitored and planning for new communications requirements constantly considered.

049. Space and earth subsystem trends

Space Subsystem Trends. In the relatively short time that satellite communications systems have been in use, great progress has been made. There are continually expanding requirements for more high-speed global circuits. This means relaying greater amounts of traffic through satellites with increased reliability. The requirement for more powerful and versatile satellites calls for increased launch-vehicle payloads and places greater demands on the finite orbit and usable frequency spectrum.

Satellite position. Developments to date have shown advantages in using geostationary orbits for communications satellites. However, present satellites aren't exactly stationary with respect to the earth. DSCS satellites orbit in a figure-eight pattern, moving as far as 3° north and south of the equator. Hence, many of the earth terminals using a satellite are equipped with costly automatic-tracking devices. To offset this, station keeping can maintain a satellite within limits so that tracking isn't required once the antenna is properly oriented.

Higher frequency bands. Today's commercial communications satellites use the 4- to 6-GHz band, and the military uses the 7- to 8-GHz band for global communications. These bands, like the lower frequency UHF band, are becoming crowded from both a satellite and terrestrial viewpoint. The trend for satellite, as well as for other means of communications, will be toward higher frequencies. Action is already underway in the 11- to 15-GHz and 30- to 35-GHz regions. These higher frequencies open new areas and provide greater bandwidths for high-data-rate links, but they also introduce problems. The 1- to 10-GHz region is favored because of its low-propagation loss as a result of oxygen and water absorption. These two losses become very serious above 10 GHz. Additionally, the capability to generate adequate power at the higher frequencies requires new development. These frequencies do permit smaller and more directional antenna with a resultant increase in antenna gain. This is partially counteracted by the accompanying increase in free space loss.

Antenna. Satellites have both earth coverage (EC) antennae for global communications and narrow-beam (NB) or spot-beam (SB) antennae for requirements concentrated in specific areas. SB antennae are more directive. By concentrating transmitter power in a smaller area, thereby compensating for space loss, system reliability is increased.

Satellite-to-satellite links. For a truly global capability, it's desirable to establish links directly from satellite to satellite, thus eliminating the use of earth relay terminals. Studies are underway and experiments are planned using optical frequency devices in an attempt to do this. It's realistic to expect such a capability within the next few years.

Improved capacity. To meet the challenge of growing requirements, satellites have increased in power and bandwidth. Additionally, recent satellites have taken advantage of the design feature of using separate transponders for the varied requirements, such as TV, voice circuits, demand assignments networks, etc. This channelization separates the different modes of operation, thus greatly reducing intermodulations. Future satellites will undoubtedly be configured to continue this trend. The gain in transmission capacity of satellites and their associated ground systems is evidenced by the increase in traffic-carrying capability.

Earth Subsystem Trends. Like the space subsystem, the earth subsystem has experienced improvements during its initial years of operation. Larger and more reliable terminals have been developed. These improvements will continue.

Receive system G/T. The receive system's capability can be measured by its figure of merit (G/T), the ratio of the receive antenna gain to the system-noise temperature. This figure of merit depends on several parameters in areas subject to further research and development.

Antenna. The design for large fixed-plant antennae is not expected to change radically. The size is limited by cost, with pointing accuracy and smoothness of the antenna surface being the major factors for large antenna. Limited progress is being made in increasing the nominal 54 percent efficiency of large parabolic antenna, but for other DOD uses, such as aboard aircraft, there should be notable improvement. Blade and phased-array antennae are research areas that should improve the gain of airborne antennae.

Intermediate radio frequency (IRF) modulation and multiple access techniques. The majority of traffic today, as in the past, is analog. With the advent of data processing, computers, and other digital devices—including encoders for secure voice circuits and wideband data units—the volume of digital traffic is growing at a far faster rate than analog requirements. As we said, the DSCS will be evolving from an analog system to a hybrid analog-digital system and, finally, to an all digital system. Much work and development effort have already gone into developing base and TDM/PCM equipment, and DOD is presently procuring such units. The TDM/PCM equipment will sample and quantize analog signals and feed them to a TDM unit to be multiplexed into a composite serial stream for transmission. The TDM output can be sent via satellite using either FDMA or time division multiple access. This trend toward digital communications will accelerate and result in the majority of DCS trunking being handled on a digital basis.

For the signals transmitted via satellite to remain digital, the present DSCS RF modem (which is FM) will be replaced with a phase-shift keying (PSK) modem. Such units are under development for the DSCS. During the coming decade, it's reasonable to assume that such units will gain in reliability, simplicity, and in ability to handle more and higher data rates. PSK offers the advantage of permitting power, bandwidth, and error rate tradeoffs, adding flexibility in circuit and system design.

Although either FDMA or TDMA can be used to transmit the PSK signal, the future will see a trend toward TDMA. Such satellite systems have already been tested and proven practical. Although, at this time, TDMA is not a common mode operationally in either the commercial world or DCS, its advantages are recognized, and plans and programs have been established to use TDMA when the PCM, TDM, and PSK units are operational and the TDMA synchronizing and control systems are in production. This trend will result in PSK/TDMA largely replacing FM/FDMA for satellite transmission of nontactical traffic. Other modulation and multiple access techniques of particular interest to the military communicator are SSMA and high-peak power/TDMA.

The SSMA field is just reaching the practical operational stages; thus, growth and improvements in data rate, jamming-to-signal ratio, and bit error-rate performance are to be expected. The basic idea behind the high-peak power amplifier is to provide a very high-level signal on the uplink to overpower jamming signals. Peak power levels of 1 MW with average power of 1 to 10 kW are under consideration.

Demand Assignment Multiple Access. Just as switches concentrate traffic and increase use of interswitch trunks, demand assignment techniques can improve the efficiency and use of the satellite's traffic-carrying capability. This is particularly true for low-duty-cycle users. Demand assignment is simply a system whereby a user requests use of satellite power, bandwidth, and frequencies when required and releases them for others to use immediately on completion of a call. SATCOM personnel have developed, tested, and begun installing such a system under the code name "Spade." This is a single-carrier-per-circuit FDMA system. Several other organizations are also developing and testing demand assignment systems using TDMA. This very flexible and efficient system should grow and be a part of satellite communication networks within the next 5 to 10 years.

Coding. Another new and exciting technical development of the past 10 years has been the theoretical analysis of error-correcting techniques and codes. This new field is moving from the theoretical to the practical era and is providing a new tool for the system engineer. Coding permits tradeoffs among power, bandwidth, bit error rate, and information transmission rate. Analytical results have shown the potential of various coding techniques. The practical hardware is now entering the field to use the benefits of coding. Further research and hardware development will result in improved performance in this emerging field.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

047. Satellite system considerations

1. What types of orbits are used for communications satellites?

2. Why do satellites use attitude control?

3. What is the purpose of station keeping?

048. Multiple-access service and system control used in satellite communications

1. What is the most common multiple access technique in satellite communications?

2. What is frequency-division multiple access?

3. Which form of multiple access is most efficient?

4. What limits the number of users sharing a satellite that uses spread-spectrum multiple access?

5. What are the two types of system control in satellite systems?

6. What actions are covered under satellite control?

049. Space and earth subsystem trends

1. What are some of the space subsystem areas being improved?

2. What are some of the earth subsystem areas being improved?

3. Which of the earth subsystem areas will probably have the most rapid change? Why?

ANSWERS TO SELF-TEST QUESTIONS

044

1. A satellite that simply reflects radio signals without any amplification.
2. Signal reception, translation, amplification, and retransmission.
3. Geostationary

045

1. The reduction in strength of a radio wave as it travels away from its source.
2. Slow fading.
3. The receiving subsystem.

046

1. Retune the local receiver to the distant station downlink frequency.
2. antennae and transponders.
3. Transmitters, antennae, and receivers.
4. Satellite earth terminals have higher quality, low-noise receivers.
5. It provides for satellite control, communication, payload control, and overall SATCOM network control.

047

1. Elliptical or circular orbits.
2. To allow more efficient use of the radiated signal from the satellite; in addition, the primary electrical source, the solar cell, will be oriented toward the sun.
3. To keep a satellite in a desired position.

048

1. FDMA.
2. Each uplink carrier is assigned a separate frequency in the satellite transponder's frequency band.
3. TDMA.
4. The total power available.
5. Satellite control, communications control.
6. Maintaining correct orbital characteristics and optimum transponder performance.

049

1. Satellite orbits, higher frequency bands, antennae, improved channel capacity, and use of more satellite-to-satellite links.
2. Receive system noise parameters, antenna designs, modulation techniques, and access techniques.
3. IRF modulation and multiple access because of the conversion to TDMA.

Do the Unit Review Exercises (URE) before going to the next unit.➡

UNIT REVIEW EXERCISES

97. (044) A satellite system that requires numerous satellites in randomly spaced orbits to provide acceptable coverage is

    a. an active system.
    b. a passive system.
    c. a synchronous system.
    d. a low-altitude system.

98. (044) A satellite system that receives a message from an earth station and immediately relays the message to another earth station is a

    a. real-time active satellite.
    b. delay satellite.
    c. reflective-surface satellite.
    d. low-altitude satellite.

99. (045) The Faraday effect, inherent to satellite communications, is caused by

    a. transmit frequency drift.
    b. satellite movement in space.
    c. the earth's movement through space.
    d. rotation of the polarization of radio waves.

100. (045) The Doppler effect, inherent to satellite communications, is caused by

    a. transmit frequency drift.
    b. transmit frequency drift off the phase-lock ground receivers,
    c. the satellite's motion in space relative to ground stations.
    d. rotation of the polarization of radio waves.

101. (046) What satellite device receives, amplifies, and retransmits signals from earth terminals?

    a. The station keeper.
    b. The regenerative repeater.
    c. The satellite amplifier.
    d. The satellite transponder.

102. (046) Station-keeping functions that help readjust a satellite's position are part of which satellite subsystem?

    a. Space segment.
    b. Earth segment.
    c. Control segment.
    d. Antenna segment.

103. (047) The basic design of a satellite communications system depends on what system consideration first?

    a. Orbit.
    b. Orbital control.
    c. Station-keeping.
    d. Satellite ground track.

104. (048) The major system control problem with time division multiple access is in the area of

    a. power.
    b. frequency.
    c. transponder complexity.
    d. network timing and synchronization.

105. (048) What satellite access system lets several users occupy the same frequency spectrum in the transponder simultaneously?

    a. Frequency-division multiple access.
    b. Time-division multiple access.
    c. Spread-spectrum multiple access.
    d. Bandspreading multiple access.

106. (049) What space subsystem is being developed for interconnecting points that do *not* have a common satellite for a relay?

    a. Geostationary orbits.
    b. Higher frequency band usage.
    c. Earth coverage (EC) antennae.
    d. Satellite-to-satellite links.

107. (049) What earth subsystem development is improving the efficiency and utilization of the satellite traffic-carrying capability?

    a. Multiple access techniques.
    b. Demand assignment techniques.
    c. Error-correcting techniques.
    d. System noise reduction techniques.

Please read the topic page for Unit 6 and continue. ➡

CABLE

Page

This unit describes the equipment and facilities used in some typical wire and cable systems. Wire systems have been around for a long time and will probably remain. As a tech controller, you must understand how the wire and cable systems work. We'll deal with metallic cables, coaxial cables, and fiber optics. One of the most important elements in any communications system is the transmission line, which transfers signals from one part of the system to another. The simplest transmission line consists of two parallel wire conductors with a power source at one end and a load at the opposite end. Since most transmission lines appear as relatively simple mechanical devices, their rather complex electrical behavior is not always fully appreciated. Because they are electrically complex, they can have a significant effect on the signals transmitted over them.

6-1. Principal Types and Characteristics of Wire and Cable

In these lessons we cover the basic types of wire and cables, along with characteristics you'll have to deal with in working with different types of wire in your communications system.

050. Basic types of wire and cable used for communications media

Wire and Cable Classifications. The term *wire lines* refers to a wide variety of physical forms and arrangements of metallic conductors. Wire lines make up both the long-haul Defense Communications System (DCS) transmission and local wire plant facilities. The type of wire to be used depends on the type of transmission that must be provided. The principal types of wire used for transmissions are open wire, paired cable, and coaxial cables.

Open wire. This was the first type of transmission line to be developed. It consists of single conductor wire tied to glass or ceramic insulators mounted on poles and separated to prevent adjacent circuit interference. There are two special types that are used most of the time. One of these special insulators permits transposition of single conductors into one main line. The other is strictly used to prevent interference between the wires. The open-wire transmission line is normally found along railroad tracks. It can handle more than one channel through the use of carrier equipment. The DCS seldom uses open-wire transmission systems.

Paired cable. A paired cable consists of two wires individually insulated from one another with paper or plastic, then twisted together to make one pair of insulated wires. Wire pairs are then twisted together with other pairs to form a cable. The cable is then covered with insulation such as lead or plastic to protect the pairs against damage. Carrier equipment can be connected to the wires to transmit multiplexed signals over the paired cable. This lets one cable serve many users. To achieve this without material interference, the individual signal levels must be maintained at specific engineered levels.

Coaxial cable. This type of cable consists of a cylindrical tube in which a wire is centered and held in place by some form of insulating material. This insulating material can take the form of a solid core, discs, or beads strung along the axis of the wire or a spirally wrapped string. Coaxial cables are generally used at high frequencies or where extended bandwidths (not obtainable with ordinary cable) are required. Attenuation in coaxial cables is considerably less than in a pair of parallel lines of the same diameter.

Coaxial cables are manufactured in a wide range of sizes (up to 5 inches in diameter) and power-handling capabilities. They are flexible, with the center conductors consisting of a single small conductor or several small conductors twisted together and encased in a dielectric such as polyethylene. Larger sizes have a center conductor of up to 1-inch copper tubing. The center conductor is surrounded by a braided copper shield covered with a noncontaminating material such as polyvinyl.

Coaxial lines have a number of advantages over other types of conductors. The shielding is perfect for both magnetic and electrostatic fields. The electrostatic field is terminated at the outer conductor so that none of the field is outside of the line. The magnetic field, from the inner conductor, extends beyond the outer conductor. An equal amount of current flows in the outer conductor, setting up a field in the opposite direction, so the fields cancel each other. These two fields add within the cable. Hence, there is neither an electrostatic nor a magnetic field outside of the cable. For the same reasons, a coaxial line doesn't radiate; it also doesn't pick up any energy, so it can be installed anywhere without being influenced by other strong fields.

Coaxial cables are used where high frequencies are required (e.g. frequency-division multiplex at group, supergroup, and baseband connections). It is also used to connect radio equipment to a waveguide feeding the antenna. Larger systems are used for submarine and buried cable systems, which we discuss later in this unit. Some disadvantages are that they cost more than two-wire lines, they're harder to install than flexible cables, and it's harder to measure the fields in a coaxial cable than in an open-wire line.

Shielded cable. There is also a fourth type of cable in our career field. It has the combined features of the paired cable and coaxial cable. Called two-wire cable, it's similar to the two-wire paired cable except that it's shielded by a copper braid like the one used in coaxial cable. The copper braid gives the cable flexibility. You can get flexibility by using unbraided tubing, but the braid lets you space the conductors uniformly during manufacture. This leaves each wire perfectly balanced capacitively to the surrounding conductor. As long as the balance is maintained, certain detrimental effects (such as high capacitance to ground when the shield is grounded) are very slight. This line doesn't radiate energy because of the shield, so it's not affected by nearby magnetic fields. Shielded cable is often used in the tech control facility between the main distribution frame and the patch bays on analog-type circuits to reduce interference and crosstalk.

Cable transmission systems can be placed on poles or other structures above ground. They may also be buried, using a lead or polyethylene covering for protection, or placed in conduits or ducts. Telephone companies use both aerial and buried cable communication systems to bring telephone service from central offices to their many subscribers. Military installations use cables to tie end communication devices (e.g. telephones, facsimile, and computer terminals to the cable). Tech Control provides an interface point at the main distribution frame for intersite communications via cable systems.

051. Cable characteristics and their effects on signal flow in transmission lines

Line Constants. Metallic lines are affected by inherent characteristics that tend to disturb the transmission of intelligence over the line. There are four primary line constants that affect the behavior of a signal along a transmission line—series resistance (R) ohms, series inductance (L) henries, shunt capacitance (C) farads, and shunt conductance (G) mhos. These electrical properties are considered to be distributed uniformly along the entire length of a given transmission line. The particular values of these properties depend mainly on the physical configuration of the transmission line and the type and size of material used in its construction. To a lesser degree, they depend on frequency, temperature, and weather conditions.

When power is first applied to a transmission line, energy from the power source does not appear all along the line simultaneously. Instead, it travels away from the source in the form of an electromagnetic wave called the traveling wave, which reaches various points of the line at different times. The travel time is determined by the value of the four fundamental properties of the line. If the line is of infinite length, the electromagnetic wave progresses down the line until all the energy dissipates due to the resistive losses in the line.

Resistors, capacitors, and inductors are thought of as separate components that are placed in an electrical circuit to insert definite quantities or lumps of resistance, capacitance, or inductance, according to circuit requirements at the point of insertion. Similarly, transmission lines may be regarded, in certain applications, as components that are inserted in an electrical circuit to produce the desired operation of the circuit as a whole. Transmission lines differ from other circuit components chiefly in the distribution of the electrical properties of R, L, C, and G (i.e., each is distributed evenly throughout the length of the line).

Series resistance. Every conductor offers some resistance to the flow of electricity. The resistance of 1 or 2 feet of wire may be of no particular consequence, but the resistance of several miles of wire is. In telephone terminology, the resistance of a line is stated in terms of ohms per loop miles. The resistance per loop mile is twice the ohmic resistance of one conductor of a pair of wires. The distributed resistance of a transmission line depends on the type and size of the wires and the frequency of the traveling wave. Resistance increases as the diameter of the wire decreases and as the frequency of the transmitted wave increases. This is expressed in the formula:

$$R = \frac{Kl}{A}$$

where l = the length of the line
K = the resistivity of the material
A = the cross-sectional area of the line
NOTE: Resistivity is the specific resistance of a unit specimen of material and is expressed in ohms per cubic centimeter.

Series inductance. Every conductor, regardless of its size and shape, possesses self-inductance. This self-inductance can be explained either in terms of magnetic field or of the electric field. The varying currents in a telephone or teletypewriter line (transmission line) result in lines of force within and surrounding the conductor itself. Where lines parallel each other or are grouped closely together, the lines of force set up by each conductor induce currents in the other lines, causing crosstalk. Power lines that carry current and are adjacent to transmission lines tend to set up lines of force much the same as in wire transmission conductors, resulting in jam pickup. The use of balanced lines minimizes the effect of this pickup. Self-inductance causes a countervoltage to be induced in the circuit by a change of current. In a transmission line through which a charging current is flowing, the voltage is induced all along the line. This indicates the inductance is distributed over the entire length of the line. The magnitude of this series inductance is determined by the size of the wires and their separation. It increases as the center-to-center distance between the wires decreases. The distributed inductance is represented by the symbol "L."

The inductance of a transmission line causes an opposition in the form of inductive reactance (X_L) to the alternating currents. Inductive reactance is a function of frequency and is expressed by the formula:

$$X_L = 2\pi fC$$

where X_L = inductive reactance
2π = constant
f = frequency
L = inductance

Therefore, as frequency increases, inductive reactance or current-opposing effect increases.

Shunt capacitance. A wire's capacitance is the capacitance between the wire and ground, between other objects, and the capacitance of the wire itself, independent of ground and all other bodies. Theoretically, if a wire is moved to an infinite distance from the earth, the capacitance of the wire to ground and to other objects becomes zero. If it were possible to study a wire under these conditions, it would be found that a charge could be taken from or added to the wire (i.e., the wire has self-capacitance). This concept is at first hard to understand because it can't be visualized directly in terms of the familiar two-place capacitor. However, let's consider that the wire illustrated in part A of figure 6-1 is isolated in free space and that oscillations can be stopped at the instant each end contains maximum charge. At this instant, slice end sections from the wire and place them as indicated in part B of the figure. These end sections and the dielectric material around the wire form a very small two-plate capacitor (fig. 6-1, points 1 and 2 in part C). This end capacitance is only part of the self-capacitance; there's also capacitance between each section and every other section in the wire. This idea of distributed self-capacitance is shown by the dotted-line capacitors between 3 and 4, and 5 and 6 in part C. The relationship of frequency and capacitance is expressed as:

$$X_c = \frac{1}{2\pi fC}$$

where X_c = capacitive reactance
2π = constant
f = frequency
C = capacitance

Shunt conductance (leakage). No insulator is perfect, and some amount of current flows through even the best insulator. The flow of current through insulation to other wires or ground is called leakage. The amount of leakage depends on the insulation resistance and varies with weather conditions. Line leakage generally increases in wet weather. The insulator (dielectric) separates the wires of the transmission line over its entire length because leakage exists at every point along the line. In open-wire lines, the dielectric between the conductors is air. In cables, the dielectric consists of the insulation surrounding the individual conductors. The best insulators conduct an extremely small amount of current. Since leakage takes place through a conducting path between the wires, this corresponding line characteristic is called shunt conductance or leakage. It is represented by the symbol "G." At times, leakage is also called shunt resistance.

Loading. Loading consists of increasing the inductance of a line, which reduces the attenuation of the higher frequencies and increases the frequency bandwidth of the line. Increasing the inductance causes a more constant attenuation at varying frequencies, but absolute delay is increased. Increasing a line's inductance also makes its characteristic impedance more constant with changes in frequency.

The most practical way to increase a line's inductance is to connect coils in series with each wire in the line spaced at equal intervals. Inductance coils used for this are known as loading coils, and the lines using them are known as loaded lines. Loading reduces the loss in the line by more fully equalizing the capacitive and inductive reactance of voice frequencies. Lines that are designed to transmit a wide range of frequencies (such as for use with carrier systems) are seldom loaded. Instead, repeaters are used to compensate for attenuation.

Reflection in Line. Another effect of the transmission line on the transmitted wave results from reflection. Reflection isn't caused by the properties of the line. It may result from a mismatch of impedance when equipment is inserted into the line, a sudden change in properties of the line (such as would result from inserting a cable into an open-wire line), or by improper matching of load impedance to the line. Maximum power is transferred to the receiver when receiver input impedance equals the characteristic impedance of the line. If reflection takes place at the receiver (or at any other point on the line) because of an impedance mismatch, there will be one pair of current and voltage waves traveling toward the receiver and another pair traveling back toward the transmitter. When only part of the transmitted power is absorbed by the receiver, part is reflected back to the transmitter. The closer the value of the receiver impedance to the characteristic impedance on the line, the greater the power absorbed by the receiver and the smaller the power reflected back to the transmitter.

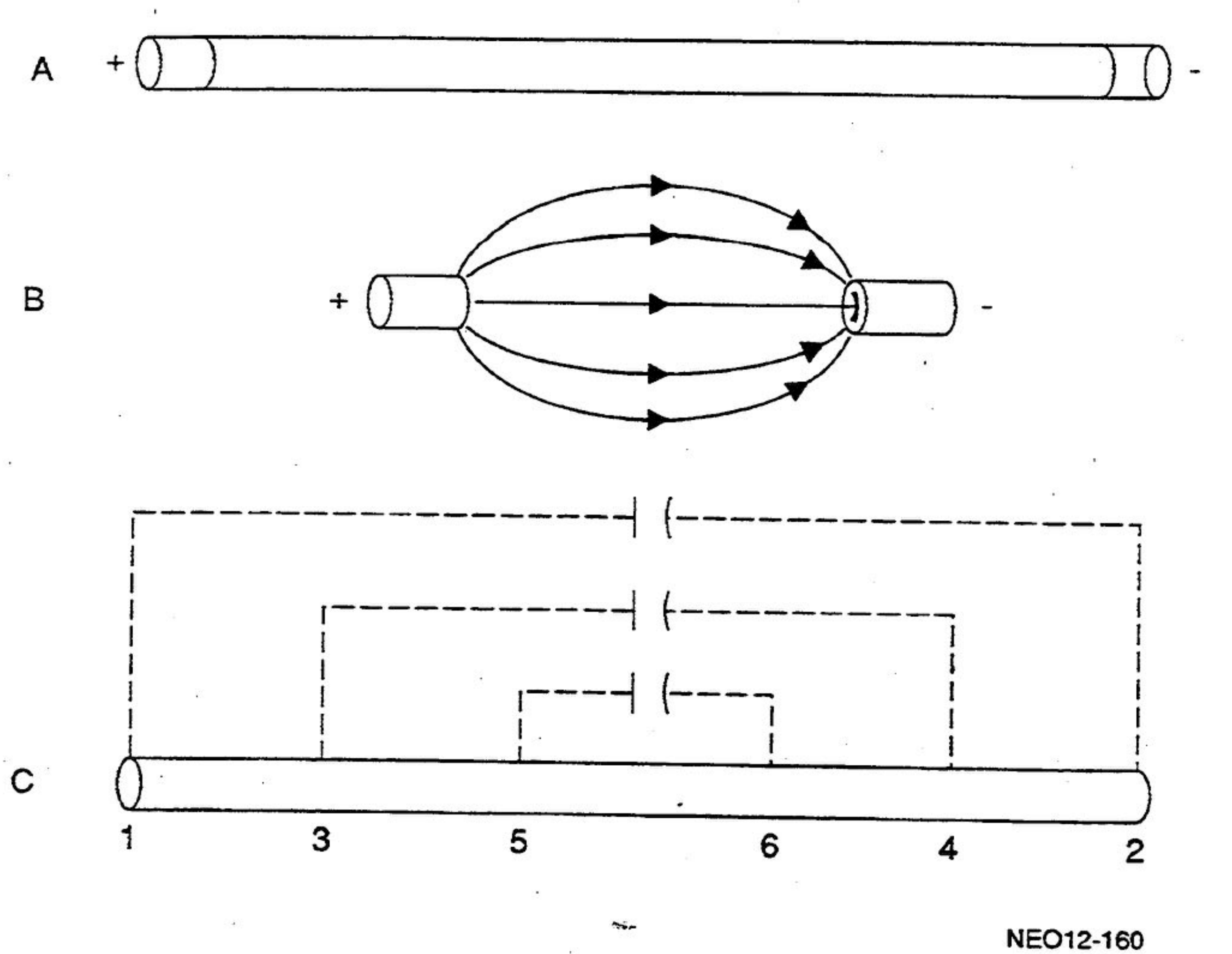


Figure 6-1. Self-capacitance of a wire.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

050. Basic types of wire and cable used for communications media

1. Name the three principal types of wire used to transmit communications.

2. What is the physical characteristic of a paired cable?

3. Which cable system is used with high frequencies and where extended bandwidths are required?

4. State the major advantage of using coaxial cable.

5. Where is shielded cable used within the tech control facility?

051. Cable characteristics and their effects on signal flow in transmission lines

1. Name the four electrical line constants associated with wire and cable communication systems.

2. What main factors determine the values of the above-line constants?

3. What determines the travel time of a traveling wave through a transmission line?

4. Explain self-inductance.

5. How do wire diameter and transmitter wave frequency affect resistance?

6. What impairment causes reflection on a transmission line?

6-2. Types of Cable Systems

We've been discussing different types of wire transmission and how the line constants of wire transmission facilities affect the traveling wave. Now let's consider the cable facilities used on some typical military systems.

052. How cable systems are interfaced with the technical control facility

Base Cable Plant. The base cable plant is the main cable distribution point for all base cables. It is maintained by inside plant maintenance (wire maintenance) and consists of large distribution frames to provide flexibility and interconnectivity. Normally, there are two basic kinds of cable plant—distribution plant and trunk plant.

Distribution plant. The distribution plant handles the various cables to different points of an installation to interconnect telephone and data service to the cable plant. Take, for instance, all the telephones in your CBPO. A cable leaves the cable plant either buried or suspended in the air by poles. At the CBPO building, the cable is terminated on an inside terminal block for final connectivity and distribution to the local users. The cable plant connects the subscribers to the trunk cable plant that, in turn, provides connectivity to the base telephone switch (PABX).

Trunk plant. The trunk plant connects the cable plant and switching centers (central offices). Trunk cables also connect the cable plant to the technical control facility (TCF). Commercial lease circuits entering a USAF installation are carried on a cable trunk or cables, which are terminated at the cable plant. This is sometimes known as the demarcation point, meaning that the commercial responsibility stops at that point and the military responsibility starts.

The circuit is then connected to the TCF via one of the trunk cables of the main distribution frame (MDF). The circuit then passes through the patching facility and any necessary equipment and exits via the same or, perhaps, another trunk cable to the cable plant for distribution to the proper location. Spare lines to the commercial carrier also may be connected to the TCF to provide redundancy.

As a tech controller, you may have to coordinate troubleshooting and restoration of subscribers' circuits with cable plant maintenance. Onbase cable systems don't use carrier systems or multiplexing. Each circuit telephone, facsimile, teletype, or computer terminal uses its own pair (2W) or pairs (4W)/(6W) to communicate, so line constants don't normally degrade onbase cable systems.

053. Characteristics and components of long-haul communication landlines

Theoretically, a transmission line can transmit frequencies ranging from zero to infinity, but for practical considerations an open-wire line is only efficient for frequencies from 0 to about 150,000 Hz. Since the voice frequency (VF) range is from 300 to 4,000 Hz, only a very small part of the line's potential frequency range is used to send a single-voice conversation over an open wire. In effect, the entire frequency range above 4,000 Hz is wasted.

There is, however, a method of reallocating (spacing) several 4,000-Hz normal voice channels between 4,000 and 150,000 Hz. This lets you transmit several conversations simultaneously without interference and thereby use the transmission line fully. This reallocation is done by carrier systems and is known as frequency-division multiplexing. Let's look briefly at the elements, performance parameters, and characteristics of the carrier systems.

Voice-Frequency Repeaters. First let's look at the single VF circuit that uses either the two-wire or four-wire part of a multipaired cable. To reduce attenuation over long distances requires repeaters. These circuits require careful engineering as to the number, location, and gains of the repeaters to avoid singing, excessive noise, and crosstalk. The requirements of the circuit determine the type of repeater to be used.

Repeaters can be applied most efficiently to circuits that have a uniform impedance over their entire length. They can also be applied to circuits that are least affected by weather and temperature changes. The more stable circuits use spiral-four, lead-covered cable, or open-wire. Using field wire for multiplexed circuits requires extreme care in repeater lineup. When two or more multiplexed circuits are installed in similar facilities on the same route, the repeaters for all of the parallel circuits should be installed in the same location. Otherwise, you'll get excess crosstalk on both two-wire and four-wire circuits.

Voice-Frequency Repeatered Two-Wire Lines. Short lines that are a little too long to be operated without any repeaters may use a single repeater at some intermediate point unless maintenance considerations make it desirable to install the repeater at one of the terminals. Lines whose net loss can't be reduced to a low enough value with one repeater may have several repeaters at roughly equal intervals.

Figure 6-2 shows a repeatered two-wire line with two sections of line and three repeaters. Those at the ends are called terminal repeaters and have comparatively low gains. This is a result of the compromise balancing network's inability to make fine adjustments, thus resulting in high return losses and requiring repeaters near the end instrument. The line side of each terminal repeater has a precision balancing network. The intermediate repeaters have two precision networks and generally have higher gain than the terminal repeaters.

Hybrids. Any device that provides impedance matching and isolation between circuits is called a hybrid junction or a hybrid. It is usually a three-winding transformer. In common telephone usage, the term refers to a junction between a balanced four-wire circuit and a balanced two-wire circuit (fig. 6-3). The hybrid network applies the power of an incoming signal from the two-wire circuit to both paths of the four-wire circuit. The balancing network attenuates the signal to the four-wire receive letting the signal flow only in the four-wire send path.

Hybrids are used in two-wire lines with repeaters like those in figure 6-2. Since the amplifiers operate in only one direction, two amplifiers are commonly used at a single repeater point, one for each direction of transmission. When a repeater of this type is placed in a two-wire line, a hybrid must be used on each side of the repeater point to provide a short section of four-wire circuitry. Most long circuits operate over four-wire carrier facilities for their entire length. They don't need hybrids at intermediate amplification points, but they do need them to connect to two-wire drops and two-wire switching equipment.

Transhybrid loss. The isolation between the transmit and receive paths of the four-wire line is often called transhybrid loss. Since high-transhybrid loss is directly related to the balance between the two-wire line and the balancing network, it's also known as transhybrid balance. The undesired loss between the two-wire line and the four-wire line is called insertion loss. If the transhybrid balance isn't precise, some of the power from the receive path of the four-wire line leaks out on the transmit path and returns to the distant end as an echo. If the repeater gain is almost as great as the line loss, the echo may go back and forth along the line several times before vanishing. This produces a ringing effect that may give a talker the impression that he or she is speaking into a rain barrel. If the gain in the line exceeds the loss, the echo does not die but builds up and becomes self-perpetuating. In effect, the line becomes an oscillator in the same way that an amplifier can be made to oscillate by using

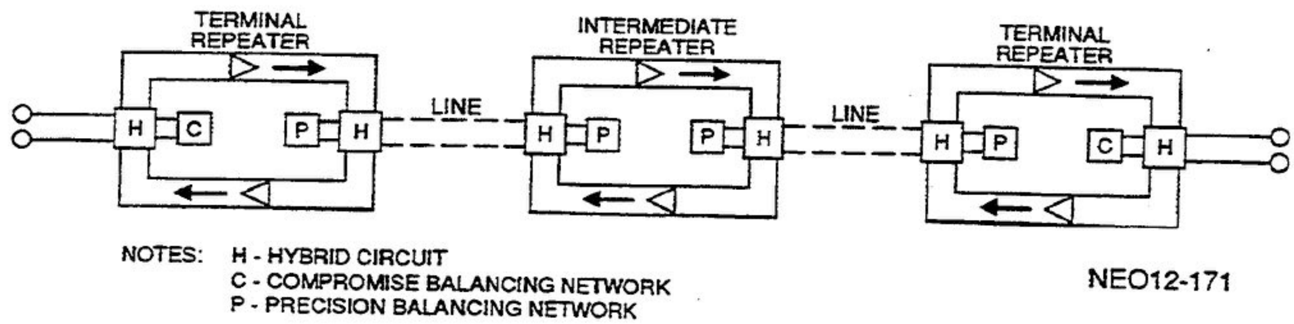


Figure 6-2. Repeatered two-wire line.

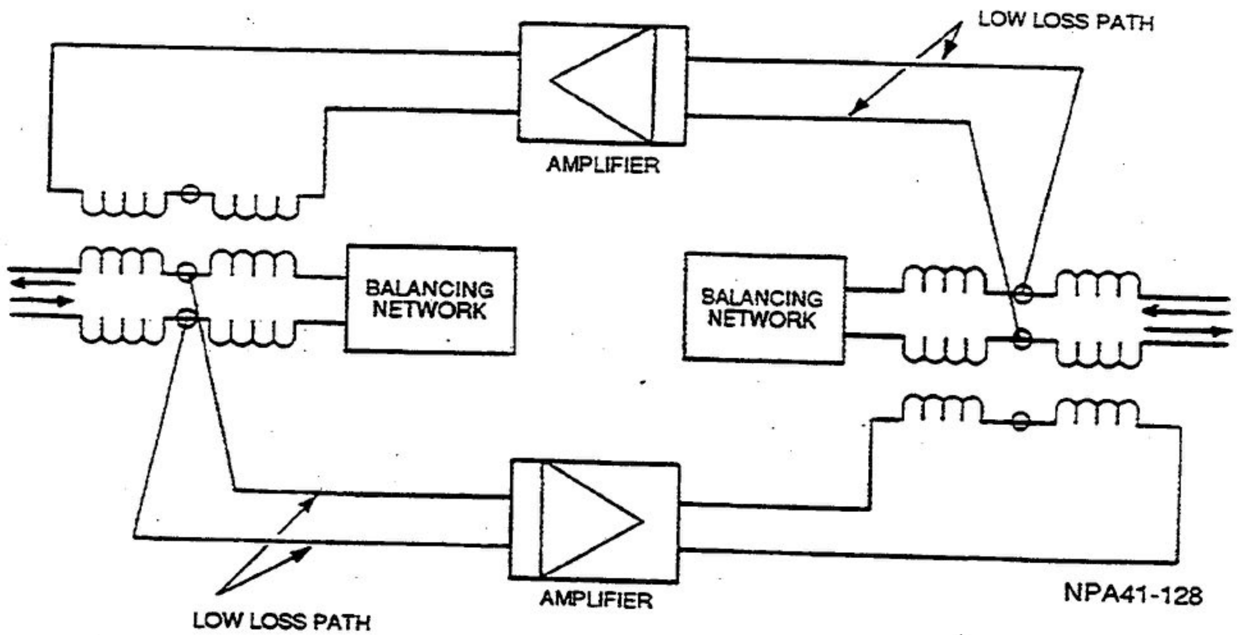


Figure 6-3. Hybrid network.

positive feedback. This condition is known as singing. It creates a howl in the subscriber's earpiece, usually making the connection unusable.

A hybrid can also produce echoes by reflecting power back down the two-wire line. Such reflections occur at any impedance irregularity. That is, if the input impedance of the hybrid fails to match the characteristic impedance of the two-wire line, some power will be reflected rather than transferred through the connection. The power reflected depends primarily on how closely the hybrid's balancing network matches the impedance of the two-wire line.

Carrier Frequency Transmission. Carrier frequency transmission facilities are wire facilities in which the basic telephone channels are transmitted and received at frequencies above the 4-kHz VF range. Using carrier modulation methods, a number of telephone channels can be translated in frequency to adjacent high-frequency bands for transmission over a single facility.

Carrier transmission techniques. A carrier facility is composed of two major parts—the carrier terminal and the carrier line. The carrier terminals consist mainly of the modulating and multiplexing equipment. The carrier line provides the broad channel over which the group of channels from the terminal equipment is transmitted. It includes the wire lines and any carrier repeaters on them. The wire lines themselves may be used by more than one facility. For example, the same wire line may be used for a 4-kHz VF channel and a carrier system. The 4 kHz VF channel often serves as an order wire for operating and maintaining the carrier facility. Two or more carrier systems can operate on the line at frequencies above 4 kHz.

The basic telephone channels derived from the carrier system are frequently used for telegraph, facsimile, or data transmission systems. These are usually low-frequency (voice-frequency) carrier systems that fall in the range of the telephone channel. The separate channels may be amplitude, frequency, or phase modulated and several of these narrowband channels may be combined into one broader channel by either frequency or time-division multiplexing. These signals are sent into the telephone channel and transmitted over the carrier wire facility by amplitude modulation and frequency-division multiplexing. This superimposition of one carrier system onto another often results in signals that are complex, having been subjected to more than one kind of modulation and multiplexing. Carrier systems differ in the way the two directions of transmission are handled. Two of the most often used techniques are physical four-wire and two-wire carrier systems.

Four-wire carrier systems. These systems use separate pairs (but the same frequency bands) for the two directions of transmission. Figure 6-4 shows a four-wire carrier system capable of handling 12 telephone channels. Either end of the system looks like the terminals of a number of VF four-wire circuits, each with its own hybrid and compromise balancing network. The outgoing branches of the four-wire circuits are applied to a carrier sending terminal. This modulates each voice circuit to a different carrier frequency band and sends them together in one broad channel over the particular carrier line that transmits toward the distant carrier receiving terminal. Here, the 12 telephone channels are separated by filters, demodulated to VF, and applied to the hybrid terminating sets of their respective telephone circuits. The two one-way carrier lines may be equipped with intermediate carrier repeaters, when required, the same as VF four-wire circuits. Each carrier repeater amplifies the group of carrier telephone channels on the line as a unit.

Two-wire carrier system. These systems use the same pair of wires, but different frequency bands, for the two directions of transmission. The principles are the same as for the four-wire carrier systems, but the two, broad, one-way carrier channels are kept separate by sending them at different frequencies on one pair of wires instead of over different pairs of wire at the same frequencies. Filters separate the two directions of transmission from each other at the terminals and at intermediate repeaters.

Equalization and regulation of carrier lines. Carrier lines must transmit both a high top frequency and a broad band of frequencies. To operate the different telephone circuits handled by the carrier system at a nearly constant net loss, some kind of regulation of amplifier gains must offset variations in line loss. Equalization may be needed to compensate for the fact that the lines have more loss for the higher frequency channels than for the lower frequency channels.

On short-haul systems, the loss variations may be small enough to be disregarded. On intermediate length systems, they may be compensated for by occasional manual adjustments at the terminals. On long-haul systems, particularly those that transmit a considerable number of channels and have a high top frequency, automatic regulating systems must be provided.

Automatic regulation is controlled by sending one or more single frequency tones (pilot frequencies) at a constant level. These frequencies lie between certain carrier telephone channels or just outside the band they occupy. The carrier repeaters and receiving terminals are equipped with devices that automatically measure the level of these pilot

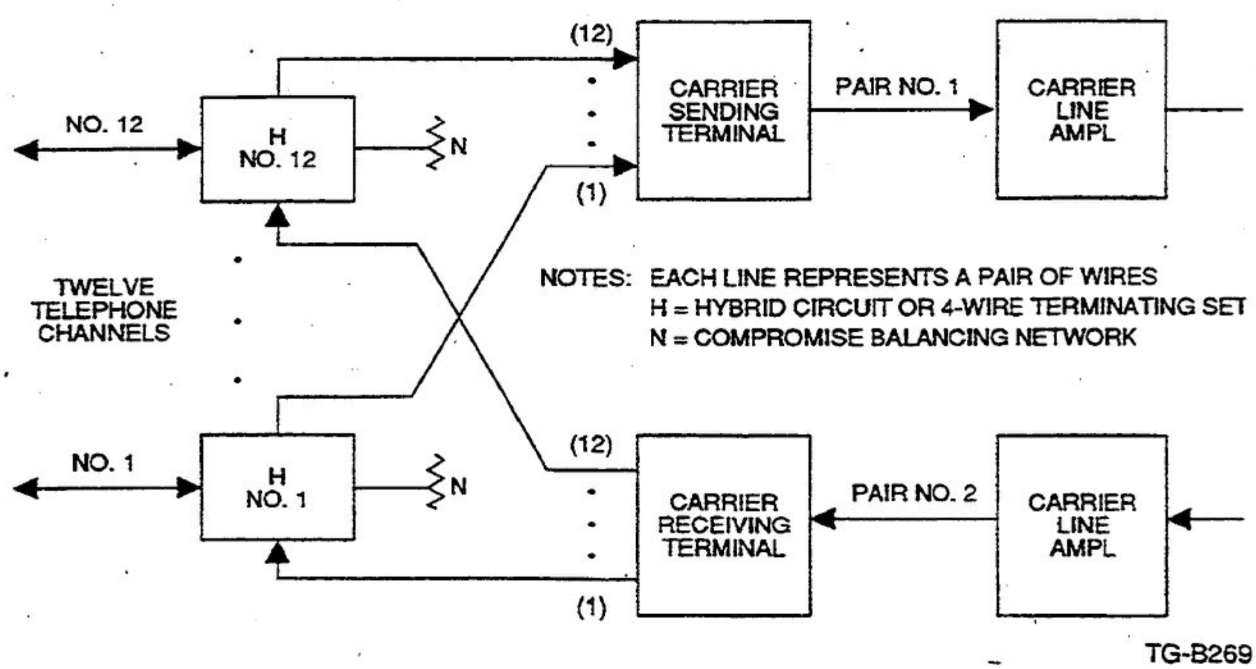


Figure 6-4. Four-wire carrier system.

frequencies and make the necessary corrections in the repeater to vary the gain when the loss of the line changes. Thus, the net loss is regulated to a constant value.

Equalization is provided by networks built into the carrier repeaters and the receiving terminal. The equalizers add loss at low frequencies where there is less line loss. This makes the overall transmission loss the same for each of the telephone channels handled by the system. In the longer multichannel systems, equalization may be varied automatically.

Noise in carrier systems. Cable systems are subject to certain types of noise that affect carrier transmission. The sources of these noises are:

- Unsoldered or poorly soldered cable connections or splices.
- Atmospheric disturbances and inherent radio transmitter noise.
- Carrier frequency flat noise—telegraph, dial signaling, and relay transients, as well as other office-generated noise voltages, such as from power amplifiers.
- Interchannel modulation and stray tones from carrier systems.

The first two aren't generally under the control of the systems designer, but the others must be given careful consideration during system development. The total noise that can be expected is large enough to require special noise reduction techniques. Elaborate transposition and suppression schemes have been used on some cable carrier systems to reduce noise to acceptable levels. In modern short-haul carrier systems, companders are used on carrier channels to reduce the interfering effect of noise by as much as 22 dB.

Companders. A compander (fig. 6-5) improves the signal-to-noise ratio of a 4-kHz voice-frequency channel, allowing operation over noisier channels than would otherwise be possible. Companders improve circuit quality for speech circuits by improving the apparent signal-to-noise ratio by as much as 22 dB. A compander operates much like an AGC (automatic gain control) circuit in radio. More gain is imparted to low-intensity signals than to high-intensity signals. The dynamic range normally runs from about -10 dB to -50 dB. This range is compressed at the transmit end and then expanded at the receive end. For transmission, the dynamic range is reduced to 3 dB. This process makes the weak signals relatively invulnerable to noise in transmission.

Crosstalk in Cable Carrier Systems. Crosstalk problems in cable carrier systems are similar to crosstalk problems in open-wire carriers. For both types of systems, the close proximity of parallel pairs creates the possibility of crosstalk paths. Slight imbalances in the electric and magnetic couplings between pairs and minor impedance variations are also contributing factors.

Far-end transverse, near-end, and interaction are the basic types of crosstalk that occur between cable carrier systems.

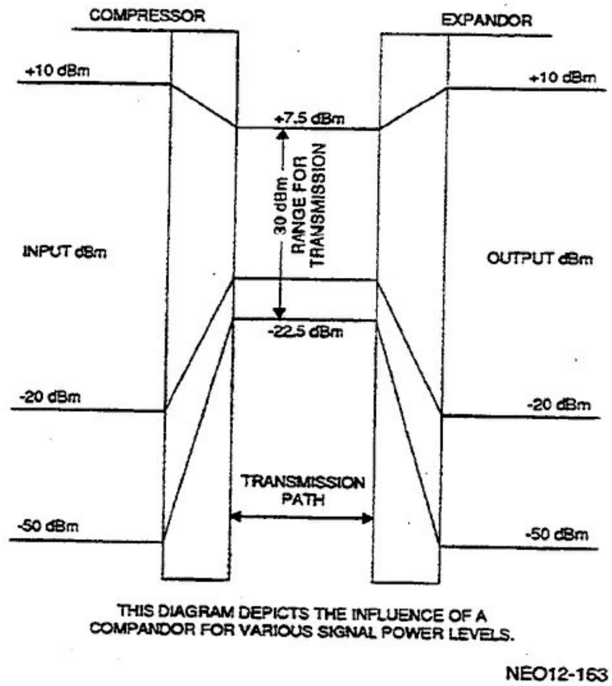


Figure 6-5. Compander.

Far-end transverse crosstalk is caused by direct coupling between parallel pairs; the far-end path is from the output of one repeater to the input of another system. Near-end crosstalk is also caused by coupling between parallel carrier pairs; the near-end path is between opposite directions of transmission. Interaction crosstalk is caused by coupling between a carrier pair and a noncarrier pair. This crosstalk may, in turn, be coupled to a second carrier pair. Several methods are used to control the effect of crosstalk in cable carrier systems. One effective method is known as frequency frogging.

Frequency frogging. Alternating the frequency allocations for multiplexed channels in cable systems to prevent singing, reduce crosstalk, and correct for the attenuation line slope is called frequency frogging. This eliminates the far-end and interaction crosstalk that's common in open-wire carrier repeater installations. Frequency inversion takes place at each repeater location; that is, a low group transmit coming in to a repeater leaves the repeater as a high group transmit. This eliminates the need for large slope equalization and adjustment in the system. Singing and crosstalk are minimized because the high-level output from a given repeater is at a different frequency from the low-level input to the other repeaters (fig. 6-6). These other methods are used in preventing crosstalk:

- Using separate pairs for opposite directions of transmission.
- Using different frequencies for opposite directions of transmission to eliminate near-end crosstalk.

- Generating masking noise to cover up low-level intelligible crosstalk.
- Installing improved cable types in new construction.
- Transposing transmission lines.

Data System Wire Line Transmission Considerations. When you use telephone circuits for data transmission, you have to consider imperfections that don't affect voice transmission very much. For example, noise in its various forms has a much greater effect on data circuits than it does on voice circuits.

Noise effects. An amount of noise that's acceptable for speech transmission could cause serious errors in digital data. To avoid errors from noise, digital data circuits must be designed on the basis of an adequate signal-to-peak noise ratio rather than signal-to-average noise ratio. If the noise on a circuit is impulse noise, a common type on wire and cable circuits, the peaks may be of such great amplitude that they make data transmission impractical without error detection or error control transmission.

Phase distortion effect. One of the most serious difficulties in transmitting data over telephone circuits is the unequal transmission velocities of different frequencies. This is called phase distortion or envelope delay distortion. The human ear is relatively insensitive to phase distortion and doesn't recognize it as a speech impairment, but the short bursts of energy necessary for data pulse transmission contain many frequencies with fixed relationships to each other in time. If some of these frequencies are transmitted at a slower rate than others, the received pulse won't have the same shape as the transmitted pulse, and errors can occur, especially if the pulses are short.

Phase jitter. Just as signal amplitude is affected by channel-induced amplitude noise (thermal, crosstalk, etc.), the phase of the signal is affected by the channel-induced phase noise. This phase noise can be generated by additive amplitude noise as well as true phase modulation of the signal in the channel. The resultant phase noise, or "jitter" characteristic, is much like amplitude noise in that it has nominal "background" jitter levels similar to the nominal amplitude noise level in the channel. Occasional, abrupt changes, or "hits," similar to amplitude impulse noise also occur. This phase jitter results in the displacement in the phase of the signals transmitted through the voice frequency channel. Phase displacement increases with the magnitude of the phase noise and varies at a rate equal to the frequencies at which the phase noise occurs.

In measuring phase jitter, we aren't concerned with long-term (very slow) changes in phase such as might be caused by the slow drift of a carrier oscillator. However, we are concerned with the maximum, instantaneous deviations from the average phase of the signal. A common cause of these deviations is the modulation of carrier supplies in frequency division multiplex systems by the power-line frequency or some harmonic of the power-line frequency. When the carrier supply frequency is used to translate the signal to their appropriate position in the frequency spectrum, the phase modulation on the carrier is transferred to the signal. This results in the phase modulation of the signal at a rate equal to the power-supply frequency, or a multiple of that frequency. There may be other causes of phase jitter, such as interfering tones on the channel or variations in the medium. These variations can cause the instantaneous phase to deviate from the average. For example, an interfering tone 21.2 dB below the signal level will cause a peak phase deviation of about 5° or a peak-to-peak deviation of 10°.

Interfering signals such as tones or noise can cause phase jitter. Normally, these causes should be discovered in other tests and kept within specified limits. Interfering tones and noise must be within acceptable limits before you conduct any phase jitter tests. Until recently, the only technique available to measure phase jitter was to observe patterns on an oscilloscope. Modern phase jitter measuring sets greatly simplify the measurement, and they're now the preferred method because of greater accuracy and ease of obtaining the measurements.

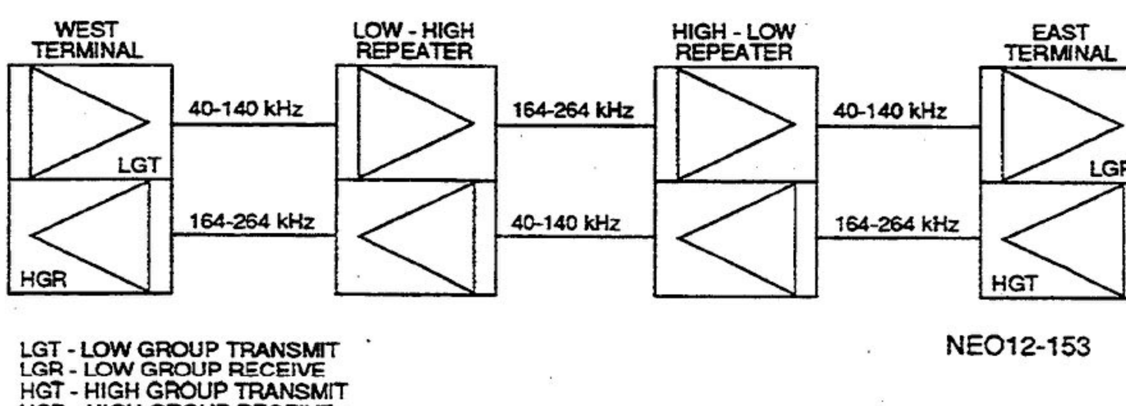


Figure 6-6. Frequency frogging.

054. How a submarine cable operates and is used

Submarine Cable Systems. A dry-land cable system is relatively uncomplicated. It requires cable, of course, and uses repeaters energized by power sources available along the cable route. Whether it's above or below ground, the system can be easily maintained because it is accessible. When it comes to an undersea cable system, access for power and maintenance is not quite so simple. Trying to repair and maintain a cable system in a marine environment can be very difficult and expensive. However, power, maintenance, and the marine environment are factors that designers have tackled and mastered over the years. Power, which has to originate from land-based sources, must be conserved to reach the widely spaced repeaters. Since repeaters must use very low amounts of power to produce maximum results, reliability plays an important part in every phase of designing and constructing an underwater system.

History. The first transatlantic cable, laid in 1858 between America and England, took 16 1/2 hours to pass a 99-word telegram. The cable system lasted only 20 days, but during the short duration, it passed 732 messages and allegedly saved the British government 50,000 pounds. In 1866, another telegraph cable was laid. This one lasted until 1927—the first year in which radio telephone using high-frequency propagation was utilized. There was little interest in submarine cables from 1927 until 1956, when a transatlantic telephone cable was laid from Scotland to Newfoundland. Presently, there are seven transatlantic (TAT) and two Canadian transatlantic (CANTAT) coaxial cables spanning the Atlantic. Five transpac cables span the Pacific, connecting Hawaii to the continental United States (CONUS). There are many more short systems connecting the mainlands to various islands.

System uses. Submarine telephone cables provide reliable communication over distances ranging from a few miles between islands to several thousands of miles between continents. In some areas, these cables are the best method of augmenting inland telecommunications since it may be easier and more economical to lay submarine cables along the coast than to install and maintain land cables or radio stations. Submarine cables also have the advantages of secrecy and freedom from the direct effects of sunspots or interfering radio transmissions. However, they may suffer from the effects of magnetic storms if the remote power feed equipment isn't designed properly.

System elements. The main elements of a modern system are the submarine cable, submerged repeaters, equalizers, and onshore terminal station equipment. The systems don't necessarily terminate at the landing points of the cable. Normal engineering practice extends the cable overland. Submerged-type repeaters seldom are used on land extensions, although they may be if necessary. The cable can be extended to a truck or toll switching center in the inland telephone network.

Cables and repeaters are laid from cable ships that can carry from 200 to 2,500 nautical miles (nmi) of deep-sea cable. For long routes, repeaters are customarily inserted or spliced into the cable on board ship to form an ocean block—the segments of cable and the repeaters between two equalizers. The actual number of segments of cable and repeaters in an ocean block varies considerably, depending on operational and physical requirements of the system. Thus, a typical 60-channel cable system designed to meet DCA standards might use repeaters at roughly 17-nmi intervals, a 0.620 inch size coaxial cable, and one equalizer about every 200 nmi. If the cable or the repeaters are damaged, a cable repair vessel can make repairs or replacement by grappling for and recovering the cable from the seabed. Since such an operation can be costly, both cable and repeaters are designed for a life expectancy of at least 20 years.

Compared with active systems, which use repeaters, a passive system provides a relatively small capacity/length capability. These systems don't use submerged repeaters. Their performance and length are limited by the maximum practical transmitting signal power and the required receive signal-to-noise ratio. Passive submarine cable systems are usually designed to provide continuous transmission over a short water crossing between overland cable systems.

Military System Considerations. Submarine cable systems are particularly oriented toward commercial rather than military application, and the DCS makes only minor use of them. They can deliver quality over long distances for military and civilian use, but they're vulnerable to such physical damage as being cut by trawlers or damaged by icebergs. Routes through deep water are more likely to escape both accidental and intentional damage. Recently developed techniques for burying cables reduce the possibility of cable damage, particularly at the shore end sections of the system. In DCS applications, the location of the terminal station involves such considerations as:

a. Available land area that can be protected militarily (may, perhaps, involve locating the station underground).

b. Proximity to an acceptable cable landing area to minimize land cable runs and to avoid long cable runs through shallow waters.

c. Logistics, including power and landline communication, to other elements of the overall system.

The exact conditions of a cable landing must be determined by boat survey to establish the nature of the bottom. Such hazards as ship anchorages, trawler operations, ice conditions, severe underwater currents, and rock formation should be avoided. The most expeditious route to deep water must be determined and evaluated.

Several types of new submarine cable systems are in various stages of development, planning, or implementation. One improvement is the impending use of solid-state repeaters. The advantages of using solid-state devices over vacuum tubes in submerged repeaters are their lower voltage and power requirements. However, the actual use of solid-state repeaters has been slowed by reliability testing requirements. The stringent reliability objectives (e.g., no more than two failures in 20 years) require that new types of components be tested thoroughly. Hence, before transistors can be used, their reliability must be established with a high degree of confidence.

Bell Telephone Laboratories has a submarine cable system using solid-state repeater amplifiers (the SF system) that provides 720 two-way voice channels with two 2,224-kHz transmission frequency bands, one for each direction of transmission. One band is 564 to 2,788 kHz and the other band is 3,660 to 5,884 kHz. Amplifying repeaters are spaced at 10-mile intervals. Terminal DC voltage of the SF system is 3,250 volts for a 4,000-mile system length as compared to voltages twice as large for vacuum-tube repeater systems. The DC power required for cable systems is often a limiting factor because of insulation and corona problems.

For DCS applications, a digital pulse-modulation system using regenerative repeaters is preferable to the commercial analog-type system. One notable advantage of regenerative digital transmission is that it permits increases in the tolerances between cable loss and repeater gain. Another advantage is that it minimizes precise measurements and adjustments during construction. However, other problems arise, notably the need for timing in a system with many regenerative repeaters in tandem.

Functional Description. Figures 6-7 and 6-8 are simplified block diagrams of two hypothetical submarine cable systems. Figure 6-7 shows a system in which a single coaxial cable is used for both directions of transmission. Figure 6-8 shows a system using two coaxial cables, one for each direction of transmission. Modern practice is to use the single-cable system.

The repeater spacing is the same for both of these systems. To accomplish this, the gain-bandwidth product for amplifiers in the single-cable system must be twice that of those used in the twin-cable system. A tradeoff, of course, can be made between repeater spacing and the gain-bandwidth performance. A single-cable system uses less cable and is less expensive to install, but its repeaters are more complex and consequently more expensive. A twin cable offers improved reliability, especially for teletypewriter circuits, since both cables must be out of order before communications are interrupted completely. However, failure of either cable will interrupt communications in voice circuits.

Shore Terminals. The input from user lines to the shore station is usually frequency division multiplexed before it is transmitted through the submarine cable. Received signals from the submarine cable are equalized, amplified, and demultiplexed before they are transmitted over landlines. In some modern systems, more efficient use of cable has been achieved by using 3-kHz channel spacing instead of the 4-kHz spacing normally used for voice channels on other media. Multiplex equipment at the terminals must be selected to match these system plans. The power separation filters shown in figures 6-7 and 6-8 isolate the high-voltage power feed input to the cable from the rest of the terminal equipment. The high-pass and low-pass filters shown in figure 6-7 separate the low- and high-carrier frequencies used in bidirectional single-cable transmissions.

Armored cable. Armored cable consists of a basic coaxial structure covered by an outer layer of steel wires. Figure 6-9 shows the current types of armored cable used in shallow water and shore-end sections.

Lightweight Center Strength Coaxial Cable. The type of deep-sea cable now in use doesn't have an outside covering of steel armor wires. The requirement for high tensile strength is met, instead, by a strong member placed within the tubular central conductor. Two types of center strength cable are shown in figures 6-10 and 6-11. Figure 6-10 is a British design in which a composite, high-tensile-strength, steel stress member is used within the center copper

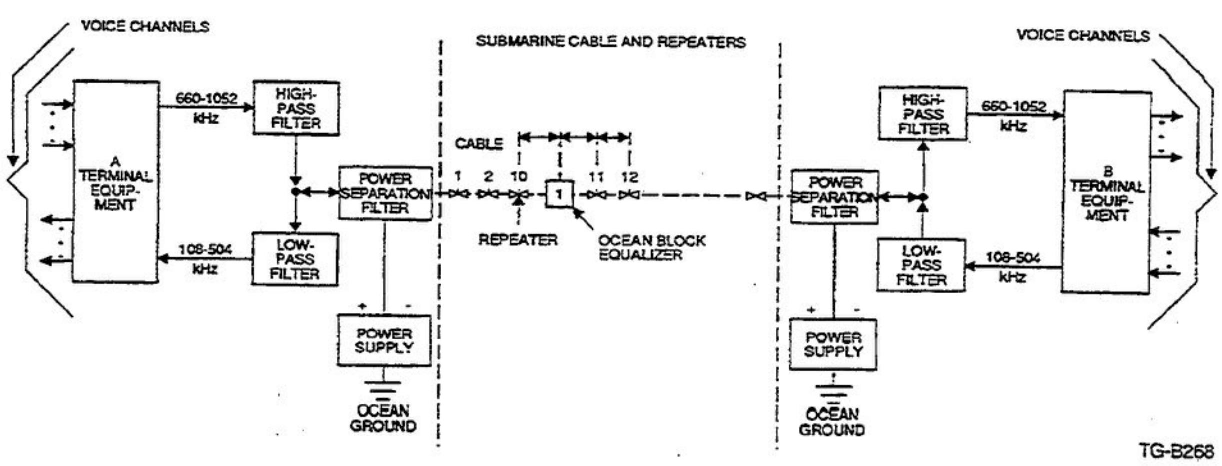


Figure 6-7. Block diagram of a single-cable system.

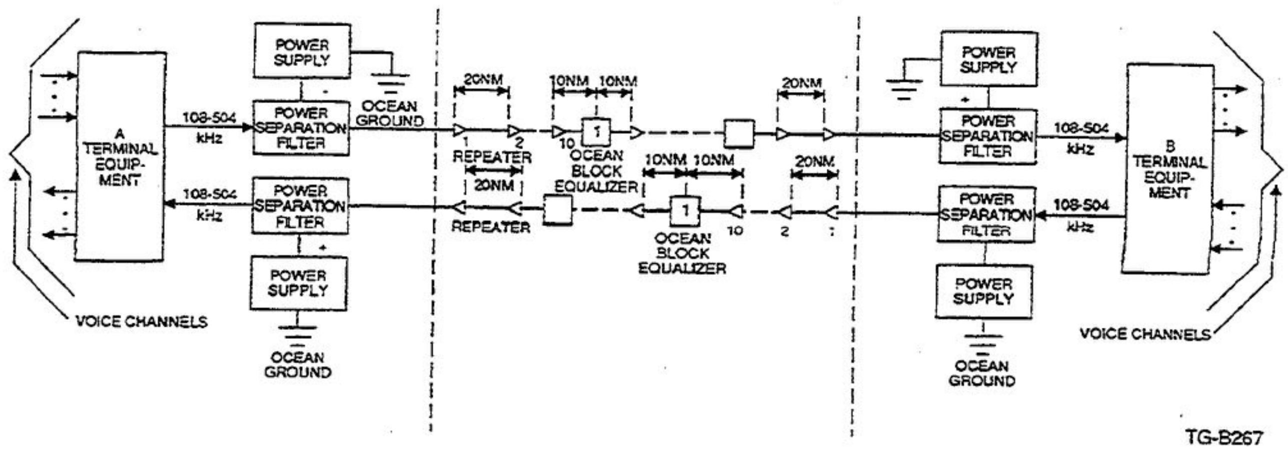


Figure 6-8. Block diagram of twin-cable system.

conductor tube. Figure 6-11 is an American design that incorporates a high-tensile-strength, nontwisting steel wire strand within the center copper conductor tube. Note that there are some other design differences. For example, in the British design, aluminum is used in the outer conductor while the American cable has a copper outer conductor. In neither type is armor protection from external damage necessary in deep water, since there are no strong underwater currents or danger of snagging at the bottom.

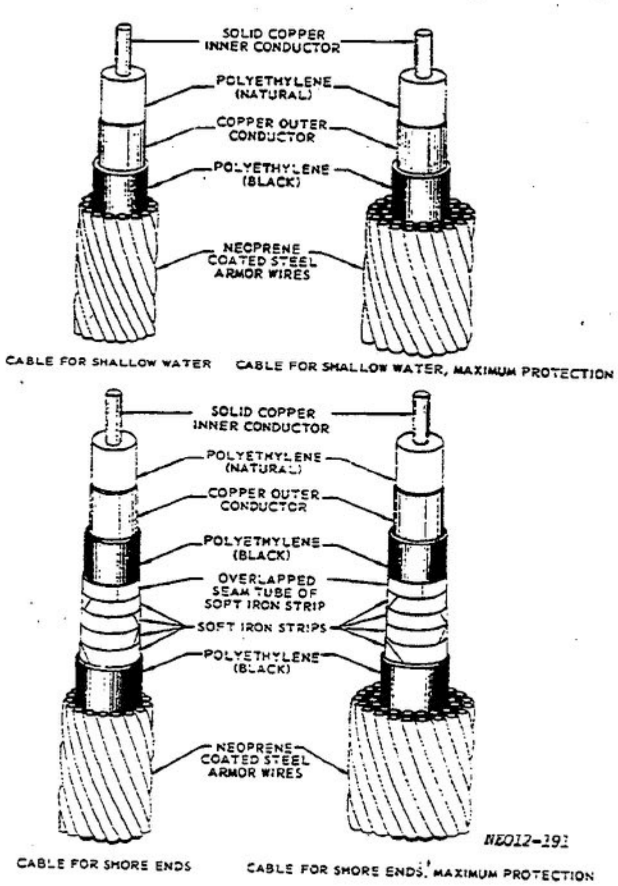


Figure 6-9. Type of shallow and shore-end cables.

Submarine Cable Repeaters. Cable design development is intimately associated with repeater design. Submerged repeaters are amplifiers that are inserted in the cable at regular intervals. The repeaters are spaced at 20-nmi intervals in the systems in figures 6-7 and 6-8. The intervals for any system depend on the size of the cable, the number of telephone and teleprinter circuits, and the repeater gain. A repeater is an assembly of one or more amplifiers and other electrical circuitry in a watertight steel housing built to withstand deep-sea pressures. The vacuum tubes (or transistors) in the repeaters are energized by direct current supplied by one or both of the shore terminal stations. On long transoceanic cables, the voltage applied to each end of the cable might be 6,000 volts or more. The direct current passes along the inner conductor, through each repeater in succession, and returns via the ocean floor. A positive DC voltage is supplied to the cable at one station between the central conductor and ground, and a negative potential is supplied at the other station.

Two types of repeaters in current use are the flexible and rigid types. The flexible repeater was used in the earliest twin-cable systems. It is long and flexible to facilitate cable laying, but this mechanical design results in large parasitic inductance and capacitance in the repeater stages. Because it's hard to design a wideband repeater using this mechanical form, its use in new wideband systems appears doubtful. Rigid bidirectional repeaters have been used in single-cable systems in conjunction with the new types of armorless cable (American design). The two-way repeater is an assembly of two amplifiers together with filters and other apparatus. It's enclosed in a single, watertight (pressure resisting) steel housing that can be attached to and laid with the cable (fig. 6-12).

Two developments have made possible the present practice of laying single-cable systems with rigid repeaters in

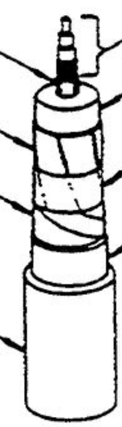


Figure 6-10. Deep-sea British light-weight (armorless) submarine cable.

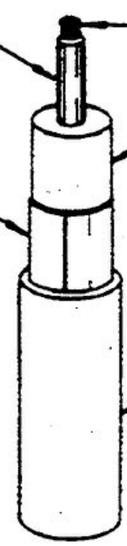
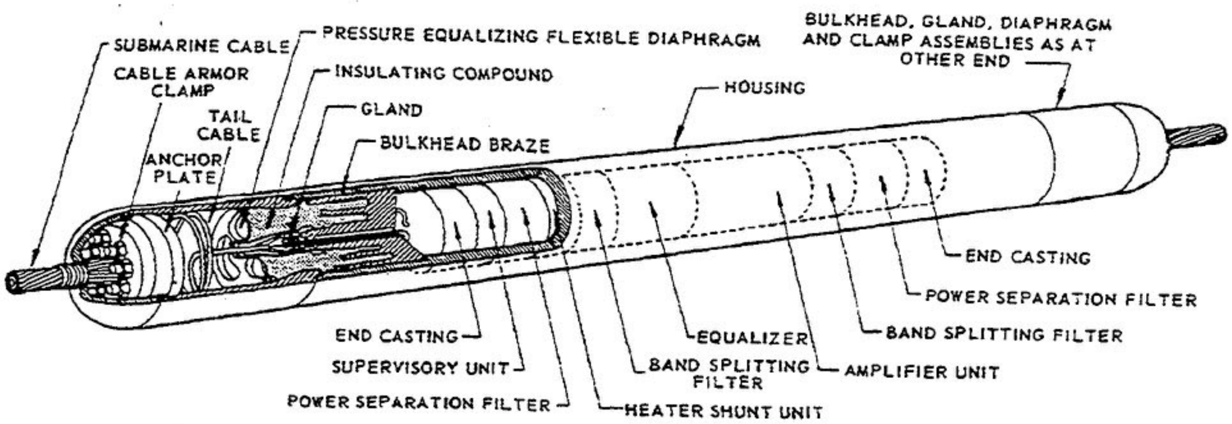


Figure 6-11. Deep-sea American (armorless) submarine cable.

deep water. One is the center strength cable that reduces kinking. The other is a laying machine that has a flexible, tractor-like, articulated tread instead of a sheave for laying out cable. This permits repeaters to be laid in line with the cable without materially slowing the ship.

A third type of repeater exhibits the advantages of both rigid and flexible repeaters, but has few of their disadvantages. The repeater's electrical subunits are mounted in a copper container for electrical screening, which is then housed in a pressure-tight stainless-steel cylinder (fig. 6-13). The two cable ends are fastened to the cable lead-in housings. An outer rubber sheath covers the entire assembly. The knuckle joints are designed to bend so that the repeater acts as a flexible unit, although its main body is a rigid capsule. This design permits cable and repeaters to be laid in one continuous operation without complex cable laying apparatus.



APPROXIMATE DIMENSIONS AND WEIGHTS			
OVERALL LENGTH	OVERALL DIAMETER	WEIGHT IN AIR	WEIGHT IN WATER
FT INCHES CM	INCHES CM	LB KG	LB KG
10 2 310	10-1/2 26.7	1320 600	1130 515

NEO12-189

Figure 6-12. Rigid bidirectional repeater typical assembly.

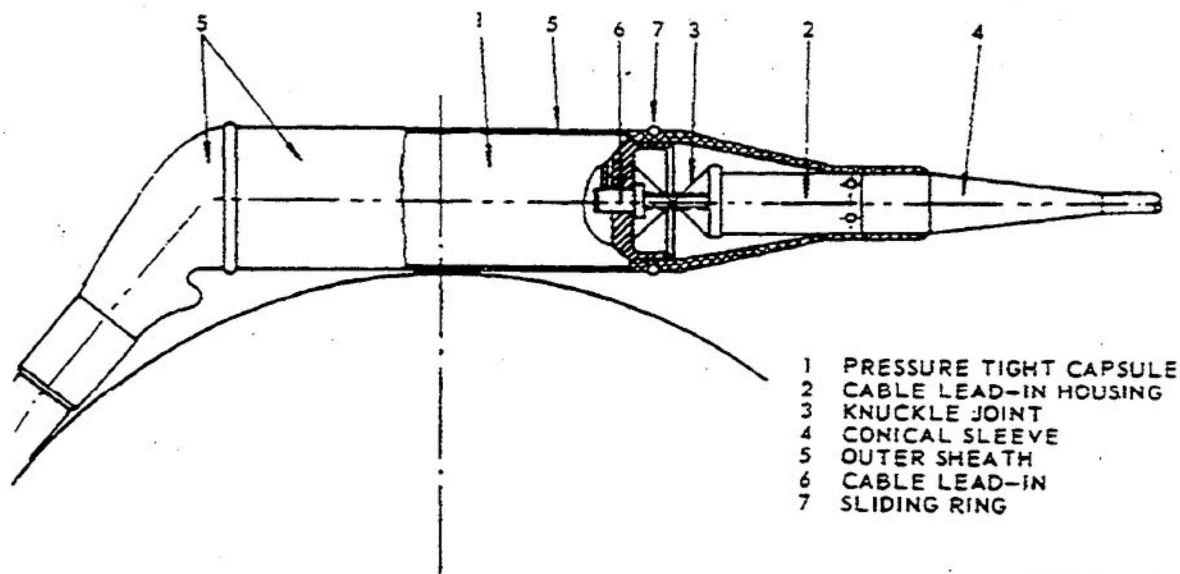


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Figure 6-13. Submerged repeater housing.

055. Operational elements of a submarine cable system

System Considerations. The basic design of submarine cable systems is directed toward producing high-grade telephony. The resulting performance also provides acceptable channels for broadcast, voice frequency telegraph systems, and facsimile. A wider channel may be provided for wideband digital data (converted into analog form) at rates of 19.2 kbs, 38.4 kbs, or more. Special equalization must be used over such circuits.

From a transmission quality standpoint, a submarine telephone cable system can be extended to any required global distance, but the practical length of a single repeatered submarine cable system is limited—mainly by the constant-current high voltage needed to power the repeaters. The current is supplied over the center conductor to all of the repeaters in series, from one or both terminal stations. If there are many repeaters, the resulting electrical potential at the terminals may reach many thousands of volts. The requirement for these high voltages imposes serious technical problems in designing suitable and reliable components for the power separation filters and other protective devices within a system; e.g., cable, repeater, and terminal equipment. Protective devices used to guard against current fluctuations and geomagnetic induced voltages are required in the remote power-feeding equipment. Additional protective devices are needed within the repeaters to prevent damage that could be caused by voltage surges.

Equalizers. Equalizers at the end of each ocean block compensate for cumulative variations between the designed and actual characteristics of cable sections and repeaters within the block. These variations consist of repeater gain, temperature effect on cable attenuation, laying effect on cable attenuation, pressure effect on cable attenuation, the mismatch between repeaters, and cable loss within the ocean block.

Equalizers are passive devices that use power separation filters to bypass the cable current. Their inner housing is usually at ocean ground. Because the equalization network is usually designed to cover the frequency range of both transmission bands, directional filters aren't always required, although some do use them. Simple equalization networks are usually incorporated in each repeater to match the gain of that repeater and the loss of the adjacent cable section. To correct equalization deviations that accrue over several repeater sections, additional equalizers are housed in individual containers much like those of the repeaters.

Power and voltage for repeaters. The power that provides heater and plate voltage to the repeaters must be closely regulated. For example, on a typical long-distance, 120-channel system, the total voltage required is 12 kV. The current must be controlled to within ±1 percent of nominal, so it varies only a few milliamperes. The thermionic tubes within the repeater amplifiers depend on this close control for their long-life expectancy. The voltage is usually series-adding, with each end contributing about 6,000 volts. The nearest repeaters to each end, therefore, have about 6,000V between their power feeding circuits and the outer conductor of the coaxial circuit. The safety of the repeater depends on power-separating capacitors that must withstand this voltage. Since the capacitors must be larger as the design voltage increases, the maximum power feeding voltage is correspondingly restricted.

The power feeding equipment must also be protected from overvoltage and the effect of earth currents. The induced voltages may reach more than 1,000V from time to time due to geomagnetic disturbances over a long route. The safety of the whole system depends on the reliability of this protective equipment.

With the advent of transistorized repeaters, many of these limiting factors have been overcome. The transistorized repeater requires only about 30 percent of the voltage of its vacuum tube counterpart. For example, an existing 60-channel vacuum tube repeater has a voltage drop of 83V, while a new 120-channel vacuum tube repeater has a voltage drop of only 26V.

Pilots. In virtually all wideband communication systems (troposcatter, microwave relay, etc.), pilots monitor and adjust transmission levels at the various terminal stations and switching points. They're used the same way in submarine cable systems. In the transatlantic 3 (TAT-3) system, a 96-kHz pilot frequency is inserted into each group. The nominal power of each pilot is -20 dBm at the zero transmission level. Another system of 36 channels uses a 92-kHz pilot for each group, in addition to a 64-kHz pilot used to synchronize the multiplex terminals. The 64-kHz sync pilot ensures that the modulation and demodulation frequencies of the two stations don't differ. The pilots can also initiate automatic protection switching from working to standby equipment to prevent loss of service in the event of terminal equipment failure.

System length limitations. There's a direct relationship between the voltage drop per repeater and maximum system length. A system that uses a lower voltage drop across a repeater can have more repeaters in line to cover a greater distance than a similar system using repeaters with a larger voltage drop. The same system might use the lower voltage drop advantage in other ways. By using the same number of repeaters, but on a shorter span of cable, you can double your bandwidth capabilities. Thus, there are considerable advantages to reducing the voltage drop per repeater in order to permit more repeaters in tandem. The number of repeaters used may be traded off against wider bandwidths, longer spans, or a combination of both.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

052. How cable systems are interfaced with the technical control facility

1. Where do base cables terminate?

2. How do the distribution plant and the trunk plant differ?

3. How is a commercial lease circuit routed through Tech Control?

053. Characteristics and components of long-haul communication land lines

1. What is the purpose of VF repeaters?

2. State the characteristics of a terminal repeater.

3. What components make up a two-wire intermediate repeater?

4. Where do hybrids need to be located on long-haul circuits that operate over four-wire carrier facilities?

5. How do two-wire carrier systems operate?

6. What is the purpose of companders in cable systems?

7. What is frequency frogging?

8. What is the most serious difficulty in transmitting data over telephone lines?

054. How a submarine cable operates and is used

1. What makes a submarine cable harder to maintain than landlines?

2. When was the first transatlantic telephone cable laid connecting Scotland to Newfoundland?

3. List the main elements of a modern submarine cable system.

4. Define ocean block.

5. How does a passive submarine cable system differ from an active system?

6. What are the advantages of using solid-state devices in submerged repeaters?

7. What is the main difference between a single-cable system and a twin-cable system?

8. What are the main purposes of the shore terminal?

9. What type of cable is used in submarine cable systems?

10. Where is the armored covered cable primarily used?

11. What is a submarine cable repeater?

12. List the two basic types of repeaters.

055. Operational elements of a submarine cable system

1. What limits the practical length of a single repeatered submarine cable system?

2. Which cable system is preferred using bidirectional repeaters?

3. What is the purpose of equalizers in cable systems?

4. What are pilots used for in cable systems?

6-3. Fiber Optic Communications

Having covered the various types of conventional wire and cable systems, let's look now at the newest and fastest growing communications system in the military inventory—fiber optics transmission.

056. Basic characteristics of fiber optics communications

Fiber Optics Cable Systems. Just as it's possible to send Morse code signals to a receiver some distance away using a flashlight, it's also possible to send signals with a light emitting diode (LED) or with a light amplification by stimulated emission of radiation (LASER) device. By using an LED or LASER source, however, you can send signals at a much faster rate and in far greater quantities. An LED, for example, can generate 2.5 milliwatts of wide-angle infrared light in a wavelength band measuring .87 µm (microns) to .92 µm. Light pulses of short duration suitable for use in T1, T2, and T3 PCM systems can be generated by pulsing an LED electrically.

An optical communications system requires, besides the light source, a medium over which the light signals are transmitted and a sensor, generally a semiconductor diode, to convert the light signals back to electrical signals. The medium by which light signals are transmitted to a receiver in optical communications systems is most certain to be one of several types of hair-thin glass fibers, some of which are presently available for use and some of which are still in the development stage. An optical fiber is actually a tiny waveguide that supports optical frequency waves using the principles of total internal reflection at the boundaries of the fiber.

Transmission over optical fiber promises advantages over copper wire in the form of larger bandwidths, freedom from crosstalk and other types of interference, low cost, and light weight. In addition, much more information can be carried at optical frequencies than at the lower microwave frequencies. Bundles of optical fibers, each capable of carrying thousands of telephone conversations, have already replaced miles of copper wire that were used for the same purpose.

History. Alexander Graham Bell's many inventions included the photophone. In this device, which he demonstrated in 1880, a beam of sunlight was reflected off a shiny diaphragm mounted on an acoustic horn. The light beam was aimed at a distant selenium photocell connected to a speaker; speech could be understood at a distance of 700 feet.

But the photophone's short-haul, line-of-sight (LOS) communication was practical in few instances, so light-beam transmissions were shelved for the better part of a century until another field of research caught up and furnished a way to channel information-bearing light and direct it where it was needed.

In the mid-1960s, C. K. Kai and G. A. Hockham, at ITT's Standard Telecommunication Laboratories in England, suggested an idea for directing light waves where they were needed. By 1970, scientists at the Corning Glass Works had made the concept work. Pieces of silica glass, stretched as thin as a human hair, became easily bendable and could serve as practical waveguides for light waves, thus the field of fiber optics was born. At the same time, semiconductor technology made possible the fabrication of efficient light sources that could be modulated with an external signal.

System Advantages and Limitations. Fiber optics is the result of the merging of two unrelated disciplines—semiconductor technology, which provided the necessary materials for the light sources and detectors, and optical waveguide technology, which provided the medium—the optical fiber cable. The reason fiber optics is so highly touted is that it has numerous advantages over other transmission media, both traditional (copper wire) and nontraditional (microwave).

Broad bandwidth. Fiber optic cable systems have more potential bandwidth than any other type of system, including coaxial cable systems. Current practical bandwidth limitations are in the 50 MHz range for systems with a geographical scope of up to 10 km or about 140 MHz in a 6 to 8 km range. Bandwidth capacity for single-mode cable is expected to reach 50 GHz per km within the foreseeable future. In typical user applications, this enormous bandwidth not only allows a single cable to act as the medium for all current data, voice, and video needs, but provides plenty of room for expansion of those needs without laying additional cable.

Immunity from electromagnetic interference (EMI) and radio frequency interference (RFI) and durability in harsh physical environments. Harsh or noisy environ ments don't affect signal quality and, as long as the appropriate protection is built around the fibers, no degradation or attenuation will be experienced. This presents a big advantage for fiber optic systems when it comes to cable routing. Optical cable can be run nearly anywhere—underground, undersea, in elevator shafts, under streets, along subway routes, and suspended aerially above such high-noise areas as railroad tracks. It can withstand temperatures up to 1,000°C and, when it's installed aerially, it's not susceptible to lightning strikes. Beyond the obvious advantages of these characteristics is the potential for savings in the amount of cable needed and corresponding installation time and cost, since the path of the cable need not be routed around traditional hazards. One of the few things optical cable must be protected against is water seepage since ice around the cable can introduce attenuation or damage the fiber.

Nonflammability. Since optical cable carries no current, it can be used in harsh environments with no fear of spark or fire hazard. For example, fiber cabling is a good choice for environments involving corrosive chemicals (except for hydrofluoric acid, which attacks glass). Even if the corrosive chemicals penetrate the jacket, data transmission won't be interrupted and no sparks will result.

Small size and low weight. Like other types of cable, fiber cable can be placed in trays or ducts, pulled through conduit, suspended in air, or buried underground. However, the fiber optic cable is so thin and lightweight (1 km of optical cable weighs 30 pounds, while the same length of traditional data cable weighs over 200 pounds) that it can be installed in existing ducts or other cable runs without adding conduit.

High security. Fiber optic cable emits no radiation and is virtually untappable without detection since signal loss can be detected almost immediately. Also, breaks in fiber cable can be isolated to within a few inches. This feature has led, in particular, to the development of fiber optic systems for the military.

Reliability of data transfer. As a direct consequence of its immunitive properties, bit error rates using fiber optic cable are in the order of 10^9 or one in every billion bits transmitted. This very low error rate will continue to improve as fiber optic technology continues to be refined. Fiber optic transmission is also immune to annoyances commonly experienced with some other transmission media, such as crosstalk, echoing, and ringing.

When comparing fiber optic links to copper-based facilities, another factor enters the picture—cost. Complete fiber optic systems, including all end-to-end transmission components and installation, are now, generally, and will continue to be cheaper than comparable copper systems, especially as the price of copper escalates. For example, a typical 3,000-foot coaxial cable installation, when taking into account the cost of running a conduit and the cost of the copper, is over 30 percent more expensive than installing a fiber optic system of the same length.

The potential bandwidth of a fiber optics cable provides the opportunity to multiplex an amount of data onto the network that is several times higher than the amount of data that can be supported by a single copper facility, thus saving on transmission costs. For longer distance applications, fiber optics is also less expensive, in the long run, since the system can be continually expanded using existing cable.

Fiber cable also wins out over copper wire in other ways. Optical fibers are made from sand or silica, the most abundant materials on earth. One pound of glass can make over 12 miles of optical fiber. Copper, on the other hand, is a depleting resource. Fibers are only about 6/1000th of an inch thick, yet they have the same tensile strength as steel wire of the same diameter. Fibers are also flexible; they can be tied into circles 1/4-inch in diameter without snapping. Fibers also conserve energy. A telephone system using glass consumes only one-third as much electricity as copper wire networks. High-speed, copper-based DS-1 (digital 1.544 Mbps) systems require repeaters every 1.8 km; with fiber optics, the number of repeaters is reduced by a factor of six. And since fiber optics has a higher bandwidth, fewer repeaters are needed at each repeater station.

While the advantages of fiber optics communications are numerous, there are a few drawbacks. The physical handling and installation of fiber optic cables can be a tedious, involved process. A technician skilled in soldering conventional coaxial cable might be surprised on first seeing the unfamiliar tools used to splice and install connectors on optical fibers. Another drawback is the complex interface equipment fiber optic cables require to make use of all that bandwidth. The circuitry that forms the "funnel into the fiber" must operate in two discrete realms—electronics and photonics. It must be of high quality for the most efficient transfer of the signal, and it must compensate for the quirks that appear in any apparatus that blends two kinds of technology. The simplicity and economy of the fiber optic waveguide itself are offset to some degree by the expense of the interface equipment.

Because fiber optics is a new field, researchers are making rapid progress in solving or reducing the seriousness of the problems involved, and costs are being driven down. Fiber optic cables have already shown their cost effectiveness in long-distance telecommunications applications, where their low loss lets telephone companies use fewer repeaters over long, continuous runs than with conventional cables. Certain other applications that demand one of the qualities at which optical fibers excel have also reached the break-even point in competition with copper. It is the unanimous consensus of both military and commercial communities that the advantages of fiber optics communications (summarized in table 6-1) far outweigh the limitations.

Military Applications. By 1974 the U.S. Navy had two fiber optics systems on board ships of the fleet. One was a secure telephone system and the other an experimental closed circuit television system. In September of that same year, a fiber optic data link carrying aircraft flight control signals from cockpit to controls was successfully flight tested by the U.S. Air Force. The Defense Department estimates that the development of a fiber optics aircraft data bus could yield annual savings of some $33 million, as weight savings alone are worth about $1,000 per pound in life-cycle costs for high-performance aircraft.

During exercise Bold Eagle 78, over 250,000 feet of 26-pair fiber optics cable was used to connect the various radios, switches, and command centers. Had 26-pair coaxial cable been used, this would have required 13 C-130 aircraft for airlift. Instead, using fiber optics cable, only 80 or so 1-km reels were needed (a partial C-130 load).

As you can see, fiber optics has already found many uses in the military. In addition to those uses we've mentioned, the Air Force has installed fiber optics systems at Strategic Air Command (SAC) Headquarters, Offutt AFB, Nebraska, for computer-to-computer and peripheral interconnections that handle satellite weather information at 15 Mbps and at NORAD HQ, Cheyenne Mountain Complex, Wyoming, connecting the tech control facility to microwave trans-

TABLE 6-1
FIBEROPTICS CABLE VS OTHER TRANSMIT CABLE

PROPERTY \ TYPE OF CABLE	FIBER OPTIC	TWISTED PAIR	COAXIAL
ELECTROMAGNETIC INTERFERENCE (EMI) IMMUNITY	YES	NO	NO
RADIO FREQUENCY INTERFERENCE (RFI) IMMUNITY	YES	NO	NO
HIGH DEGREE OF TRANSMISSION SECURITY	YES	NO	NO
ELECTRICAL ISOLATION	YES	NO	NO
NO CROSSTALK	YES	NO	NO
NO ECHOES OR RINGING	YES	NO	NO
TEMPERATURES TO 1000 DEG CENTIGRADE	YES	NO	NO
ELIMINATION OF SPARK/FIRE HAZARDS	YES	NO	NO
LOW COSTS	YES	YES	NO

mitters and to Peterson AFB, Colorado. Many other installations have been completed or are in the early stages of development.

057. Elements of a functional fiber optics transmission link

Functional Description. A basic fiber optics transmission link (fig. 6-14) consists of a transmitter that accepts an analog or digital input and projects it along the cable in the form of light pulses, a fiber optic cable, and the receiver or detector, which accepts the light input and converts it back to analog or digital form.

Transmitters. The transmitter on a fiber optic link has the task of generating a packet of infrared light or photon for each set of digits received as input from a data source. The data flows unidirectionally in half-duplex mode (two-way, full-duplex communications can be achieved using two-fiber cables). Only one transmission channel is provided, although multiple conversations can be multiplexed onto the cable using time-division or wave-division multiplexing techniques.

The light signals from the transmitter are conveyed as a series of pulses, so the light source must not only be able to emit a bright, highly directional signal, but it must also be able to be turned on and off as quickly as possible. The more rapid the modulation of the light source is, the more information can be conveyed in a given time. There are two types of semiconductor light sources in use today for fiber optic transmission—light emitting diodes and lasers.

Light emitting diodes (LEDs). LEDs are used widely in transmission systems over short distances, up to about 1 km, with analog or digital signals up to 10 Mbps. LEDs radiate

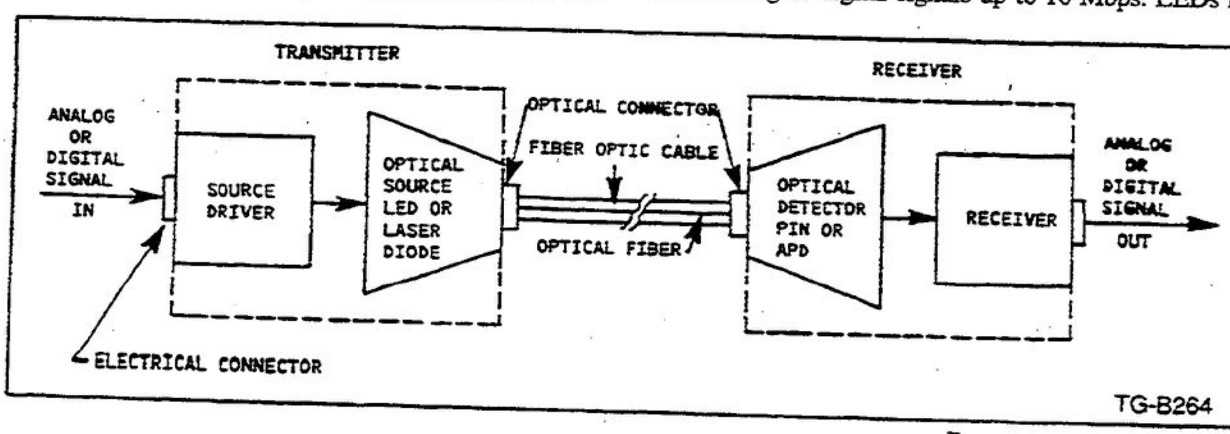


Figure 6-14. Simple fiber optic link.

with an optical power proportional to the driving current and put out scattered light. The LEDs used in fiber optics systems are refined versions of what is found in today's pocket calculators. They aren't as powerful as lasers, but they're so much less expensive that they're currently the most widely used light source for fiber optic transmission. Most use gallium arsenide (GaAs) to generate the light source.

LASERs. The most promising light source for fiber optic transmission is the LASER, or injection laser diode (ILD). Well suited for digital fiber optic transmissions, the LASER has numerous advantages over the LED. Composed of gallium arsenide doped with aluminum (GaAlAs), LASER pellets are mounted on transistor heat sinks. When current is driven through the diodes, the resultant light is much more powerful than the light given off by the LED. It is also much more directional than the LED, resulting in less scattering.

Due to the high number of modulations it can produce (some LASERs can turn themselves on and off over a trillion times per second), a LASER is better able to exercise the full bandwidth of the fiber. In addition, using LASER as the light source in a fiber optics system results in longer transmission without repeaters. Also, when repeaters are necessary, the coupling efficiency (the amount of light lost through connectorization) is much better than with the LED.

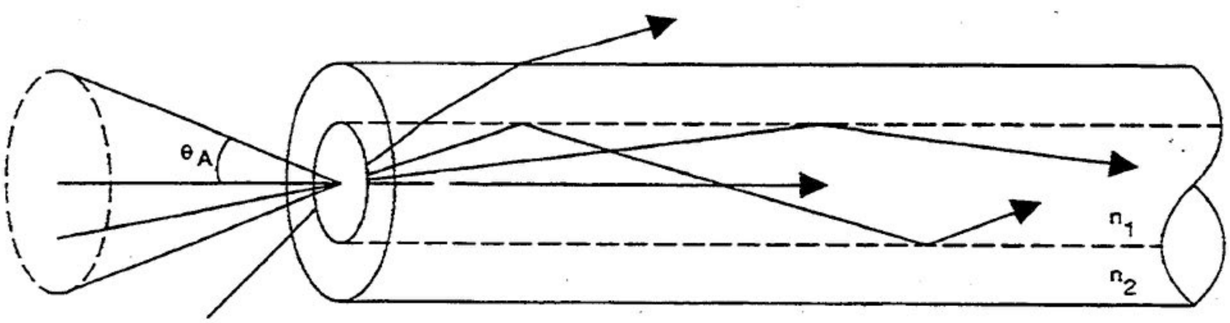
However, LASERs do have some drawbacks. For example, they are much more expensive than LEDs. Also, they are sensitive to heat; as a result, some temperature compensation circuitry is necessary to stabilize the power output. Much progress has been made toward increasing LASER lifetimes: whereas, in the 1960s, LASERs lasted only a few hours. Refinement has produced LASERs that can last over 10 years without failure.

Optical fiber wavelength regions. Two types of optical transmission technology are currently in use. They are distinguished by the region or wavelength range supported. The *short wavelength region* type supports wavelengths from 800 to 900 nanometers with rather large optical losses—about 3 to 4 decibels per kilometer. These systems use GaAs light sources and silicon detectors to achieve repeaterless operation over a distance up to 10 km. They represent the majority of systems in use today. The second, newer type, supports wavelengths from 1,000 to 1,600 nanometers and is known as the *long wavelength region*. In this region, the loss and dispersion properties of the optical fiber improve dramatically. A whole new set of components, based on gallium, indium, arsenic, and phosphorous elements, is being developed to support this technology. High capacity, long wavelength systems such as these are capable of repeaterless operation over 50 km.

Fiber optic cable. In an optical fiber, light goes in one end and comes out the other, no matter how many twists and turns the fiber makes along its length. This defies our everyday experience that light travels in straight lines. The fiber can do this because its designers have carefully applied a phenomenon called total internal reflection.

Refraction. Refraction occurs because light moves faster through some materials than through others. (It moves at its well-known 186,280 miles-per-second speed only in a vacuum.) In the simple case of glass-to-air interface, a light wavefront in a glass medium (represented in fig. 6-15 in a simplified form as a ray) approaching the boundary at a relatively steep angle has its direction changed as it suddenly encounters a region where it can travel faster.

Total internal reflection. Fiber optics transmission is based on the optical principle known as "total internal reflection." According to Snell's law of refraction, when light passes from one medium to another, such as from glass to air, the ray will bend. If the incident ray meets the surface



$$\text{Sin } \theta_A = \sqrt{n_1^2 - n_1^2}$$

n_1 = CORE REFRACTIVE INDEX

n_2 = CLADDING REFRACTIVE INDEX

$n_1 > n_2$

TG-B257

Figure 6-15. Refractive index.

at such an angle that the refracted ray is bent at an angle of more than 90°, then light cannot emerge at all and is totally, internally reflected. This phenomenon occurs at the boundary of two transparent media, such as glass and air, having different refractive indexes.

As you can see in figure 6-16, light is directed into the optical fiber at angles that fall within an area known as the "acceptance cone." The numerical aperture (NA), which defines the acceptance cone half-angle of the fiber, is the important parameter here. Light waves (information bearing light pulses) injected at angles within this cone will be wave guided through the optical fiber, while rays entering at steeper angles will be lost.

Receivers. Fiber optic receivers or detectors are photodiodes that convert light to electrical current. Photodiodes are used because they are small and inexpensive and need little power to drive them. They possess a high spectral sensitivity and response time and are well matched to the bandwidth of the transmitters. The two types of photodiodes in common use today are the PIN diode and the avalanche PIN diode or APD.

The *PIN diode* is the most simple and inexpensive type of photodiode and is adequate for a wide range of applications. Positive-intrinsic-negative (PIN) diodes have a large intrinsic region located between the P and N-doped semiconducting regions. For every photon of light absorbed by the device, a single-electron pair is produced from the P-N junction and generates a current on the load circuit.

A more sensitive and more expensive type of receiver is the *avalanche PIN diode* (APD), in which each incoming photon triggers an avalanche of electrons. The internal gain is amplified to produce a larger current than the PIN diode. Although APDs require more power than PIN diodes to operate, the resultant current gain is many times that of PIN diodes. Also, background noise causes less interference with an APD than with a PIN diode, which allows for higher transmission speeds along the link. However, APDs do require some sort of temperature compensation circuitry since they're sensitive to temperature changes. Photodectors are best suited for digital transmission (including digitized voice) since analog transmission introduces a large degree of unavoidable distortion at the receiving end.

Fiber optic modems and multiplexers. In addition to the basic elements for a fiber optics transmission link (transmitters, fiber optic cables, and receivers), a system may include modems and multiplexers as shown in figure 6-17.

Modems. A pair of fiber optic modems, one on each end of a fiber optic link, can be used to connect one end-user device to another. The modem usually provides an industry-standard RS-232-C port that connects to the end equipment plus two fiber optic cable jacks, one for transmitting and one for receiving. It also contains all of the transmitting and receiving elements necessary to carry out transmission.

Multiplexers. A pair of fiber optic multiplexers can be used in place of modems when more than one end-user device, or computer port, must be connected to either end of the cable. The multiplexer uses time-division or wave-division multiplexing techniques to create multiple channels to accommodate the various inputs. Multiple RS232-C ports are usually provided for connection of local and remote terminals connected via conventional facilities.

In addition to the pair of fiber optic jacks for the main outbound link, the multiplexer may have additional fiber optic jacks to connect user devices to the local multiplexer via fiber optic cable. Only one fiber optic modem is required, on the device end of the line, to complete this link, since the data does not need to be reconverted at the multiplexer end.

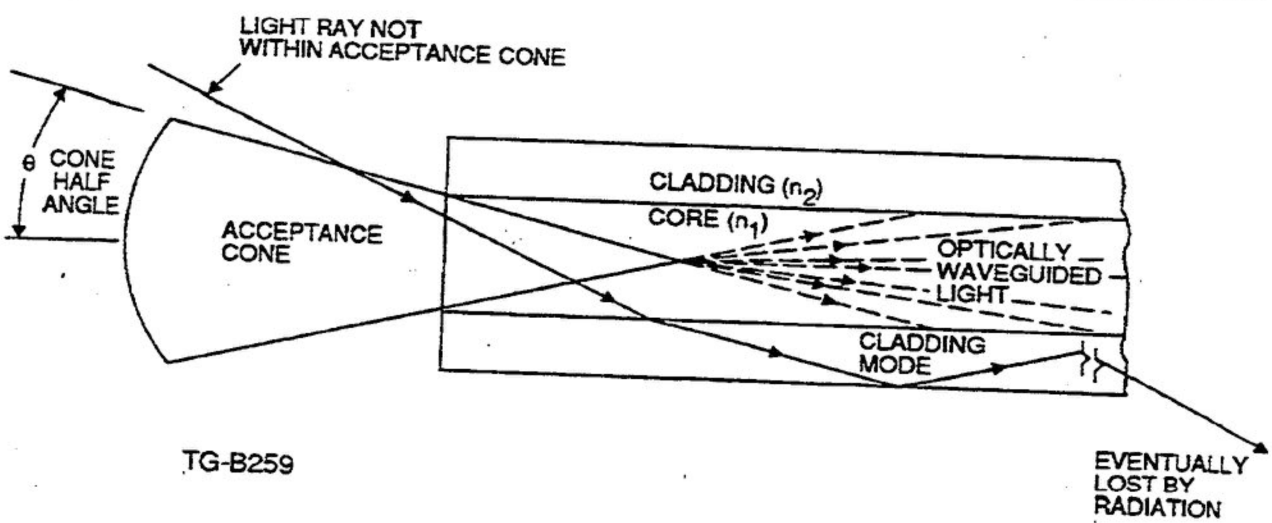


Figure 6-16. Acceptance cone.

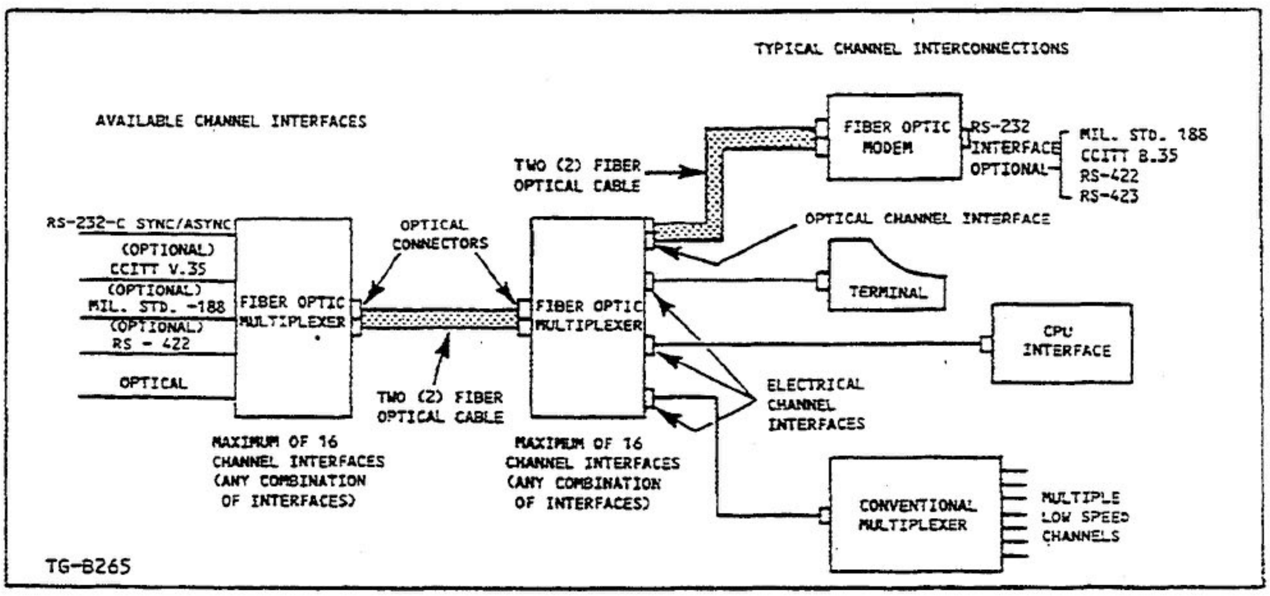


Figure 6-17. Typical fiber optics system configuration.

058. Characteristics of optical fiber cable

Optical Fiber Cable. Figure 6-18 illustrates the composition of an optical fiber. Optical fiber cables have three sections—the core, the cladding, and a plastic coating referred to as a jacket. The core is found in the center of the cable and consists of one or more very thin strands or *fibers* usually 50 or 125 microns in diameter, made of glass or plastic. Each fiber is surrounded by its own cladding, a glass or plastic coating that blankets the core and has optical properties different from those of the core.

The entire core is then surrounded by a jacket composed of plastic and other materials layered to protect against moisture, crushing, and other damaging forces such as burrowing animals. The jacket is designed to meet specific environmental needs. For example, aerially-suspended optical cables in harsh environments may have a reinforced steel cable incorporated into the jacket to strengthen against ice formation and high winds. The cable may then be enclosed in buffers for added protection. These buffers may be polymer tubes, in which a cable floats freely, or hard encasings, for protection against crushing. Strands of fiberglass may also be built into the jacket for additional protection.

All three of the fiber's components vary in thickness. The core and cladding vary as a function of the technology. The jacket's width varies as a function of the application. Vendors of fiber optic cables either have in stock or will manufacture cables to meet virtually any requirement. High fiber-count cables ranging from 30 to 144 fibers and beyond are produced using a "minibundle" design (fig. 6-19). In these designs, 6 or 12 suitably coated fibers are stranded together about a suitably diminished core and then contained in a loose

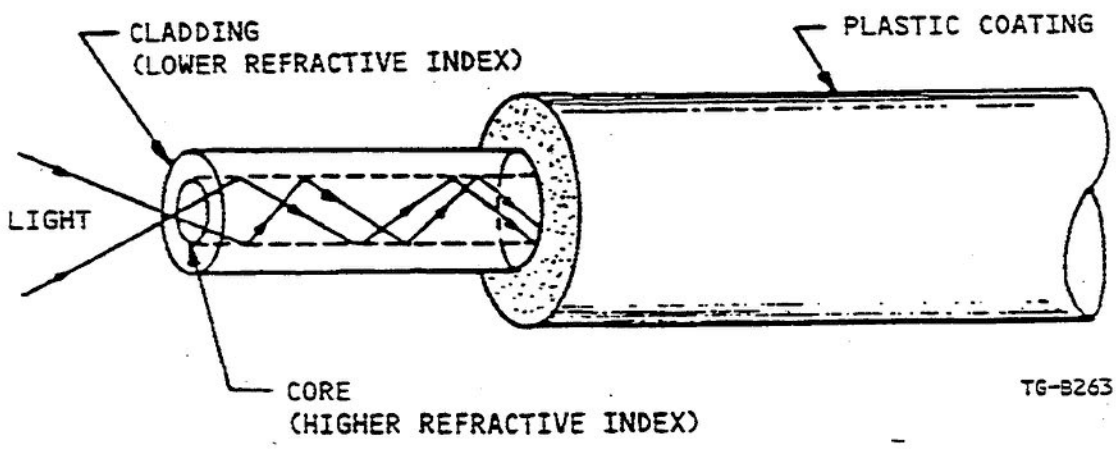


Figure 6-18. Composition of an optical fiber.

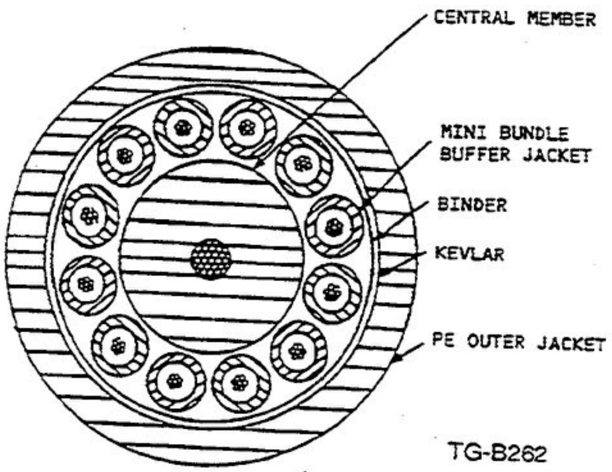


Figure 6-19. Minibundle cable with 108 fibers.

buffer jacket. Cable cores consist of an appropriate number of minibundle buffer jackets symmetrically arrayed about an overcoated steel central member and secured with binder tape.

Types of Optical Fibers. Optical fiber waveguides are made in two major classifications, one of which is subdivided into two varieties. The major division is between fibers that convey light in single or multiple modes, where a mode can be thought of as a group of waves bouncing through the wave-guide at a given incident/reflectance angle. The multimode fibers are differentiated by the profile of the refraction index across the fiber's diameter.

Multimode step-index. Multimode step-index is the oldest type of optical fiber cable and has the lowest bandwidth capacity. Bandwidth of multimode step-index fiber ranges from 10 MHz to 100 MHz/km. The core of the multimode step-index cable (fig. 6-20,A) is surrounded by a glass cladding with a lower refractive index than the core. This discontinuity, or "step" in the refractive index, creates a boundary between the core and the cladding. Light rays sent through the fiber hit this boundary at a glancing angle and are totally reflected back toward the center of the core (total internal reflection).

In multimode cables such as this, the core may be tens of micrometers to perhaps a millimeter in diameter. Because of this relatively large diameter, the rays of light reflected back toward the center of the core take a number of different paths, which can differ in length. This phenomenon is called *dispersion* and causes the light pulses to spread out as they travel along, reducing the fiber's potential bandwidth. This problem, known as *pulse spreading*, gets worse as the fiber core increases in diameter. Multimode step-index cables are found in short-distance, low-bandwidth systems, where there is a need for easy interconnections. Multimode cable is the easiest type to connect or splice since alignment of the core is not much of a problem.

Multimode graded-index. Multimode graded-index cable uses a more complex light-carrying technique and, although it's more sophisticated than multimode stepindex, it's easier to mass produce. It also exhibits much higher band-width properties, ranging from 200 MHz to 1,000 MHz/km. Multimode graded-index fibers (fig. 6-20,B) guide light through refraction instead of reflection. With graded-index fibers, the refractive index of the core gradually decreases from the center to the outer perimeter. Thus, the boundary between the core and the cladding is gradual, not sudden. Instead of a step in the refractive index, there is more of a slope. Light attempting to pass from the core through this "graded" area is gradually bent back toward the center of the core, not sharply reflected. With graded-index fibers, although the light waves may travel different paths, they will travel nearly the same distance. As a result, pulse spreading is minimized.

Multimode graded-index cable is used for all current long-distance fiber optics telecommunications links. There are at least 37,000 miles of this type of cable in service on over 60 major routes. Since it is produced in quantity and requires less material than the multimode step-index cable, it is often less expensive. To overcome problems associated with connecting fibers of different core diameters, de facto standards for this type of fiber have developed that call for a core diameter of 50 microns, with a cladding 125 microns thick.

Single mode. The third type of optical cable is single mode. In its latter stages of development, single-mode cable has an incredible bandwidth capacity of up to 50 GHz/km. With single-mode optical cable (fig. 6-20,C), the core diameter is limited to a few micrometers, thus limiting the

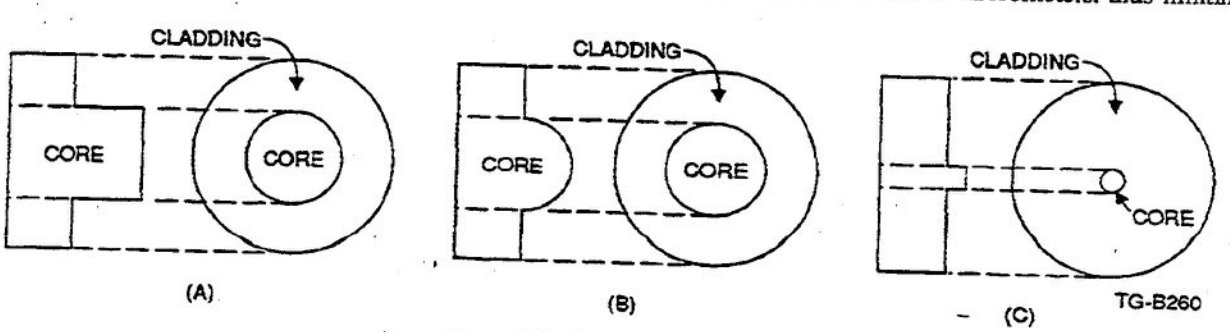


Figure 6-20. Three types of wire.

light to a single path. Since light injected into the fiber can't vary in either the path it takes or the length of the path, pulse spreading is eliminated. The light is guided by "smoothing" the wave, resulting in the highest maximum bandwidth.

Single-mode cable has advantages in size, performance, economy, reliability, and design flexibility over the multimode cable, but a few problems must be solved before single-mode fiber systems become practical. The most significant is that, due to the small size of the wire, it's hard to splice the cable and transfer light into the fiber. The industry is making a concentrated effort (particularly in Japan where single-mode fiber is the standard) to eliminate these stumbling blocks and unleash the potential of single-mode fiber optics systems.

Some of the potential uses for single-mode cable are: undersea transmission, in which the need for long repeater spacing is obvious; local broadband fiber optic networks, where the cable capacity is used for trunking; fiber optic sensing systems; and long-haul integrated services digital networks, which can support numerous services, including high-speed transmission of voice and data, teleconferencing, and broadcast over a single-fiber optic link.

One of the main reasons fiber optics technology has become commercially practical is the decline in the price of the cable. Multimode cable is readily available and inexpensive. Single-mode cable, although more expensive to produce than multimode grade, will become less expensive as more and more vendors, especially those from Japan, try to gain a foothold in this promising market and as manufacturing techniques continue to be refined.

Signal Degradation. Assuming that digital signals, such as those produced by a PCM terminal, were to be used in a hypothetical system, they would appear as bursts or flashes of light occurring within a uniform array of timeslots. To be able to decipher the message represented by the signals, the receiving end must be able to distinguish the bursts of light not only in intensity but also in time. Signal degradation in a fiber mainly occurs in the form of attenuation (dimming of light intensity) and differential delay (the broadening of the signal in time).

Attenuation. The extent to which a multimode fiber can accept and transmit light energy depends on the angle at which the light rays enter the fiber. Relative to the axis of the fiber, this angle must be less than the critical acceptance angle (Θ_c) of the particular fiber being used. In general, only about 4 percent of the total wide-angle light initially emitted by the LED is transmitted in the optical fiber. The attenuation of light energy traveling in a fiber is mainly due to absorption and scattering. Absorption loss is caused by impurities such as iron, copper, nickel, and cobalt in the fiber. These materials usually are trapped in the glass from which the optical fiber is made. For a good quality fiber, the total amount of metallic ion impurities shouldn't be more than one part per million. To meet these requirements, intensive research by fiber manufacturers has produced fabrication methods that provide glass of such great purity that absorption loss is minimized in the manufacture of the latest experimental fibers.

Power loss due to scattering is caused by imperfections in the core material and by flaws in the region where the core interfaces with the cladding. Rayleigh scattering, another type of scattering that causes attenuation in optical transmission, is caused by the existence of tiny dielectric inconsistencies in the glass. Because these material inconsistencies are small with respect to the particular wavelength propagating in the fiber, scattering of light energy takes place in all directions almost uniformly.

The transparency of optical fiber to be used for communications must be extremely high for a system to operate efficiently over an acceptable distance. For example, for a given intensity of light of a certain wavelength, a particular optical fiber might convey the energy 1,000 meters, whereas in high-quality optical glass and ordinary window glass or water, the energy would be conveyed only about 5 meters and 1 meter, respectively, for an equal amount of loss.

Differential delay. For silica, material dispersion alone results in pulse spreading on the order of picoseconds in 1 km. Pulse spreading is markedly affected by the spectral width of the source. For LEDs, depending on a particular design's characteristics, spectral width results in pulse spreading from just below 1 to 5 nanoseconds over 1 km of optical waveguide. A spectrally narrower, solid-state injection laser decreases the pulse spreading by roughly one order of magnitude.

The degradation of light by differential delay (pulse broadening or spreading) in modern optical fibers has more significant effects on transmission than does scattering. The cause of pulse broadening begins with the angle at which a ray from a light source enters the fiber. Those rays entering a multimode step-index fiber parallel to the fiber axis travel the shortest distance to the receiver, while those entering at various angles must be reflected by the cladding and, thereby, travel a longer distance to the receiver. The difference in time of arrival at the receiver of the various rays causes a spreading of individual pulses. If the difference in arrival time between the fast and slow rays exceeds the time interval allowed between pulses, a pulse overlap occurs.

Because pulse spreading increases with fiber length, it's important that light rays travel as close to the core as possible. For this to happen, the difference in refractive indexes of the core and cladding must be kept small, thus also keeping the critical acceptance angle small. Pulse broadening must be especially limited in systems processing higher bit rates, since higher data speeds mean a shorter time interval between pulses and, consequently, less tolerance for errors due to pulse spreading.

A departure from the step-index method of confining light energy to the core is a graded-index optical fiber developed by the Nippon Sheet Glass Company of Japan. Called Selfoc (abbreviation for "self-focusing"), this graded-index fiber consists of one material interspersed with a second material in such a way that the index of refraction decreases at a faster and faster rate with distance from the axis of the fiber. By this means, the light rays travel back and forth across the axis of the fiber in a sinusoidal manner, with the refractive index reaching a maximum value at the fiber's center and a minimum value at the surface. Because the speed of a light ray varies inversely with the refractive index of the material through which it propagates, it travels slower in areas close to the center and faster in regions farthest away from the center. The effect of this action is that all rays traveling in the Selfoc fiber will reach the receiver at nearly the same time.

One additional method of eliminating differential delay is by constructing a step-index fiber with a core so small that only a single electromagnetic mode is allowed to propagate. This single-mode technique eliminates the interference that is created when light rays of different wavelengths propagate along the fiber. However, this type of fiber construction requires use of the monochromatic light that only a laser can produce. Also, the single-mode fibers are hard to manufacture and hard to handle in practical applications, although they have the potential for carrying much more information than other fibers. Semiconductor LASERs are currently being developed that may be used with single-mode fibers. This kind of compatibility between available components and those yet to be developed may some day revolutionize the field of wideband communications.

Please write your response to unit self-test questions and then check the text answers at the end of the unit.

SELF-TEST QUESTIONS

056. Basic characteristics of fiber optics communications

1. What lets you send signals at greatly increased data rates and in greater quantities?

2. What is the expected bandwidth per kilometer of a single-mode fiber optics cable?

3. At what maximum temperature can a fiber optics cable operate efficiently?

4. What advantage is offered by optical cable for transmission security?

057. Elements of a functional fiber optics transmission link

1. What are the three basic elements of a fiber optics transmission link?

2. What two light sources are used in fiber optics transmitters?

3. What are the ranges of the short- and long-wavelength regions?

4. How must rays be injected into an optical cable to ensure they are wave guided through the fiber?

5. What two types of photodiodes are used today?

058. Characteristics of optical fiber cable

1. Explain the basic construction of a fiber optics cable.

2. What are the three types of optical cable?

3. What is the bandwidth of multimode graded-index cable?

4. What is the cause of absorption loss?

5. What is differential delay?

ANSWERS TO SELF-TEST QUESTIONS

050

1. Open wire, paired, coaxial cable.
2. Paired cable consists of two conductors, individually insulated from one another and twisted together. The pair may be twisted together with other pairs and covered with a protective covering.
3. Coaxial cable.
4. Coaxial cable doesn't radiate or pickup any energy to cause interference.
5. Used to connect analogous-type circuits from the patch bay to the main distribution frame.

051

1. Shunt capacitance, series inductance, series resistance, and shunt conductance.
2. The particular values depend mainly on the physical configuration and the type of material used in the transmission line.
3. Travel time depends on the values of the four fundamental properties of the transmission line.
4. The property of a circuit that causes a counter-voltage to be induced in the circuit by a change of current in the circuit.
5. Resistance increases as the diameter of the wire decreases and as the frequency of the transmitted wave increases.
6. A mismatch in impedance between equipment and line.

052

1. Base cable plant.
2. The distribution plant connects all the base subscribers to the cable plant, and the trunk plant connects the plant to the central office (PABX), Tech Control, or commercial carrier.
3. A commercial lease circuit enters the installation on a trunk cable and is connected to the base cable plant. It is then cross-connected on the distribution frame to a trunk cable connection in the tech control facility. The circuit passes through the necessary equipment in the TCF and back out on a trunk cable to the base cable plant, where it is cross-connected through a distribution cable to the subscriber.

053

1. To reduce attenuation in a long-haul cable circuit.
2. Located at the end of a cable and provides low gain.
3. 2 amplifiers, 2 hybrids, and a precision balancing network for each hybrid.
4. At the two-wire drop and two-wire switch equipment.
5. The two-wire carrier systems use the same pair of wires and different frequencies for transmit and receive.
6. Provides an effective improvement in the signal-to-noise ratio on the 4-kHz VF circuit.
7. Inverting from a low frequency to a high frequency and vice versa at a repeater installation to reduce crosstalk.
8. Phrase distortion or envelope delay distribution.

054

1. Power availability and accessibility.
2. 1956.
3. Submarine cable, submerged repeaters, equalizers, and onshore terminal station equipment.
4. The segment of cable including the number of repeaters between equalizers.
5. Passive submarine cable don't use submerged repeaters.
6. Solid-state repeaters have lower voltage and power requirements.
7. A single cable uses only one cable and is cheaper to install; repeaters are more complex and more expensive. A twin cable offers more reliability for digital communications.
8. To provide an interface point for the different multiplexes and power to drive the repeaters.
9. Coaxial.
10. Mainly used for shallow water and shore-end sections.
11. It's an assembly of one or more amplifiers and other electrical circuitry used to amplify the signal.
12. Flexible and rigid types.

055

1. The constant-current high voltage necessary for powering the repeaters.
2. A single-cable system.
3. They compensate for the cumulative variations between designed and actual characteristics of cable sections and repeaters within an ocean block.
4. Pilots are used for monitoring and adjusting transmission levels and switching to spare equipment.

056

1. The use of LEDs or LASERs as a light source.
2. 50 GHz.
3. 1,000°C.
4. Fiber optics cable emits no radiation and can't be tapped without detection.

057

1. Transmitters, optical cables, and receivers.
2. LEDs and LASERs.
3. 800 to 900 nanometers and 1,000 to 1,600 nanometers, respectively.
4. They must be injected at angles that fall within the acceptance cone.
5. PIN diodes and avalanche PIN diode.

058

1. The cable has a central core with one or more glass or plastic fibers. The core is surrounded by a glass or plastic coating called the cladding. A jacket made of plastic or some other hard material is then used to protect the cable.
2. Multimode step-index, multimode graded-index, and single mode.
3. 200 MHz to 1,00 MHz/km.
4. Absorption loss is caused by the presence in the fiber of impurities such as iron, copper, nickel, and copper.
5. Pulse spreading or broadening.

Do the Unit Review Exercises (URE) then complete ECI Form 34, Field Scoring Answer Sheet.

UNIT REVIEW EXERCISES

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to ECI Form 34, Field Scoring Answer Sheet. **DO NOT RETURN YOUR ANSWER SHEET TO ECI.**

108. (050) The advantage of using coaxial cable over open-wire and paired cable is that coaxial cable
    a. is less expensive.
    b. is easier to install.
    c. handles higher frequencies.
    d. emits electrostatic fields outside its shield.

109. (050) Which type of cable does *not* radiate energy and is *not* affected by nearby magnetic fields?
    a. Open wire.
    b. Shielded.
    c. Twisted pair.
    d. Multipair.

110. (051) In telephone terminology, the resistance of a line is stated in terms of ohms per
    a. metric foot.
    b. metric mile.
    c. loop mile.
    d. cubic meter.

111. (051) What do loading coils equalize to reduce the amount of line loss in a voice-frequency-cable transmission line?
    a. Resistance and inductive reactance.
    b. Capacitive and inductive reactance.
    c. Resistance and shunt conductance.
    d. Capacitance and shunt conductance.

112. (052) Who maintains a base cable plant?
    a. Outside plant maintenance.
    b. Wideband maintenance.
    c. Computer maintenance.
    d. Inside plant maintenance.

113. (052) What do you call the demarcation point of commercial leased circuits at the cable plant?
    a. Commercial equalization point.
    b. Military line conditioning point.
    c. Commercial responsibility start/stop point.
    d. Military user interconnection point.

114. (053) How do you reallocate voice channels to the 4,000 to 150,000 Hz range of a cable transmission system?
    a. Pulse code modulation (PCM).
    b. Time division multiplexing (TDM).
    c. Frequency division multiplexing (FDM).
    d. Amplitude modulation (AM).

115. (053) Far-end transverse crosstalk occurs on the far end of the path
    a. from the output of one repeater to the input of another.
    b. from the output of one repeater to the input of another system.
    c. from the output of a system to the input of the first repeater.
    d. from the output of one system to the input of another system.

116. (054) The two types of cable used in submarine systems are
    a. open-wire and shielded cable.
    b. armored pair cable and shielded cable.
    c. center-strength coaxial cable and paired cable.
    d. armored and center-strength coaxial cable.

117. (054) What determines the intervals at which submarine cable repeaters are spaced?
    a. The type and size of cable, cable length, and expected cable loss.
    b. The number of circuits, size of the cable, and repeater gain.
    c. The type and size of cable, and calculated maximum baseload loading.
    d. The cable length, expected cable loss, and repeater gain.

118. (055) What allows a cable system to have more repeaters in line to cover a greater distance?
    a. A high voltage drop.
    b. A wider bandwidth.
    c. A high-voltage transmitter at the terminal.
    d. A low-voltage drop.

119. (056) What has made very high data rate transmission possible on a fiber optics cable?

   a. The use of light-emitting diodes.
   b. The broad bandwidth of the cable.
   c. THe low signal to noise ratio of the cable.
   d. The multiplexing technique used in fiber optics.

120. (056) What is the current practical bandwidth limitation for a 10-km fiber optic cable?

   a. 20 MHz.
   b. 35 MHz.
   c. 50 MHz.
   d. 140 MHz.

121. (057) How much loss is expected in the short optical fiber wavelength region per kilometer of cable?

   a. .01 to .05 dB.
   b. 0.5 to 1.5 dB.
   c. 1.0 to 2.5 dB.
   d. 3.0 to 4.0 dB.

122. (057) What is an advantage of using an avalanche PIN diode (APD)?

   a. An electron pair is generated for every photon of light absorbed.
   b. This type has a lower power requirement than a PIN diode.
   c. It is the simplest, most inexpensive type of photodiode.
   d. It generates a current gain many times that of a PIN diode.

123. (058) What is the bandwidth of multi-mode step-index optical fiber cable?

   a. 10 MHz to 100 MHz/km.
   b. 100 MHz to 200 MHz/km.
   c. 200 MHz to 1000 MHz/km.
   d. Up to 50 GHz/km.

124. (058) What causes absorption loss in a fiber optic cable?

   a. Impurities in the fiber.
   b. The angle at which a ray from a light source enters the fiber.
   c. Differences in the refractive indexes of the core and cladding.
   d. Imperfections in the region where the core interfaces the cladding.

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