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SPECIAL TEXT

SPECIAL FORCES RADIO ANTENA

DEPARTMENT OF ARMY WIDE TRAINING SUPPORT

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FOREWORD

Antenna design, construction, orientation, and the merits of one antenna system over another has been the subject of much discussion among Special Forces radio operators. Generally speaking, in a group of five radio operators there will normally be five different opinions on which antenna system is best for a specific operation. Chances are that they will all be correct to some degree. It would be presumptuous of anyone to make a statement that this particular antenna system is best and that it will provide the best performance under any circumstances. Each radio circuit provides a separate set of circumstances and may require a different solution. Many radio operators have a "FAVORITE" antenna system which they use over and over again under all circumstances. This can be dangerous and should be avoided.

This antenna handbook is designed to give you a simple explanation of antenna theory design and construction which should take any guesswork out of the problem of determining which antenna system is best suited for a given set of circumstances.

Why a separate handbook on antennas? It must be realized that the implementation of a highly efficient antenna system is the only way you as radio operators can influence the radio circuit. The major influencing factors of any radio net are normally power, frequency, and antenna construction. The radio has its own power output which normally cannot be changed. The frequency which you are to operate on is normally assigned to you so there is no way to increase the efficiency of your radio net through frequency selection. That leaves us with antennas alone as the one means of improving the signal strength within a radio circuit.

This book was not designed for radio engineers. It was designed to give the radio operator a basic understanding of antennas. Many of the terms and diagrams may appear oversimplified in order to present a complex subject in such a way so as to be understood by everyone. Keep in mind that there is only one best antenna system, and that is the one that works and gets the job done.

INTRODUCTION

Basic antenna design and construction involves a compromise between the most efficient electrical design and the most practical mechanical construction for a particular transmission path length and physical location. A popular story goes like this, "I used every formula, design, and difference in construction ever taught to provide the desired effective radiated power and nothing worked. Then I got mad, threw the wire over a bush (tree, house, or whatever) and got 'five-by' contact. You can talk all the principles of antenna characteristics you want, but I know you are wrong. What works is a good antenna."

If at the point in time radio operator X established the "five-by" contact described above, time was suspended temporarily, and an extensive engineering analysis conducted, all factors needed to transmit intelligence superimposed on a given frequency would have been found.

What are these "mysterious" (sometimes it seems), elusive factors which influence whether or not communications are established? Whether employed in direct action, unconventional warfare, or stability operations, the name of the game is expertise!

Let's briefly discuss the reliability factors for improvement of any transmission path, whether a conventional net or a net using maximum transmission security procedural techniques. Improvement can be made by any one, or a combination of, the following:

(1) Higher power transmitter.

(2) More-efficient transmitting antenna.

(3) Receiving antenna capable of permitting greater discrimination against the noise sources.

(4) Review of frequency selection to insure best choice for each time of day.

(5) Change of the type of service to one that tolerates a poorer signal to noise ratio. (e.g., changing from phone operation to CW.)

Improvement by providing more radiated power is extremely difficult to obtain. To improve from 48 to 90 percent reliability requires approximately 100 times as much power, and 100 times again is required for an improvement from 90 to 99 percent reliability.

Equipment used in Special Forces operational detachments is usually low-powered and developed in a man-carry configuration.

The handbook you are about to read is designed to familiarize the reader with principles which can be used to insure maximum benefit is derived when using detachment communications equipment. The "best" of the combination of factors listed above can be applied and still communications may be marginal or unsuccessful. The difference between marginal and successful communications in each instance lies with you, the individual Special Forces communications supervisor or assistant, and the degree of professionalism and competence you possess.

TABLE OF CONTENTS

CHAPTER 1

RADIO WAVE PROPAGATION

CHAPTER 2

RADIO ANTENNAS

CHAPTER 3

GROUNDS

CHAPTER 4

SIMPLE ANTENNAS

CHAPTER 5

INDOOR ANTENNAS IN CITIES

CHAPTER 6

OUTDOOR ANTENNAS IN CITIES

CHAPTER 7

INDOOR ANTENNAS IN RURAL AREAS

CHAPTER 8

OUTDOOR ANTENNAS IN RURAL AREAS

CHAPTER 9

DIRECTIONAL ANTENNAS

CHAPTER 10

COMMUNICATIONS SECURITY

CHAPTER 1

RADIO WAVE PROPAGATION

1.1 WAVE CHARACTERISTICS.

Communication between persons is the exchange of ideas, opinions, or information by voice, letter, or code. For two persons to communicate, it is necessary that some form of energy be transferred from one point to another. The distance between these two points may vary from a few feet to thousands of miles.

When the two persons are within talking distance, they may communicate by voice which is a form of sound energy. If the two persons are not within hearing distance, other means of communication must be used.

Primitive people use drums and hollow logs to create sound energy for communication through the jungles. Sound energy sent out from logs and drums is coded to carry information which is understood by the natives.

Sight, or light energy, is also used to communicate between two points. Smoke signals, signal flags, mirrors, and lamps are used to send coded messages under certain conditions. Communication by the use of light and sound energy, however, is obviously limited to short distances.

The discovery of electricity opened the way for establishing the present methods of communication over long distances. Early experimenters discovered that sound energy could be changed into electrical energy and carried from one point to another on wires. This method was a vast improvement over earlier ones, but was expensive and limited to use only under ideal conditions. Scientists continued their experiments with electricity in an attempt to discover a system for communicating over long distances without wires.

By the close of the last century, scientists performing experiments with high-voltage capacitors had found that when they short-circuited a charged capacitor (the transmitter), it would cause a small spark to fly across a second capacitor (the receiver), located 6 or 7 feet away. This spark appeared across the second capacitor even though the two capacitors were not connected by wires.

Shortly after this discovery, Marconi repeated the capacitor experiment and found that by using high-frequency electrical signals, the distance between the transmitter and the receiver could be increased from a few feet to several miles. Measurements made by Marconi during these experiments proved that transmitted signals traveled across the earth at the speed of light. Of more importance, Marconi discovered that he could send Morse code between distant points by means of the tiny sparks described above. The energy which escapes from the short-circuited capacitor into the surrounding air and causes a spark to appear on the second capacitor is called radiated energy.

The energy escaping from the transmitter is radiated in much the same way as heat waves are radiated from a fire or sound waves are radiated from a musical instrument. When radiated energy is used to communicate between distant points, it is called radio radiation.

Although there are many kinds of radiation such as radio, heat, light, sound, etc., they all differ in form and behavior. Since all radiation is sent outward in the form of waves similar to those present when a pebble is dropped into a still pond, these differences in form and behavior are called "wave characteristics."

Sound waves are created by compression and expansion of air. If a stringed instrument is plucked as shown in figure 1-1, or a drum is struck, visible vibrations are set up on the strings or drum cover. These vibrations cause the air around the instrument to vibrate or expand and compress in step with the string or drum vibrations. The compressions and expansions of air spread outward in all directions at the speed of sound and strike the ear of the listener. When these waves reach the ear, vibrations are created in the ear structure, and the sound of the instrument is heard. Sound waves have their own wave characteristics which differ from the wave characteristics of radio waves.

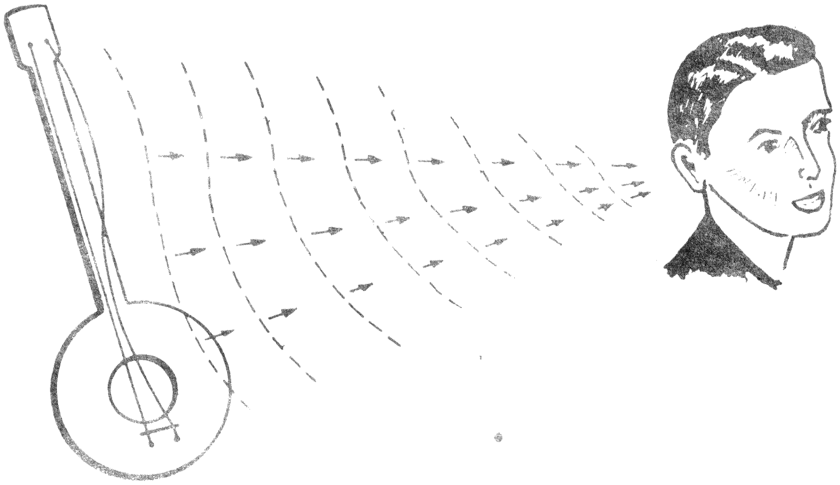

Figure 1-1

1.2 WAVE MOTION.

Vibration, heat radiation, and radio radiation produce effects at some distance away from their source due to their wave characteristics. As mentioned earlier, these waves have motion. This motion acts through the air to produce the same effect at the receiver that is present at the source or transmitter.

When a stone is dropped into a still pool of water, as shown in figure 1-2, circular ripples are formed around the point of impact and spread outward toward the shore. A close study of these ripples reveals the presence of two types of wave motion.

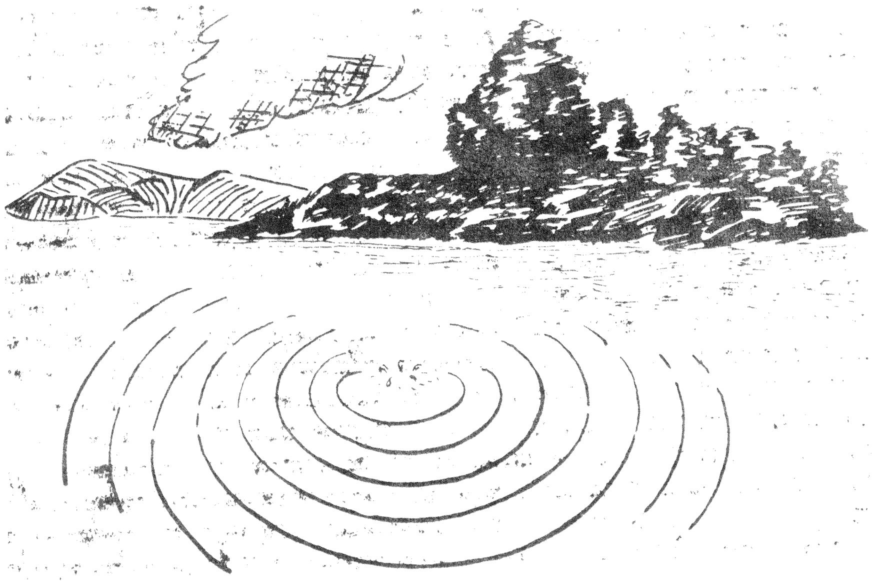

Figure 1-2

First, we note that little peaks and valleys are formed on the surface of the water and make the wave or ripple visible to our eye. This is the stationary wave characteristic since the peaks and valleys in any one ring around the point of impact have only an up and down or vertical motion. That only vertical motion is present in any one ripple can be shown by placing a light wooden chip on one of the ripples and observing the motion of the chip. The chip will bob up and down in the water, but neither the ripple nor the chip move any further from the point of impact or any closer to the shore.

Secondly, we may note that although the first ripple created by dropping the stone in the pool remains in the same position, more ripples are formed and spread outward until they reach the shore line. These new ripples are identical to the first one and have the same wave characteristics. If a chip is now placed on a ripple near the shore, it will have vertical motion identical to the chip near the point of impact. The distance between the first and second chip and between the second chip and the shoreline will remain constant. Here then we have action transmitted between two points by wave motion through a water medium.

Another simple way to examine the motion of a wave is to create one in a rope. If a piece of rope about the length of a room is anchored waist high on one wall as shown in figure 1-3A, wave motion may be created by grasping the free end of the rope and moving the hand vertically, up and down, with a rapid motion. When the free end of the rope is moved in the vertical plane, a wave pattern made up of peaks and valleys is set up in the rope, as in figure 1-3B. In electrical terms, the peaks are called "maxima" and the valleys are called "minima." The vertical distance between the maxima and minima is called the "amplitude" of the wave motion.

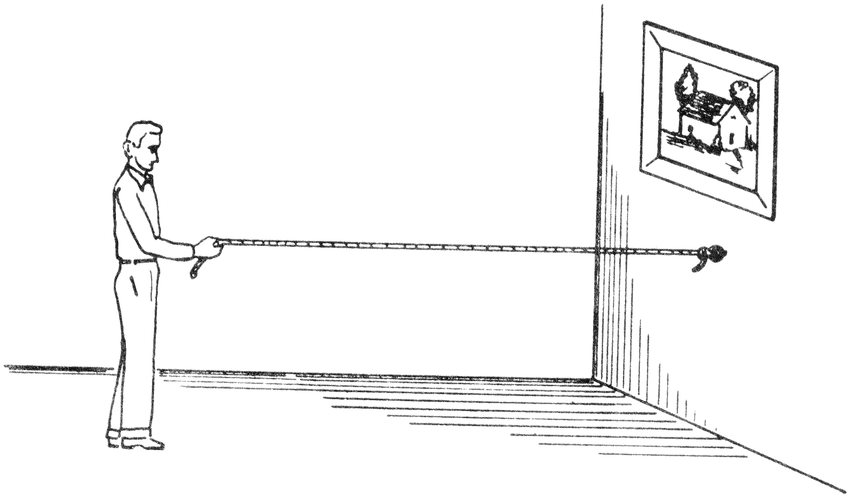

Figure 1-3A

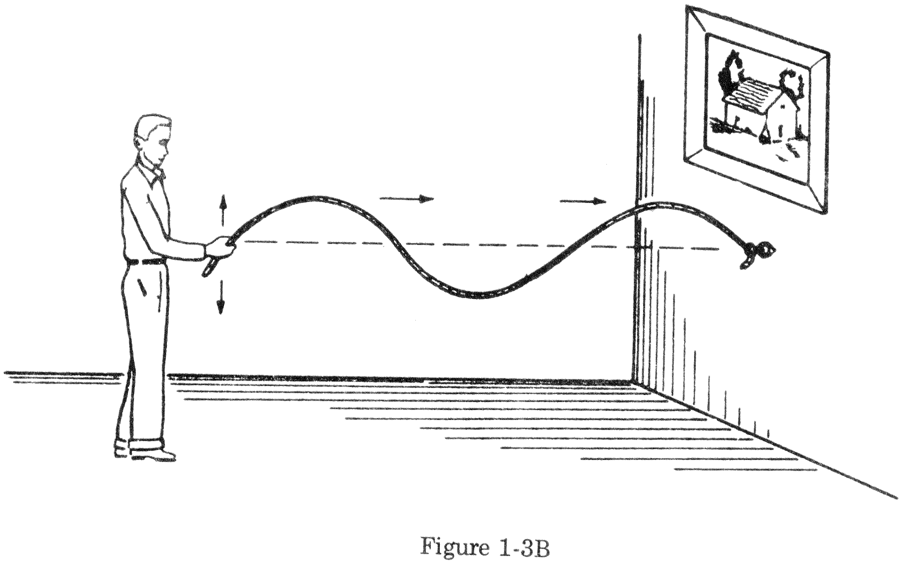

Figure 1-3B

It will be noted that the wave pattern repeats at several points along the length of the rope before it reaches the fixed end. In this example of wave motion, we have created a wave motion similar to the water wave or ripple, and have limited its extent by fastening one end of the rope to the wall. The wave stops at the wall just as the water ripples stopped at the shoreline.

If we imagine a very long rope, perhaps 100 feet long, we can demonstrate the creation of many waves along the rope by rapid vertical motion of the free end. If we move the free end of the rope up and down slowly, we can create just a wave or two at a time which will travel down the length of the rope and come to a stop against the anchored point.

In experimenting with wave motion in a rope, we see two ways in which wave motion can be affected. First, the speed of the up and down motion of the rope determines the number of maximum and minimum points occurring along the rope. If we move the free end of the rope up and down slowly, there may be two or three points of maximum and minimum amplitude on the rope as shown in figure 1-3C.

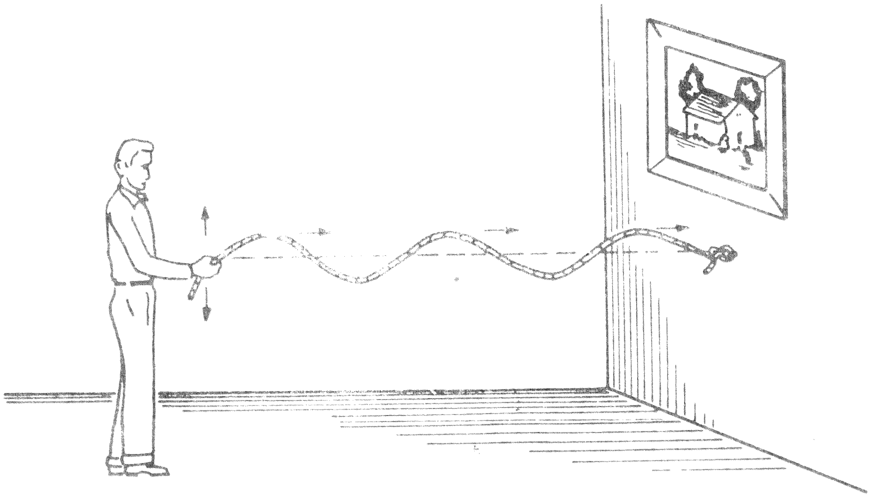

Figure 1-3C

If the free end of the rope is moved up and down rapidly, a larger number of maxima and minima occur as in figure 1-3D.

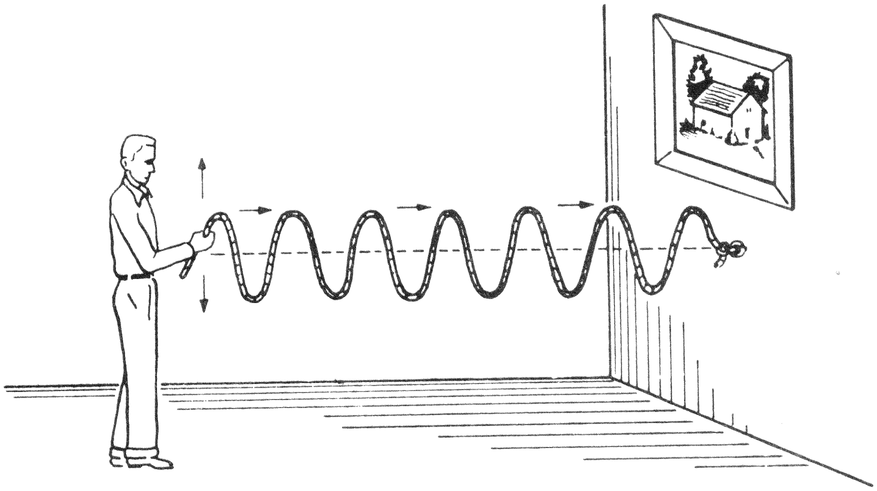

Figure 1-3D

The rate at which the free end of the rope is moved up and down determines the number of waves present on the rope. The number of times the end of the rope completes one up and down motion per second determines the frequency of the wave. Each complete wave, which includes one maximum and one minimum, visible on the rope represents one cycle of wave frequency. The more waves that exist on the rope, the greater the frequency of the wave. If we double the rate of vertical motion of the hand, the frequency is doubled, and we get twice as many points of maxima and minima on the rope.

Secondly, the vertical distance the free end of the rope moves determines the amplitude of the wave motion as shown in figure 1-4. If we move the hand up and down at the same frequency, but vary the vertical distance traveled, we find that we are changing the amplitude of the wave motion in the rope by the amount the vertical distance is varied.

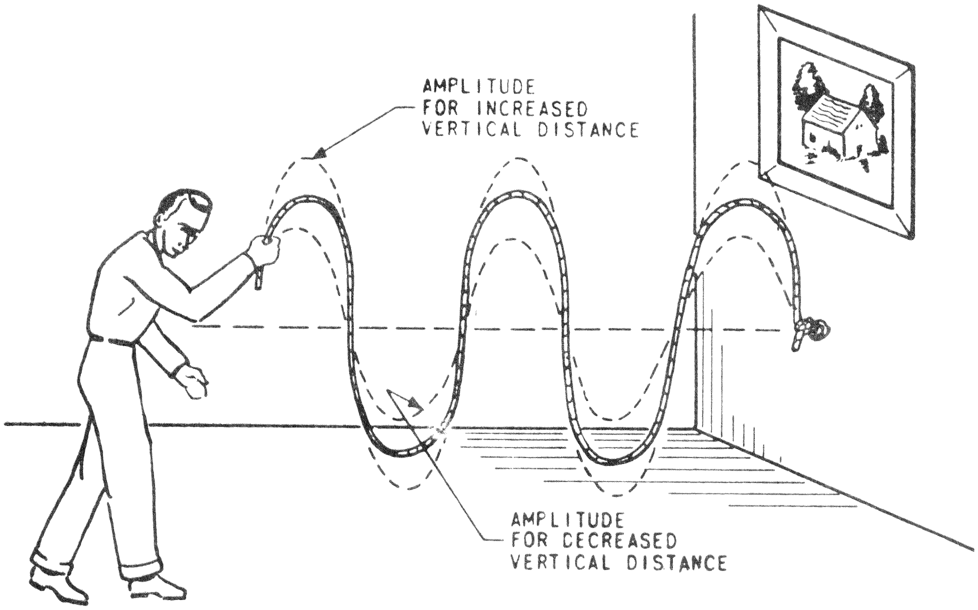

Figure 1-4

As mentioned above, the vertical distance between maxima and minima is called the amplitude of the wave motion. Another important property of waves is the amplitude characteristic of the wave. The amplitude characteristic is the vertical distance from the rope, if it were stretched tightly in a horizontal position, to either a maximum or minimum point of the wave. The amplitude characteristic of the wave is one-half as large as the amplitude of the wave motion.

The horizontal position of the rope from which amplitude characteristic measurements are made is called "reference" point and is shown as a dashed line in figure 1-5.

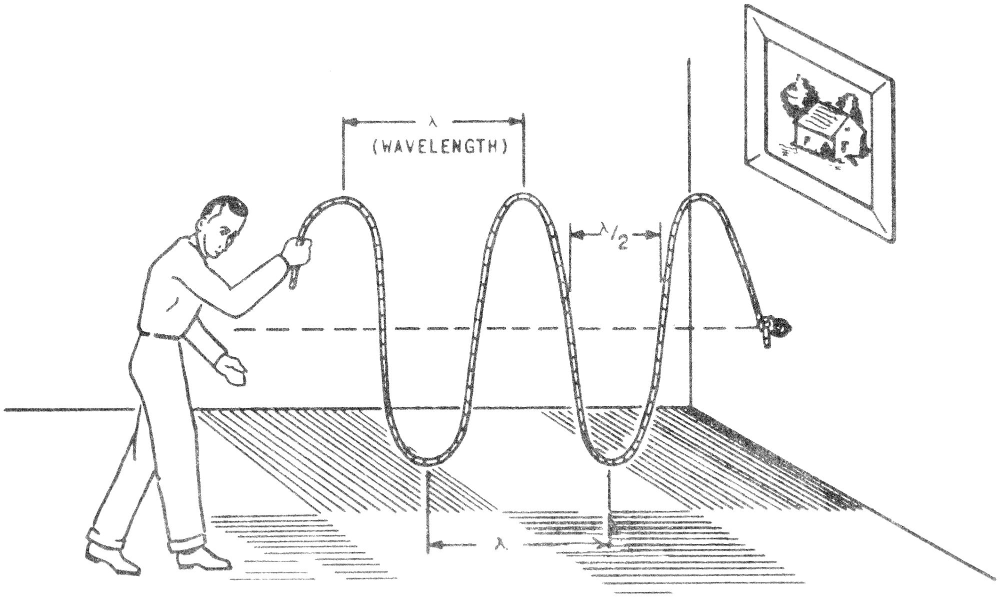

Figure 1-5

We have seen that a wave has both an amplitude and a frequency characteristic. These two wave properties are independent of one another since we can vary the motion of the free end of the rope in two independent ways, speed and amplitude.

A third important characteristic of a wave is the length of one wave which is called wavelength. A wavelength is the distance a wave travels along the horizontal reference line in passing through one maximum and one minimum. The wavelength may be measured from any point on one wave to an identical point on an adjacent wave. These measurements may be made from maximum to adjacent maximum, or from minimum to adjacent minimum as shown in figure 1-5.

Also shown in figure 1-5 is a dashed horizontal reference line along which wavelength may be measured. The distance between adjacent points at which the wave cuts the line is equal to one-half wavelength. The distance between every second point where the wave cuts the dashed line is equal to one wavelength. As shown in figure 1-6, a single wavelength is the distance the wave travels along the reference line while one cycle of wave frequency is being traced out.

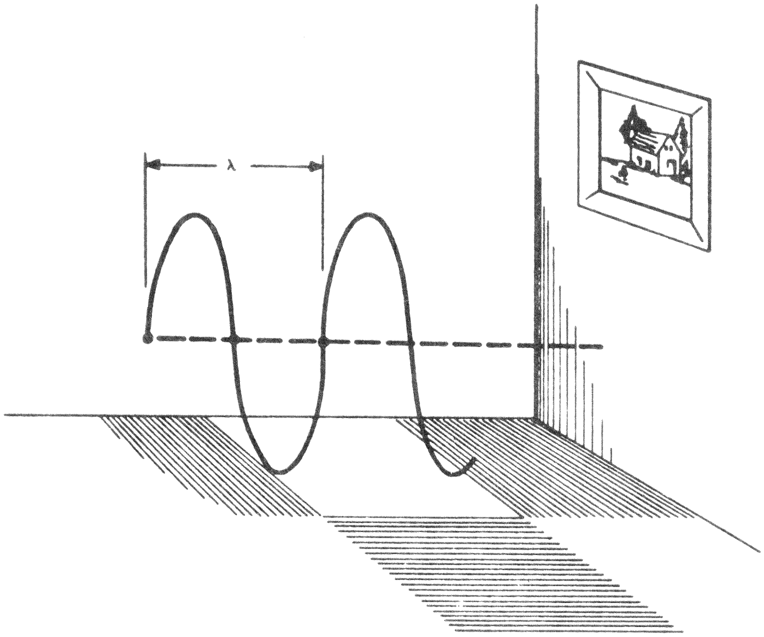

Figure 1-6

If we again take the 100-foot rope as an example, and move it vertically at a rate which gives 10 maxima and 10 minima along the 100-foot length of rope, we will see 10 waves having 10-foot wavelengths and a frequency of 10 cycles. If we start at a point where the wave cuts the reference line and trace out one cycle of wave frequency, we would pass through one maximum and one minimum and would have traveled 10 feet, or one wavelength, along the rope.

It should be remembered that when the wavelength is long, there are only a few waves present. Long wavelengths occur with slow vertical motion or low frequency. Short wavelengths occur with rapid vertical motion, or high frequency. The higher the frequency of a wave, the shorter will be its length.

The relation between frequency and wavelength is always true because the wavelength times the frequency must equal the speed at which waves travel over the earth. In radio wave communication, this speed must equal the speed of light. The relationship between frequency and wavelength for radio waves may be written as follows:

wavelength (λ) ,X frequency (f) = speed of light

or

$$\frac{\text{speed of light}}{\text{frequency}} = \text{wavelength}$$

1.3 WAVEFORMS.

In our discussion of wave characteristics, we have seen that a wave may be described as having three reference points. These points are maxima, minima, and the horizontal reference line. If we inspect the wave along the horizontal reference line at any instant, we see that it is changing from a maximum lobe to a minimum lobe and repeating this cycle. Since the wave keeps changing amplitude above and below the line by the same amount, that is, it alternately goes above and below the reference line, we refer to it as an alternating wave. The alternating waveforms described above for the rope experiments are identical to those used in radio communication.

Another way of picturing alternating waveforms is to imagine a paddle at the center of a pool of water, and to use this paddle to disturb the surface of the water instead of the stone. If we move the paddle rapidly as in figure 1-7, we will create waves just as we did by dropping the stone into the water. The paddle can be said to have an alternating motion, back and forth, which creates the alternating waveform on the surface of the water.

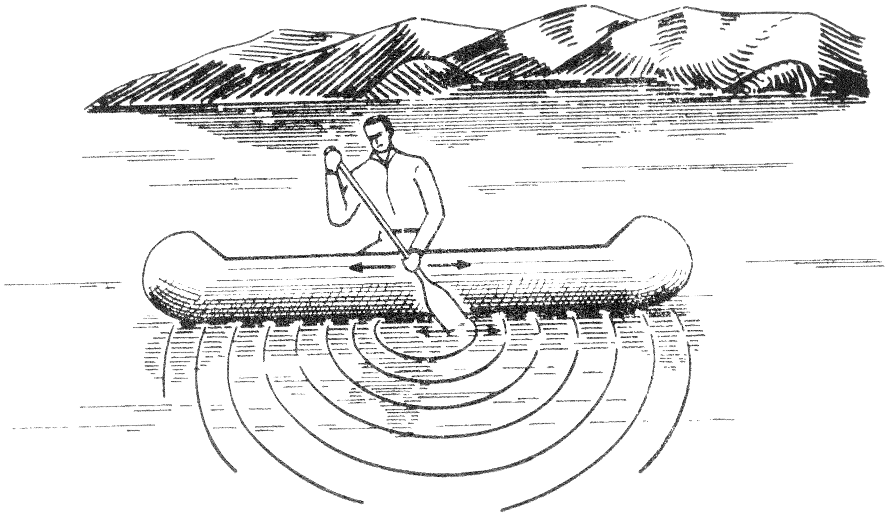

Figure 1-7

Radio communication uses radio frequency waves which have a frequency of thousands of cycles per second. The term "Cycles Per Second" (CPS) has been replaced with the term "Hertz" (HZ) in honor of Heinrich Hertz who, in 1887, demonstrated that electromagnetic energy could be sent out into space in the form of radio waves. Radio waves have two new properties which we have not considered in our rope and water experiments. These properties are an electric field and a magnetic field. We saw in the water experiment that the wave imparted a vertical motion to a wooden chip placed close to the point of disturbance. The wave motion of the water caused by the dropping of the stone also imparted similar motion to a chip near the shore line. We may think of the motion imparted to the chip located near the point of impact as being caused by an equivalent electric field, and the motion of the chip near the shore as being caused by the equivalent magnetic field.

Actually, in radio wave radiation, the energy is divided equally between the electric and magnetic fields which travel together outward from the antenna. The electric and magnetic fields are at right angles to one another.

If we were able to see the wave front formed by the radio wave at a great distance from the transmitter, we would see two sets of parallel lines at right angles to one another. One set of parallel lines would be magnetic lines of force, and the other set would be the electric lines of force. The combination of these two sets of lines is called a wave front. The direction of travel of the wave would be at right angles to the wave front, coming toward us as we face the transmitter. Figure 1-8 shows this complex wave concept in perspective.

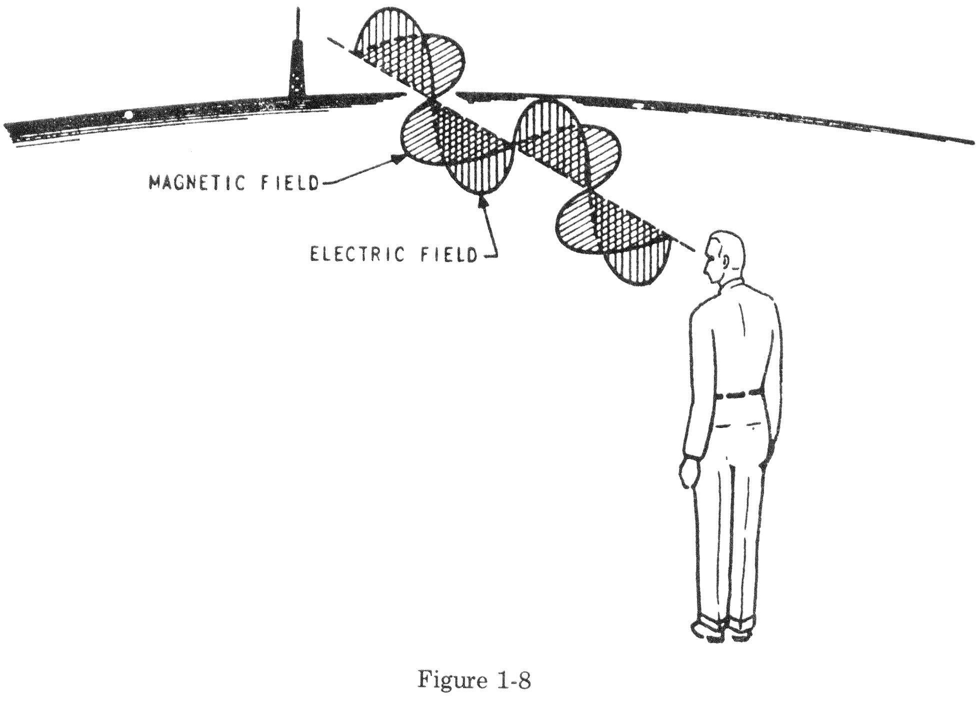

Figure 1-8

In radio communication, radio frequency energy is fed into a wire called an aerial, or antenna, which may be mounted in a number of ways. It can be mounted in a vertical position, for example, from the ground into a tree as shown in figure 1-9, or it may be stretched between two trees and made parallel to the surface of the earth as shown in figure 1-10.

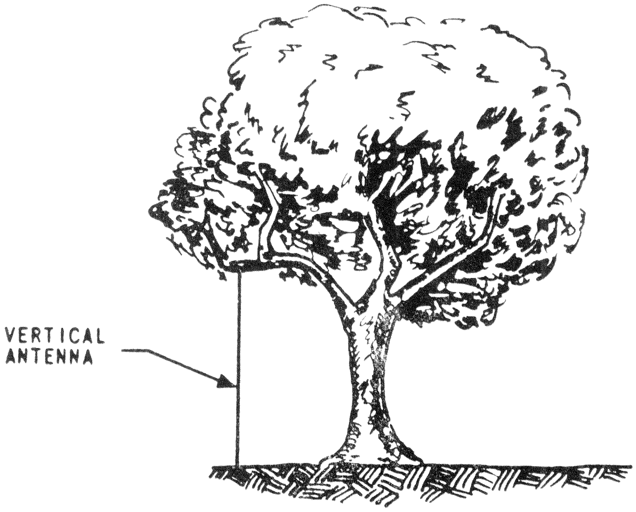

Figure 1-9

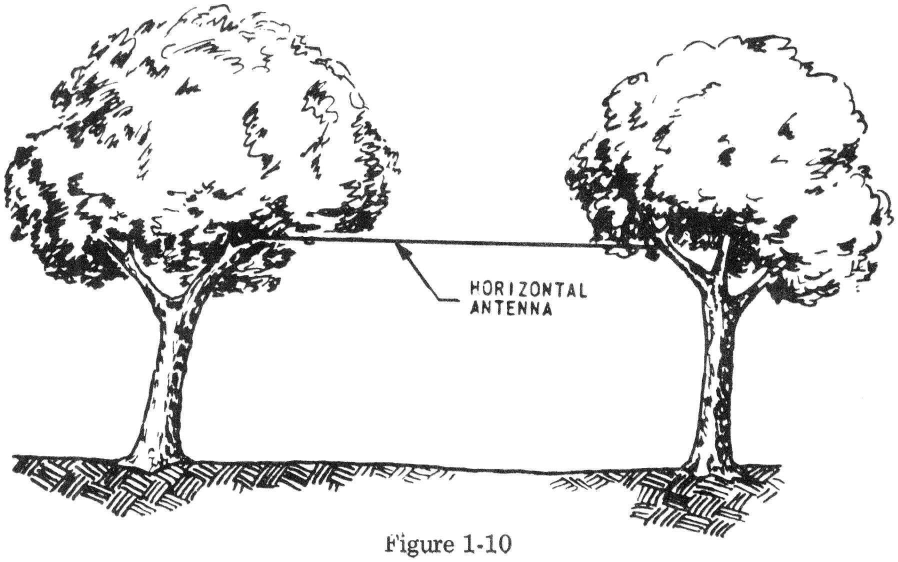

Figure 1-10

The electric field of the radio wave is always parallel to the long dimension of the antenna. The direction of the electric field determines the polarization of the radiated wave. Therefore, if our wire is vertical, the radiated wave has a vertical polarization. If the wire is horizontal, the radiated wave is horizontally polarized. Polarization is important, as will be seen later when we examine the interaction between the radiating wire and the reflecting surfaces which influence the radiated wave.

Figure 1-11 represents the frequency of a wave as the frequency range increases from 10 hertz to 30 million hertz (30 megahertz). The human ear can detect frequencies up to approximately 15,000 hertz (15 kilohertz). A 15,000 hertz signal would be heard as a high-pitched whine. At frequencies less than 100 hertz, the sound would have a very low pitch such as a slow beat of a base drum. Sound frequencies between 10 hertz and 15,000 hertz travel at a speed of 1100 feet per second in air at sea level.

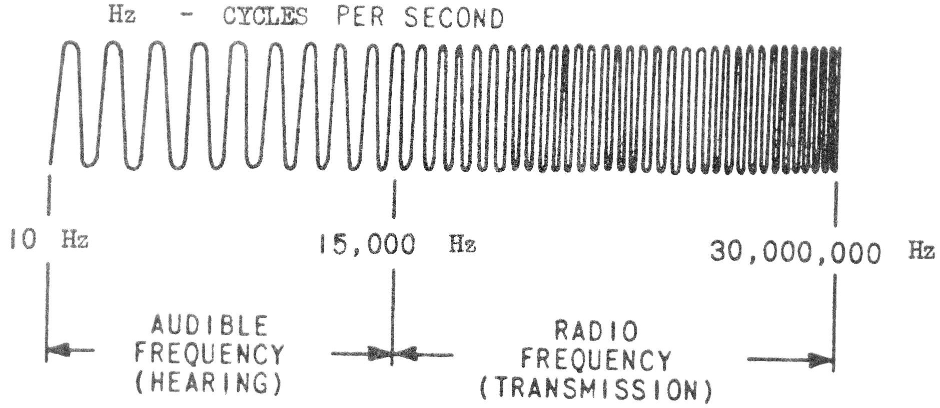

Figure 1-11

Radio frequencies between 15,000 hertz and 30 megahertz travel at the speed of light, or 186,000 miles per second.[1] In other words, a radio wave can travel around the earth, a distance of 25,000 miles as shown in figure 1-12, in about one-seventh of a second.

If we could ignore the effect of the earth and other factors on the radio wave as it travels through space, the field strength or amplitude of the wave would decrease in proportion to the distance from the transmitter. Actually, the attenuation, or decrease in strength of the radio wave is greater than this distance factor would indicate. For one thing, the earth is a spherical ball, and the radio waves do not go through the earth but bend around it. This causes additional losses that increase the attenuation of the wave with distance from the transmitter.

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[1] Of course, radio waves are an electric phemomena and sound waves are a purely mechanical series of compressions in air.

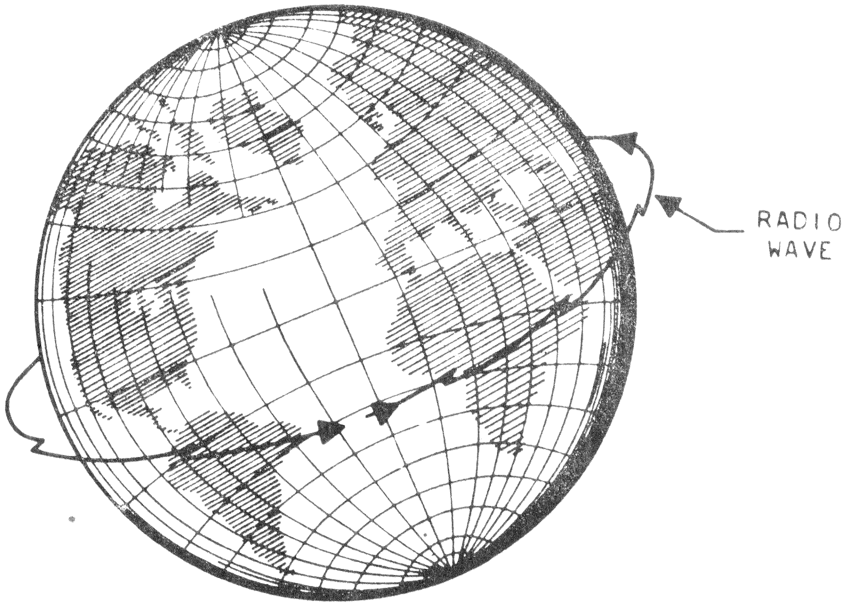


Figure 1-12

1.4 THE GROUND WAVE.

Radio waves travel close to the earth at certain frequencies. These waves are called ground waves. Figure 1-13 shows the way ground waves take a direct or reflected course from the transmitter to the receiver, or may be conducted by the surface of the earth and also refracted by the troposphere. The ground wave can be considered as being composed of one or more of the following components: the direct wave, the ground reflected wave, the surface wave, and the tropospheric wave.

The frequency characteristics of the ground wave and the conductivity of the earth determine in large part the particular component that will prevail along any given signal path. At frequencies below 30 MHz with good earth conductivity the surface wave is predominant. To be effective, the surface wave must be vertically polarized, except in heavily wooded or jungle areas. In such areas, horizontal polorization provides better results.

When considering radiation from a vertical antenna, the conductivity of the earth's surface is very important. Conductivity is a measure of the ability of a medium to conduct electric current, or the efficiency with which a current is passed. Conductivity of the earth is a very important consideration at low radio frequencies.

If a sheet of electrical conducting copper, which causes practically no attenuation of the radio wave, could be laid down upon the surface of the earth between the transmitting antenna and the receiving antenna, propagation would be extremely good. However, since this is impossible with the large distances involved, the earth must be used. Copper may be

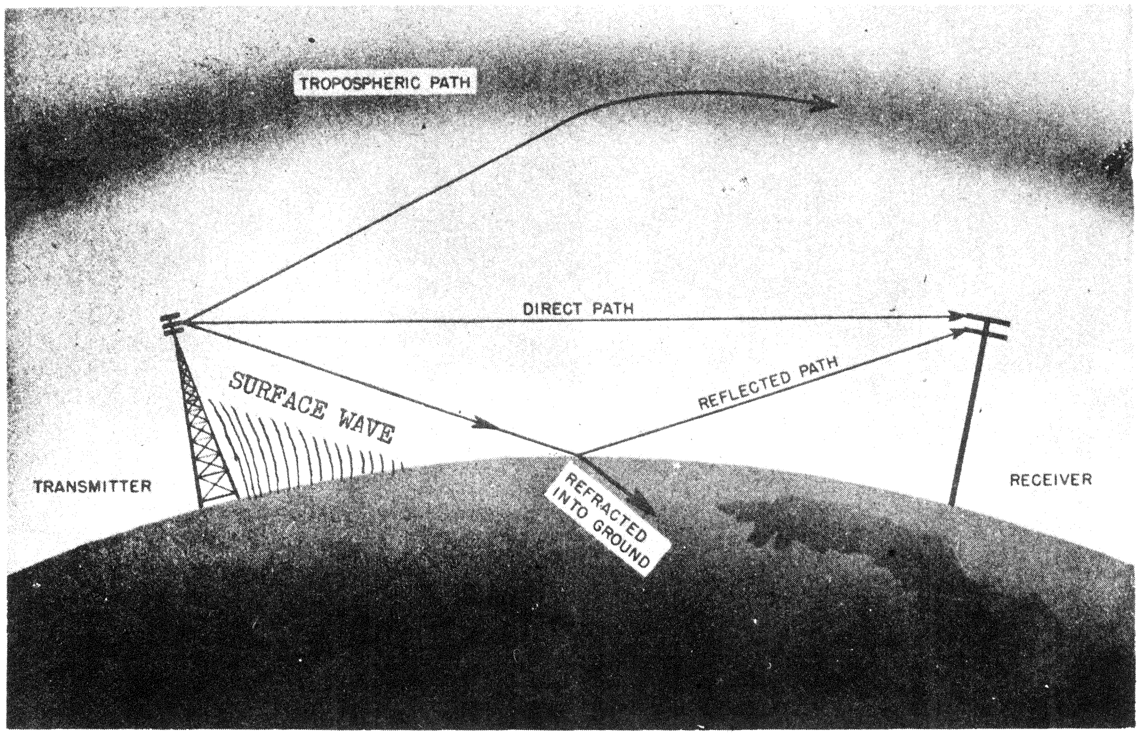


Figure 1-13

buried in the earth for a short distance from the base of the antenna to reduce the ground attenuation in the strong signal fields near the antenna.

Beyond the limits of the buried copper, which is called a ground screen, the type of soil and water in the propagation path will largely determine the attenuation of the radio wave. For comparison, sand, which is a very poor conductor, may have a conductivity rating of about 0.5. On the other hand, sea water has a conductivity of about 5,000 and does not attenuate the wave nearly as much as the sandy soil. Average soils vary in relative conductivity between 0.5 and 30. The conductivity of fresh water is about 10.

Conductivity can be influenced to some extent by the use of good ground systems and careful selection of antenna sites. For example, constructing a vertical antenna in the tidewater area is one way to get a very good ground system since the conductivity of salt marsh is very high. If we were limited to a sandy location, we could improve the conductivity by soaking the area periodically with water.

Geographical features, such as those shown in figure 1-14, are also important in ground-wave propagation.

At frequencies greater than 30 MHz, the losses suffered by the surface wave become so excessive that transmission is usually possible only by means of the direct wave. Where the direct wave is the predomiant component, the difference between vertical and horizontal

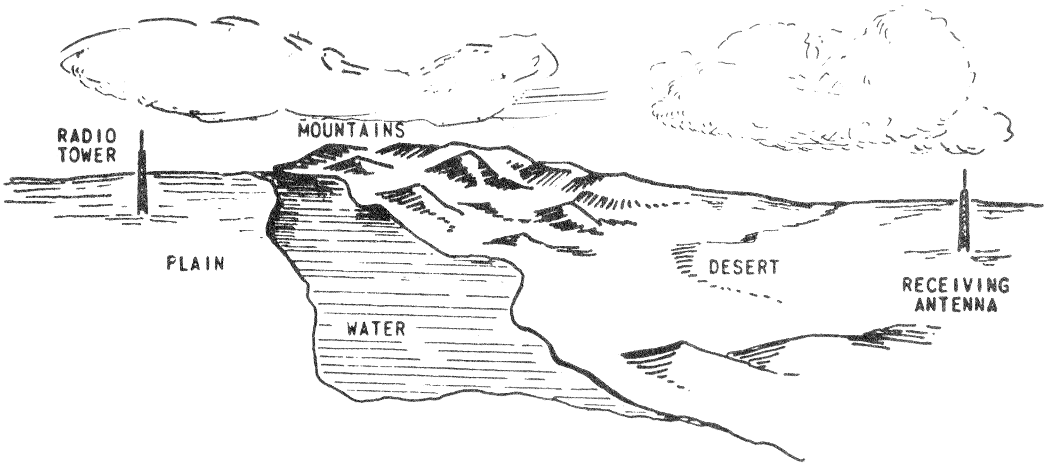


Figure 1-14

polarization is negligible. The direct wave is limited only by the distance to the horizon, or line of sight. The direct wave range, therefore, can be extended greatly by increasing the height of receiver and transmitter antennas. Thus, it should be noted that whereas the distance range of the ground wave at low frequencies can be effectively increased only by increasing radiation power, the distance range of frequencies of 30 MHz and higher can be effectively increased by increasing antnna heights as well as increasing radiation power.

The ground reflected wave suffers a phase shift caused by the wave being reflected by the earth and the longer path it travels to reach the receiving antenna. There are variables in both of these factors, and the phase shift will not always be the same. If the direct and reflected waves arrive at the receiving antenna in phase there will be an increase in signal strength; however, if they arrive out of phase there will be a decrease in signal strength. A decrease in signal strength caused by this phase shift can be overcome to a certain degree by increasing or decreasing the height of either or both the transmitting or receiving antennas.

The tropospheric wave is that component which is refracted in the lower atmosphere by rapid changes (in respect to height) in atmospheric humidity. Such conditions are present almost continuously in the tropics and over large bodies of water, particularly at heights from 100 to 500 feet. The amount of refraction of the tropospheric wave increases as the frequency increases, providing interesting communication possibilities at 50 MHz and above.

1.5 THE SKY WAVE.

The sky wave is a radio wave which has been radiated into the atmosphere and which has been bent or reflected back toward the earth by ionized layers in the upper atmosphere as shown in figure 1-22.

Certain atmospheric conditions cause small particles of air to become electrically charged and form invisible ionized layers above the surface of the earth. Ionized layers cause radio waves to bend, and under certain conditions will reflect the wave back to the earth.[2]

Upon its return to earth, the sky wave may be detected by a receiver located at a point "B," as shown in figure 1-29, or it may be reflected back to the ionosphere and again reflected back to earth and be detected at point "B" as shown in figure 1-30. Thus we see that sky-wave propagation depends on two boundaries, the earth and the ionosphere.

1.6 THE IONOSPHERE AND RADIO WAVE PROPOGATION.

The ionosphere is formed by the action of the sun on the upper atmosphere of the earth. The degree of ionization depends upon the time of day, the time of the year, and upon the 11-year sunspot cycle. The ionization caused by sunlight decreases rapidly after sundown, and reaches a minimum about midnight. After sunrise, ionization increases rapidly, and the ionized layers become stronger reflectors of radio waves. (See figures 1-15 through 1-20)

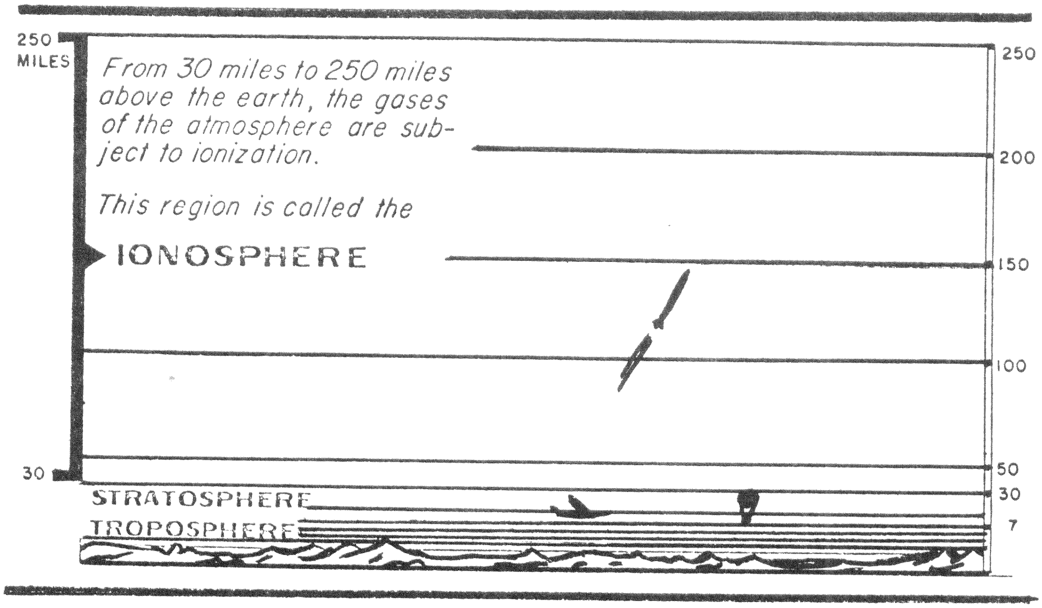


Figure 1-15

[2] It is found that all frequencies below about 30 MHz (the exact upper limit depends on the angle of radiation and time of day and varies over a large range) are bent back to earth. Above this frequency, the energy goes through the ionosphere and into outer space.

CAUSES OF ATMOSPHETRIC IONIZATION:

Ultra violet rays.

Particle radiation.

Cosmic rays.

Meteors.

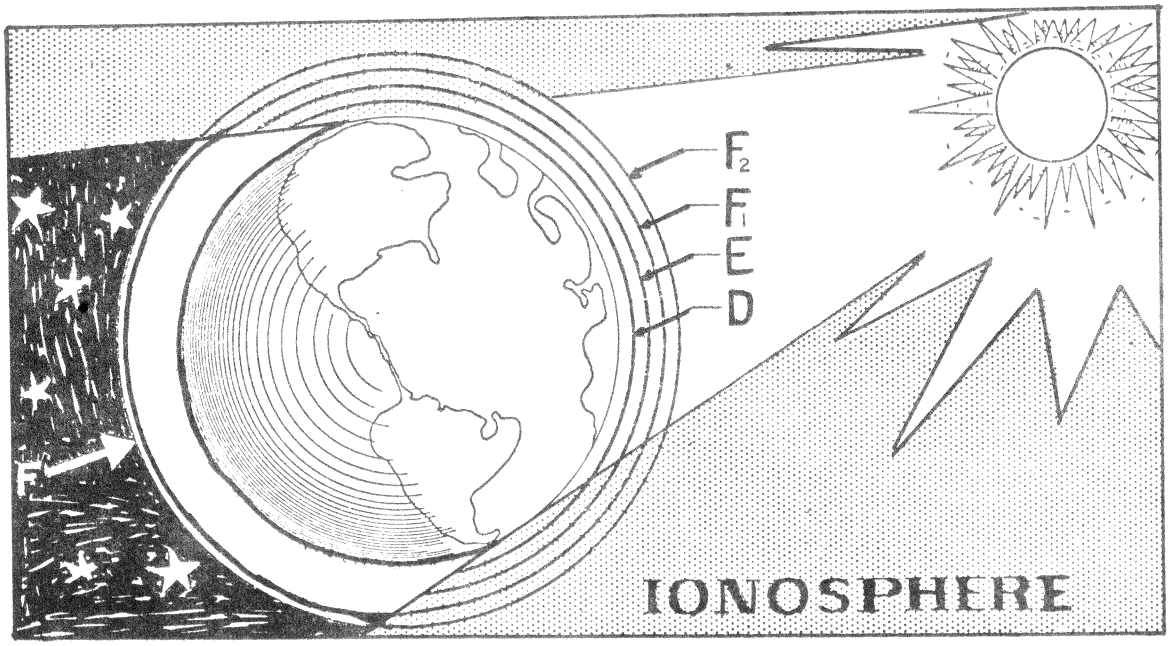


Figure 1-16
The ionized region is broken up into several "layers." By daylight, these layers take the positions illustrated.

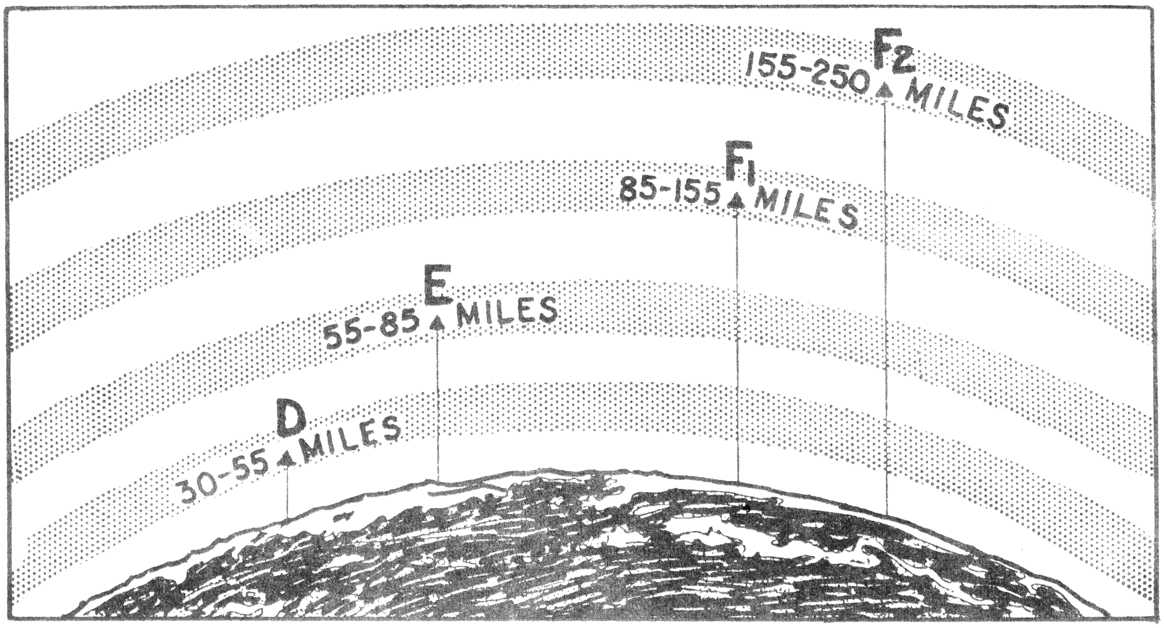
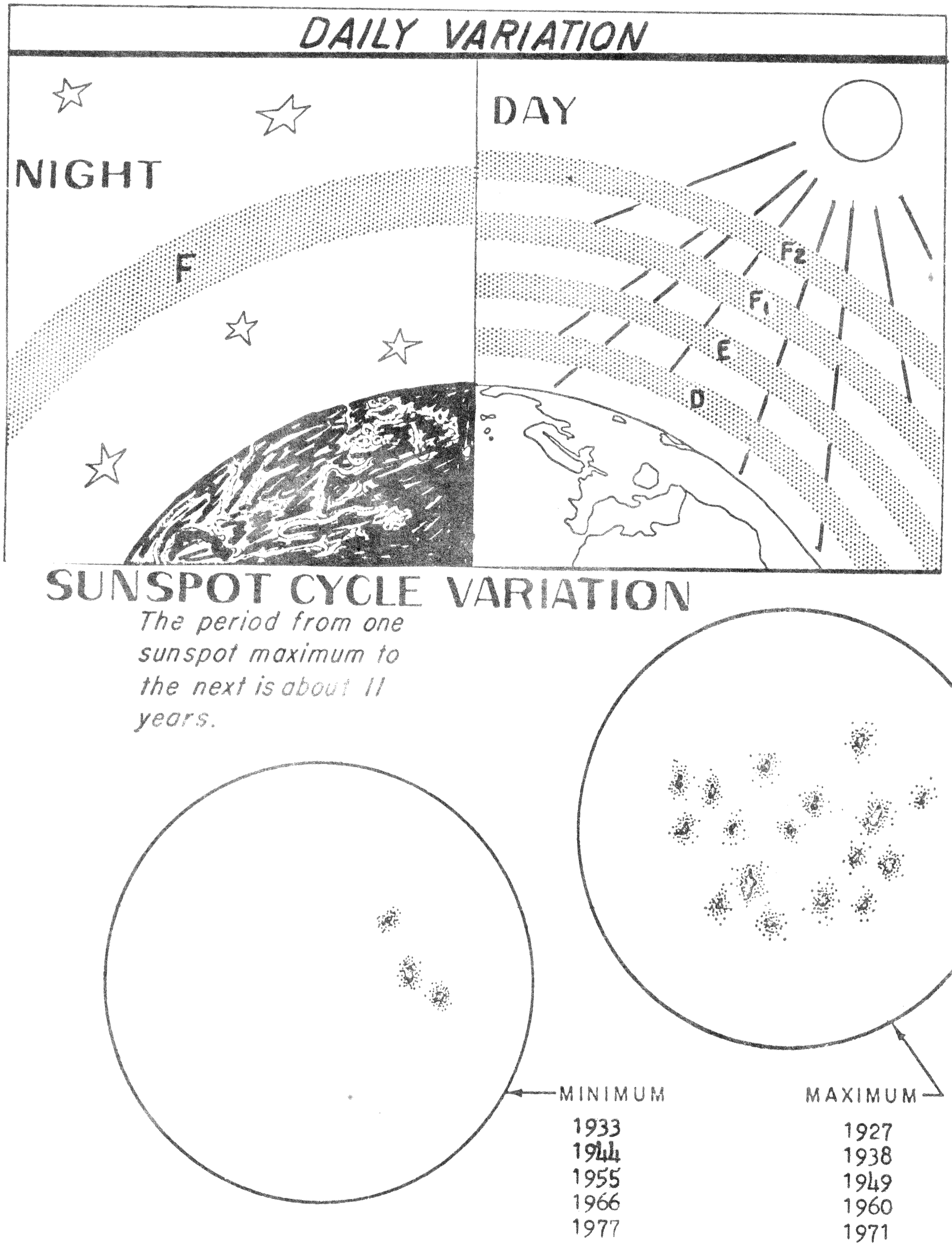


Figure 1-17

NORMAL VARIATIONS IN THE IONOSPHERE

Daily variations	24 hours.
Seasonal variations	12 months.
Sunspot cycle variations	11 years.



The period from one sunspot maximum to the next is about 11 years.

Figure 1-18

There is only one principal ionized layer at night

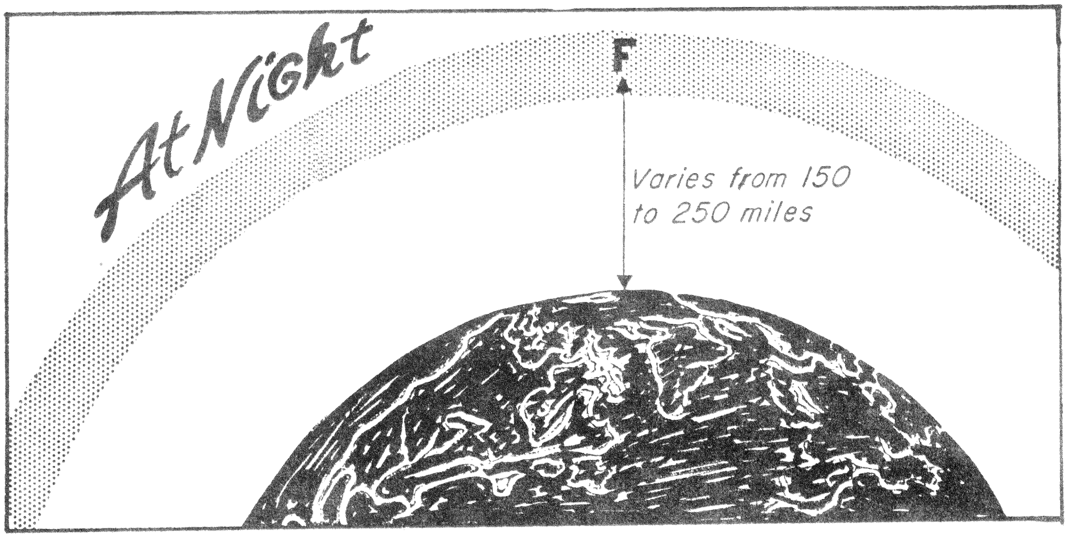


Figure 1-19

IONOSPHERE STORMS

Definition: Any marked or sudden deviation from normal conditions of height or frequency.

Effect: Normally reliable frequency may become useless. Signal may weaken or "blackout"

Duration: Several minutes to several weeks. Tendency to repeat every 27 days.

Ionosphere storms usually originate in North and South Polar Regions.

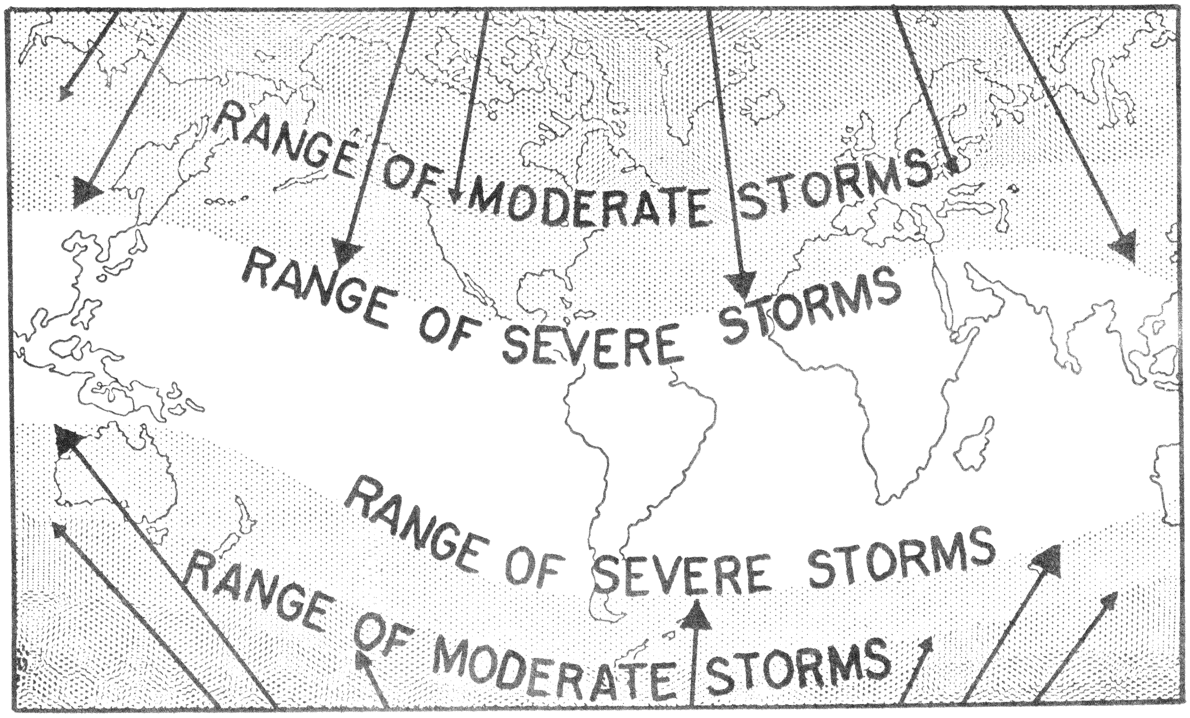


Figure 1-20

The extent to which a radio wave is bent in the ionized layer depends upon the degree of ionization and upon the length of the radio wave. The greater the ionization in the ionosphere, the greater the possibility that the radio wave will be bent back to earth. (See figures 1-21 through 1-24.)

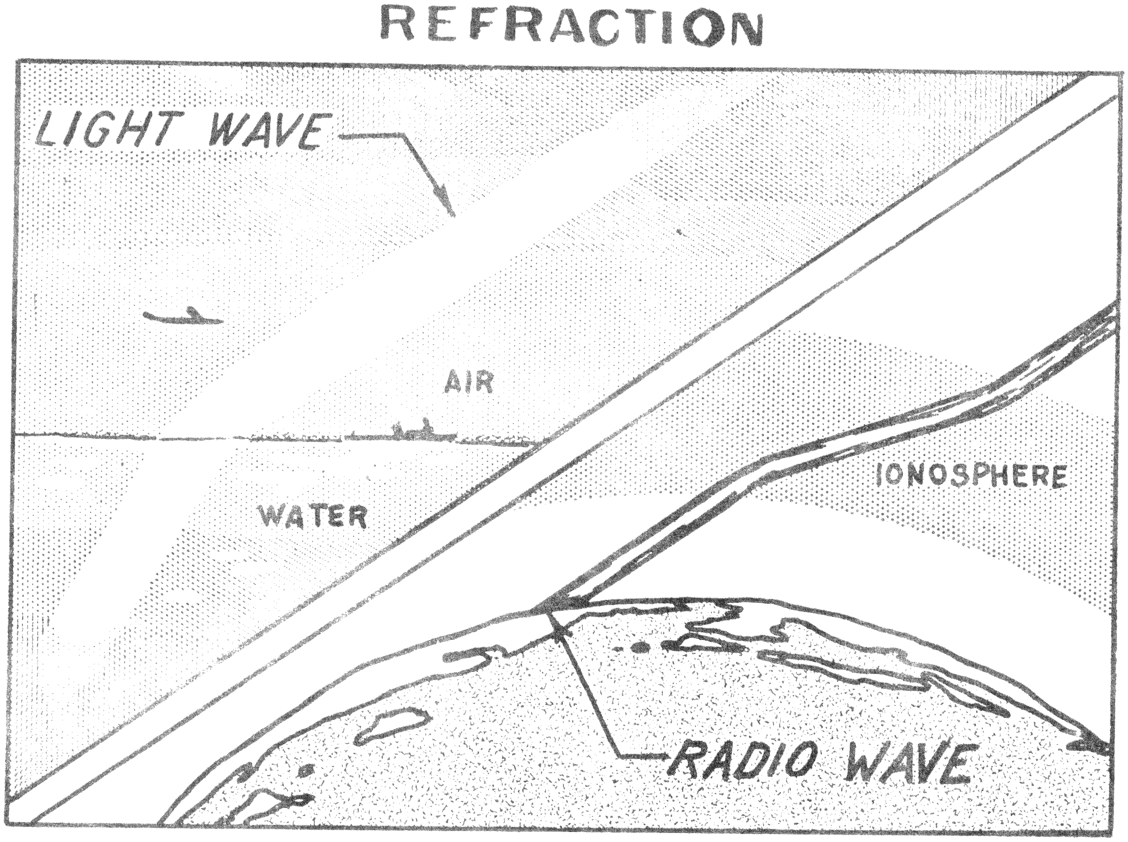


Figure 1-21

Sufficient bending will cause radio waves to return to earth....

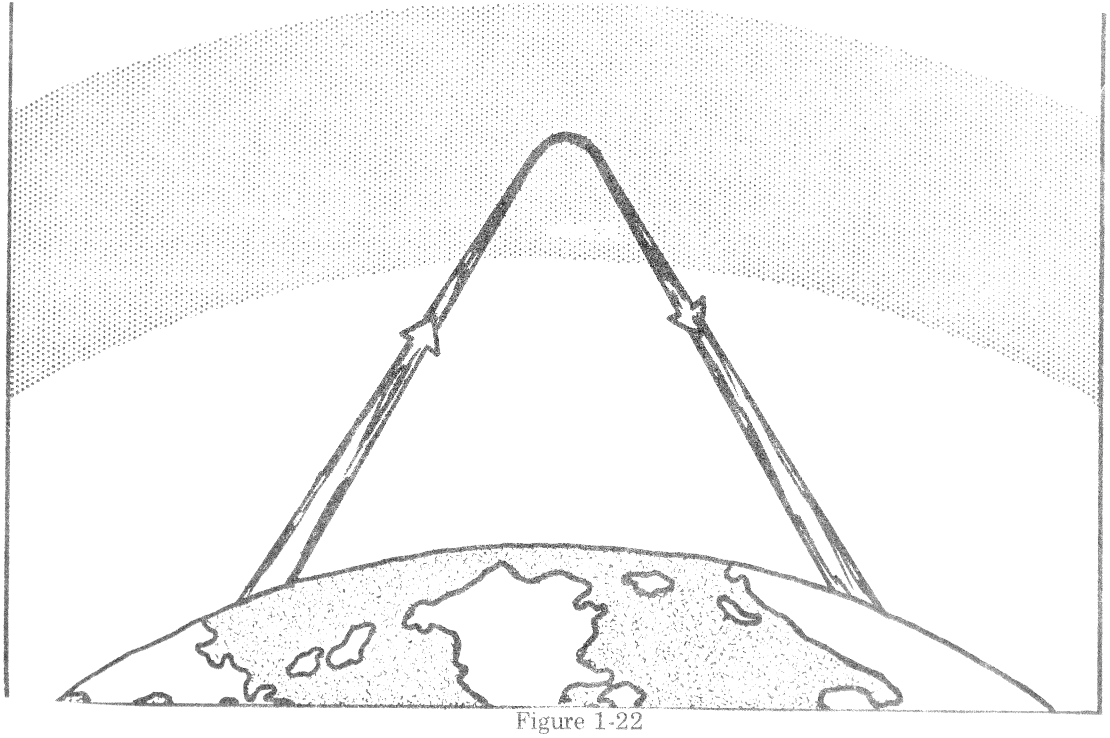


Figure 1-22

IONOSPHERE REFRACTION is most effective in the high frequency (HF) band.

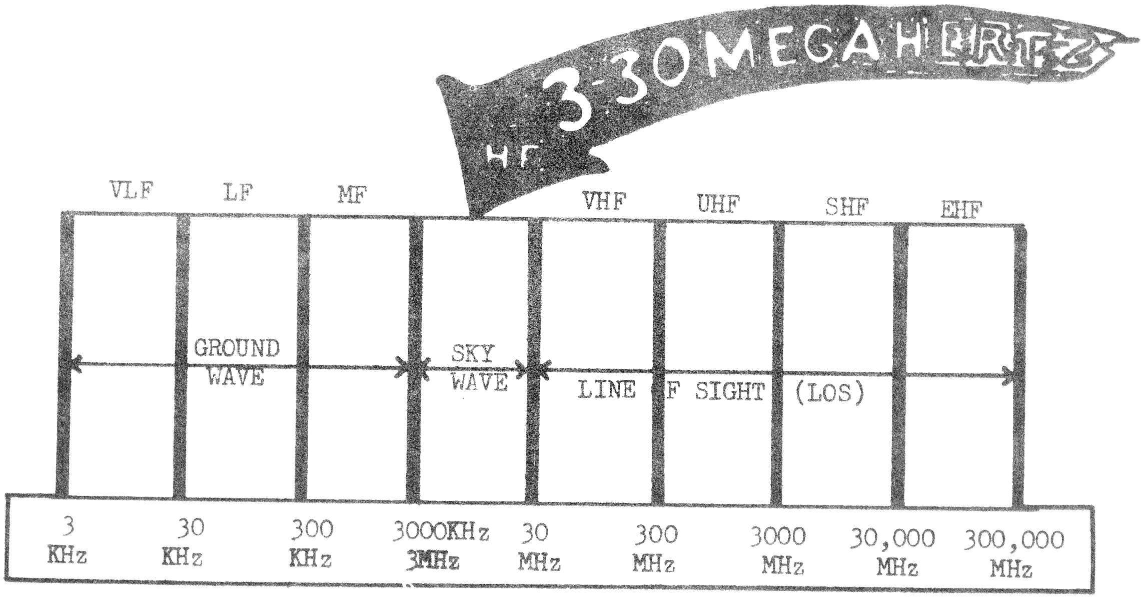


Figure 1-23

IN THE HF BAND -- Higher frequencies are bent less, that is, higher frequencies have more penetrating power.

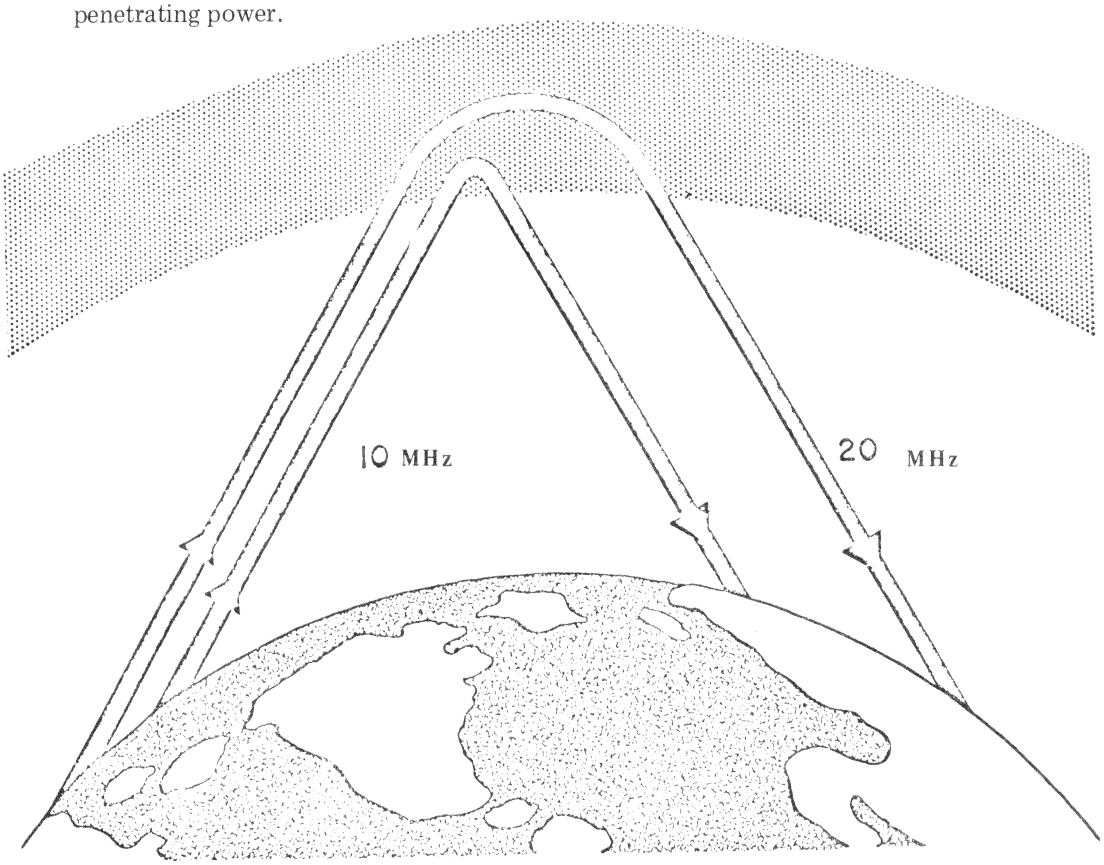


Figure 1-24

There is usually a critical path and critical frequency involved in sky-wave communication. In some cases, the bending in the ionosphere is not sufficient to return the radio wave to the earth. In these cases, the wave escapes through the ionosphere and is not useful for earth radio communication.

Other factors which influence the ionization over various portions of the earth are seasonal, and depend upon the angle of arrival of the sun rays over the particular area. Since all factors affecting sky-wave transmission must be considered when planning a communication system, the problem of selecting the proper transmitting frequency becomes quite complex. It is a procedure in which daily, seasonal, and sunspot cycle variations must be taken into account. (See figures 1-25 through 1-26.)

CRITICAL FREQUENCY -- VERTICAL INCIDENCE

Critical frequency of any layer is the highest frequency that will be reflected vertically from that layer.

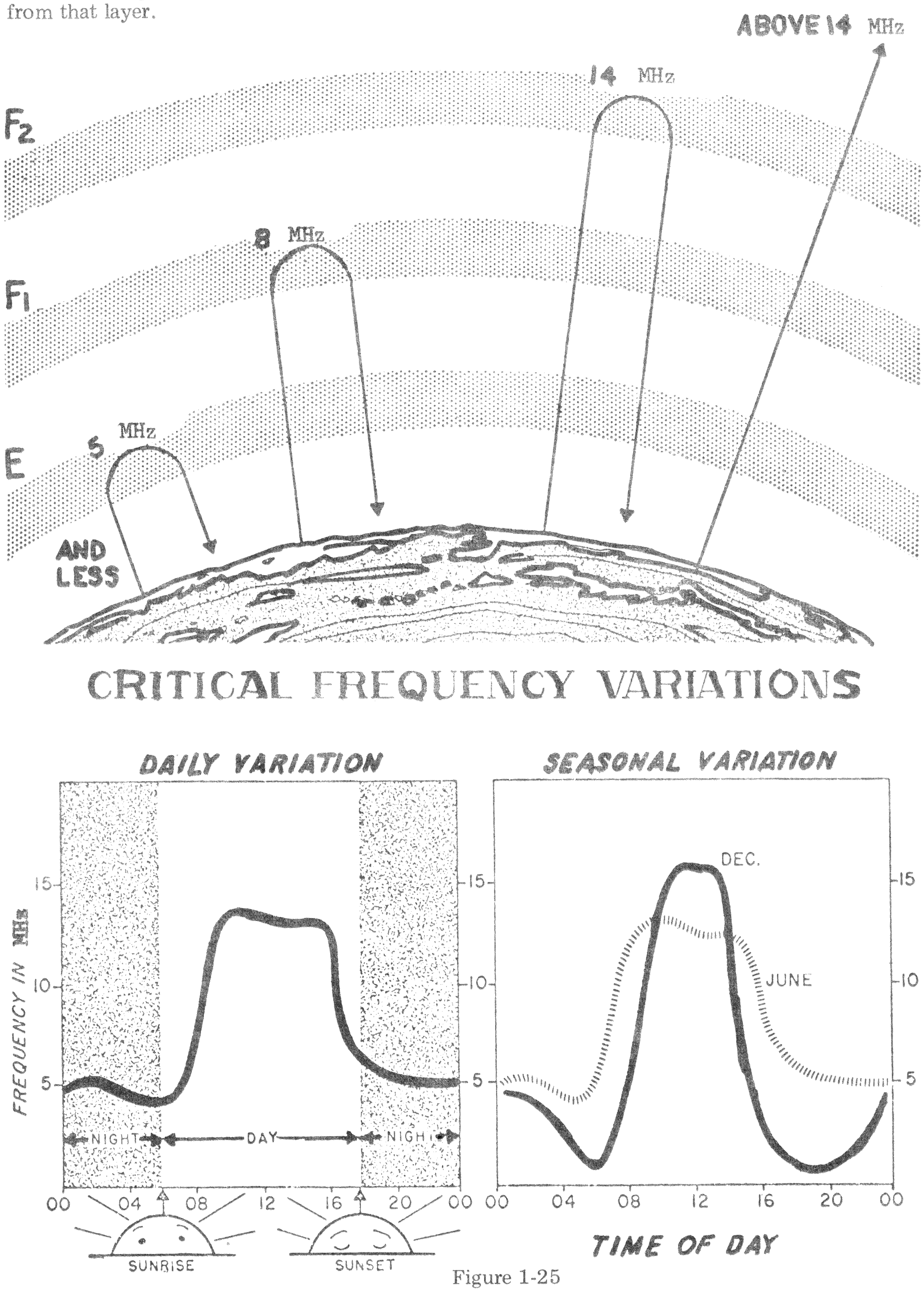


Figure 1-25

MAXIMUM USABLE FREQUENCY (MUF)

15MHz is the highest frequency that will return to earth at point B; that is, 15 MHz is the MUF for distance AB.

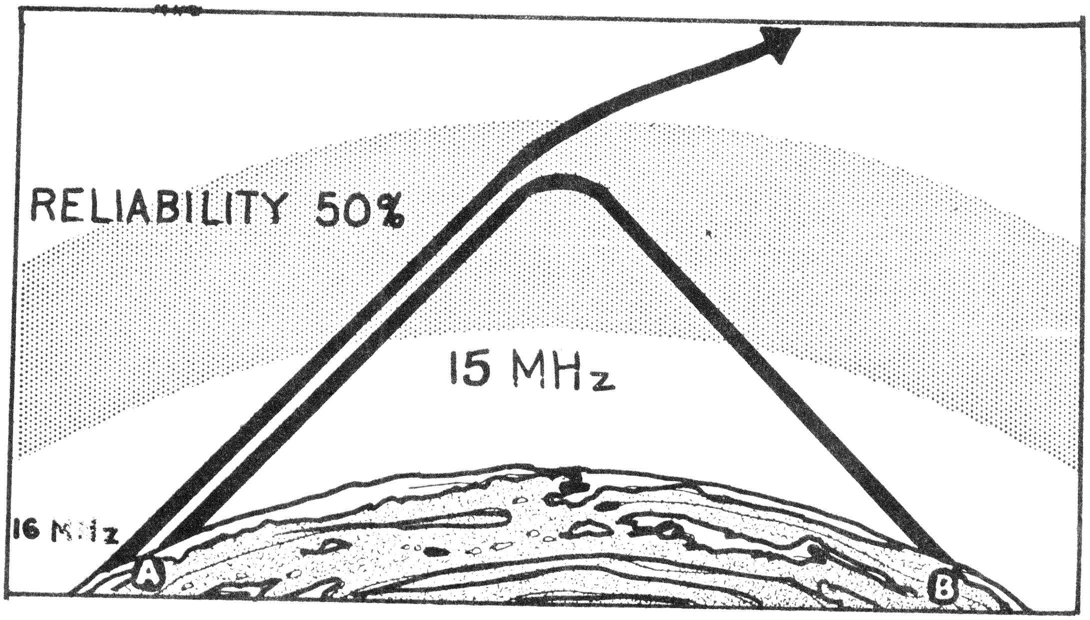


Figure 1-26

LOWEST USEFUL HIGH FREQUENCY (LUHF -- OR LUF)

For any given radio link, LUHF is that frequency below which signals will be unreadable, due to noise and weak signal intensity.

LUHF is determined by:

Radiated power of transmitter.

Length of transmission path.

Ionosphere absorption.

Noise level at receiving point.

Antennas used.

Type of service (emission).

Time of day and season.

OPTIMUM TRAFFIC FREQUENCY (FOT)

To provide a safety factor, and to increase reliability, we choose an OPTIMUM TRAFFIC FREQUENCY (FOT) slightly below the MUF.

F2 layer FOT = MUF x 0.85
F1 & E layers FOT = MUF x 0.97.

The region between the transmitting antenna and the point at which the reflected radio wave returns to earth is called the skip distance. The sky-wave signal will not be heard within this region. Skip distance depends on the angle of departure of the radio wave from the antenna, and the height of the reflecting ionosphere layer. The angle of departure of the signal from the antenna is called the "vertical angle." The lower the vertical angle, the greater the skip distance. Since higher frequencies undergo less bending in the ionosphere than lower frequencies, the skip distance increases as higher and higher frequencies are used. (See figures 1-27 through 1-28.)

SKIP DISTANCE AND SKIP ZONE

AC is the skip distance. BC is the skip zone.

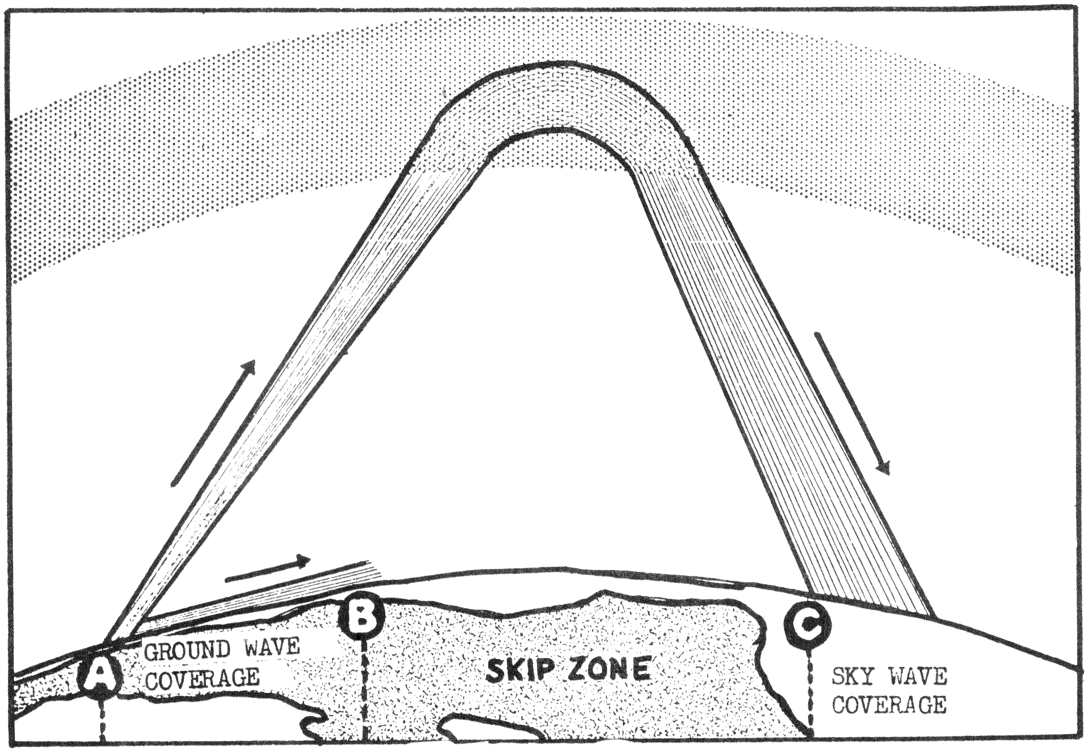


Figure 1-27

With a good conducting surface there may be no skip zone.

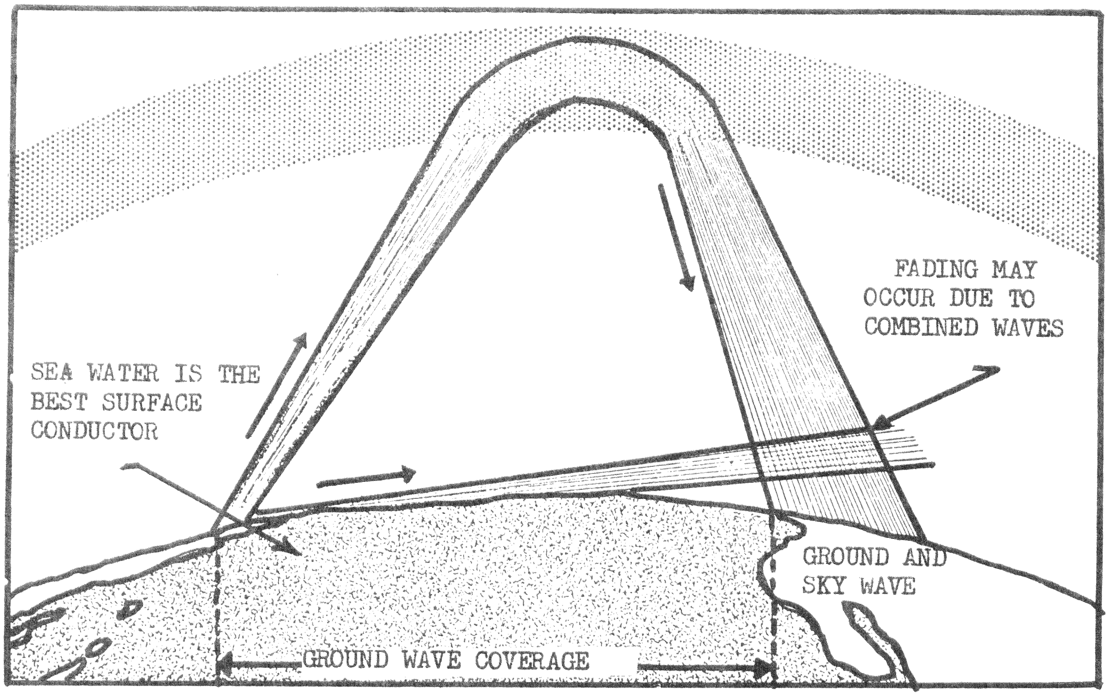


Figure 1-28

The angle at which the radio wave reaches the earth on its return from the ionosphere depends on the angle at which it left the transmitting antenna. Under certain conditions, communication between two points may be established via an earth reflection. The smaller the angle between the radiated wave and the earth, the greater will be the distance covered when the radio wave is reflected by the ionosphere. Similarly, the greater the angle made with the earth by the radiated wave, the shorter will be the transmission distance. (See figures 1-29 through 1-30.)

SINGLE HOP TRANSMISSION

Distance AB less than 2500 miles (4000 KM).

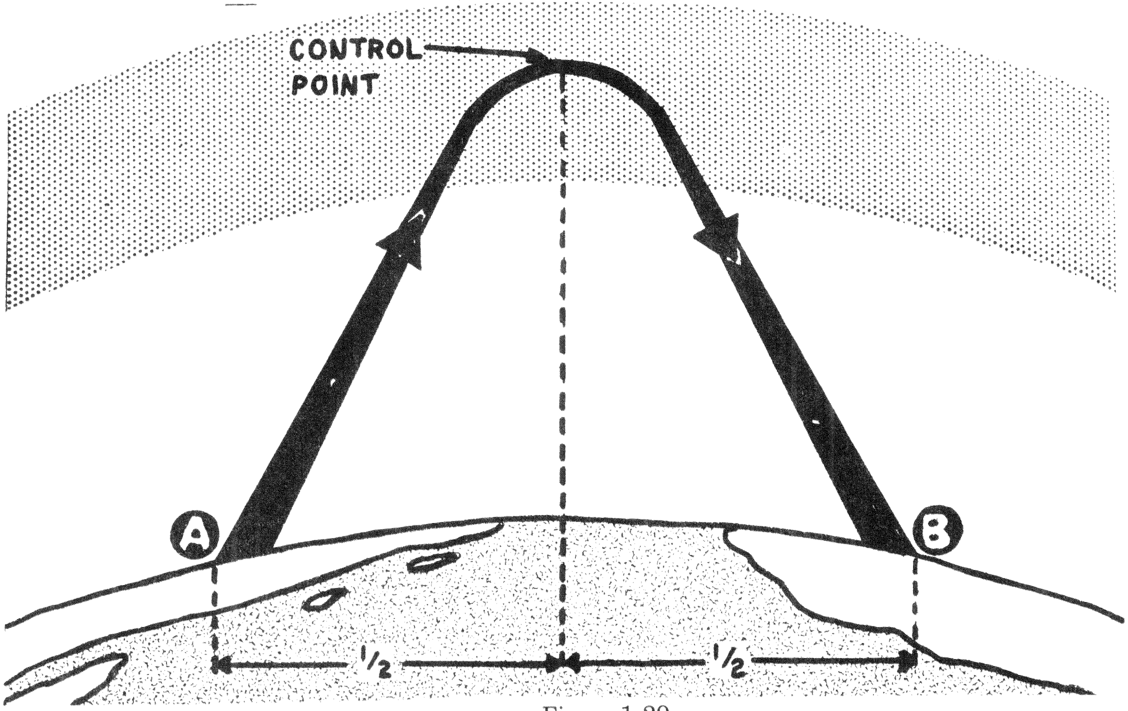


Figure 1-29

MULTIPLE HOP TRANSMISSION

Distance AB more than 2500 miles (4000 KM).

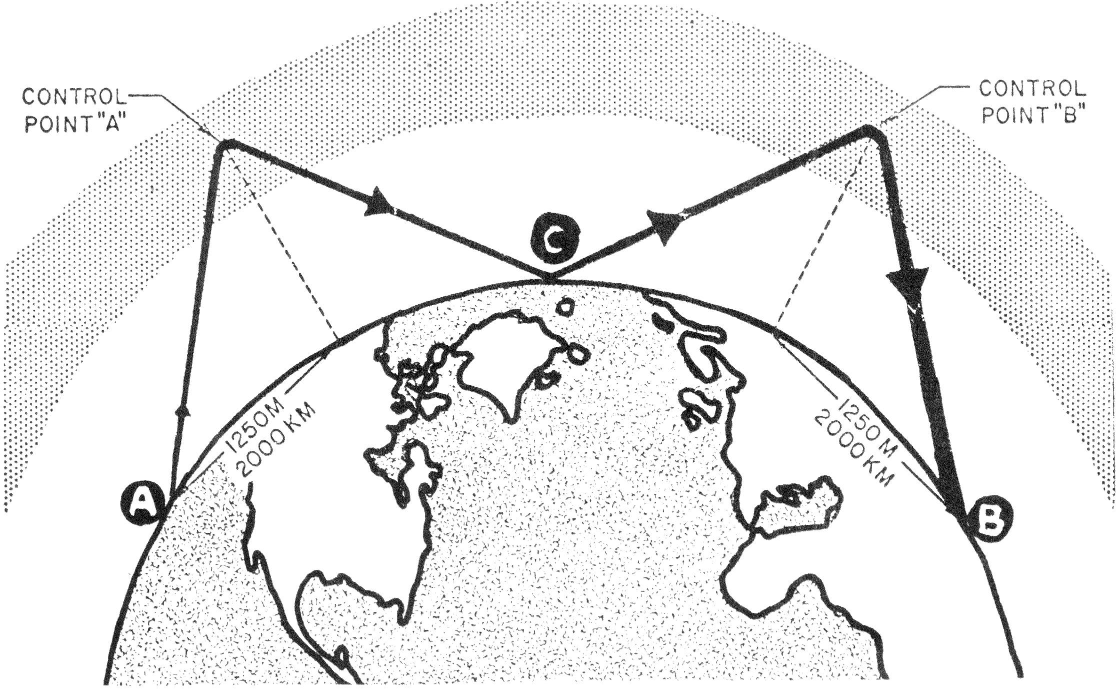


Figure 1-30

CHAPTER 2

RADIO ANTENNAS

2.1 THE RADIO ANTENNA.

Radio frequency waves are electromagnetic waves which are capable of traveling through space. The waves consist of alternating cycles of electric and magnetic (electromagnetic) energy. They travel through space in much the same manner as the waves examined in the water and rope experiments. Radio waves are radiated from the transmitting antenna into space as a result of the alternating electric field surrounding the antenna.

The radiated waves of radio frequency energy are propagated through space and arrive at the receiving location where they induce electrical energy in the receiving antenna. The energy induced into the receiving antenna is identical to that existing in the transmitting antenna.

If a single radio frequency wave, which may be treated as an alternating current, is applied to one end of a length of wire, the wave will travel along the wire until it reaches the other end. If an insulator is placed at the far end of the wire, the current cannot continue beyond the wire, and the wave bounces back or is reflected from the end point. The resulting wave on the wire is similar to the standing wave created on the rope where the direct wave was reflected from the fixed end at the wall.

If we look carefully at the looping structure formed in the rope, we will see a reflected pattern on the rope in addition to the direct wave motion imparted to the rope. The reflected portion of the wave, shown as a dashed line in figure 2-1, is similar to the radio frequency wave as it bounces back from the end of the wire antenna.

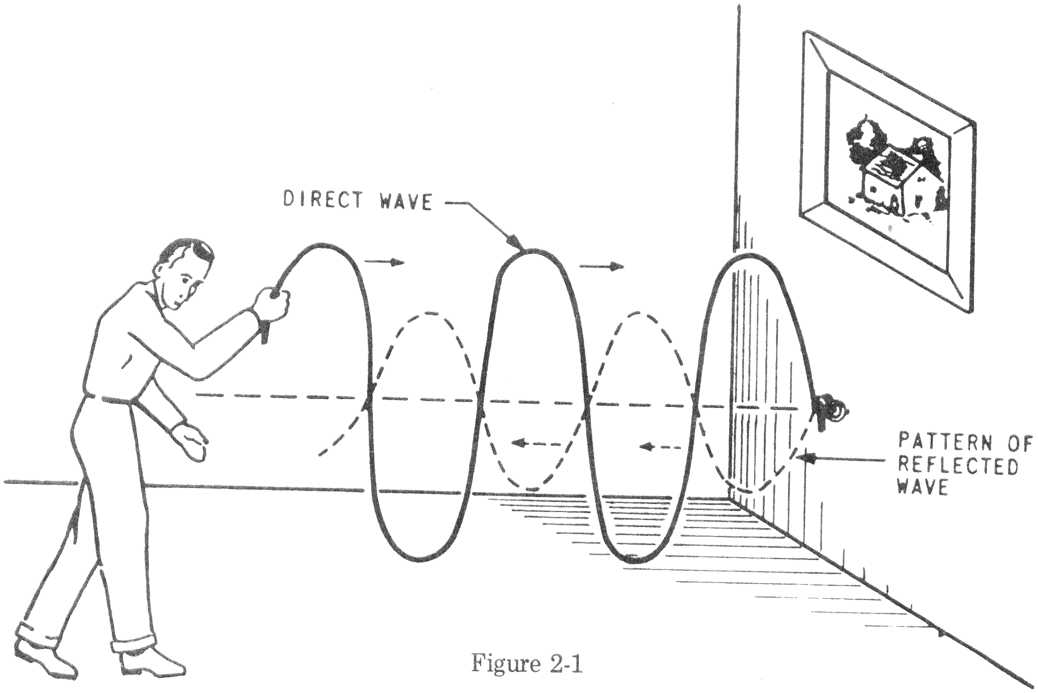


Figure 2-1

When the reflected wave reaches the starting end, it will again be reflected. The wave will continue to be reflected first from one end and then the other until all of its energy is dissipated in the resistance of the wire. The repeated travel of the wave from one end of the wire to the other is termed "oscillation." If only one wave is fed into the wire, these oscillations will die out rather rapidly as mentioned above. However, if another wave is fed into the wire to replace the energy dissipated each time the reflected wave reaches the starting point, a continuous oscillation of energy will be maintained along the wire and radiation will occur.

The speed of travel of a radio frequency wave of any frequency is constant (approximately 186,000 miles or 300,000,000 meters per second). The length of one cycle of a radio frequency wave depends upon the speed and the frequency of the wave. Since we know the speed of any radio wave, we can find its frequency if the wavelength is known, or we can find its wavelength if the frequency is known. For example, if we use a frequency of 300,000,000 hertz, as portrayed in figure 2-2, the length of one cycle (or its wavelength) would be 1 meter. In effect, we have determined the wavelength of the frequency in question by dividing the distance traveled by the wave in 1 second by the number of cycles occurring in that second.

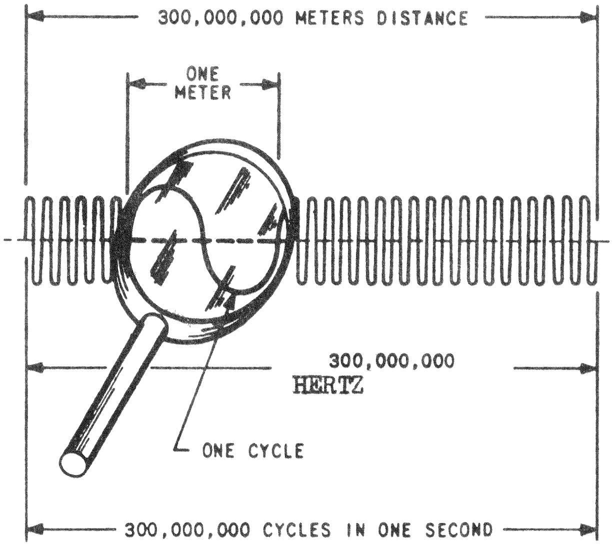


Figure 2-2

To avoid cumbersome figures in the millions, a factor of one million (mega) can be used to calculate the frequency or wavelength. Using this factor in the foregoing example, we will have 300 megameters divided by 300 megahertz which is equal to 1 meter in wavelength (1 meter is equal to approximately 3.28 feet).

The frequencies used in short-wave communication are 3 million hertz (3 megahertz), to 30 million hertz (30 megahertz). The wavelengths at these frequencies are obtained as follows:

300 megameters ÷ 3 megahertz = 100 meters or 328 feet

300 megameters ÷ 30 megahertz = 10 meters or 32.8 feet

Figure 2-3 represents the frequencies between those we can hear, and the highest radio frequencies in which we are interested. At audible frequencies, below 15,000 hertz maxima and minima in the waveform are a great distance apart, and the wave is said to have a long wavelength. Under an imaginary magnifying glass, any one cycle has a waveform as shown, but the actual wavelength becomes shorter and shorter as the frequency goes higher and higher.

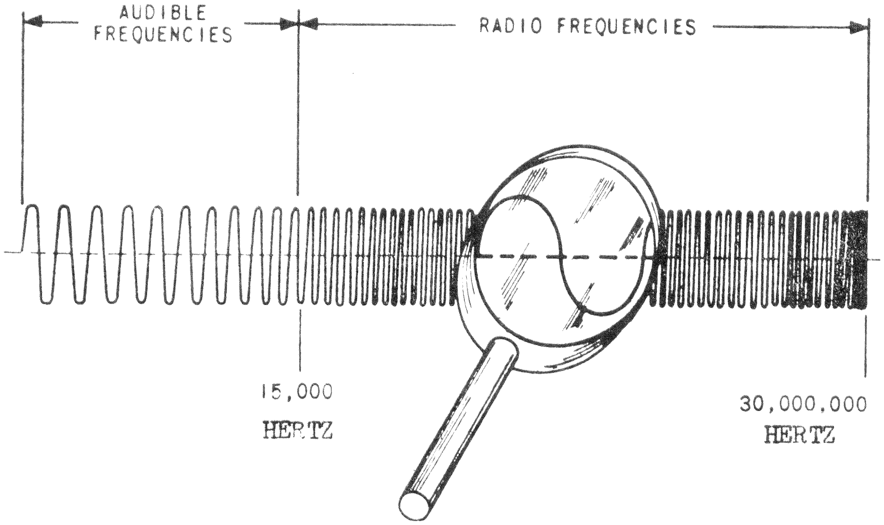


Figure 2-3

For an antenna to be an effective radiator, its length must be such that energy impulses fed to it will arrive at the proper time to reinforce the oscillating currents in the antenna element. The alternating radio frequency (r-f) voltage applied at one end of the wire antenna causes an alternating radio frequency current to flow along the wire at a rate determined by the frequency of the (r-f) voltage. Since the waves travel along the wire at 300 megameters per second, the length of the antenna wire must be such that a wave will travel from one end to the other and be reflected back to the starting point during the period of one cycle of (r-f) voltage. For convenience, this might be pictured as shown in figure 2-4.

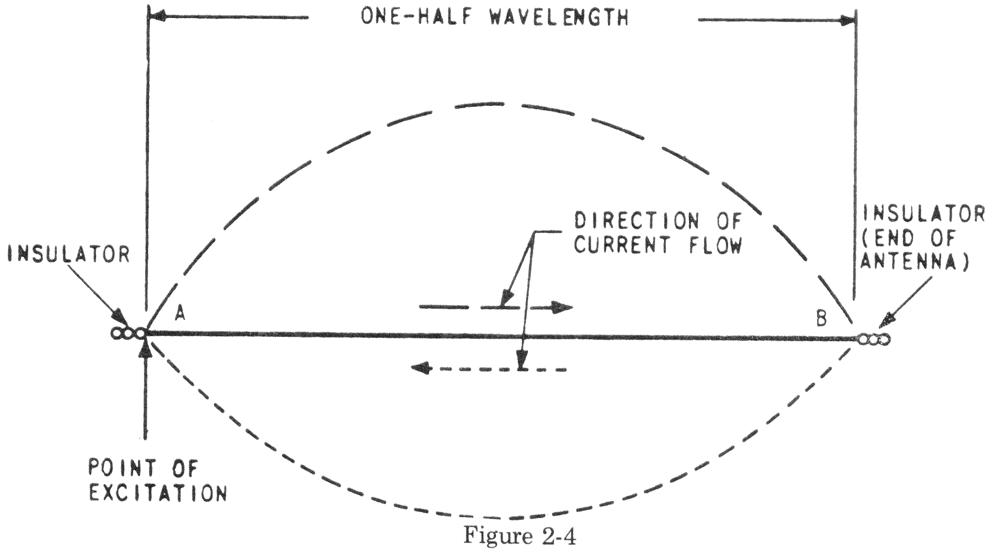


Figure 2-4

In the first or maximum half of the alternating cycle, the energy will travel in the direction shown. Since the wire stops at point "B," the wave will be reflected in the reverse direction as indicated. By the time the second half of the alternating cycle reaches point "B," the reflected portion of the first half-cycle will have returned to the starting point. The returning energy will arrive just in time to add up in a maximum direction with a new wave of r-f energy entering the wire at that instant. Thus, if the antenna is of proper length, oscillatins will build up along the wire, and that part of the energy which is not dissipated in the wire resistance will be radiated as discussed in chapter 1.

When the reflected wave arrives back at the source in time to reinforce a new half-cycle which is just beginning, the antenna is said to be resonant. If an r-f voltage is applied to one end of a half-wave resonant wire as at point "A" in figure 2-4, electrons will move along the wire away from point "A" toward the end "B" during one alternation of the applied voltage. At point "B," no further flow of current can occur along the wire since the wire comes to an end. As more and more electrons reach point "B," we may say that a crowding of electrons occurs at this point. This point is a high-voltage point.

These same electrons are then reflected back toward point "A." As they approach the source or starting point, there will also be a crowding of electrons at this end of the wire. In a resonant wire, newly supplied electrons from the transmitter arrive in time to add to the reflected electrons, and a high voltage is also created at this point.

We have defined current as the movement of electrons along a conductor, and have defined voltage as a gathering of electons at a point. Since there is very little electron movement at the end points of the half-wavelength resonator, they will be points of minimum current and maximum voltage. Electron flow at the center of the resonator, due to the movement of direct and reflected electrons, however, will be large, and maximum current energy will be present at the center point. The voltage or potential energy at the center of the wire will be a minimum since electron crowding does not occur at this point. The distribution of voltage and current energy along a half-wavelength antenna or resonator can be illustrated by standing waves as shown in figure 2-5. The vertical distance from the antenna wire to the wave marked "current" or "voltage" represents the amplitude of either current or voltage at any point along the wire.

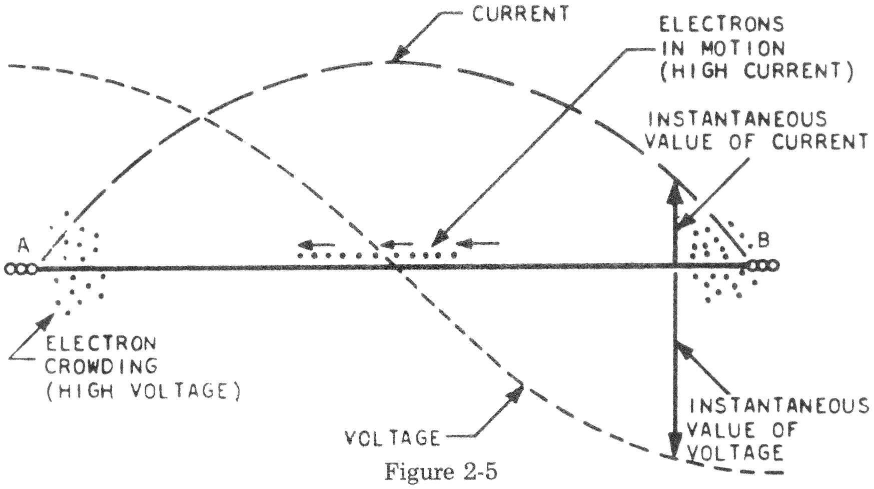


Figure 2-5

As shown in figure 2-5, each standing wave is one-half wavelength. One is called a current wave, and the other a voltage wave. The axis of the wire may be considered the reference or zero plane. As illustrated, the current wave is zero at the ends, and a maximum in the center. The voltage wave, on the other hand, is a minimum at the center and a maximum at each end.

The standing-wave illustration describes the condition of resonance in a half-wavelength transmitting antenna. Since at resonance, the waves traveling back and forth along the antenna reinforce each other, maximum energy is radiated into space. If the antenna is not resonant, there will be little reinforcement of the reflected wave since the direct and reflected waves will arrive back at the source at different times, and will tend to cancel each other. When this condition exists, the energy fed into the antenna is lost through cancellation of direct and reflected waves, and the radiation efficiency will be much lower than at resonance.

Electrical currents set up in an antenna by a voltage applied across the antenna terminals always encounter some degree of resistance in the antenna circuit. Certain materials such as porcelain, offer very high resistance to electrical current flow and are used as insulators on the ends of transmitting antennas. Insulators prevent energy leakage into trees or other types of antenna supports.

Certain types of wire, particularly copper or aluminum wire, offer very little resistance to current flow, and are, therefore, good electrical conductors.

As we have seen in our discussion of standing-wave patterns on antennas, the transmitting antenna presents a resistance, or more properly an impedance, to the passage of r-f energy at every point along its length. At the ends, the impedance becomes high due to the crowding of electrons. Minimum impedance occurs at the center of the wire where the current is the highest, and where the electrons or electrical charges are most free to move about. Figure 2-6 illustrates the way in which this condition can be portrayed graphically along the half-wavelength antenna.

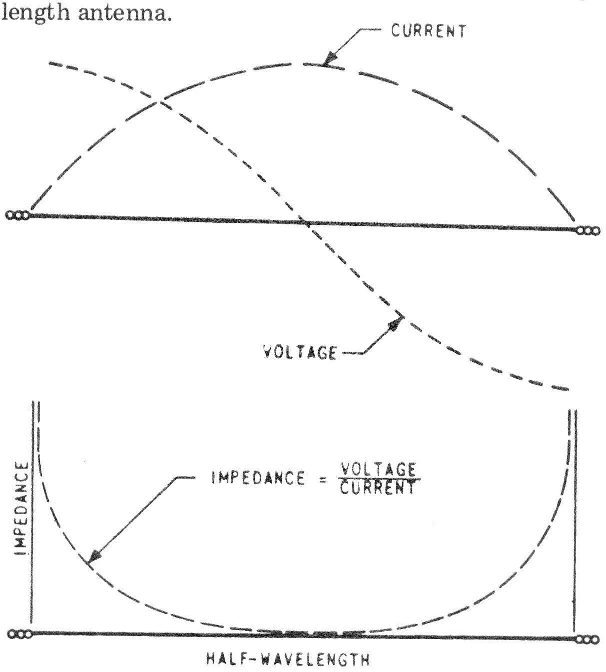


Figure 2-6

The impedance of the antenna is highest at the ends and lowest in the middle. As illustrated in figure 2-6, the antenna impedance varies from point to point along the length of the antenna. This impedance must be thought of as a complex quantity involving radiation resistance together with capacitive and inductive reactances. The capacitive and inductive reactances are undesirable in an antenna, and we try to minimize or tune them out when we resonate the antenna system.

Capacitive or inductive reactance may be pictured as introducing losses in the antenna circuit since they cause the energy to be stored rather than radiated. Even when reduced to a minimum, the inductive and capacitive reactances cause some of the energy supplied to the antenna to be returned to the transmitter instead of being radiated.

Where a grounded antenna is used, there may be losses in the ground connection which will waste some of the energy supplied to the antenna circuit. Ground losses must be held to a minimum by making the best ground connections possible. Poorly grounded antennas will dissipate large amounts of power in the ground connection, thereby reducing the amount of energy radiated for communication purposes.

The energy radiated from an antenna creates electrical charges in the space around the antenna which travel away from it in all directions. The strength of these charges, or the signal strength, in any direction (antenna directivity will be discussed in a later section) depends upon a number of factors such as antenna height above ground, vertical angle of the antenna with respect to ground, and the influence of surrounding objects. As an example, imagine an antenna mounted inside of a large, sheet metal building. Since the metal building sides are good conductors of electrical charges, most of our radiated energy will be absorbed in the walls and very little, if any, will be propagated out through space. (See figure 2-7.)

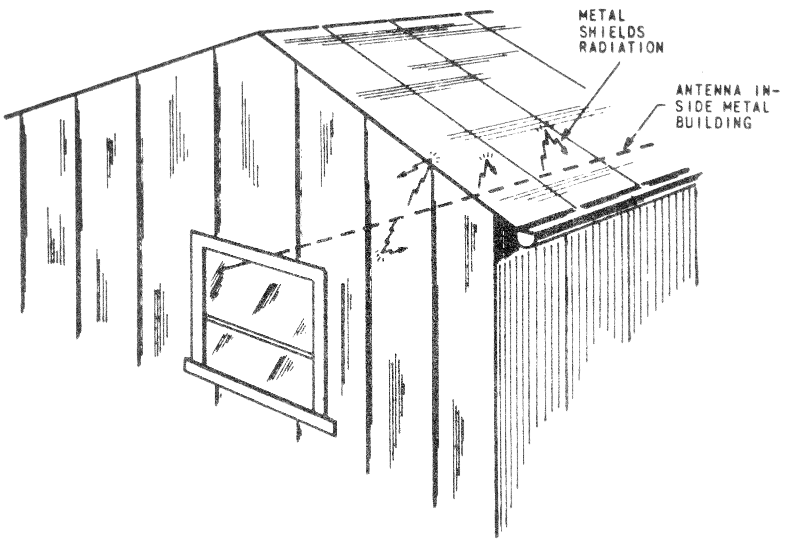


Figure 2-7

Other objects more frequently encountered around antenna sites also influence radiation, but to a much lesser degree. If objects such as walls of buildings, trees, communication or power wires, receiving antennas and other conducting objects are near the antenna, they will absorb some of the radiated energy. Absorption of radiated energy by nearby objects reduces the amount of energy propagated toward the receiving antenna.

Since water is a fairly good conductor of electric charge, the absorption losses in surrounding objects usually increase when they are wet. When constructing an antenna system, great care should be taken to obtain proper insulation and as much separation between antenna and surrounding objects as is feasible.

As discussed in chapter 1, a half-wave antenna can be quite long, particularly at the lower frequencies in which we are interested. At 4 megahertz, for example, a wavelength is equal to 300 megameters divided by 4 megahertz or 75 meters. Half of this value, 37.5 meters or 123 feet, is the length required for a half-wave antenna. If this much space is not available, then a shorter wire can be used, if absolutely necessary.

Where a shorter wire is used, its effective electrical length must be artificially increased to make it act like a half-wave wire. For example, if only 30 meters of space are available, the remaining 7 1/2 meters can be wound around a box or other insulator to simulate the additional length. Actually, when a wire is coiled, its effective electrical length becomes considerably shorter than its physical length before coiling. Usually, about one-third more wire must be added to the coiled portion to resonate the antenna under these conditions.

2.2 ANTENNA POLARIZATION.

A horizontally polarized antenna is one which runs parallel to the surface of the ground, and which should be at least 5 to 15 meters high. A typical horizontally polarized antenna is shown in figure 2-8. In this example, the transmitter is located on the second floor or in the attic of a two-story dwelling. The antenna is led out through the window and connected to a tree at the far end. A half-wave antenna for a 10-megahertz frequency is shown. The length, in this case, is one-half of 300 megameters divided by 10 megahertz, or 15 meters (49 feet).

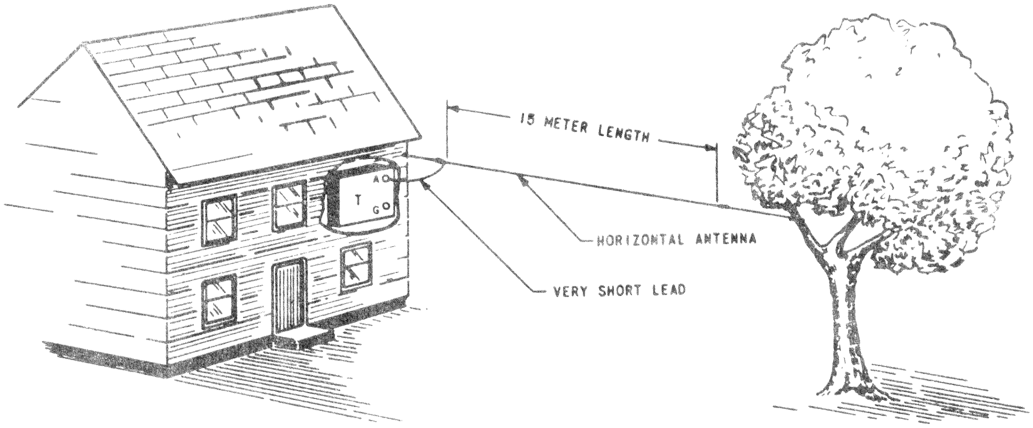


Figure 2-8

Most of the antenna length should be free and in the clear, and should be separated from other wires such as telephone and power lines by at least the length of the antenna. A good insulator should be used between the far end of the antenna and the tree connection as shown. Another piece of wire, or preferably a length of twine or rope, should be used between the supporting end of the insulator and the tree.

Where the wire enters the window of the room in which the transmitter is located, it should be kept as far as possible from metal objects such as window screens, curtain rods, or metal blinds. The wire should be run directly from the window to the transmitter. An additional insulator may be necessary at the transmitter end, as indicated, to keep the wire from sagging.

A vertically polarized antenna is one in which the antenna is perpendicular to the surface of the earth. A typical vertical installation is shown in figure 2-9. This type antenna requires a ground connection which may be secured by tying to a water pipe inside a dwelling, a metal rod driven into the ground, or to buried metal plates.

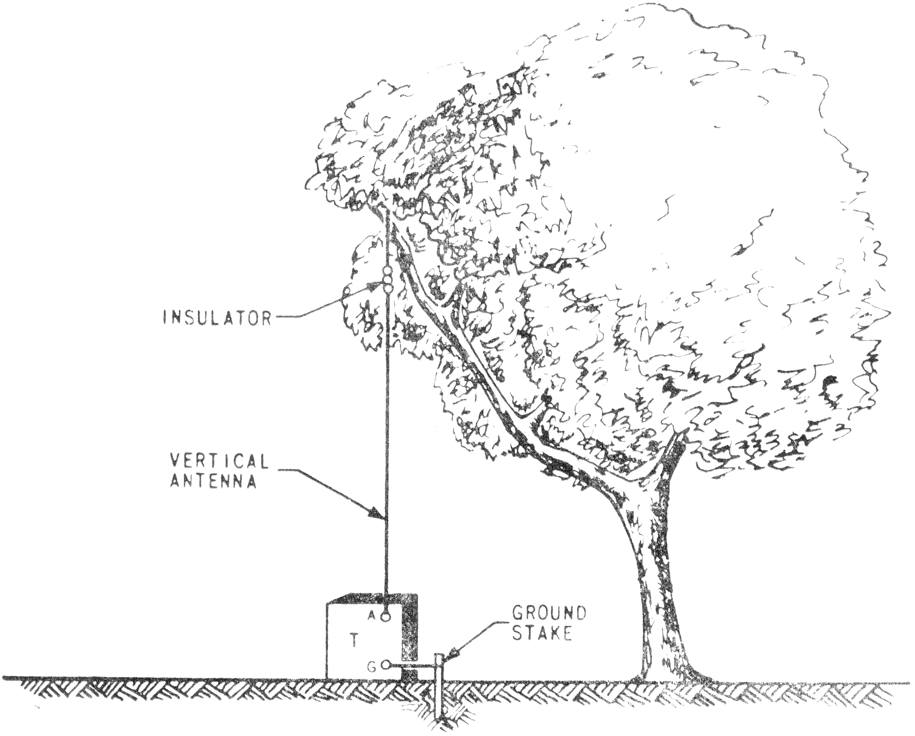


Figure 2-9

It is important to realize that when a grounded vertical antenna is employed, the ground acts as one-half of the half-wave antenna. In other words, the physical resonant length for this type of antenna, known as the "Marconi" antenna, is a quarter-wavelength. The length of a Marconi antenna for 10-megahertz operation would be 1/4 of 300 megameters divided by 10 megahertz, or 7.5 meters (25 feet).

The ground effect with a Marconi antenna may be pictured as shown in figure 2-10. This figure also illustrates the "image" concept which is applied to all grounded antennas when describing their radiation patterns. As shown by the standing wave of voltage in figure 2-10, the transmitter connection to a Marconi antenna is at a point of low voltage.

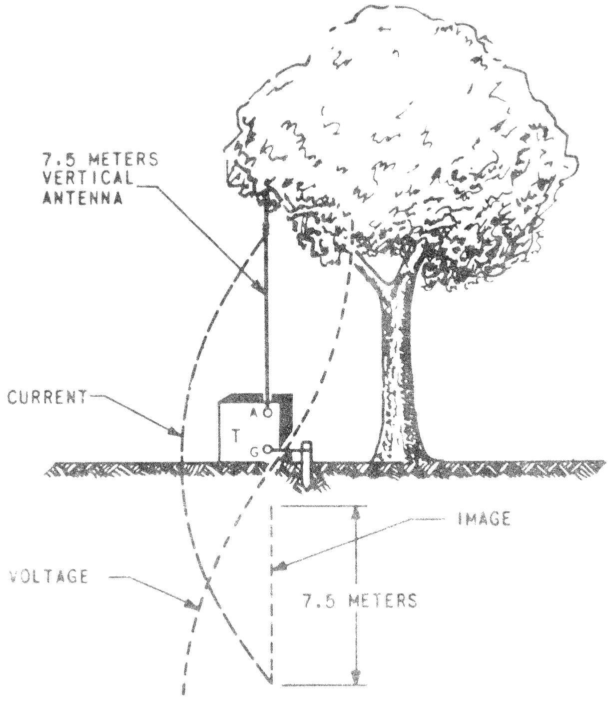


Figure 2-10

This feed point corresponds to a point of high current where the radiation resistance of the system is at a minimum. The resistance of the ground connection must be kept low in proportion to the radiation resistance, since power from the transmitter will be divided between the two in the same proportion. The power dissipated in the ground resistance part of the circuit is wasted.

In general, high antenna radiation efficiency depends upon securing a resonant wire system, a high ratio of radiation resistance to loss resistance, and adequate clearance between the antenna and surrounding objects. If the transmitted signals are sent to a receiving system which has a vertically polarized receiving antenna, a vertical transmitting antenna will give the best results. The opposite is true when horizontally polarized receiving systems are used.

The best antenna for transmitting is usually the best antenna for receiving, particularly on frequencies near the transmitting frequency. Modern receiver sensitivities are such, however, that satisfactory reception is possible with short lengths of wire. Receiving antenna dimensions are, therefore, less critical than the dimensions of transmitting antennas.

At frequencies in the 3 to 30-megahertz range, vertical antennas are best for ground-wave communication over distances of 10 to 20 miles. A good ground system is necessary to insure satisfactory ground-wave transmission. For medium distance communication, from 20 to several hundred miles on the 3 to 30-megahertz range of frequencies, horizontal polarization will give the best results.

On the higher frequencies between 6 and 30 megahertz, either type of polarization may be used for sky-wave communication over distances up to several thousand miles. Transmitting frequencies are chosen in accordance with the techniques developed for determining the maximum usable frequency. After the maximum usable frequency is found, allowances are made for daytime and nighttime conditions, the season of the year, and the sunspot cycle.

2.3 RADIATION AND DIRECTIVITY.

The waves from an antenna are not of equal strength in all directions from the radiating wire. The radiation falls into definite patterns in both the vertical and horizontal planes. If we had a small antenna inside a very large hollow ball as illustrated in figure 2-11, and removed from the influence of the earth and surrounding objects, waves of equal strength would be radiated in all directions.

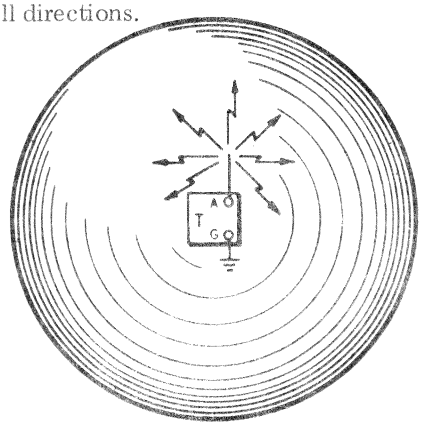


Figure 2-11

Actually, in the presence of the earth and surrounding objects, the antenna can be pictured as being enclosed within the upper half of a hollow ball-type structure which is cut in half by the earth's surface. Using this concept, we will now examine the antenna radiation pattern and determine the variation in signal strength for all directions within the hemisphere.

Our examination will include radiation upward toward the dome of the hemisphere, and outward toward the circular edge in all directions of the compass as shown in figure 2-12. The amount of signal radiated in a given direction depends upon the angle at which the waves leave the earth and their direction along the ground from the antenna.

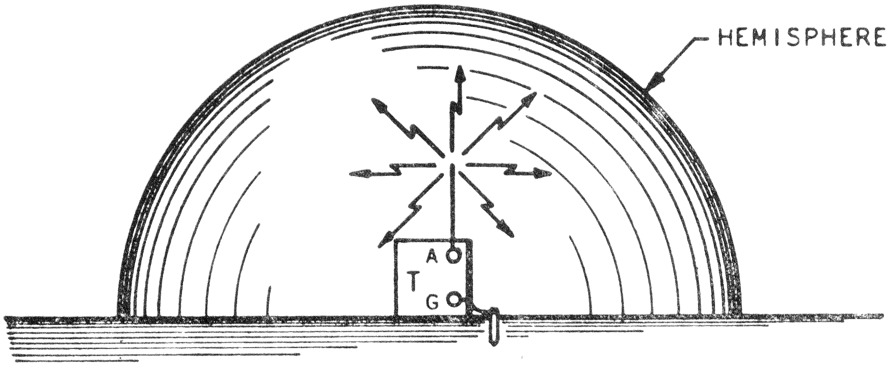


Figure 2-12

The shape of the radiation pattern for a particular type of antenna is determined by the way the electrical charges are distributed along the resonant wire. For a half-wave resonant wire antenna, the radiated signal is at a minimum off the ends of the wire, and a maximum at right angles to the length of the wire.

The shape of the radiation pattern for a horizontally mounted half-wave antenna is shown in figure 2-13. In this illustration, the lengths of the arrows indicate the relative power radiated in each direction from the antenna. It will be noted that the longest arrows, and therefore the strongest radiation, are in the vertical or upward direction. The shortest arrows, representing minimum radiated power, are in the outward or horizontal direction. Since the most effective radiation from a horizontal half-wave antenna occurs at a high vertical angle, this type of antenna is useful for relatively short distance sky-wave communication on frequencies below 5 megahertz.

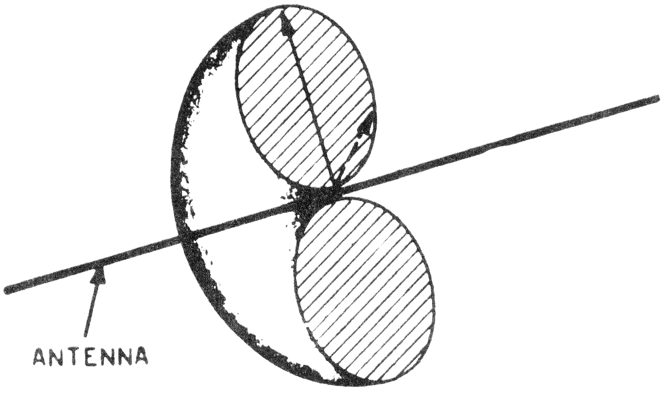


Figure 2-13

The radiation pattern for a grounded vertical antenna is shown in figure 2-14. For this type of antenna, the maximum and minimum radiation directions are exactly opposite those of the horizontal half-wave antenna. Maximum radiation occurs at low angles of radiation with respect to the earth, and minimum radiation occurs in the upward direction.

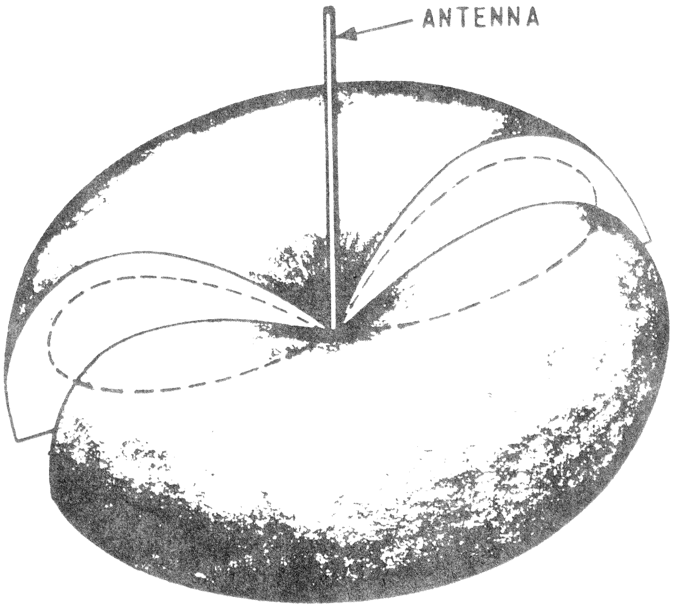


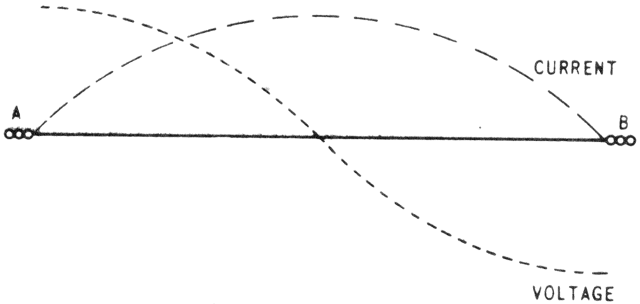
Figure 2-14

Maximum low-angle radiation makes the vertical antenna ideal for ground-wave communication over short distances. It is also useful for long distance sky-wave communication on higher frequencies where vertical radiation angles between 10 and 30 degrees are typical of the communication paths.

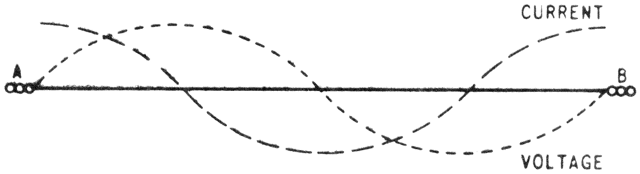
If the ground connection for the vertical antenna is poor, or an installation is made over low-conductivity soils without an extensive copper radial ground plane, the radiation pattern will be tilted upward as illustrated by the dashed lines in figure 2-14. This illustration serves to emphasize the importance of a good ground for the vertical antenna.

Directivity or directional patterns may also be obtained in antenna systems by using antenna wire lengths that are greater than one-half wavelength. Just as the rope standing-wave pattern could be varied in accordance with the rapidity of moving the free end, a wire is capable of being resonant at more than one frequency. The lowest frequency at which it will resonate, with the radio waveforms reinforcing one another, is called its fundamental frequency. Actually, the antenna wire can have two, three, four, or more maxima and minima on it as did the rope, and it can thus be resonated at approximately any whole multiple of its fundamental frequency.

Figure 2-15 shows a wire with a standing wave of fundamental frequency, and the same length wire resonating at double the fundamental frequency. This is called second harmonic operation. Antennas operated at harmonic frequencies have directional radiation patterns which are more complex than those for a simple half-wave antenna. These prove useful for special applications. In general, the directivity of multiple half-wavelength antennas is such that maximum radiation occurs off the end of the wire rather than at right angles to it. In some cases, as will be discussed later, very long wires mounted close to the ground may be used to receive or transmit signals in the direction they are run.



FUNDAMENTAL FREQUENCY



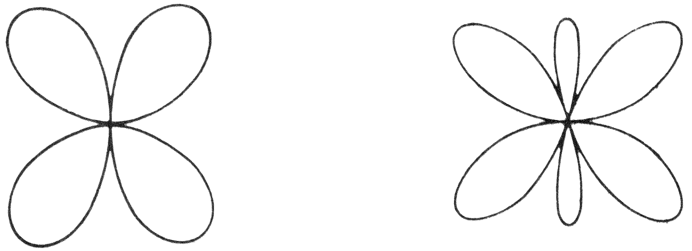
2ND HARMONIC OR TWICE FREQUENCY

Figure 2-15

Figure 2-16 shows horizontal radiation patterns for one wavelength, one and one-half wavelength, two wave length and four wavelength antennas. In contrast to the half-wave antenna pattern shown in figure 2-13, these patterns have directional lobes which increase in number as the length of the antenna is increased. It is also important to note that the radiation along the wire axis increases with length while that at right angles decreases. The directional characteristics of multiple half-wavelength antennas are extremely important to remember when orienting the antenna to provide the best results over a desired communication path.

As discussed earlier, radio waves are reflected from the ground. Since all antennas are related to the surface of the earth in terms of spacing from it, these reflections have an important effect upon the antenna directivity.

Just as the standing-wave pattern is created by reflection from the discontinuity at the end of the antenna, so are the electrical characteristics of the antenna modified by the waves reflected from the ground near the antenna. Figure 2-17 shows the effect of height on the radiation resistance of a horizontal center-fed antenna (dipole) suspended above gound.



ONE WAVELENGTH

ONE AND ONE-HALF WAVELENGTH

TWO WAVELENGTH

FOUR WAVELENGTH

Figure 2-16

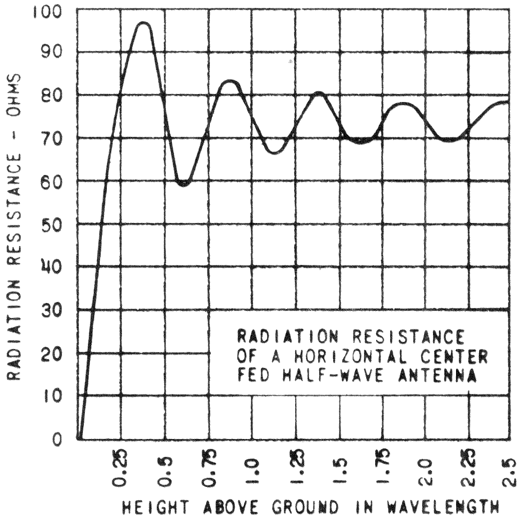


Figure 2-17

The height of either a horizontal or a vertical antenna above the surface of the earth affects the radiation characteristics of the antenna. Antenna height above ground determines the way in which the direct energy from the antenna, and the reflected energy from the ground, combine to form various directional patterns. Figure 2-18 shows typical vertical radiation patterns for vertical antennas mounted at various heights above ground. The reflected waves may arrive at just the right time to reinforce the direct wave, or the times of arrival may be such that complete cancellation occurs. All values of reinforcement and cancellation between these two extremes are also possible.

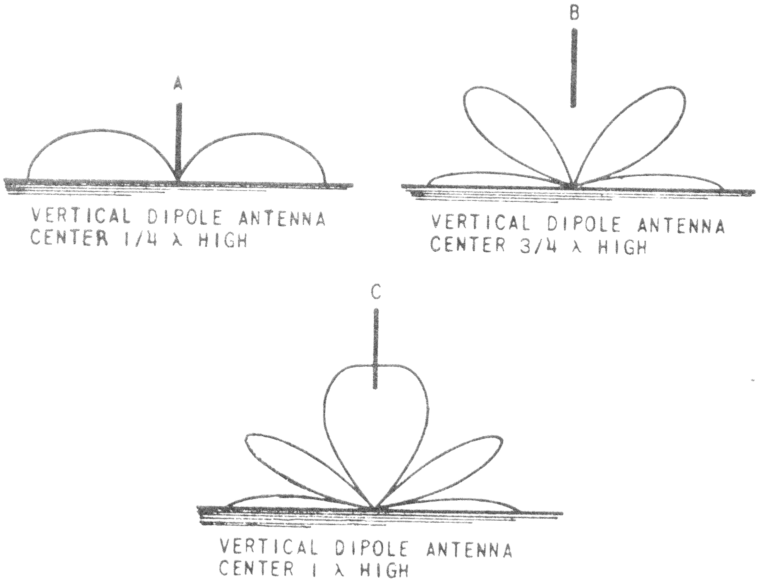
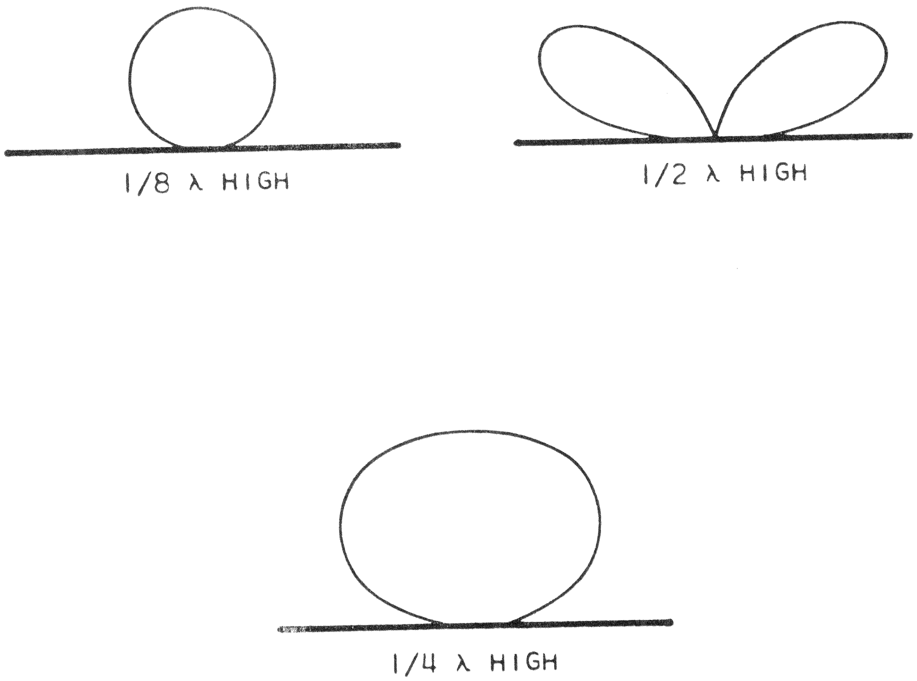


Figure 2-18

If the ground were a perfect reflector of radio waves, the field strength in some directions could be twice that of the direct wave. This would represent complete reinforcement. In other directions, the field strength could be zero. This would represent complete cancellation. For the directions between these two extremes, values of field strength from zero to twice the direct ray could exist. This would represent all degrees of reinforcement and cancellation lying between the two extremes.

Since the ground reflected waves are always upward, they affect the radiation pattern in the vertical plane only, and are not a factor in the directivity along the surface of the earth. Actually, as previously discussed, the conductivity or reflecting property of the ground is not perfect. This imperfection prevents both complete reinforcement and complete cancellation from occurring in actual antenna systems. These conditions can, however, be approached very closely under ideal operating conditions.

The effect of height above ground on the vertical radiation characteristics of a horizontal half-wave antenna is shown in figure 2-19. Several vertical patterns are shown for varying heights above ground in terms of wavelength. It can be seen that, depending on the vertical angle of radiation required for the communication path, height above ground is an important factor. Thus if the path is a relatively short one, say 200 miles, and the frequency used is 4 megahertz, the pattern for one-eighth wavelength height will be quite good. However, for a 2,000-mile path, low angle radiation will be required. In this case, a half-wavelength height above ground and a frequency of approximately 15 megahertz will be much more effective.



1/8 λ HIGH

1/2 λ HIGH

1/4 λ HIGH

Figure 2-19

Fortunately, for practical applications, these physical heights are relatively easy to obtain. Although the height in fractions of wavelength above ground increases for low-angle radiation at higher frequencies, the wave-length becomes physically shorter as the frequency is increased. For example, at 4 megahertz and one-eighth wave-length above ground,

one wavelength (λ) = $\frac{300}{4}$ = 75 meters = 246 feet

and 1/8 λ = 9.37 meters = 31 feet.

While at 15 megahertz, a half-wavelength above ground would be more effective and,

$\lambda = \frac{300}{15}$ = 20 meters = 66 feet.

1/2 λ = 10 meters = 33 feet.

Horizontal antenna radiation at various vertical angles is also influenced by the length of the wire employed. Figure 2-20 shows how radiation tends to move toward the lower vertical angles as the antenna length becomes greater. Figure 2-19 shows the effects of height above ground on radiation characteristics. All of these factors must be considered together when selecting the best design for a particular communication problem.

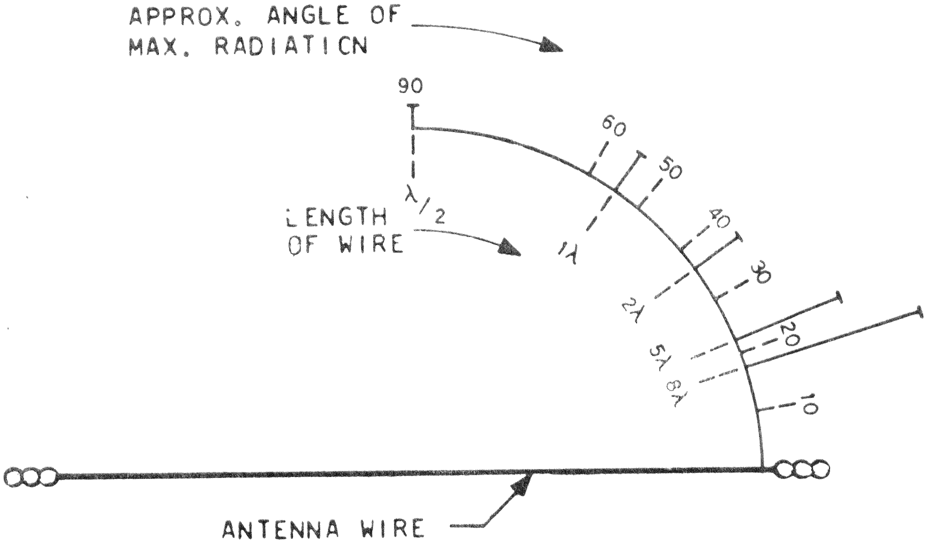


Figure 2-20

It must be appreciated that while horizontal and vertical antenna directivity characteristics have been treated separately for the sake of emphasis and clarity, in reality, a three-dimensional problem is involved. Figure 2-21 illustrates a radiation from a vertical antenna such as that shown in figure 2-18B. For communication over a specific communication path, the operator need not be concerned with the total radiation pattern, but he should know enough about antenna design to be reasonably certain of sufficient radiation in the desired direction.

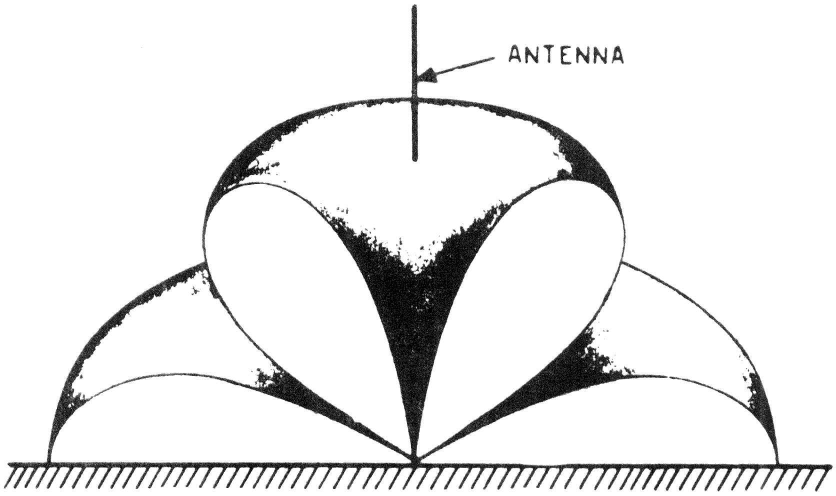


Figure 2-21

CHAPTER 3

GROUNDS

3.1 THE EARTH AS ONE BOUNDARY OF THE TRANSMISSION MEDIUM.

Radio-wave characteristics and the manner in which radio-wave fields may be set up by an antenna system have been discussed in chapters 1 and 2. When the radiated field is used for communication, it must be transmitted to the point where reception is desired, by either ground-wave or sky-wave propagation. The surface conditions of the earth affect the transmission of signals by both sky wave and ground wave.

The term ground wave includes the surface wave, the direct wave, the ground-reflected wave, and the tropospheric wave. One characteristic common to all components of the ground wave is that they travel over or near the surface of the earth and are affected by the conductivity and terrain of the the earth's surface. The effectiveness of ground-wave transmission to remote points will depend upon whether water, mountainous terrain, deserts, or tropical areas lie in the path of propagation.

The surface of the earth also forms one boundary for sky-wave transmission, but its effect is not so direct as in the case of ground-wave propagation. Ionization in the upper regions of the earth's atmosphere caused by radiation from the sun results in ionized layers which we have seen, are capable of reflecting radio waves which strike them. Radio waves reflected by the ionosphere are termed sky waves. Sky waves may travel directly to a receiving location over a one-hop path, or may be propagated to more distant receiving locations over a multiple-hop path. Multiple-hop paths are caused by repeated reflection of the waves between the ionized layer and the earth's surface. Typical multiple-hop propagation is illustrated in figure 1-30 of chapter 1.

3.2 INFLUENCE OF GROUND ON ANTENNA RADIATION AND DIRECTIVITY.

We normally refer to the radiating wire and the surface over which it is erected as the antenna system. When considering general propagation problems, we will extend the antenna system concept to include the receiving antenna and the entire path between transmitting and receiving locations. We will also refer to the area around the antenna, extending out to a distance of several wave-lengths, as the "near zone." The area beyond the near zone will be termed the "far zone."

The lines of force existing in the near zones of two typical antenna systems are illustrated in figure 3-1A and B. The radio transmitter power fed into either type of system encounters some resistance. This resistance may be broken down into three parts, two of which are wasteful, and one of which is useful for communication purposes.

A portion of the power fed into an antenna system is absorbed in the ohmic resistances encountered in the antenna wire and the lead-in wire. Where a grounded vertical antenna is used, additional power is absorbed by the resistance of the ground connection. Another loss resistance factor encountered in the near zone is caused by undesirable coupling of radio frequency energy into surrounding trees, buildings, and the ground. These losses are referred

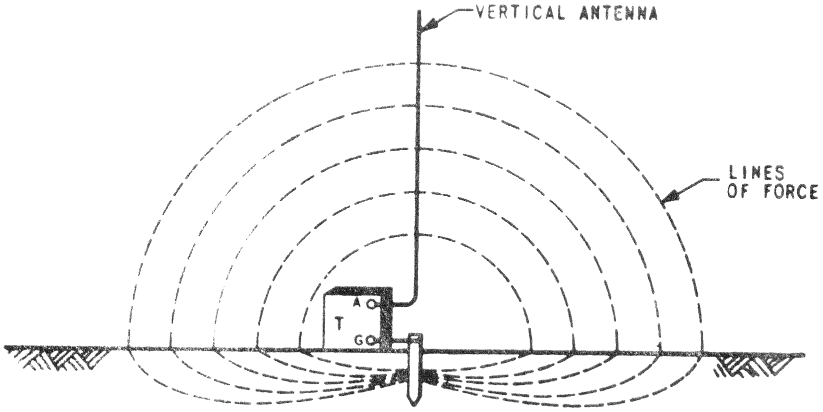


Figure 3-1A

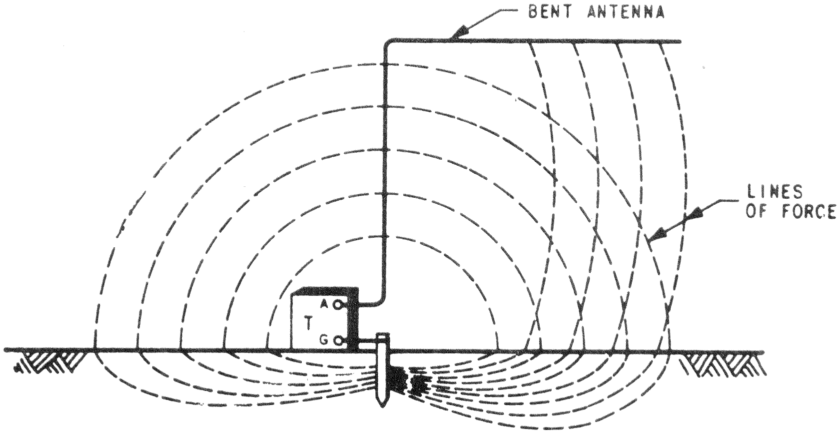


Figure 3-1B

to as dielectric losses since they are caused by wireless coupling instead of a direct-wire connection as illustrated in figure 3-2. Power absorbed by these resistances is wasted since it reduces the amount of power available for radiation.

The third, and useful type of resistance, is that termed radiation resistance. Radiation resistance causes a loss of power by the antenna in the form of radiated energy. In erecting antenna systems, the main object is to make the radiation resistance as high as possible with respect to the various loss resistances present in the system.

When a portion of the radiating system is formed by the earth, as in the case of a vertical antenna, a considerable loss of energy occurs when the ground system is too small.

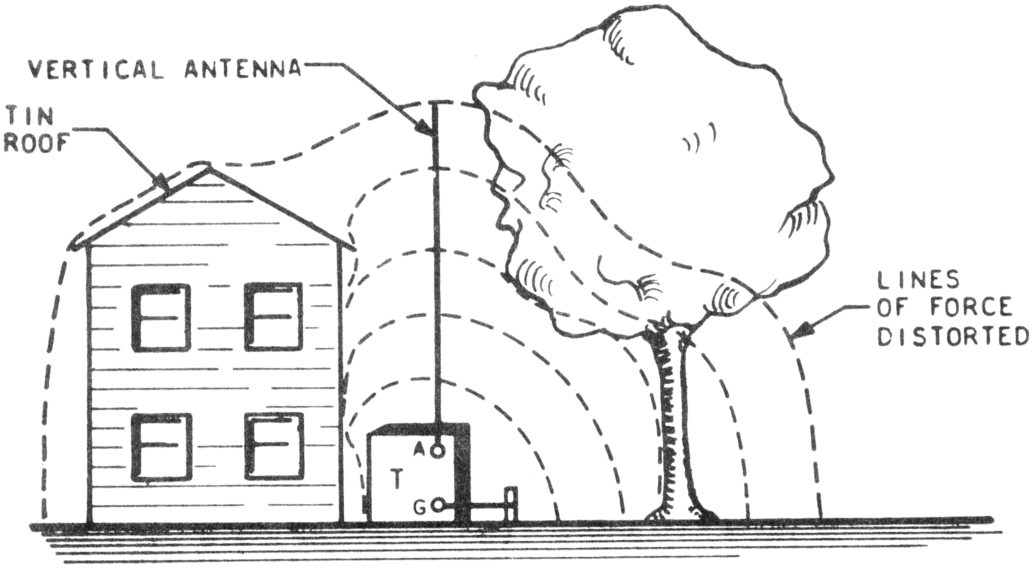


Figure 3-2

This loss occurs because of the high resistance paths followed by the radio-wave currents as they travel through the earth. Figure 3-3 shows an improved ground scheme for one of the cases illustrated.

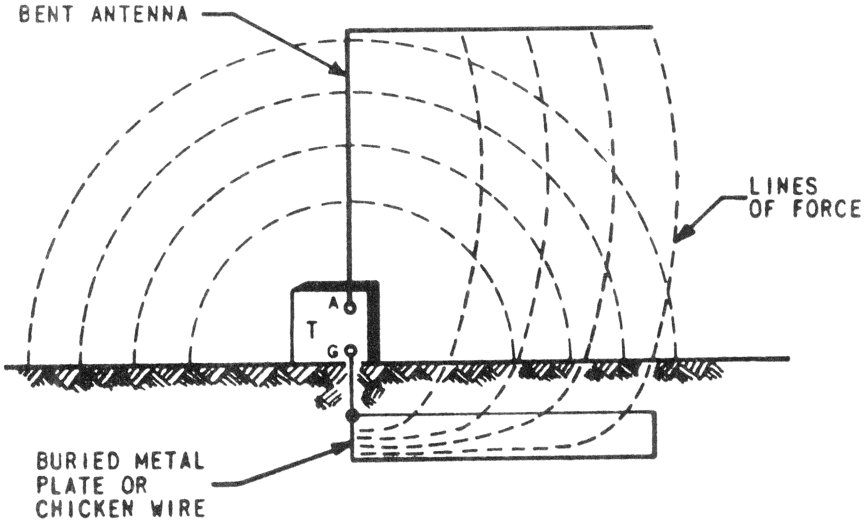


Figure 3-3

Antenna radiation patterns are determined by the antenna location with respect to the earth, and the influence of reflections from the earth's surface. Figure 3-4 illustrates radiation from a vertical antenna of length A-B. A direct wave will be radiated from the wire and propagated directly toward a distant point "P." An identical component of the signal will also reach "P" along the ground-reflected path marked "OEP."

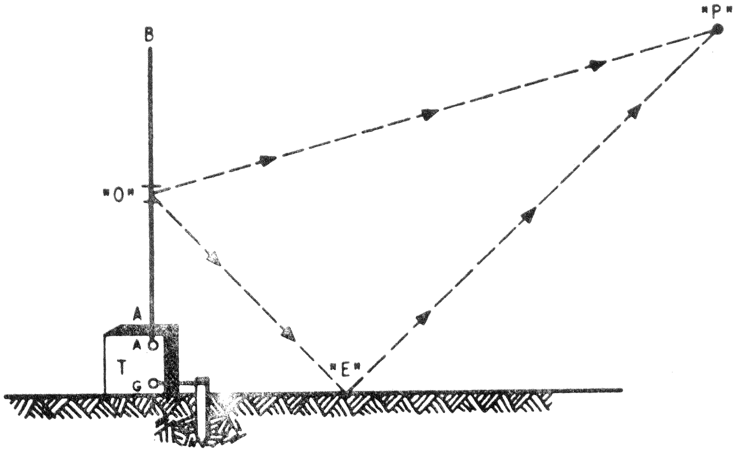


Figure 3-4

Since the radiation along path "OEP" travels a greater distance, a partial reinforcement or cancellation may occur at point "P" if the two waves do not arrive in exact time phase. When point "P" is close to the ground, the paths traveled by the two waves are nearly equal. In this case, waves from the vertical antenna reinforce one another and the signal strength at "P" is almost doubled.

At angles high above the ground, the reflected wave has traveled further than the direct wave, and the waves tend to cancel at the distant point. In this case, the radiation directly above the wire, A-B, is a minimum. These factors are important when planning antenna systems for particular cases to be outlined later.

3.3 THE GROUND AS AN ELEMENT OF THE ANTENNA CIRCUIT.

In a vertical radiating system, the radiation characteristics illustrated in figure 3-4 may be simplified by supposing that an "image" antenna exists just below the surface of the ground. As illustrated by figure 3-5, the geometrical dimensions of the image antenna are identical to the one-quarter wavelength Marconi antenna installed on the surface. The ground connection may be regarded as making the system equal to a half-wavelength antenna because of the "image" portion of the system.

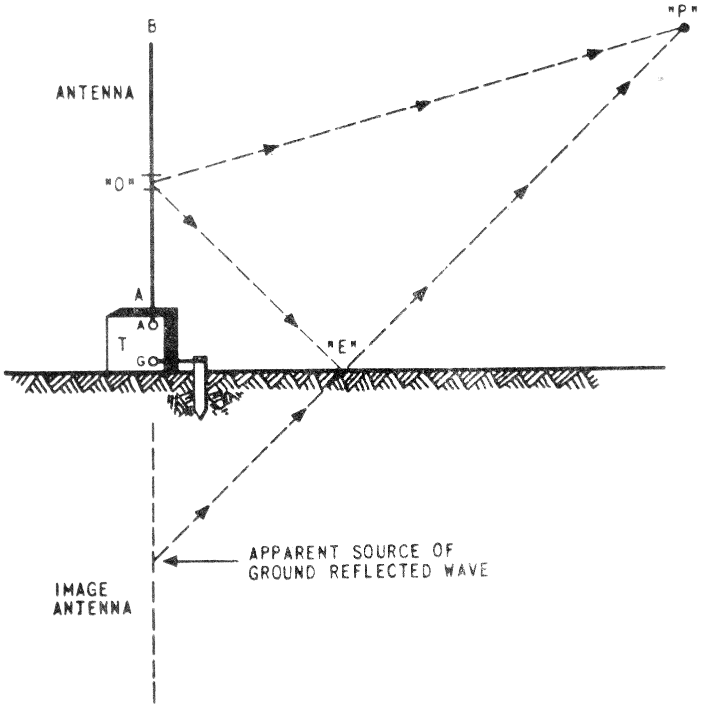


Figure 3-5

The ground for the Marconi antenna should be constructed of wires or metal plates buried deep enough to reach moist soil. In city locations, reasonably good grounds can usually be made to water pipes at the point where they enter the house. If there are no water pipes available, a ground system may be formed by driving a number of 6 to 8-foot lengths of metal rods into the ground. These rods should be spaced several feet apart and connected together at a common point to form a ground system. Figure 3-6 shows a typical ground rod arrangement.

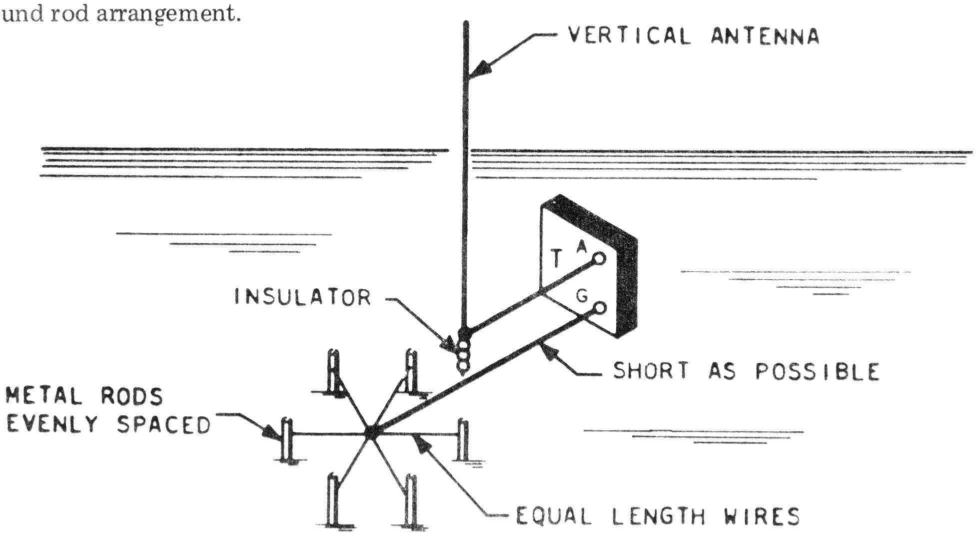


Figure 3-6

A more effective ground system than the one formed by metal rods is shown in figure 3-7. In this system, wires buried 2 to 4 inches in the ground and connected to buried metal plates at the end points provide an excellent return path through the earth. The plates may be omitted if they are not readily available. The buried wires should be as long as or longer than the radiating wire.

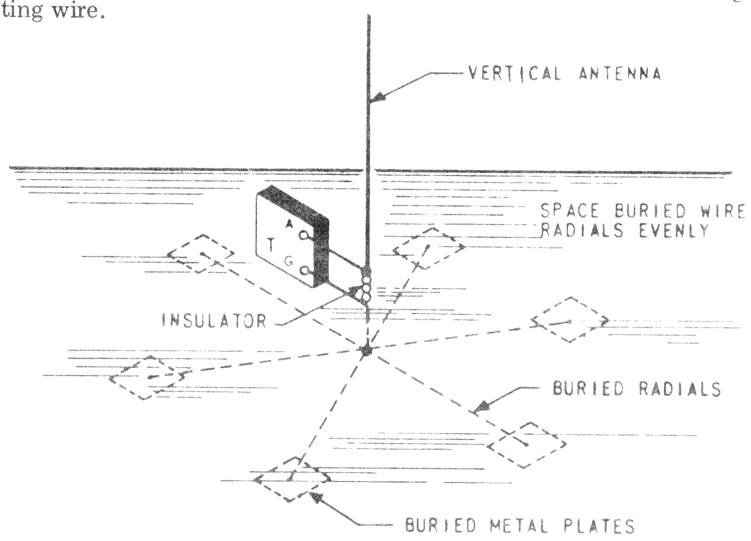


Figure 3-7

Where installations on roofs of tall buildings or over rocky terrain make actual earth grounds unfeasible, the ground may be simulated by a counterpoise. A typical counterpoise is shown in figure 3-8. It may consist of one or preferably more wires arranged beneath the radiating element to form a return circuit for the radio-wave currents in the near zone of the antenna. In general, the counterpoise wires should be at least as long as the antenna wire, and symmetrically distributed with respect to the radiating wire. If properly installed, the counterpoise provides a satisfactory substitute ground.

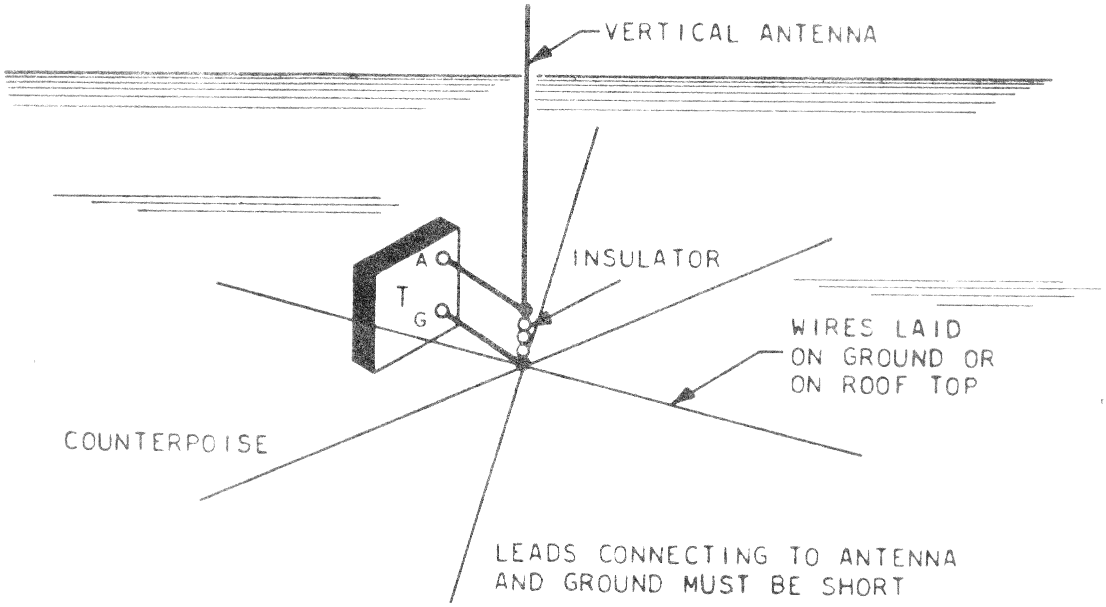


Figure 3-8

3.4 INFLUENCE OF TYPES OF GROUND.

In many of the previous examples, the earth has been assumed to be a perfect conductor. Actually, it must be viewed as something between a good conductor such as copper wire, and an insulator such as a piece of porcelain. Since the earth is less than a perfect conductor of radio waves, it may be regarded as a leaky insulator or a leaky dielectric which exhibits capacitive properties of its own.

The earth influences radio propagation as though it contained both resistance and capacitance. The conductivity of the earth plays an important part in low-frequency propagation, while propagation at higher frequencies is mostly affected by the earth's dielectric or capacitive characteristics.

The use of the earth for part of the propagation medium may be judged by the following characteristics:

1. The wave reflected from the ground may not be as strong as the wave striking the ground from the antenna. The difference in power of the radiated and reflected waves represents a loss of power. This power loss is due to the less than perfect conductivity of the soil, and its relatively poor capacitive dielectric properties.

2. The wave reflected from the ground may differ in characteristic shape from that of a wave reflected from a perfect conducting surface.

3. For less than perfect conductivity, reflection does not take place at the exact surface and an "image" antenna below the surface will not provide a true picture.

There are many different types of soil found throughout the world. In general, those having the poorest conductivity and dielectric constants are the dry, sandy soils. Many areas are extremely rocky, and these too have poor conductivity and dielectric constants. The highest conductivity and dielectric constants are encountered in good farm soil and black loam areas where ground vegetation flourishes.

The presence of moisture causes wide variations in ground characteristics. The conductivity and dielectric constant for any type soil can usually be improved by wetting the soil, as shown in figure 3-9.

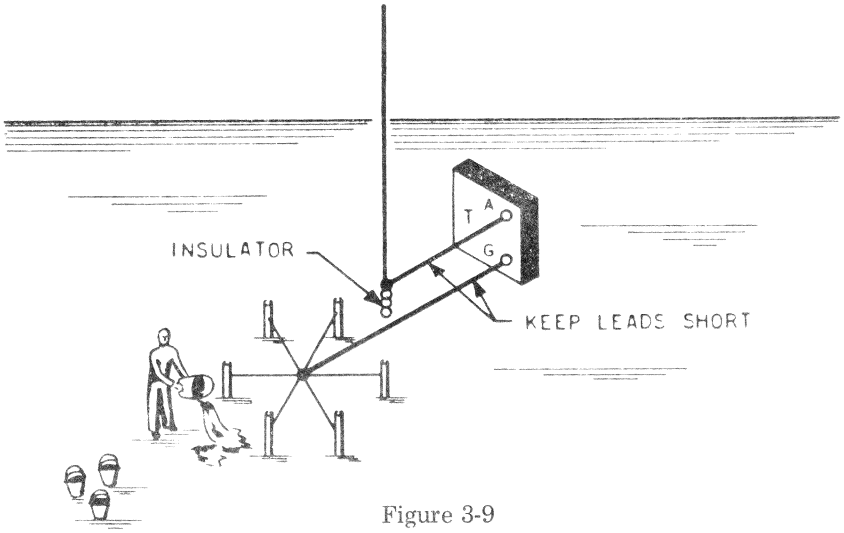


Figure 3-9

A chemical treatment method of improving the connection to ground is shown in figure 3-10. Where a permanent installation is possible, the chemical treatment illustrated will be very worthwhile. The chemicals used should be salt or some of the sulphates such as magnesium or copper. Several large buckets of the material should be poured into the trench and thoroughly wet down with water.

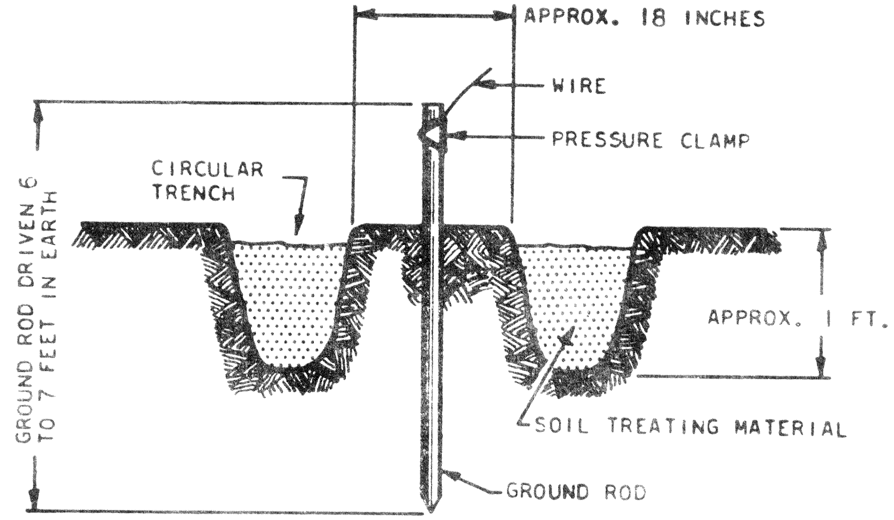


Figure 3-10

Ground systems will usually be most effective in marsh or swamp areas which are bare of trees and underbrush. Salt water has a much higher conductivity and dielectric factor than fresh water. Where a choice between salt water and fresh water is possible, the salt water area should be used.

3.5 CONNECTING TO GROUND.

In general, a satisfactory ground system can be secured by installing a ground screen of good radio frequency conductors in the near zone of the antenna. The ground screens can be formed of buried metal plates symmetrically arranged about the antenna system, buried chicken wire, or lengths of cooper wire radials arranged as illustrated in the foregoing sketches.

When the ground forms part of the radiating system, as in the case of the Marconi antenna, the electrostatic lines of force about the antenna travel from the radiating wire to ground through the capacity between the two. These lines of force must then return through the earth to the bottom of the radiating wire. In this process, energy losses occur in the resistance of the earth. Although the amount of earth available to carry these lines of force is large, the depth of penetration is limited to soil near the earth's surface. Surface soil is a poor conductor of radio frequency currents.

Where it is impossible to secure a good ground for an outdoor antenna system, a counterpoise may be used. The counterpoise consists of a number of wires laid on the earth's surface and symmetrically arranged about the vertical radiating wire. Although it is not as effective as a ground screen, the counterpoise provides a return path for the lines of force to the antenna. The counterpoise radials should be at least as long as the radiating wire. Since the counterpoise will provide a capacitive connection with the earth, the system may be regarded as a grounded one.

Various other forms of substitute ground connections may be employed where the more effective grounds are unavailable. Antenna systems using such grounds, however, will perform less satisfactorily than those with good ground systems.

Buried metals or driven rods may be used as grounds. A typical buried metal ground may consist of old water tanks, large metal containers such as oil cans or drums, household screens, pieces of old stoves, or other large appliances. The metals used should be free of paint or enamels to provide low-contact resistance. Rusty surfaces should be avoided or scraped clean and bright.

Metal rods driven into the ground will also provide a usable ground. While best results are obtained with copper plated steel rods, other metals such as lengths of piping, awning rods, car axles, metal spouting, and similar objects may be used. Junk yards are good sources for metals to be used in improving grounding facilities.

For indoor locations, it may be necessary to use a water pipe or radiator pipe for a ground connection. A cold water pipe connection is best since these pipes normally have a more direct path to ground than the hot water pipes. Where possible, the connection to a cold water pipe should be made at the point the pipe enters the ground. This, of course, will not be possible under certain conditions such as a second-story installation in a two-story house.

Where a water pipe ground connection is made a distance from the point at which the pipe enters the ground, the length of pipe between the connection and ground will act as part of the radiating element. In this case, it may be necessary to change the length of the antenna as illustrated in figure 3-11.

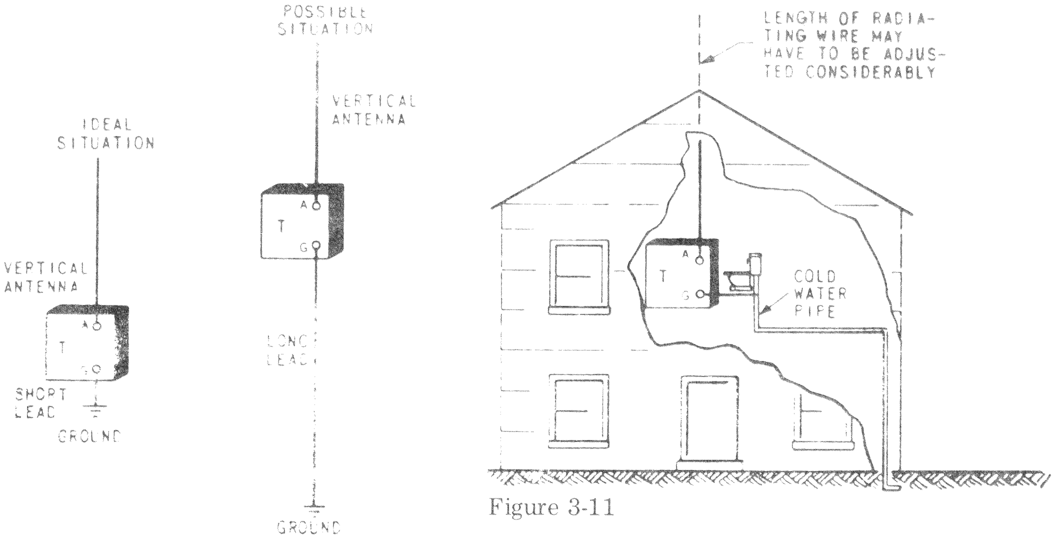


Figure 3-11

It is very important that a good electrical connection be obtained when making the ground connection. To obtain a good electrical connection, the metal to which the ground terminal of the transmitter is to be connected should be thoroughly cleaned by scraping or sandpapering. The wire from the transmitter ground terminal to ground should be kept as short as possible. If available, a pressure-type ground clamp should be used to make the ground connection.

Where the use of a ground clamp is not feasible, the ground connection may be soldered. If neither of these methods can be used, the contact resistance can be reduced by binding the joint with twine or electrical tape to increase the contact pressure. Before making the ground connection, the end of the connecting wire should be thoroughly cleaned of insulation, enamel, and oxidized films. Several turns of the cleaned wire should then be wrapped around the metal grounding object. Where possible, the end of the wire should be terminated in a twist loop as shown in figure 3-12. A lever may be used to increase the contact pressure of the joint as illustrated. Extreme care should be taken, however, to avoid kinking or otherwise damaging the wire since such damage increases the wire resistance.

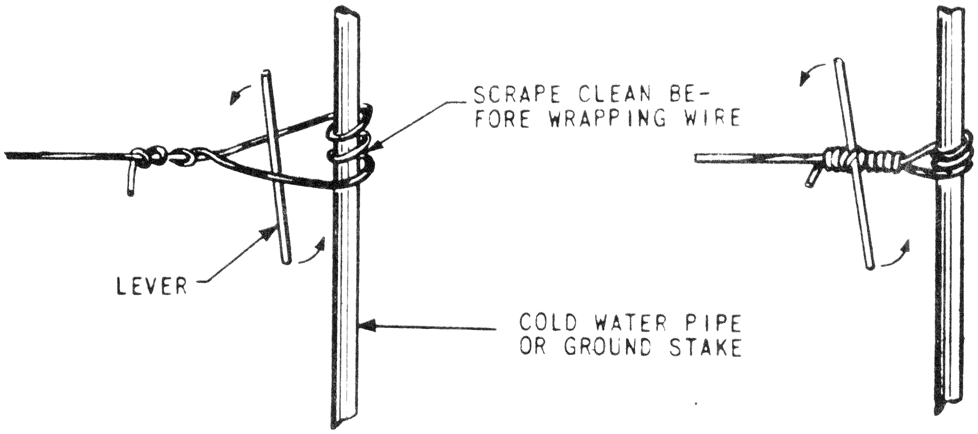


Figure 3-12

Grounds may at times be obtained by tapping to existing ground systems. Lightning rod installations are usually well-grounded. Quite frequently, the supporting structures for high frequency receiving antenna installations have been grounded to protect the receiving elements from lightning. House electrical systems are usually grounded near the power metering terminals, but extreme caution should be used in connecting to a powerline ground. Sometimes this ground is connected to the nearest cold water pipe, in which case the operator can employ the same technique.

3.6 IMPORTANCE OF GROUNDS.

Ground systems are particularly important where a Marconi antenna is employed. With this antenna, the actual length of the resonant wire is a quarter-wavelength since the earth acts as an additional quarter-wavelength.

When metals other than driven stakes are used for a ground, it is not necessary to bury them more than 6 to 8 inces below the surface of the earth. Burial depths greater than 6 inches are not required since the lines of force tend to stay near the surface. Improvement of the contact between metal and ground by soaking with water will also become more difficult if the burial depth is greater than 6 inches.

When horizontal antennas or loop radiators are used, ground systems are not so critical, and in some cases may be omitted entirely. For these and certain other practical antenna arrangements, the return path for radio frequency currents is through an active element of the antenna system. Ungrounded antenna operation will be more fully explained in a later chapter.

CHAPTER 4

SIMPLE ANTENNAS

4.1 RESONANCE.

Any length of wire connected to a radio frequency transmitter will radiate transmitter power, but certain lengths of wire radiate more efficiently than others. Figure 4-1A shows the distribution of r-f energy along lengths of wire, A-B, A-C, and A-D. In each case illustrated, the initial wave of radio frequency energy (AXC) results in a reflected wave (CYA) when the original current reaches the end insulator and can go no further. The distance (OX) represents the amplitude of the direct wave, and (OY) represents the amplitude of the reflected wave. The difference between the direct and reflected waves represents the energy radiated.

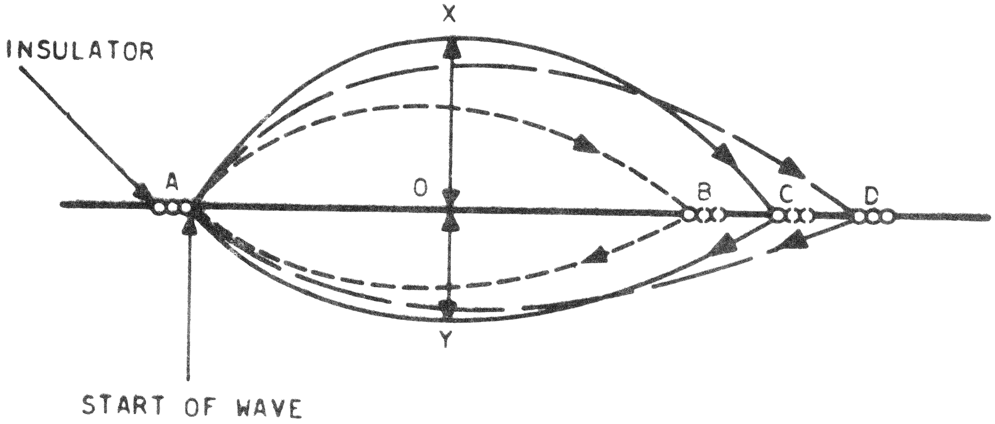


Figure 4-1A

In a half-wave antenna, the wire length is the same as a half-wavelength of the radio frequency energy, and the reflected wave arrives back at the transmitter terminal just in time to reinforce the next power cycle. In practice, it is not advisable to directly feed a half-wave antenna at the end, due to its very high impedance at that point. Figure 4-1A illustrates the fact that as wavelength decreases, frequency increases.

In the preceding chapters, it has been assumed that the speed of radio energy along a wire is identical to that in free space. Actually, the speed at which radio waves travel along a wire is slightly less than 300 megameters per second. Because of this difference in speed and other effects, the antenna lengths used in practice are approximately 5 percent less than those computed for free space waves. To compensate for the effects mentioned above, the formula for computing antenna length must be modified by inserting a correction factor:

The modified formula which is used in all practical half-wave or multiple half-wave antenna design computations is as follows:

$$\text{Antenna length (in meters)} = \frac{(N-.05)\ 150 \text{ megameters}}{\text{frequency (in megahertz)}}$$

$$\text{Antenna length (in feet)} = \frac{(N-.05)\ 492}{\text{frequency (in megahertz)}}$$

Where N = the number of half-wavelengths desired and .05 = the correction factor.

For example, if a half-wave antenna were selected for 10 megahertz operation, the wire length would be

$$\frac{(1-.05)\ 150 \text{ megameters}}{10 \text{ megahertz}} = 14.2 \text{ meters or } 46.8 \text{ feet}$$

A three half-wavelength antenna for 10 megahertz would be

$$\frac{(3-.05)\ 150 \text{ megameters}}{10 \text{ megahertz}} = 44.3 \text{ meters or } 145 \text{ feet.}$$

As seen from the above formula, when a multiple half-wavelength antenna is used, the correction factor remains the same as for a single half-wavelength. This is due to the fact that the correction must be made for only one of the half-wavelength sections.

Figure 4-1B is a graph showing the relation between a half-wavelength and frequency. This graph may be used to determine the corrected length of a half-wave antenna for any frequency from 3 to 30 megahertz. In addition, the figure shows wavelength and quarter-wavelength dimensions in both meters and feet.

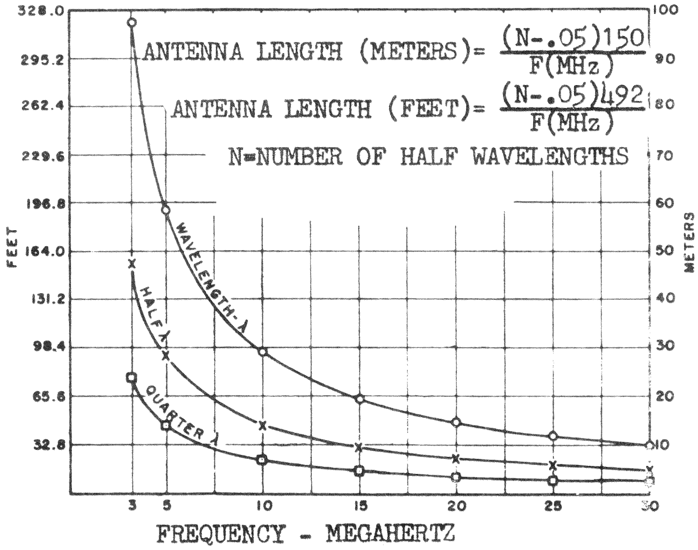


Figure 4-1B

Figure 4-1C shows the results of using a wire too long for a particular frequency. Here the frequency is such that a half-wave cycle A-B is traced out before the end of the antenna, as established by the insulator, is reached. Instead of being reflected back at the end of a half-cycle, the wave continues along the wire with a new half-cycle. When the energy finally reaches the insulator, it will be reflected back as an out-of-phase wave (DYX). This reflected wave will not arrive back at the original point at the right time to reinforce the next cycle of radio frequency energy. Radiation from this antenna will be poor.

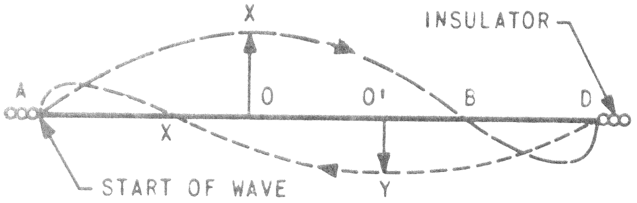


Figure 4-1C

Figure 4-1D shows the results of using an antenna wire A-B too short for a particular frequency. The reflected wave again does not arrive back at the point of origin "A" at the proper time to reinforce the next energy cycle, and the radiation efficiency of this antenna is also poor.

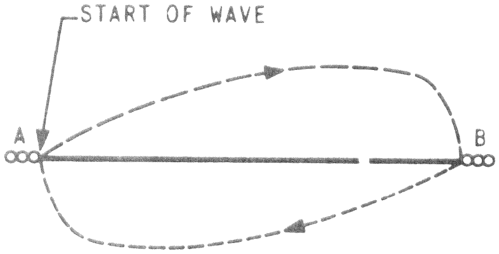


Figure 4-1D

These examples serve to illustrate the importance of obtaining antenna system resonance. Many radio transmitters have antenna matching networks which compensate for errors in antenna length. When properly matched, the antenna will be resonant and the direct wave from the transmitter reaches the antenna in phase with the reflected wave. It can be seen from this discussion that it is important to properly adjust the matching network or "antenna loading" control. There are some losses in matching networks and it is better to have a resonant system (1/4 λ 1/2 λ, 3/4 λ, 1 1/4 λ, etc.). These losses are not too serious, however, and even antennas far from resonance will radiate quite well if the matching network is properly tuned.

4.2 ANTENNA DESIGN.

Antennas take many forms ranging from single wires to directional arrays. One of the most simple antennas is the Marconi antenna—a grounded antenna in which the ground connection from the transmitter may be pictured as establishing one-half of the antenna system. The physical length of the actual radiating wire will be a quarter-wavelength.

Figure 4-2A shows a convenient way to analyze the Marconi antenna. A quarter-cycle of energy is illustrated with zero current at the top end of the wire and maximum current at the top end of the wire and maximum current at the point of feed near ground. The Marconi antenna may also be bent in the forms illustrated in figures 4-2B and 4-2C. In these cases, its polarization may be either mostly horizontal or mostly vertical, depending upon the direction of the wire section in which most of the current flows.

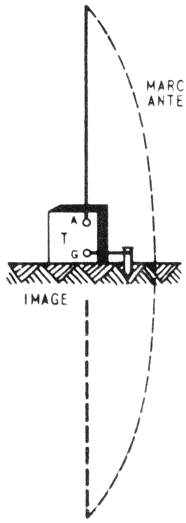


Figure 4-2A

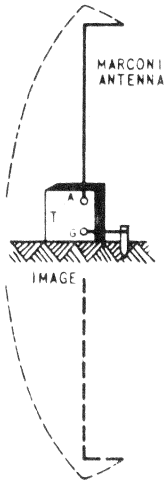


Figure 4-2B

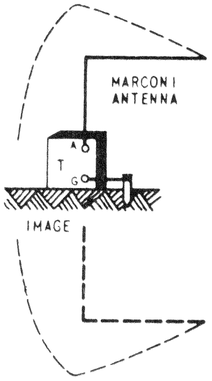


Figure 4-2C

The antenna shown in figure 4-2D is commonly called the Hertz antenna. With this antenna the ground does not act as one-half of the radiating system since the antenna itself is one or more half-wavelengths long. The transmitter ground in this case insures a static or lightning discharge path to the earth. Various methods of feeding power to a Hertz antenna are illustrated in figures following 4-2D.

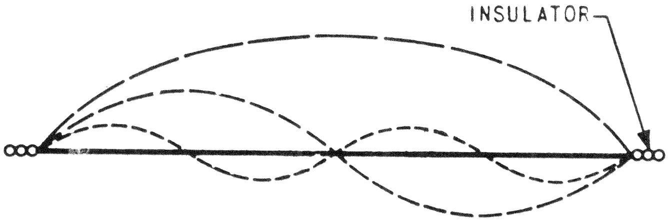


Figure 4-2D

It is not practical to feed a half-wave antenna at one end because the impedance at the end of a half-wavelength of wire is extremely high as shown in figure 2-6, chapter 2. The transmitter may be inserted in the center of the half-wave wire where its impedance is lowest (around 70 ohms), as shown in figure 4-2E. Space restrictions sometime require that the sides of a half-wave antenna be swung together as shown in figure 4-2F. This will increase the signal strength in the direction to which the sides are bent, and reduce it in the opposite direction.

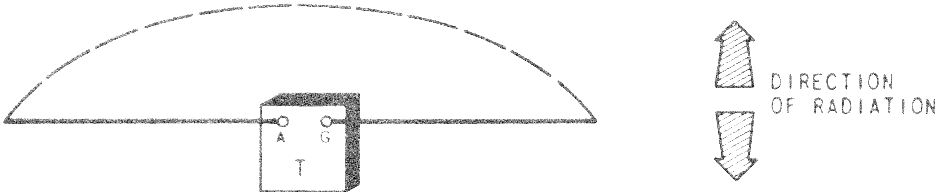


Figure 4-2E

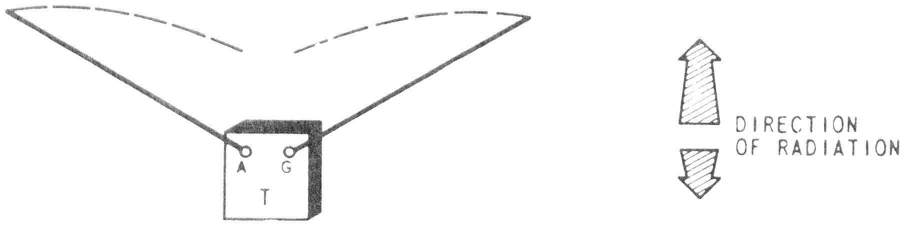
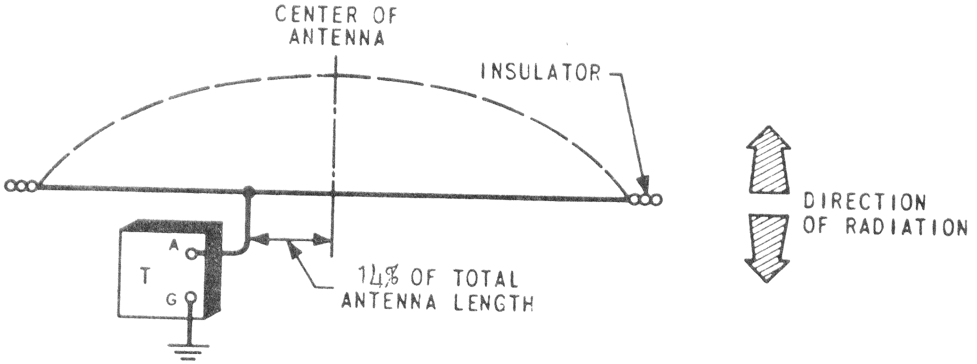


Figure 4-2F

A very effective method of feeding a half-wave antenna is to use a single wire connected to a point 14 percent of the total length of the antenna from the center of the wire. This point has an impedance of about 600 ohms which is the impedance of the single wire feeded and which will usually be within the matching range of the transmitter. Such an arrangement is shown in figure 4-2G.



HERTZ OFF-CENTER FED HALF-WAVE ANTENNA

Figure 4-2G

In confined quarters such as small rooms, the loop antenna may be the most feasible type. Figures 4-3A, 4-3B, and 4-3C illustrate the development of a loop in which a half-wave antenna is bent to conserve space, and still form a moderately efficient radiator. We may first imagine that the half-wave center fed radiator is divided into eight equal parts which are stretched vertically between points "A" and "J" as illustrated in part (A) of the figure. The direction of the instantaneous currents in the straight wire at any instant during a half-cycle is as shown by the arrows.

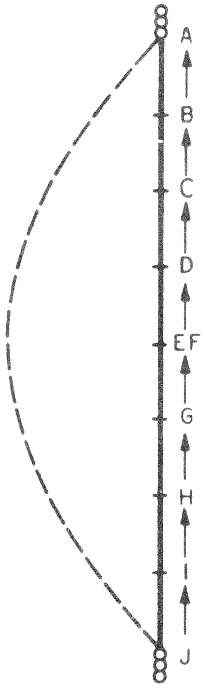


Figure 4-3A

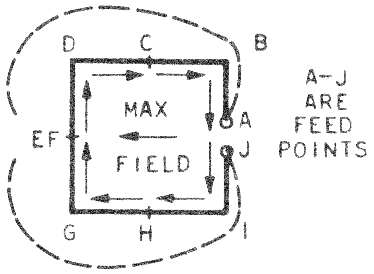


Figure 4-3B

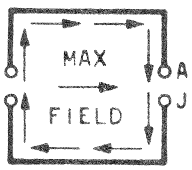


Figure 4-3C

If this wire is bent into a square with right angles at "B," "D," "G," and "I," it will take the form shown in part (B) of the figure. The distribution of the current about the loop is indicated by the dashed lines, and the direction of the current is indicated by the arrows. The current maximum occurring at the center of the wire between points "D" and "G" causes the field strength to be a maximum in the plane of the loop, and in the direction looking from the low current side toward the high-current side. This is shown by the arrow (maximum field) in the center of the loop.

Unfortunately, the characteristic impedance across points "A" and "J" is too high for a feed point since they are actually the ends of the half-wave antenna. However, if the side opposite the feed terminal is open-circuited as shown in part (C), the impedance at points "A" and "J" will drop to approximately 50 ohms, a value which can be more readily matched to the transmitter. The current maximum will then occur at the feed terminals "A" and "J" rather than on the side opposite them, as is the case with a closed loop. The direction of maximum field will be reversed as indicated.

Strictly speaking, this latter configuration is no longer a loop since it is not completely closed. However, its square form is maintained. If the development of the loop is examined it will become apparent that each side of the loop is one-eighth wavelength long. Whereas the space required for a half-wavelength straight wire at 15 megahertz would be 31 feet, (9.5 meters), a square area about 8 feet on a side (2 1/2 meters) will accommodate a loop for this frequency.

If this type loop is mounted vertically on the wall of a room its radiation will be vertically polarized. If the loop is installed parallel to the floor (under a rug or on the ceiling) its polarization will be horizontal. The directivity in either case will be as indicated in the figures. This type loop will not be as efficient as a straight half-wave dipole, but it will be more directive. It will be found when receiving, for example, that a signal from the favored direction of the loop will be somewhat stronger than a similar signal received off the back side of the loop.

The development of a larger loop, where space is available, is illustrated in figures 4-4A, 4-4B, and 4-4C. Here we can imagine a piece of wire one wavelength long at the operating frequency, and with the current distribution shown in part (A) of the figure. We recall from our study of radio frequency waveforms that the direction of the current reverses in each successive half-wavelength. This is indicated by placing the dashed current waveform to the left of the wire on one half-wavelength, and to the right of the wire in the next half-wavelength.

As shown in the square loop developed in the figure, the direction of the current reverses at a point halfway around the length of the loop. Such current reversals always occur at the junction of half-wave sections of wire. The directional characteristics of this type loop are opposite to those in the small loops of figure 4-3. The radiation from the larger loop is maximum perpendicular to the plane of the loop (broadside), and minimum in any direction within the plane containing the loop.

If the loop shown is mounted vertically with the feed terminals at a vertical side as shown in part (B), its polarization is mostly vertical. If the feed terminals are moved to the center of one of the horizontal sides of the loop as in part (C), the polarization becomes mostly horizontal. Thus, the point of feed provides a convenient method of remembering the polarization factor.

In constructing any of the foregoing antenna loops, care should be exercised to avoid sharp corners, which are used in the drawings for convenience only. The wire should be shaped to provide rounded corners.

It is permissible to use frequencies which are approximately 10 percent above or below the optimum frequency for which an antenna is designed. While the efficiency of a well-designed antenna will be somewhat lower when it is operated at other than its resonant frequency, interference from other stations or the desire to avoid detection sometimes make a small frequency change necessary.

When it is necessary to make slight changes in frequency, the loading of the transmitter to the antenna, i.e., the antenna matching network, should be carefully trimmed so that the antenna is always resonated to the frequency of operation. The radiation efficiency of a resonant system is many times that of a nonresonant wire. Thus, a grounded antenna

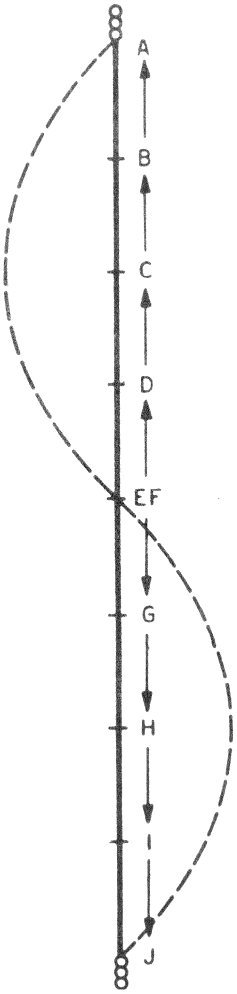


Figure 4-4A

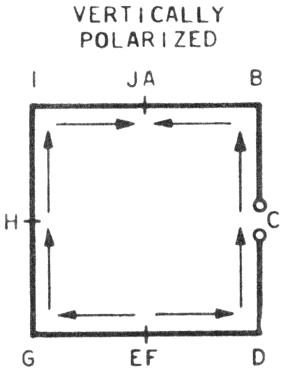


Figure 4-4B

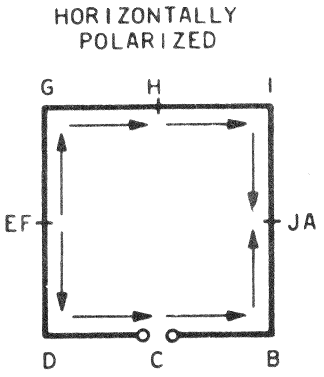


Figure 4-4C

MAX. DIRECTIVITY TOWARD AND AWAY FROM OBSERVER

(Marconi) should always be some odd multiple of a quarter-wavelength (1/4λ, 3/4λ, 1 1/4λ) while an ungrounded antenna should always be an even multiple of a quarter-wavelength such as λ/2, λ or 1 1/2λ. See figures 4-5A and 4-5B. This arrangement provides for a low-impedance, (high-current) feed point in the case of the Marconi antenna, and helps to insure a near resonant condition for the ungrounded antenna.

Antenna lengths discussed in the preceding examples refer to the electrical length. It is sometimes important to be able to change the electrical length of a wire by the insertion of a coil of wire. For example, where space does not permit the erection of a half-wavelength of wire which would be fed off-center (as in figure 4-2G), the additional wire may be coiled into a series inductance which will be the electrical equivalent of the required length given in figure 4-1B.

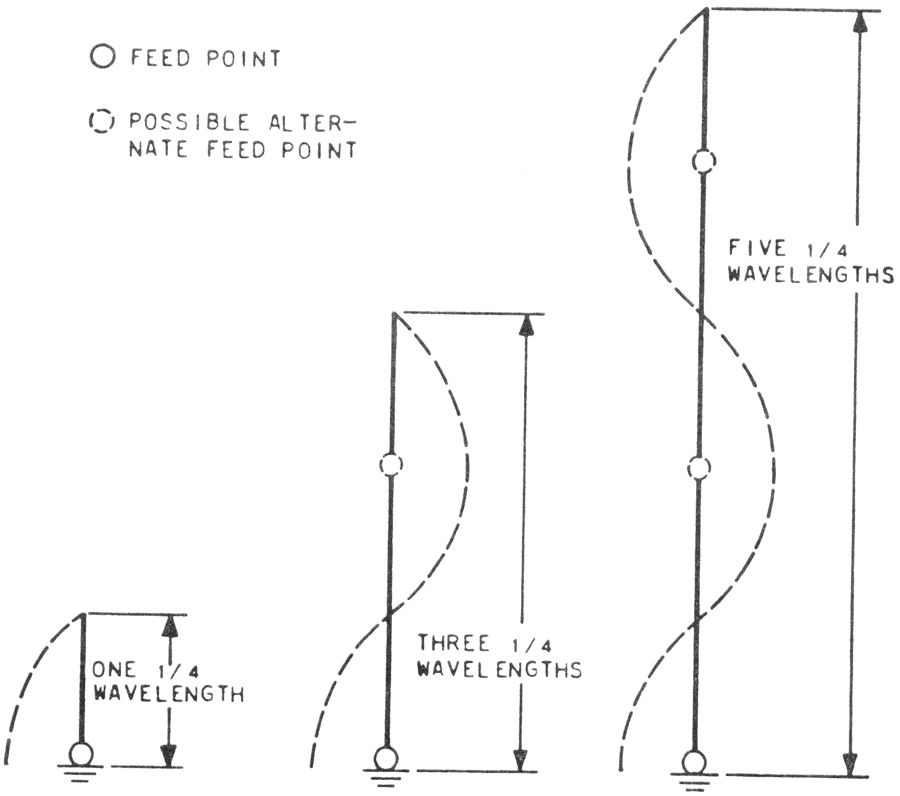


Figure 4-5A

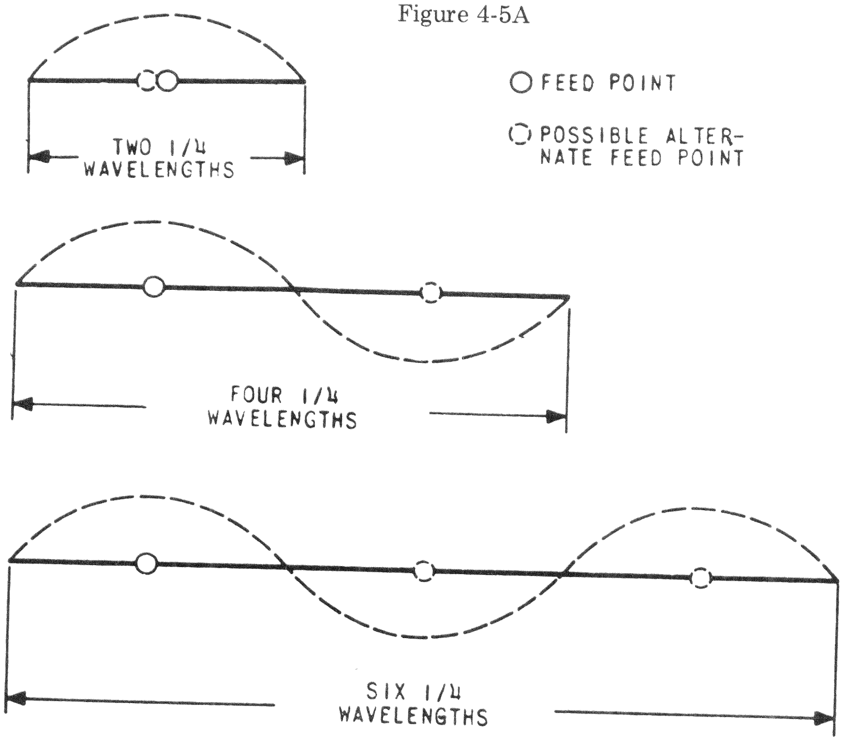


Figure 4-5B

Wires which are too long can be shortened electrically by as much as one-eighth of a wavelength by means of a fixed condenser (such as might be obtained from a broadcast receiver) located near a point of maximum current. Figure 4-6 illustrates three antennas, all of which have the same electrical length although their physical lengths differ appreciably.

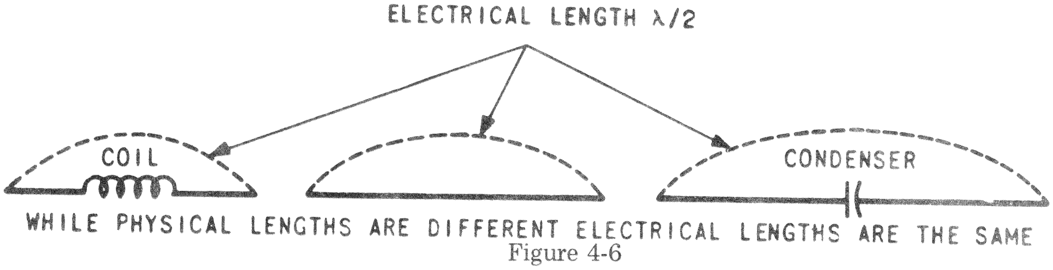


Figure 4-6

Figure 4-7 shows how correct electrical length may be simulated by the use of inductance or capacitance.

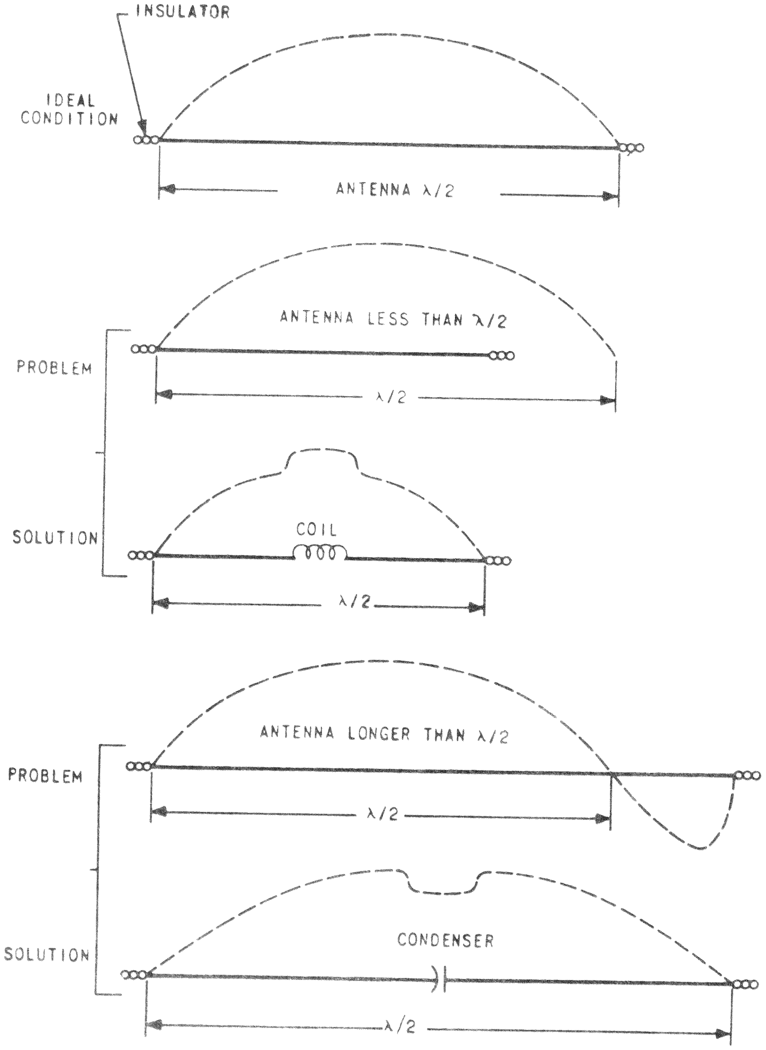


Figure 4-7

A very important requirement is to secure proper transfer of radio frequency power from the transmitter to the radiating system. This problem may be pictured as illustrated in figure 4-8. If we are interested in filling the glass within the shortest possible time without spilling any water, we must match the flow of water to the size of the glass. Using this analogy, our transmitter might be likened to the pitcher and our antenna to the glass.

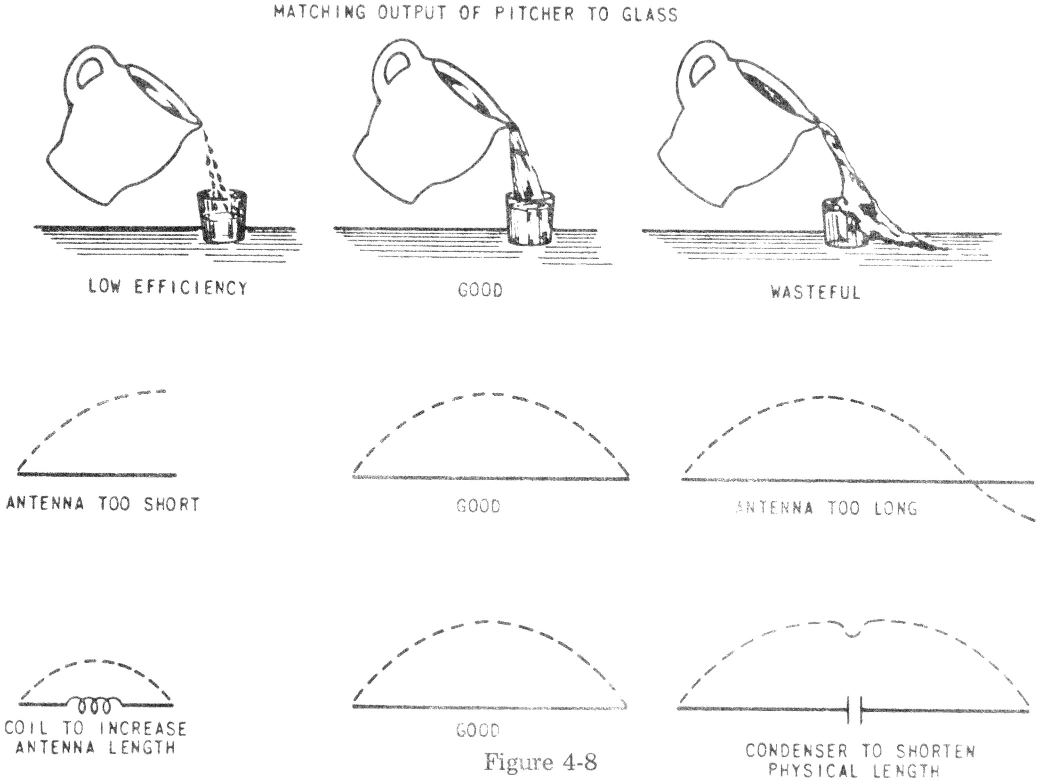


Figure 4-8

The figures below the graphic illustrations show what may be done to increase efficiency when the antenna is too short or too long. Retuning the transmitter output is important each time any change is made in the antenna, or when the antenna system is moved to a different location. This should be done even though the antenna may look the same physically to the operator. The transmitter should be checked from time to time in accordance with methods given in the instruction book to insure proper functioning.

4.3 METHODS OF FEED.

Figure 2-6 in chapter 2 shows the approximate impedance presented to a transmitter at any point along an antenna. The impedance is expressed as the ratio of the instantaneous current to the instantaneous voltage at any point along the antenna. The operator should not try to feed the antenna at a high-impedance point, such as the end of a half-wavelength wire.

If a half-wavelength radiator is employed it may be fed as shown in figure 4-2G. Wires which are multiples of a half-wavelength should always be fed near a point of current maximum as illustrated in figure 4-9. Thus, the antenna operates on one of its harmonic modes, when a wire longer than a half-wavelength is used.

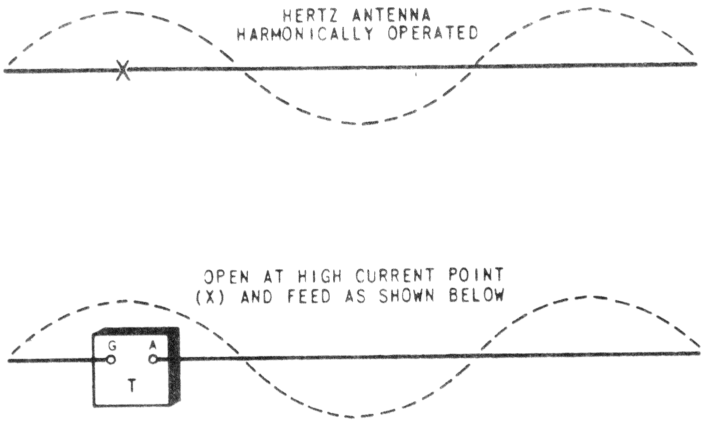


Figure 4-9

Sometimes, as in figure 4-2G, a half-wavelength antenna may be fed by a single-wire transmission line to allow operation at a distance from the antenna. The actual ground connection to the transmitter in this case may have a relatively high resistance without causing appreciable loss of radio frequency energy. This is due to the small amount of current flow in the relatively high-impedance feed (500-600 ohms as compared to about 35 ohms for a Marconi antenna).

A single-wire feeder connects to either side of the current maximum in the antenna. To match the single wire feeder impedance of about 600 ohms, the feeder is connected a small distance "D" away from the exact center of the antenna. The distance "D" is 14 percent of the total length of the antenna as previously explained. Antennas fed in this manner however, cannot be operated on their harmonic frequencies.

The feeder should come away from the antenna at a right angle for as great a distance as possible. Sharp bends in the feeded should be avoided, and good clearance from surrounding objects maintained.

4.4 VERTICAL ANGLE OF RADIATION.

As outlined in chapter 1 on Radio Wave Propagation and chapter 2 on Radio Antennas, the optimum vertical angle of radiation for sky-wave propagation depends upon the frequency used and ionospheric conditions. Energy radiated at angles higher than the optimum angle is largely lost in space. Radiation at angles lower than the optimum provides weaker signals at the receiving station. For this reason, horizontal directivity along the ground is less important than the horizontal pattern measured at the desired vertical angle of radiation. For example, the horizontal radiation pattern as measured on the ground is considerably different from the pattern in the horizontal plane which would be obtained at a vertical angle of 30 degrees. A still greater difference from the pattern azimuth characteristic will be obtained at a vertical angle of 60 degrees as in figure 4-10.

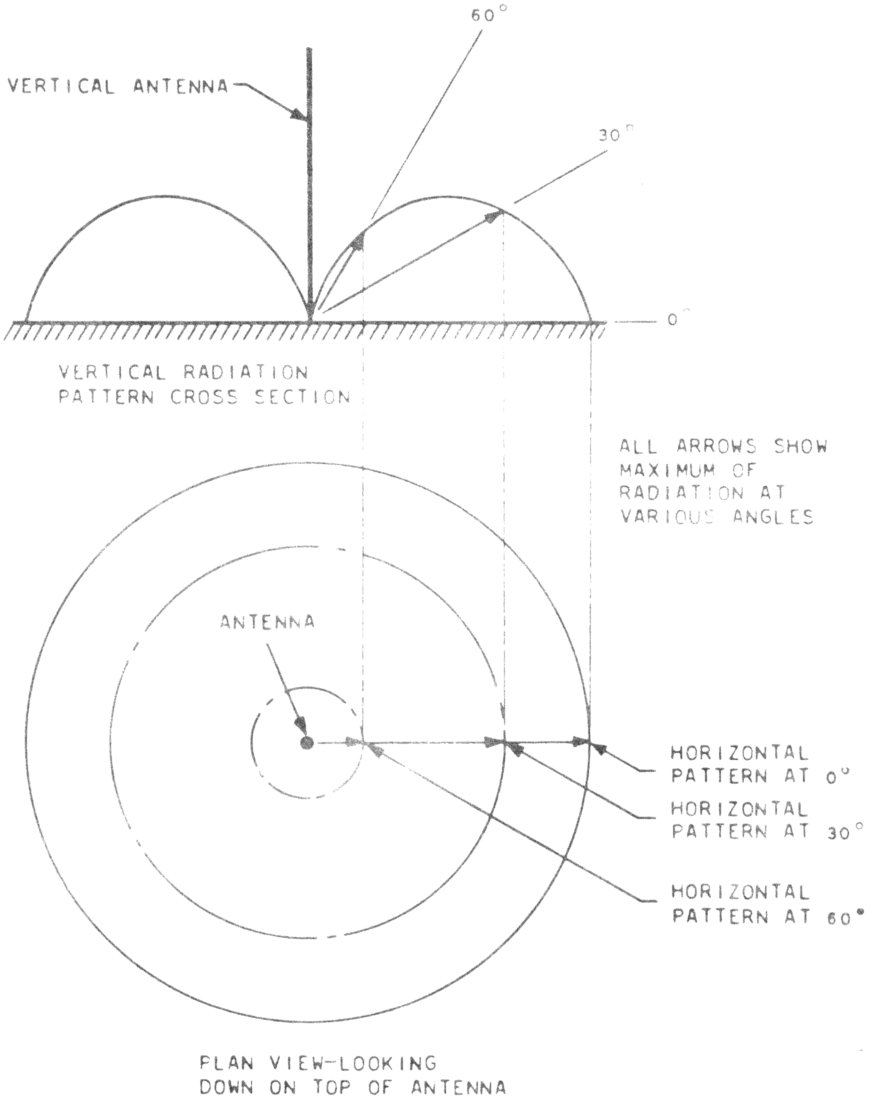


Figure 4-10

In general, radiation at an angle of approximately 30 degrees above the horizon is most effective for fairly long-distance communication on frequencies between 3 and 8 megahertz. The energy radiated at angles greater than 30 degrees above the earth at these frequencies is effective when short distance communication (short skip), out to a few hundred miles is desired. These conditions are illustrated in figure 1-29, chapter 1.

For operation on the higher frequencies, from 8 to 30 megahertz, the most effective angle of radiation for any kind of antenna is usaully between 10 and 15 degrees above the horizon. Communication over path lengths of thousands of miles is possible on these higher frequencies, usually by means of multiple-hop transmission, as illustrated in figure 1-30 of chapter 1.

The height of an antenna above ground is the controlling factor in determining its vertical radiation pattern. The orientation in the compass direction of the antenna determines its horizontal directivity. These considerations are therefore important in selecting frequencies and antennas for dependable communication.

In general, vertical antennas are good for long-distance communication because their radiation is directed at low angles with respect to the horizon. Vertical antennas however, require good ground systems if they are to be efficient, unless, like loops, they are of special design. In addition, their use at frequencies below 8 megahertz is not recommended when short communication paths (up to a few hundred miles) are involved because vertical antennas do not furnish the high-angle radiation required for these paths. The horizontal antenna, by contrast, is better suited for relatively short distance sky-wave communication because of its good radiation at high vertical angles. (See figure 1-15 in chapter 1).

While most antennas consist of an appropriate length of straight wire, it is frequently necessary to use bent antennas for portable operations. Some of these antennas are shown in figure 4-11. The loop antenna previously discussed is a special form of the bent antenna. When it is necessary to bend an antenna wire to get it into the space available, the wire should not be kinked or bent sharply but should make a fairly smooth change from one direction to another. Sometimes this may be done by taping it against a curved surface, or by forming it into a curve if it is mounted on a wall or under a rug.

If the wire is supported in the air, it should be supported from at least two points along the curved section. In any event, sharp bends should be avoided. Unnecessary stress, which may cause the wire to stretch or change diameter, should be avoided since such variations cause a serious increase in the electrical resistance.

When bent antennas are used, it is important that the operator visualize the current distribution of the radio frequency wave on the wire. This may be determined by remembering that the radio frequency current will always be a minimum at the insulated ends of the wire. This fact provides a good starting point to determine the current distribution of a radio frequency wave on any antenna. The current will always be a maximum at the center of an ungrounded system, and this fact can often be of assistance in handling the antenna installation.

In general, the greatest radiation takes place from that portion of the wire where the current is a maximum. For this reason, the operator should make every effort to keep the wire in the clear at these points. Some typical current distributions on bent antennas are indicated in figures 4-12A, 4-12B, and 4-12C.

Since the Marconi antenna is only a quarter-wavelength long, and the current must be a minimum at its free end, the current will be a maximum one-quarter wave-length away, that is, at the feed point. The operator must also remember that when a high current feed point is used, losses due to ground resistance become very important. Care should therefore be

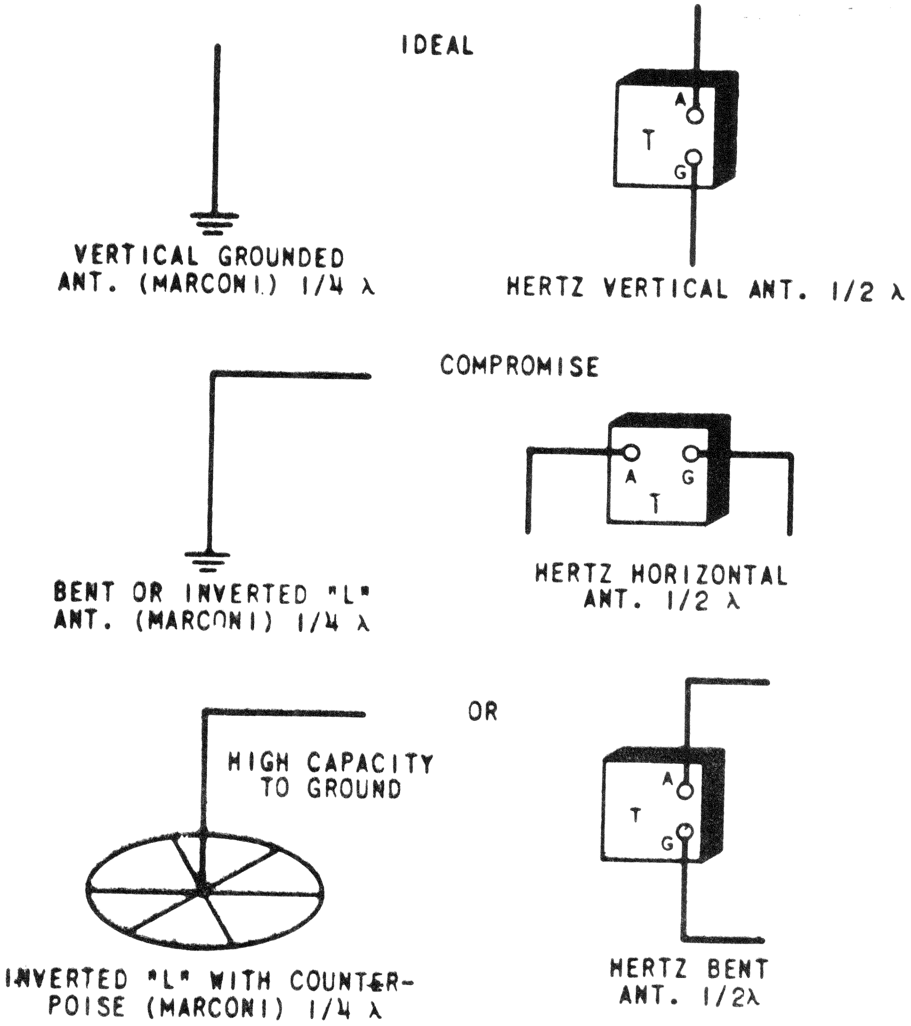


Figure 4-11

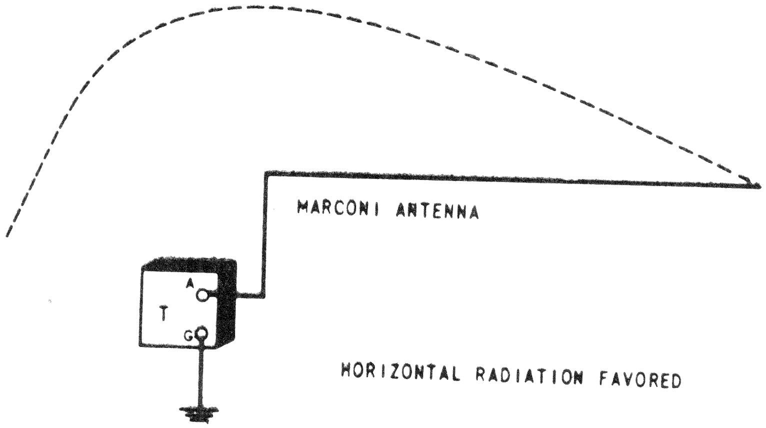


Figure 4-12A

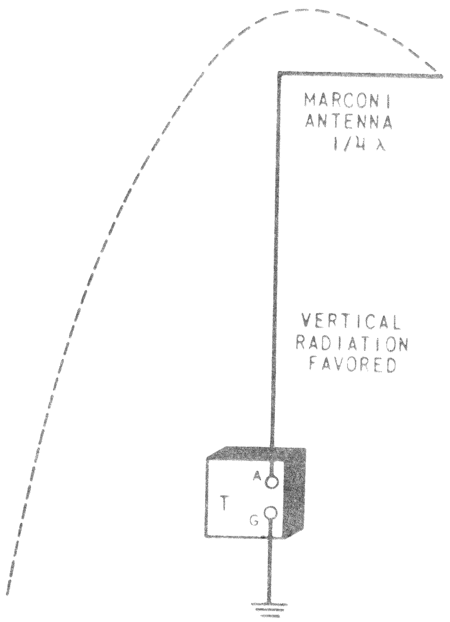


Figure 4-12B

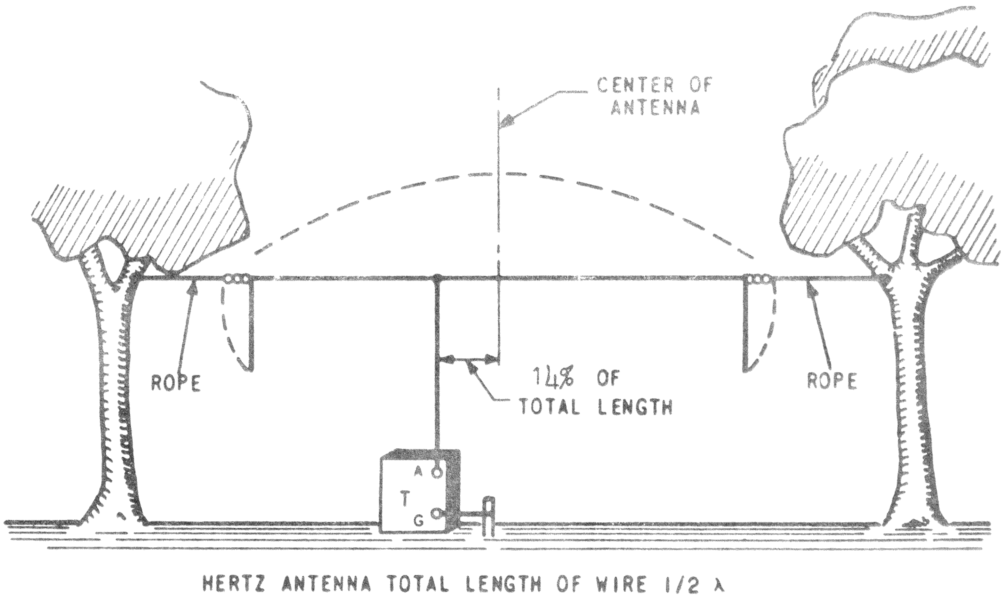


Figure 4-12C

exercised to see that the wire is not deformed or stressed, and that good ground connections are made to provide the lowest resistance possible, (NOTE: When high current feed is being used, an incandescent bulb such as a flashlight bulb, in series with the antenna lead is a useful resonance indicator. It will glow brightly when the antenna is properly loaded).

While bent antennas radiate both vertically and horizontally polarized waves, the predominant polarization is determined by the longest section of the wire. For example, in figure 4-12A, the antenna will have a strong horizontally polarized component, while the antenna shown in figure 4-12B will have predominantly vertically polarized radiation. If the amount of bending is kept to a minimum, the efficiency of the antenna will not be decreased appreciably. This is illustrated in figure 4-12C which shows that the current toward the ends of the wire is small compared to the current along the center portion of the antenna. This knowledge is useful in concealing antennas and in utilizing trees or other supports which are not quite as far apart as they should be for the most efficient type of installation.

4.5 COUPLING THE ANTENNA TO THE TRANSMITTER.

The antenna is the last link in the chain of transmission over which the operator has control. The purpose of the antenna is to effectively radiate the signal to the receiving location. To function properly, the antenna should draw the maximum possible energy from the transmitter. This can be achieved by proper coupling and matching of the antenna to the transmitter.

To obtain adequate antenna efficiency, the antenna's impedance must be matched to that of the transmitter's output circuit. When impedances are matched, the efficiency of the antenna will be high because it will be handling the maximum current that the transmitter can supply to it.

Since the antenna usually cannot be attached directly to the transmitter, it is necessary to transmit the power to the antenna through a transmission line. Each type of transmission line has a characteristic impedance; common values are 52, 75, 300, 600 ohms.

When the output impedance of the transmitter matches the characteristic impedance of the transmission line, the transfer of power from transmitter to line occurs with a minimum of loss. A mismatch of impedance at this point causes poor transfer of power into the line, and causes reflection of power back into the transmitter that can often cause overheating and burnout.

When the transmission line has been matched to the transmitter and is terminated in an antenna that matches the line's characteristic impedance, the line transfers maximum power into the antenna. Under these conditions the line is said to be flat--it is nonresonant. There are no reflections and no standing waves. When it is fed by a flat transmission line, the antenna is receiving maximum current and radiating very efficiently--the transmission line is not radiating.

When receiving, the proper transfer of signal energy from the antenna to the receiver requires the same careful attention to impedance matching. In the case of transceivers, the use of a common antenna frequently eliminates the receiving problem when the line and the antenna are matched for efficient transmission.

Resonant transmission lines are not used as antenna feedlines with tactical equipment. They sometimes radiate energy that should be radiated only from the antenna. Reflection of energy within the line can cause serious losses and destroy the efficiency of the system.

The impedance of a half-wave antenna varies from approximately 73 ohms at the center to approximately 2500 ohms on each end. The output impedance of the transmitter is variablc between certain limits by the use of a matching network within the transmitter being used. Transmission lines have different characteristic impedances according to the type being used. Three basic types of transmission lines are coaxial cable, twisted pair, and single wire.

Coaxial cable (concentric) consists of one conductor inside another conductor separated by an insulating material (dialectric). (See figure 4-13.) Flexible coaxial lines are made of a solid or stranded inner conductor surrounded by by a braided outer conductor (shield). The two conductors are separated by a dialectric and the entire cable covered by some type of insulation. The ratio between the inside diameter of the outer conductor and the outside diameter of the inner conductor determines the characteristic impedance of the line, and the conductors are manufactured to meet specific requirements. Coaxial lines are generally used for connection at low-impedance feed points on the antenna such as the center of a half-wave antenna. Before using coaxial cable, insure the impedance is known and that it matches the transmitter output impedance and the impedance at the point of feed on the antenna. When hooking up coaxial cable to a transmitter, the center conductor is connected to the antenna terminal, and the outer conductor is connected to the ground terminal. No counterpoise or ground is required to complete the antenna circuit. The main advantage of coaxial cable is its shield, which prevents radiation and insures maximum transfer of power to the antenna. The shield also prevents the transmission line from picking up stray interference. The main disadvantages are its weight, availability, and difficulty to repair in the field.

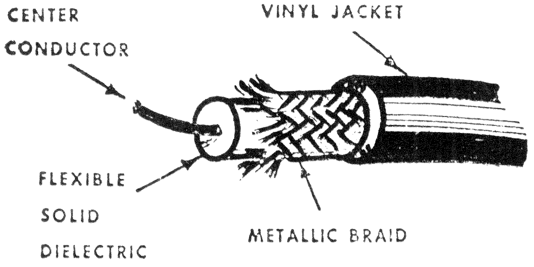


Figure 4-13

Twisted pair transmission line consists of two insulated conductors twisted together to form a pair, such as lamp cord or field telephone wire. (See figure 4-14.) The characteristic impedance of a twisted pair line is approximately 70-80 ohms, which makes it a good field expedient for feeding a half-wave doublet. The main advantage of twisted pair is its availability in the field and ease of construction. The main disadvantage is the high-line loss associated with it. When hooking up twisted pair to HF antennas, either conductor may be connected to the antenna or ground terminal on the transmitter, however, if used with VHF antennas such as a ground plane, the conductor which is connected to the vertical radiating element must be connected to the antenna terminal on the transmitter.

Figure 4-14

The single wire feeder is, as the name implies, a single conductor, which may be insulated or bare. The characteristic impedance of this line is from 500-600 ohms. The point on the half wave antenna which will match this impedance is approximately 36 percent from the end of the antenna, or 14 percent from the center. A precaution to observe when using a single-wire feeded is to keep it at right angles to the antenna for at least 1/3 wavelength. This prevents antenna coupling to the line. The main advantage of the single wire feeder is its availability and ease of construction. The main disadvantages are that it requires a highly conductive ground return circuit or good counterpoise, and the radiation losses are high, since there is no other conductor to cancel its radiation field. The single-wire feeder is connected to the antenna terminal, and the ground terminal on the transmitter is connected to a counterpoise or good earth ground.

Good results can be achieved if the following basic rules are followed when connecting transmission lines.

1. Select a transmission line which matches both the transmitter and the antenna.
2. Keep the line at right angles to the antenna.
3. Keep the line as short as possible.
4. When the line is part of the antenna, as with a long wire or inverted "L," the line must come straight from the antenna to the transmitter and not come in contact with trees, supports, ground, etc.

4.6 TWO WIDE-RANGE ANTENNAS.

If we measure the input impedance at the end of a 35 ft. slant-wire antenna, we find that the resistance and reactance vary widely at different frequencies. An example of such an antenna is shown in figure 4-15.

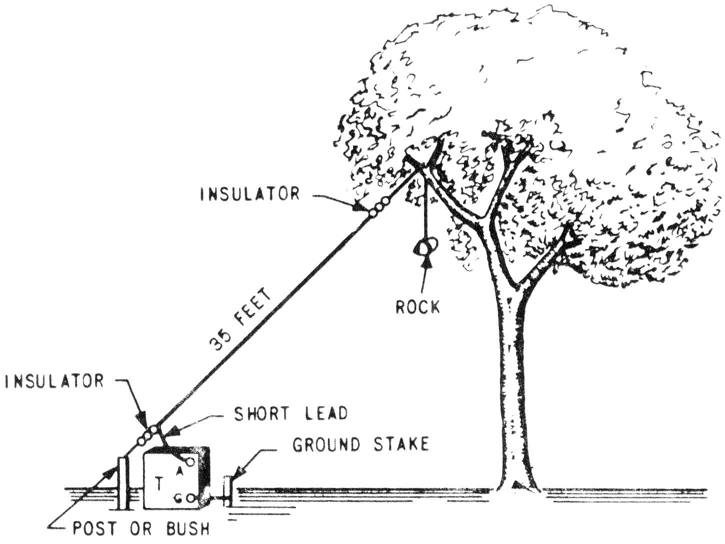


Figure 4-15

Whenever the values can be transformed by the coupling and matching networks, the antenna can be efficiently matched to the transmitter. However, there are certain frequencies at which a network ceases to function properly since too great an impedance transformation is required. As this limit is approached, the network absorbs power and is critical to use. However, an antenna of this type can be used over a wide range of frequencies, as long as operation near the critical half-wave and full-wave points is avoided.

Figure 4-16 shows another type of antenna known as an "L." This particular example has two 25-foot legs. This antenna can also be fed satisfactorily over a wide frequency range and has unusable frequencies different from the slant-wire antenna.

The usable and unusable frequency ranges for the two antennas discussed above are plotted in figure 4-17. A comparison shows that in most cases where one antenna ceases to function properly the other can be used successfully.

Thus a match can be achieved for almost any frequency by using the proper type antenna. The antennas treated in this section can be viewed as simple compromise antennas which may be used under a wide variety of conditions. The burden of achieving a resonant system is placed upon the transmitter-matching unit which tends to involve greater losses. However, these antennas are quite good on the higher frequencies above 7 megahertz when their lengths are greater than a quarter-wavelength.

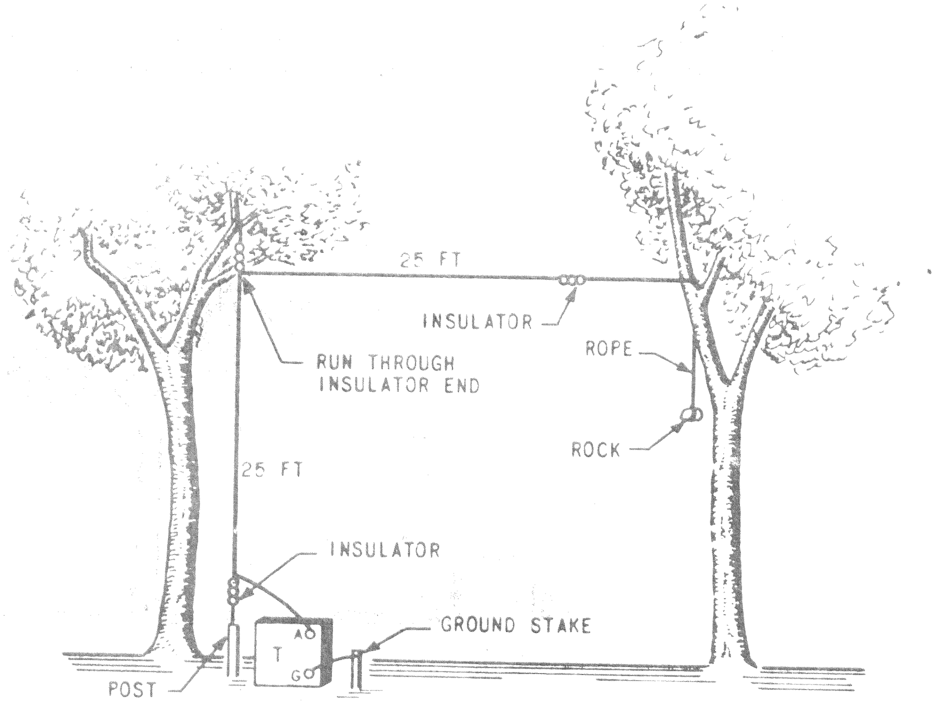


Figure 4-16

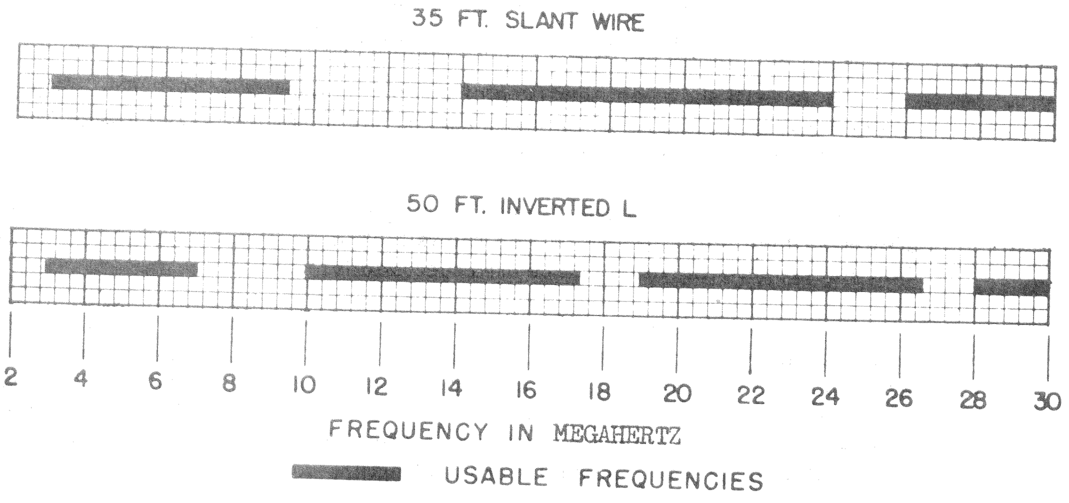


Figure 4-17

The operator must always remember to retune the transmitter output circuit for maximum indication each time a new setup is made. Even if this involves a change in frequency of the transmitter only, and no change in the antenna itself, this final step must never be omitted.

4.7 OTHER VARIETIES OF SIMPLE ANTENNAS.

The antennas previously discussed have been made up of one-fourth, one-half, or one wavelength wires. There exists, in addition, a group of end-fed antennas which deserve careful consideration. These are termed long wire antennas and have dimensions greater than one wavelength. Where space permits, long-wire antennas have several advantages over shorter antennas. Because of their greater length, they have a power gain compared to the half-wavelength antennas.

The strength of the radio signal produced at a distance is influenced by the effective radiating area of the transmitting source. Where this effective radiating area is increased by the use of longer wires, a given transmitter provides stronger signals at greater distances. Figure 4-16 shows how the gain of an antenna increases with the length of the radiating wire in wavelengths. It also indicates how the direction of the maximum power lobe changes as the antenna is lengthened.

For example, a four-wavelength antenna doubles the effective power of the transmitter. Similarly, for a four-wavelength wire, the angle of the radiation with respect to the wire is about 25 degrees. As has been stressed, this is of great importance in orienting the antenna in the proper direction. To provide optimum communication in the desired direction, correct orientation must be observed.

Since the vertical pattern of an antenna is affected by the height of the antenna, it is advisable to keep long wires at least 25 feet above ground. To achieve best results, the antenna should be oriented at an angle determined by its length as discussed above, and the bearing on a great circle route to the base station. For example, if the bearing along the great circle propagation path from the transmitter is 205 degrees, the four-wavelength antenna wire should be led out from the transmitter at 205 degrees plus or minus 25 degrees (230 or 180 degrees). (See figure 4-18.)

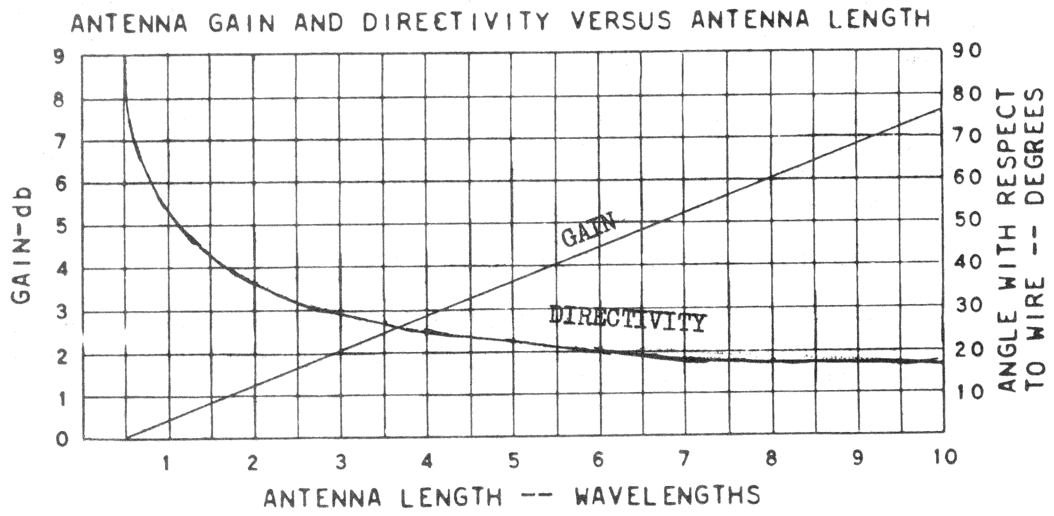


Figure 4-18

The slant-wire or tilted antenna is frequently the simplest type of antenna to install and provides a good combination of vertical and horizontal directivity. Figure 4-19 shows a slant-wire antenna which may be fed from either the ground or the elevated end.

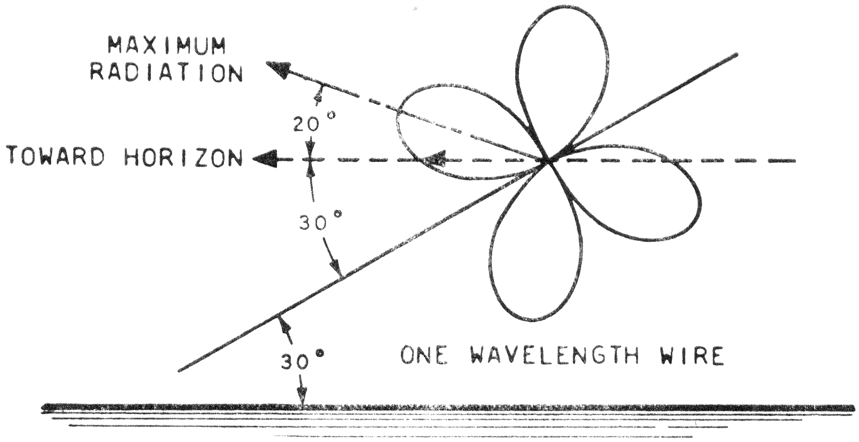


Figure 4-19

The wire selected should be approximately one wave-length long, but differing from this exact dimension by 10 to 15 percent. The antenna should make an angle of about 30 degrees with the earth.

As illustrated in the figure, operation under these conditions provides good, low-angle radiation. The horizontal directivity will be a maximum in the direction in which the wire slopes from top to bottom. For example, if the operator were to be located in the upper floor of a windmill structure, the wire could be excited from the upper floor and run downward to a fence post or small stake which is in line with the base station. The low end of the wire could be connected to an insulator which is guyed 6 to 10 feet (2-3 meters) above ground level.

Opportunities may arise in which the operator can employ a version of the slant-wire antenna, termed the inverted "V." This antenna is arranged as shown in figure 4-20. The angular dimensions shown should be observed.

The wire length used in the inverted "V" antenna is about two wavelengths. The antenna is highest above the ground at its center point, and can be excited at one end as shown. It will tend to be bidirectional in the plane of the wire. Gain is achieved by virtue of in-phase addition of the radiating lobes.

4.8 CONSTRUCTION OF ANTENNAS — GENERAL.

In later chapters, particular attention will be given to installation of antennas in specific city and rural locations. However, construction practices common to almost all antenna systems will be considered in this section.

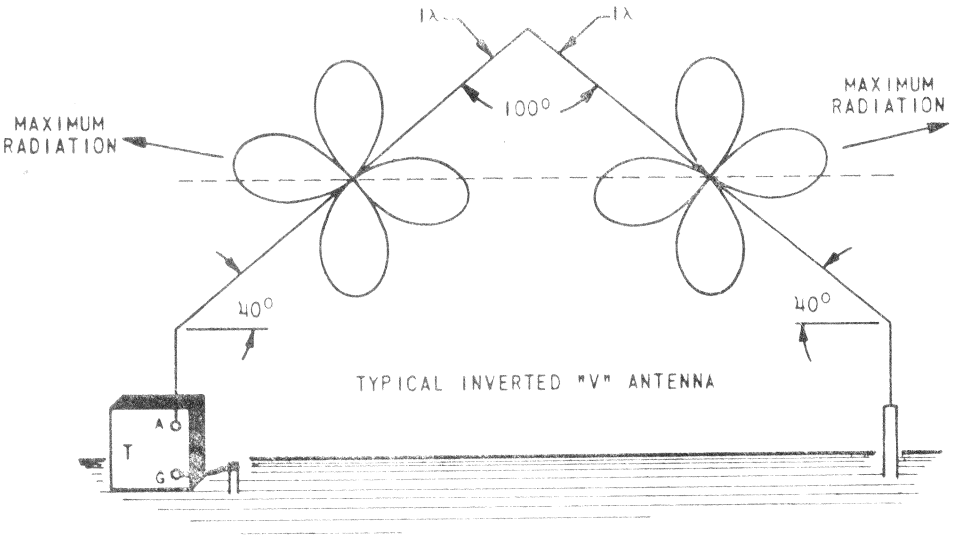


Figure 4-20

The proposed site of the operation should be examined for possible antenna supports and transmitter operating locations. The direction of the base station should be used as the basis for making these selections. Some compromise can be made where necessary by bending the end of the antenna, although in general, it should never be bent more than 90 degrees, and the major length of wire must have the required orientation.

When the bearing toward the base station has been determined, a suitable type of antenna must be selected. Let us assume that a simple end-fed wire appears to be best for the particular situation. The length of the wire will depend on the frequency of transmission. Using the charts and graphs supplied, the operator should select the best length of wire for the physical conditions and operating frequency. The wire may be measured, cut, and the insulators attached before the operator arrives at the transmitter location if desired, so that the antenna may be erected in a minimum of time.

A slant-wire may be installed rapidly by using a tree as an end support. The leader or twine beyond the insulator at the end of an antenna may be tied to a stone and thrown high into the branches of a convenient tree as in figure 4-21.

The next problem is that of a good ground connection. The grounding techniques described in chapter 3 should be reviewed and an appropriate system selected. In many instances, particularly in urban locations, water pipe or other existing grounds may be the most practical to use.

Anything which rises above the ground to the necessary height can be considered for an antenna support. Trees, poles, roof eaves, spouts, silos, and even sand dunes in desert areas can serve to hold up one end of an antenna. As a last resort, a 50-foot length of wire may be laid on the desert sand if the actual ground is at least 5 feet below the blow-sand surface. Since such an installation is at best questionable, and would normally be used in an area containing sand dunes, the sand dune supported antenna will give much better results. When the problem of concealing an antenna is of primary importance, it is often advisable to use existing supports rather than put up a new structure which may draw attention.

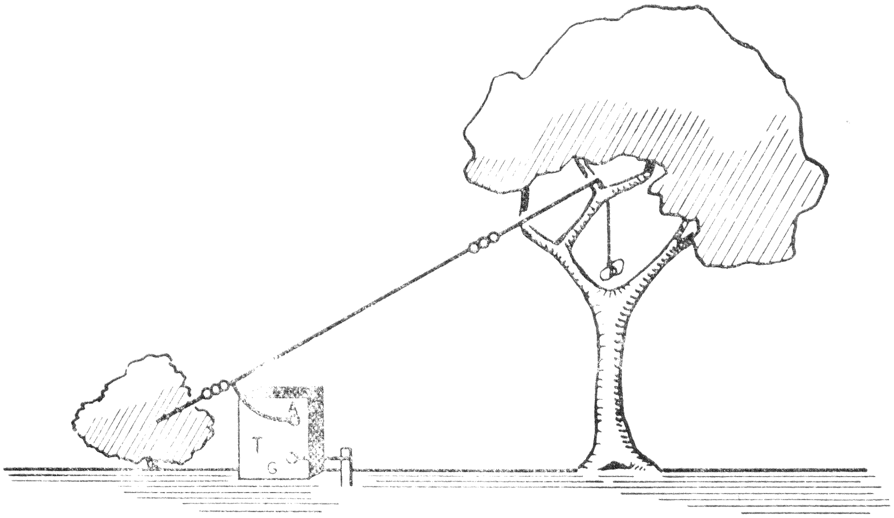


Figure 4-21

There are several devices which may provide a starting point. In many areas buildings are protected by lightning rods which may be used as vertical radiators when properly modified. Such antennas are inconspicuous and usually clear of surrounding objects. The technique suggested for using a lightning rod system is to break the ground connection and insert the transmitter between the ground and the down lead from the chimney or roof top. This will usually provide a usable vertical or inverted "L" antenna.

Another antenna structure available in some areas is the rainspout or gutter. By isolating this metal structure from the ground the operator may simulate a vertical, horizontal, or bent antenna.

Inside houses, room trim or furnishings may serve to conceal the antenna if cut to proper length. Curtain rods or valances can be used to hide the antenna, or if properly connected together, may be used as a part of the antenna. As these structures are a small fraction of a wave-length, loading coils may be necessary to construct a workable makeshift antenna.

In some areas existing antenna structures, normally employed for receiving purposes, may be transformed into transmitting antennas by a few simple steps. Low frequency, FM, and TV antennas may be modified to serve well as transmitting antennas.

The windmills found in certain countries may be converted into antennas or used as antenna supports. Some types of windmills are suitable for concealing both operator and antenna.

In some areas it may be feasible to disguise an antenna as an ordinary telephone or power wire, but it is not good practice to place an antenna too close to existing lines. It should be remembered that maintenance by service personnel could result in discovery of a semipermanent antenna installation.

The size of wire actually used in the radiating system may vary from time to time. The standard wire furnished with the transmitter is of course recommended. Any wire from metal tape to relatively fine wire approaching heavy darning thread in size will usually function satisfactorily. The use of very fine copper wire, however, is not recommended since its tensile strength is not very great and it may easily pull apart. When relatively fine wire is employed, considerable attention must be given to providing adequate support. When over 50 feet of such wire is used, danger of sag and breakage exists.

Where a connection between one length of wire and another, or between wire and grounding metals is made, the wires should be soldered if at all possible. Wires to be soldered must be thoroughly cleaned and shined by scraping with a knife or sandpaper. Rosin core solder is recommended to avoid oxidation of the heated surfaces.

Insufficient heat at the junction of the wires may result in a high-resistance rosin joint. Conversely, if too much heat is applied to small diameter wire, its low-resistance property may be lost. The soldering iron tip should be placed on the junction of the two metals to be joined to bring them to proper soldering temperature before solder is allowed to flow onto the surface. While a small amount of solder may be placed on a well-tinned iron to increase the efficiency of heat transfer to the joint, the final step should be to apply the solder to the joint and not to the iron itself. At the proper joint temperature, the solder will flow and replace the preliminary rosin chemical cleaning action, and a good joint will be formed.

Where considerable physical stress is present on the antenna wires, it is important to have a good mechanical as well as electrical joint. Solder is not mechanically strong since it contains so much lead. In making joints, therefore, it is best to first make the best mechanical joint possible without soldering, and then add solder as described above for electrical contact. Figure 4-22 shows several examples of how to make a good mechanical joint and how to avoid a poor one. It must be borne in mind that copper wire is relatively soft and will break when subjected to continued bending. The joint, however, must not be made so rigid that all of the stress is concentrated in a very small region.

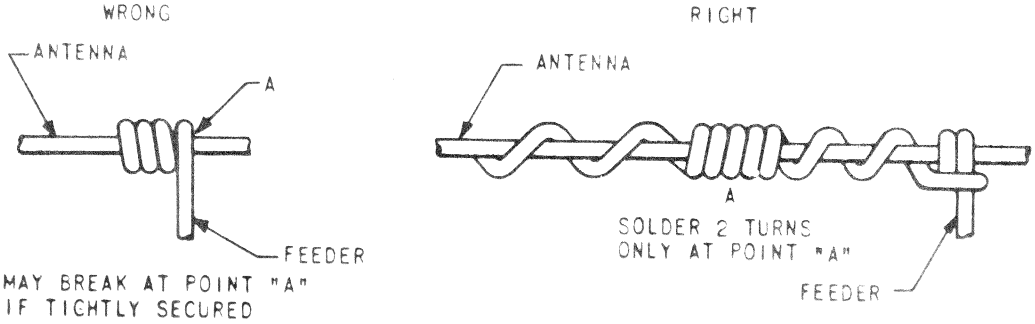
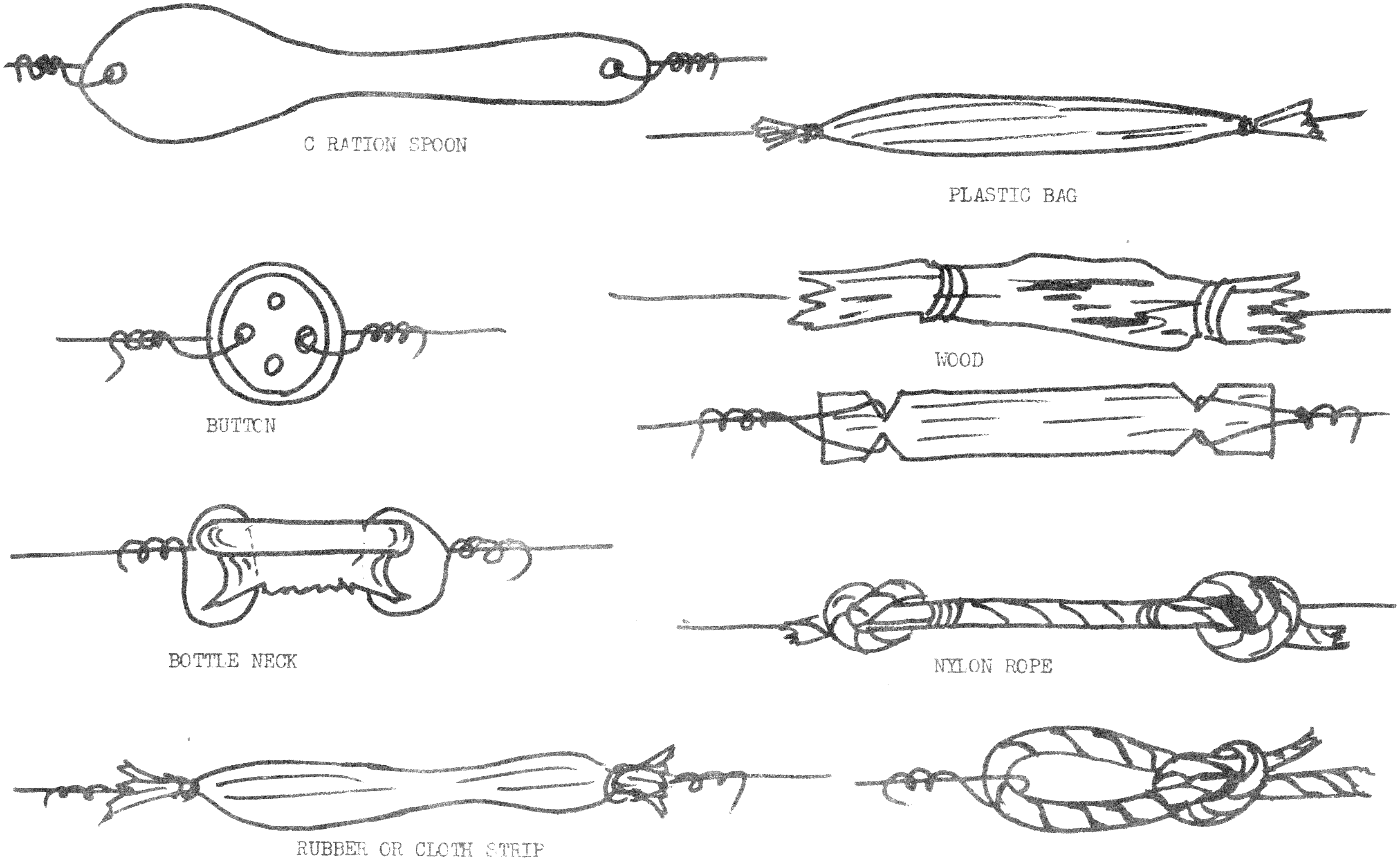


Figure 4-22

Connections to waterspouts or metal surfaces may often be made with the aid of self-tapping metal screws. The screw and the surface to be tapped should be thoroughly cleaned. The end of the wire may then be wrapped around the screw and clamped between its head and the clean metal surface.

Figure 4-23 shows several ways in which the end of an antenna wire may be insulated. Any sturdy, dry, insulating material may be used to support the antenna.

EXPEDIENT INSULATORS



BEST: PLASTIC, GLASS GOOD: WOOD FAIR: CLOTH, ROPE

FIGURE 4-23

CHAPTER 5

INDOOR ANTENNAS IN CITIES

5.1 INTRODUCTION.

The first four chapters have provided the reader with a general background in radio-wave propagation and antenna theory. The next four chapters will deal with specific antennas and specific environments. In each case several possible antennas will be described to illustrate the technique of applying antenna theory to specific situations. These situations describe actions that may be taken by a radio operator establishing communication with his home or base station.

5.2 INDOOR ANTENNA CONSIDERATIONS.

Certain basic principles govern the operation of indoor antennas. The radiation pattern of an indoor antenna will be affected by building walls, wiring, and plumbing. Furthermore, all building materials absorb some of the signal energy which is lost for communication purposes. Certain types of buildings, we shall see, absorb so much r-f energy that operation within them is impractical.

The operator should always try to put his indoor antenna at the side of the building toward his base station; i.e., if the base station lies to the south, the operator should use rooms on the south side of any building in which he may be operating. Similarly, where multistory structures are involved, the operator should occupy the top floor of the building whenever possible. Every effort should be made to obtain a room located higher than other buildings in the immediate vicinity. Locations on alleys, elevator shafts, or small indoor courts are not desirable.

Recent studies and measurements have shown that, in the 3 to 30 megahertz frequency range, wood, thatch, brick, cement block, tile, and plaster building materials do not seriously attenuate radio signals. Successful operation in buildings made of these materials is entirely feasible, although building wiring may distort the normal radiation pattern of the antenna. On the other hand, the operator should avoid attempting to operate from buildings constructed with metal walls, reinforced concrete, and plaster with metal lath.

The operator should make a preliminary inspection of any building from which he proposes to operate to see if metal reinforcement is present. This can be done in the basement, or by prying up capstones at the top of a building wall. If metal is found, the building is probably reinforced and should be avoided unless the window openings are very large.

Metal lath may be detected very rapidly by three methods. The wall can be checked by sliding a magnet along the plaster. If it pulls toward the wall in certain places the wall contains metal. If no magnet is available, a small hole may be cut in the plaster and the material beneath examined. The compass used by the operator to find the bearing to his station can be moved slowly along a wall to check for metal reinforcement. If the compass point deflects from its normal direction as it is moved, metal is probably present.

The operator should test his antenna arrangement while receiving. Amateur or broadcast stations from various countries may be used as a relative guide to check antenna orientation and efficiency. This is particularly important in large buildings where physical heights above ground, combined with the effects of building wiring make radiation patterns unpredictable.

5.3 INSTALLATION OF INDOOR ANTENNAS.

In selecting an antenna site within a building a four-step procedure must be followed.

(1) Make sure the building walls are not constructed of reinforced concrete or metal lath.

(2) Determine the bearing to the base station.

(3) Determine which antennas will fit in the room or rooms available and consider each antenna's pattern.

(4) Select the antenna which appears to have the best characteristics for the problem involved, then build it.

Figure 5-1 shows how an antenna may be stretched through doorways and adjacent rooms for greater length. In a single room, some bending of the wire can be tolerated in order to secure an efficient length, as shown in figure 5-2.

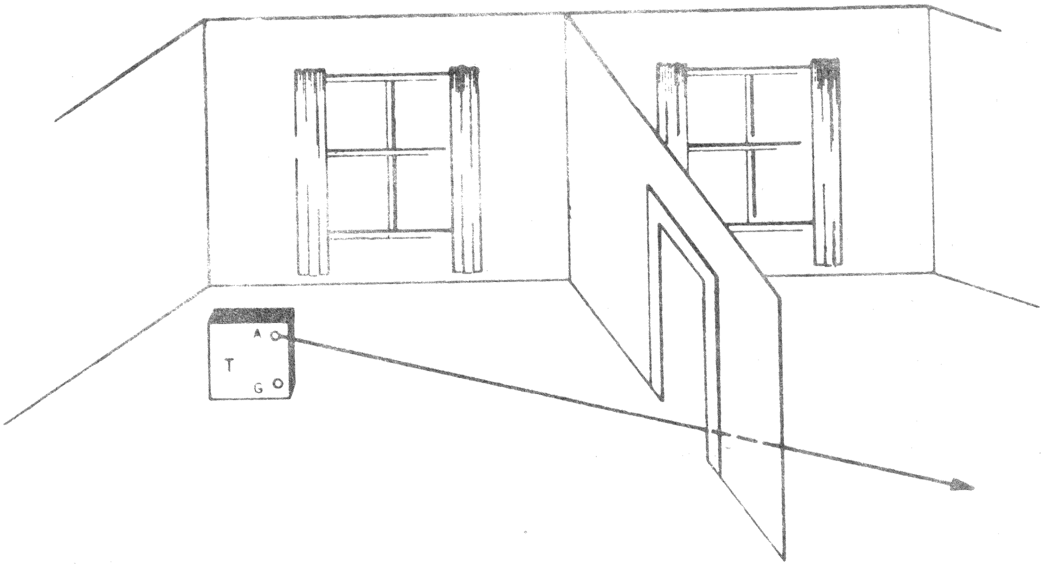


Figure 5-1

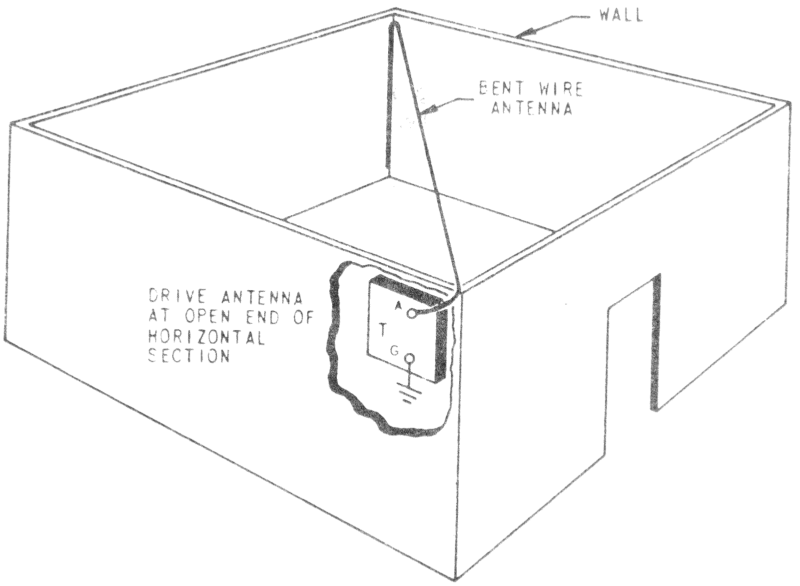


Figure 5-2

In a very small room the antenna can be run around the molding, as in figure 5-3. The best solution in this room however, would be a loop antenna, with proper orientation determined by the feed point of the transmitter.

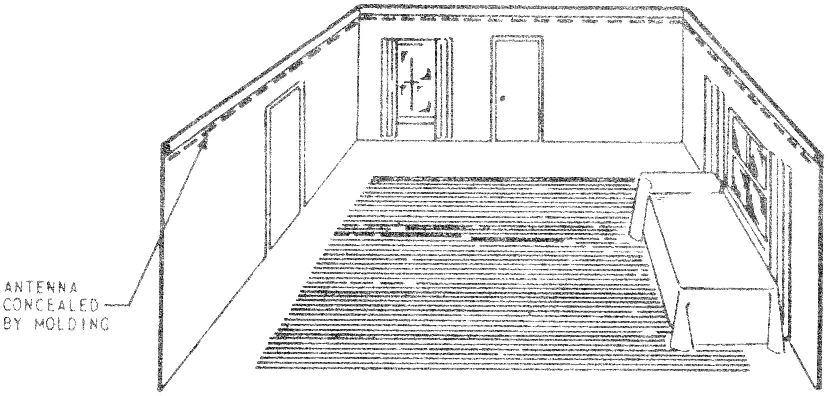


Figure 5-3

The operator should keep in mind that the high-current portions of the antenna do most of the radiating. The effects from bending can be made quite minor if directivity and radiation are based on the position of the long straight portion of the wire.

Grounding indoor installations usually presents a problem. However, since most office, hotel, and residence buildings have running water, the cold water pipe should normally provide a satisfactory ground. In addition any large mass of metal (with its inherently high capacity to the earth) may be used. Typical makeshift grounds include bed springs, file cabinets, window screens placed on the floor parallel to the earth, air conditioning or heating ducts, piping, or metal furniture. As a last resort a scrambled wire ground, consisting of wire spread out on the floor beneath the ground terminal of the transmitter may be used. This wire should be at least as long as the antenna.

In many buildings, space between the ceiling of the top floor and the roof may be available. In a wooden building, an antenna may be concealed between the boards and bearing studs or along roof rafters as in figure 5-4. Sometimes the wire can be placed on top of the roof if color or line contrast which would make the wire obvious is avoided. The down lead may be brought in behind spouting, as indicated in figure 5-5, and connected to the transmitter inside the room.

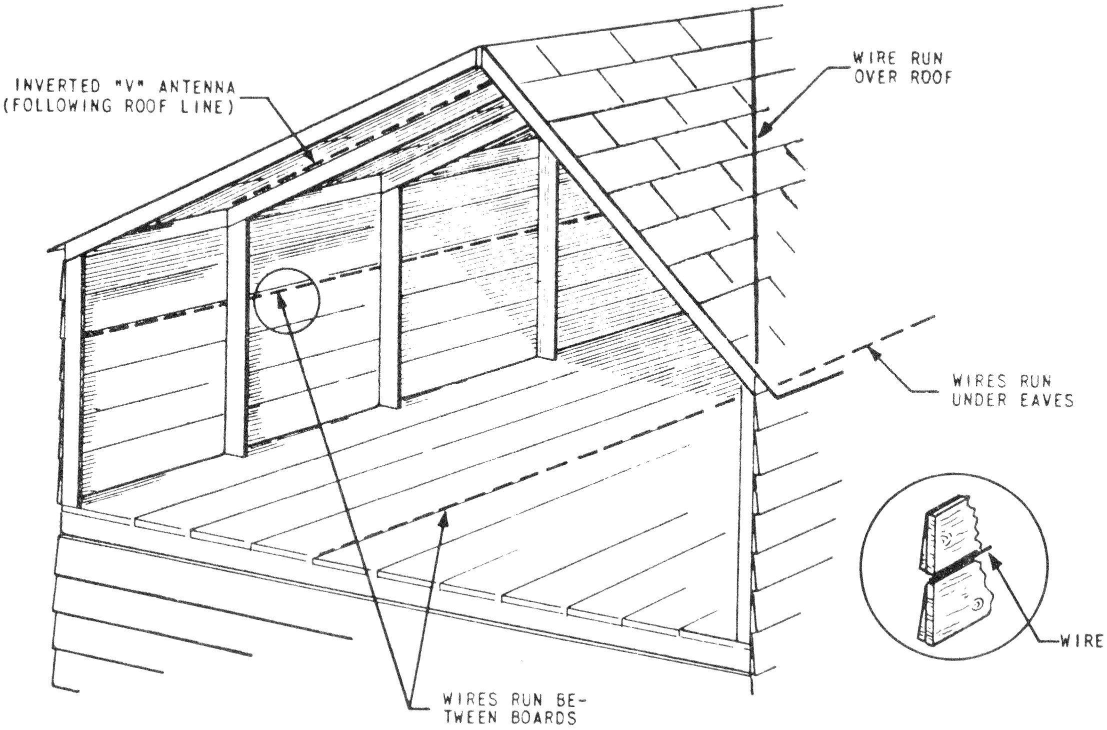


Figure 5-4

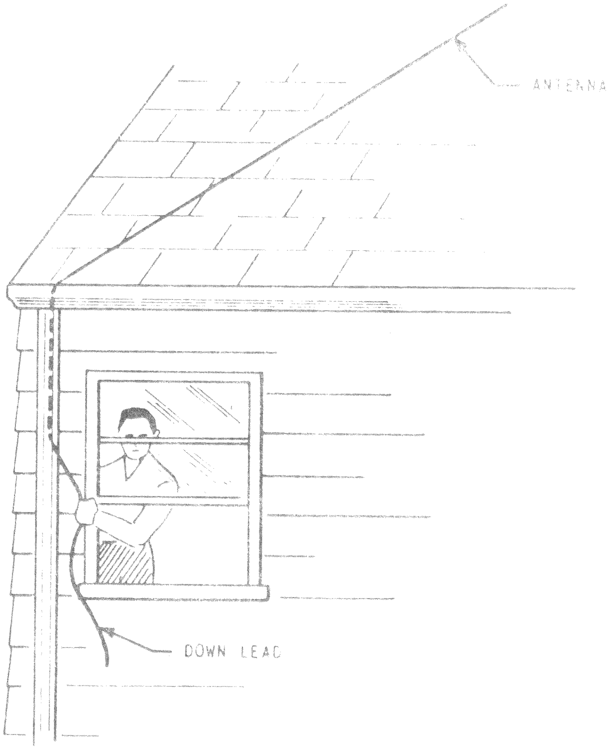


Figure 5-5

Other antenna configurations are suggested in figure 5-6. The antenna selection will depend upon the radio frequency assigned and the amount of space available. Dry wood is a fairly good insulator, and the wire may be attached with staples or short loops of dry string.

In smaller houses, the antenna may be installed as shown in figure 5-7. The transmitter can be installed in the basement of the house or on the ground floor level for ease in grounding. The operator must make sure that the stairway used runs in the direction of his base station.

Antennas installed in basements are too close to the ground to radiate well and should not be used except as a last resort. Their high-angle radiation however, is sometimes effective for short distances (100-500 miles). If a basement antenna is constructed, extreme care should be given to details of antenna length, orientation, and good construction practice.

5.4 SELECTION OF POSSIBLE ANTENNAS.

In selecting possible antennas the operator should not immediately reject all antennas which seem too large for the space available. As described in chapter 4, there are several methods of loading which will allow a short antenna to be resonated at a frequency lower than the natural frequency of the wire. Even with a loading coil, however, the antenna may be so short at low frequencies that it would be an ineffective radiator. A good rule of thumb

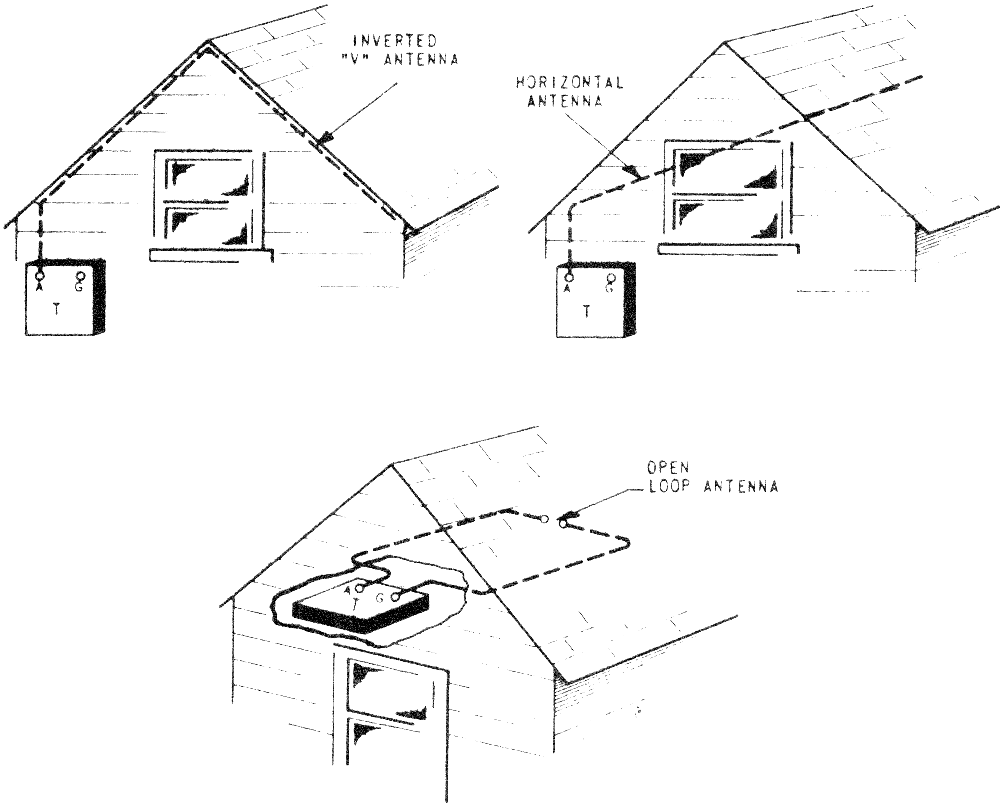

INVERTED "V" ANTENNA
A
G
T
HORIZONTAL ANTENNA
A
G
T
OPEN LOOP ANTENNA
A
T
G

Figure 5-6

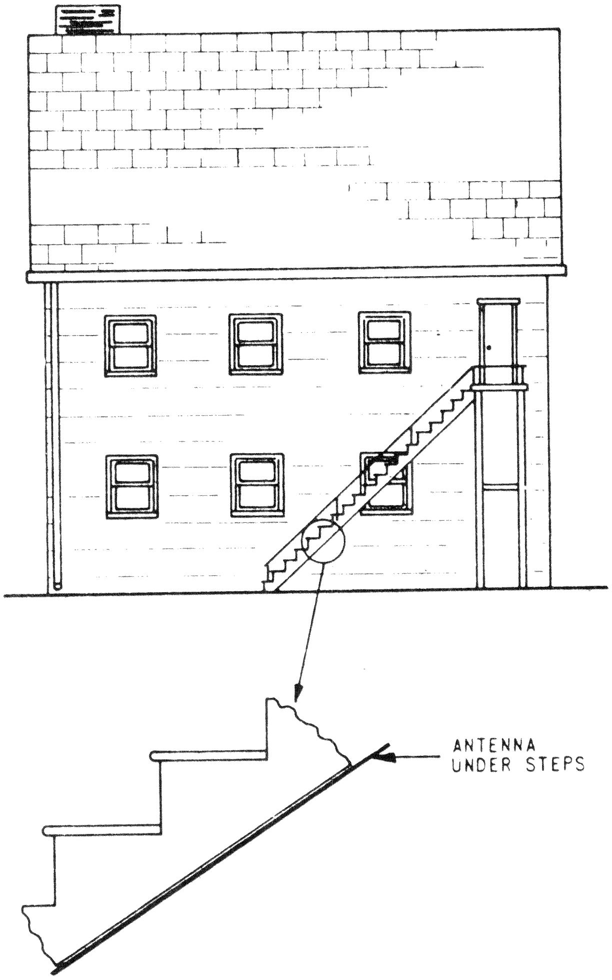


Figure 5-7

is not to operate where the longest dimension of the antenna is less than one-eighth wavelength at the assigned frequency. Thus, with a frequency of 4 megahertz, the operator should not try to use a room smaller than 10 meters long. (See figure 4-1B, chapter 4.) In a room 3 meters on a side, operation below 12 megahertz is not advisable. It should be remembered that the longest dimension available in any room is the diagonal between opposite corners of the room at the floor and ceiling level. Maximum antenna length may be obtained by using this diagonal dimension.

Once a usable room has been found, the operator should determine all possible antenna runs. End fed wires will be best for small, long rooms, and "V" and loop antennas, will be best for square rooms. If the room is large enough, almost any antenna can be erected for all except the very lowest frequencies.

To illustrate the techniques described above, let us assume that the operator has a 31 ft. x 31 ft. room with a 15-foot ceiling. If the direction of the base station is at right angles to the outside wall, the operator should consider using a wire suspended in the room parallel to this wall and located about 6 feet above the floor. With a transmitting frequency of 15 megahertz, a half-wave antenna would be 31 feet long so that the insulators would be placed at the sides of the room and the whole 31-foot dimension used.

After the 31-foot wire is suspended with insulators at each end, a separate vertical wire should be attached between the antenna terminal of the transmitter and a point one-seventh (14 percent) of the total length of the antenna from the center of the wire. Thus, the point of vertical feeder attachment would be 4.3 feet from the center of the wire, or 11.2 feet from the end of the wire. (A half-wave wire should never be fed at the end, due to its high impedance at this point.) The ground terminal of the transmitter should be attached to a cold water pipe or scrambled wire ground. Such an antenna will radiate well at right angles to the run of the wire, and thus meet the requirement for maximum directivity at right angles to the outside wall of the room. The feeder wire should be brought away from the antenna at right angles, and the transmitter and its associated wiring should be kept as far away from the radiating wire as possible.

If no ground is available, the antenna may be center-fed by placing the transmitter in its center supported by stacked tables. The antenna is cut in the exact center, and one end connected to the antenna terminal and the other end to the ground terminal of the transmitter as in figures 4-2E or 4-2F in chapter 4.

When only a 15 ft. x 15 ft. x 15 ft. room is available, the operator may use a slant-wire antenna tipped toward the direction of desired propagation. The end of the antenna toward the base station should be placed at floor level and the opposite end of the antenna placed at ceiling level. The maximum length of wire which could be obtained in this type of installation would be about 1.4 times the width of the room or 21 feet. To simulate a half-wavelength for 15-megahertz operation, it is necessary to make up the remaining 10 feet of antenna. To do this, about 15 feet of wire should be closely wound on an oatmeal box or a newspaper rolled into a cylinder about 4 inches in diameter. This coil is inserted in the center of the antenna and the point of feed from the transmitter made at one end of the coil. The ground terminal of the transmitter should be connected to the nearest cold water pipe or mass of metal. With such a slant-wire antenna the lobe of radiation toward the top of the room is tipped toward the base station and fairly good low-angle radiation is achieved.

On the other hand, the wire may be fed in the center as previously described, with the coil split into two parts and placed near the insulators at each end of the antenna.

Figure 5-8 shows how a horizontally polarized "L" antenna may be used in a 15 ft. x 15 ft. room. The wire should be strung about two-thirds of the way up the wall and kept away from the wall about 6 inches. When the wire is end-fed directly from the antenna terminal of the transmitter, it should not be used at frequencies for which the wire approaches a half-wavelength. The antenna shown has a total length of 33 feet. Figure 4-1B of chapter 4 indicates that such a wire would be suitable for use as a quarter-wave, end-fed antenna for approximately 7.5 megahertz. Actually, it would serve as a fairly good antenna throughout the range of about 5 to 12 megahertz. The ground terminal of the transmitter should be connected to a cold water pipe with the shortest possible ground connection.

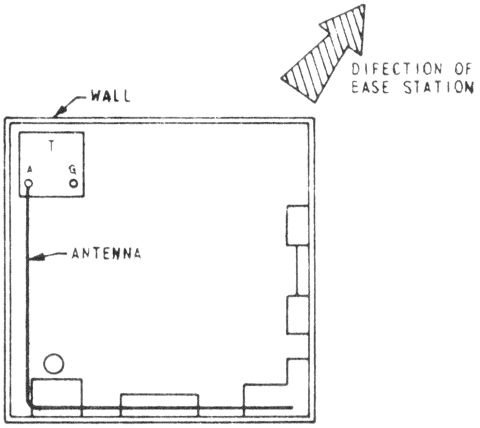


Figure 5-8

If the room opens onto a hallway, the operator has a much wider choice of antennas. For example, the antenna may be run from a low point in the direction of desired transmission out through a door and down the hallway to a point near the ceiling. If possible, the angle of slope should be about 30 degrees to provide the best low-angle radiation. In such a system, the antenna slopes downward toward the transmitter which sould be located at the end toward the base station. In office buildings or other structures having long hallways, the long wire antenna discussed in chapter 4 may be used, providing the hallway points in the general direction of the base station.

The loop antenna described in chapter 4 could also be used in the 15 ft. x 15 ft. room. Since the total length around the loop is 60 feet, it could be used at about 8 megahertz as a half-wave loop, and at 16 megahertz as a full-wave loop. A loop installed parallel to the ceiling will be horizontally polarized, and the main radiation will occur at high angles. Therefore, if a great distace is involved, a vertically mounted loop having a lower radiation angle should be used.

The directive characteristics of these loops have been discussed in chapter 4. For a half-wavelength loop, one side of the loop would start at the antenna terminal of the transmitter, and the other side of the loop would terminate at the ground terminal of the transmitter. No ground would be necessary in this case. The far side of the loop would be open. Directivity considerations as shown in figure 4-3 of chapter 4 would determine the side of the loop in which the transmitter would be inserted.

In a very small room, about 10 ft. x 10 ft. x 12 ft., the lowest usable frequency would be about 12 megahertz. An antenna for this frequency would be a loop constructed in the maximum (diagonal) dimension. It should be remembered that a half-wavelength loop installed perpendicular to the floor will be vertically polarized, an should be fed on one side as shown in figure 5-9.

5.5 CONCEALMENT OF INDOOR ANTENNAS.

By careful installation, indoor clotheslines, drape pulls, and even picture hanging wires may be made to serve as makeshift antennas.

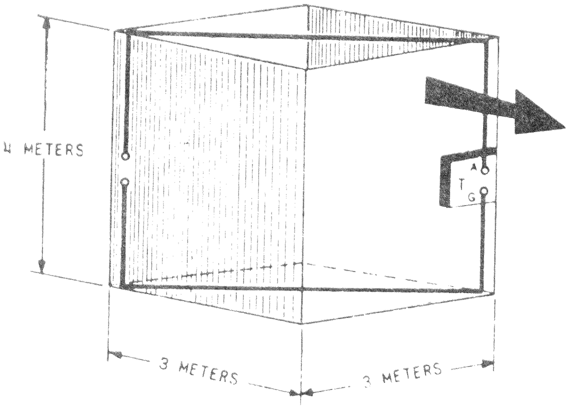


Figure 5-9

Rapid removal of the antenna may be necessary upon occasion and the operator may wish to incorporate quick-disconnect features in his system. Figure 5-10 illustrates a technique in which a weak link is installed between the antenna insulator and the drapery tie-back. When rapid removal is necessary, the weak link may be broken with a snap of the wrist and the antenna put quickly out of sight.

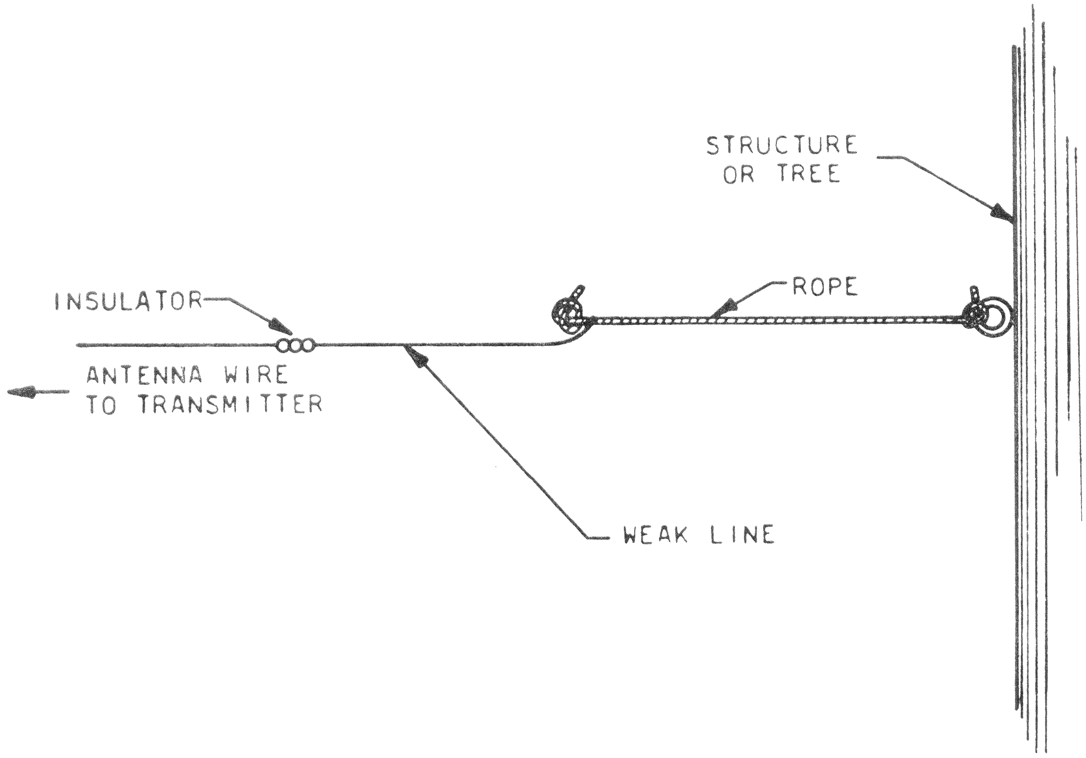


Figure 5-10

Here are a few basic rules regarding concealment:

DO NOT run an antenna near a window unless investigations indicate that it cannot be seen from outside.

DO NOT leave an antenna in an area which is subject to periodic maintenance.

DO try to locate pictures and other wall ornaments so that their hooks can be used for antenna support.

5.6 MISCELLANEOUS CONSIDERATIONS.

The operator must select indoor locations where noise from public transportation such as busses and streetcars is not present. Also to be avoided are locations near service equipment such as elevators, oil burner motors, and pumps which create electrical sparking noise. Where severe noise from any source is encountered, difficulty will be experienced in receiving. Reception may be used as a guide in avoiding poor locations of this sort. In general, a location which is poor for reception of signals will also be poor for transmitting signals.

* * * * * *

DO'S AND DON'TS FOR INDOOR OPERATION IN CITIES.

DO check to be sure building is not reinforced with metal.

DO consider antenna design carefully and select the best antenna for each situation.

DO use all space available to secure a resonant antenna if possible.

DO use loading coils where necessary to increase effective length of antenna.

DO use loop- or center-fed antennas where no ground connection is available.

DO run all power cords at right angles to antenna.

DO NOT end feed a half-wave antenna.

DO NOT make the installation in a noisy location.

DO NOT locate on side of building opposite from the base station.

CHAPTER 6

OUTDOOR ANTENNAS IN CITIES

6.1 OUTDOOR ANTENNA CONSIDERATIONS.

From the standpoint of signal propagation, outdoor antennas are much more effective than indoor antennas. Distortions in the radiation pattern are less likely to occur and there are no building materials or wiring to dissipate signal power. The operator using an outdoor antenna can be much more confident that he is "getting out" than his indoor counterpart.

Supports for the outdoor antenna can be found almost anywhere. Trees, shrubbery, utility poles, and nearby buildings can be used to good advantage. In some countries, where there is no extensive radio broadcasting, distribution lines for government loudspeaker programs will be found. The poles used to carry these lines may be used to support a low-power transmitting antenna, although long leader rope should be used to avoid coupling the radio frequency transmission into these audio lines and causing clicks which may be heard in nearby loudspeakers. When using utility poles carrying telephone or power lines, it must be remembered that periodic maintenance inspections on these poles would almost certainly lead to detection of any permanent antenna. These poles may serve however, as an antenna support overnight or for a very limited time. A telephone or electric wire which has been disconnected at the pole, but left hanging between the pole and a house, makes an ideal transmitting antenna.

Trees are the best antenna supports available in many cases. A nonconducting leader rope tied to the antenna should be lashed to a high branch of the tree. The antenna should be kept well clear of the tree. If wire is used as a leader, an insulator should be inserted between it and the antenna.

Figure 6-1 shows a typical horizontal antenna installation. Note that the insulators at each end of the antenna are well separated from the tree and the house. The antenna should be slack enough so that it will not snap as the tree is moved by the wind.

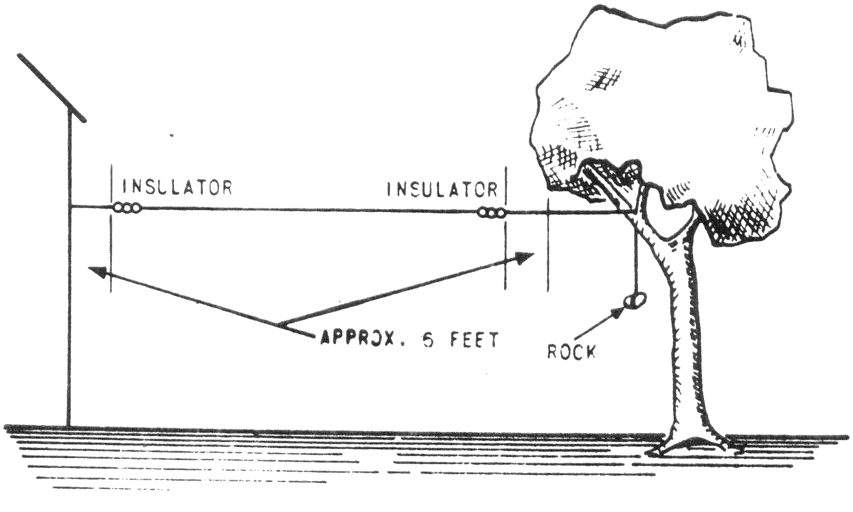


Figure 6-1

Shrubbery or bushes may be used to secure the low end of a slant-wire antenna running from the upper story of a building. A typical setup is shown in figure 6-2. Notice that the low end of the antenna may be raised or lowered by adjusting the length of the supporting string or rope. The antenna itself should be kept at least 6 feet above the ground, and should make an angle of about 30 degrees with the earth. This method would be suitable for securing the ends of an inverted "V" antenna.

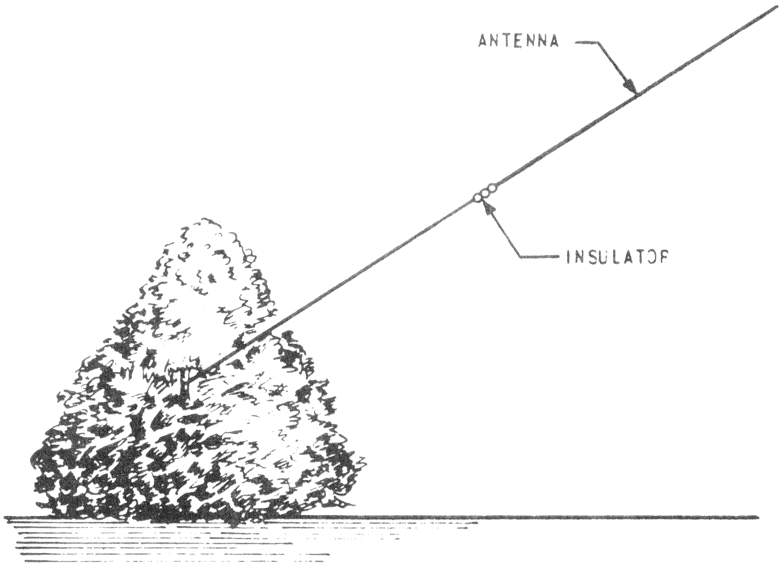


Figure 6-2

Nearby buildings should be considered when seeking supports for an outdoor antenna. Tie points to building structures can often be made as indicated in figure 6-3. A leader may be looped around a chimney, or tied to a hook installed in a roof eave or hole drilled through a rainspout.

In figure 6-4, a utility pole acts as one end of the antenna support. Extreme care should be exercised in making such an installation to avoid high-voltage lines. High-voltage lines may be identified by the large insulators separating them from the cross-tie. The pole shown is typical of a communication system in which very small insulators are adequate to handle the low voltage present on the line. In connecting an antenna to a utility pole, it is imperative that at least 10 feet of nonconducting leader be used to eliminate the possibility of the antenna swinging against the power or telephone lines.

Ideally, the leader should be at least a quarter-wavelength long and run at right angles to the utility wires, to prevent electrical coupling to them. Interference to the utility service would be almost certain to result in inspection of the line and discovery of the antenna. For the most part, such an installation should be limited to a single night's use if this is appropriate for the assigned schedule.

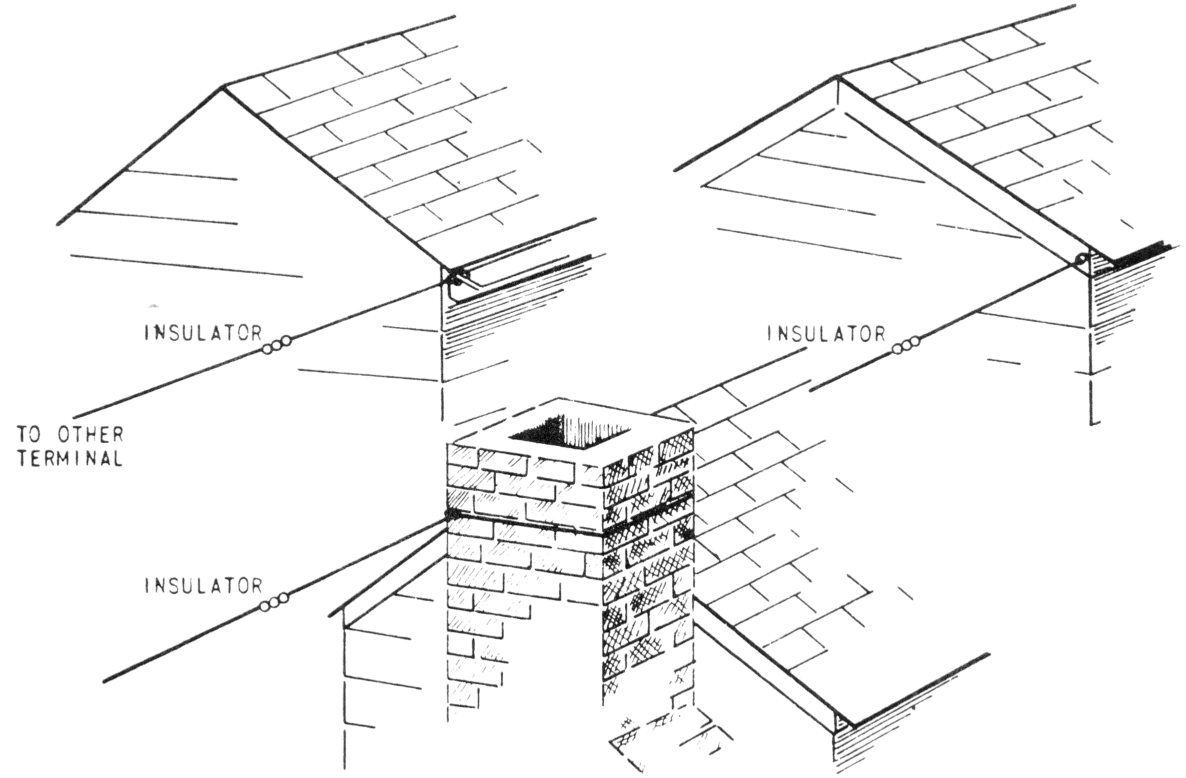


Figure 6-3

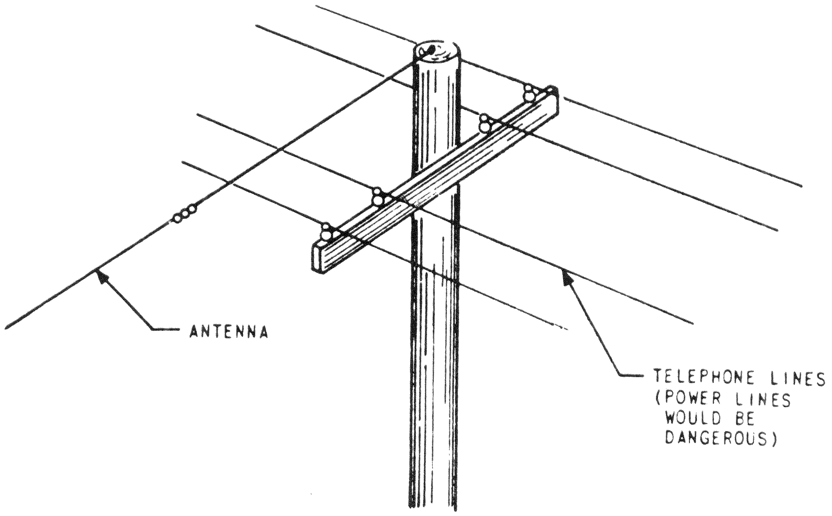


Figure 6-4

High-frequency antennas for FM and television may also be used for supporting one end of an antenna as shown in figure 6-5. The receiving and transmitting antennas should be kept at right angles whenever possible to eliminate coupling between them. In figure 6-6, an existing antenna installation is used as a support for a temporary antenna. Antenna masts for two-way radio systems used by trucking or utility companies may permit an installation such as that shown in part (A) of the figure. This type of installation could be made only under special circumstances, and it might have to be removed after each transmission.

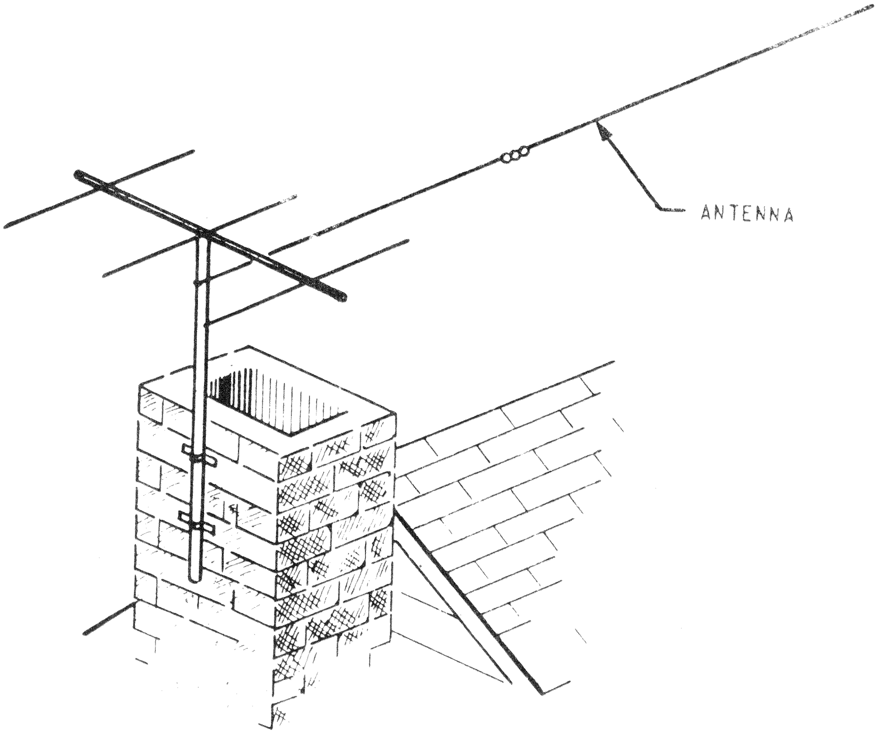


Figure 6-5

Part (B) of figure 6-6 shows how guy wires for a high frequency antenna may form a part of a slant-wire radiating system. Such guy wires are broken into short lengths by insulators, but these may be bypassed by short jumper wires with battery clips.

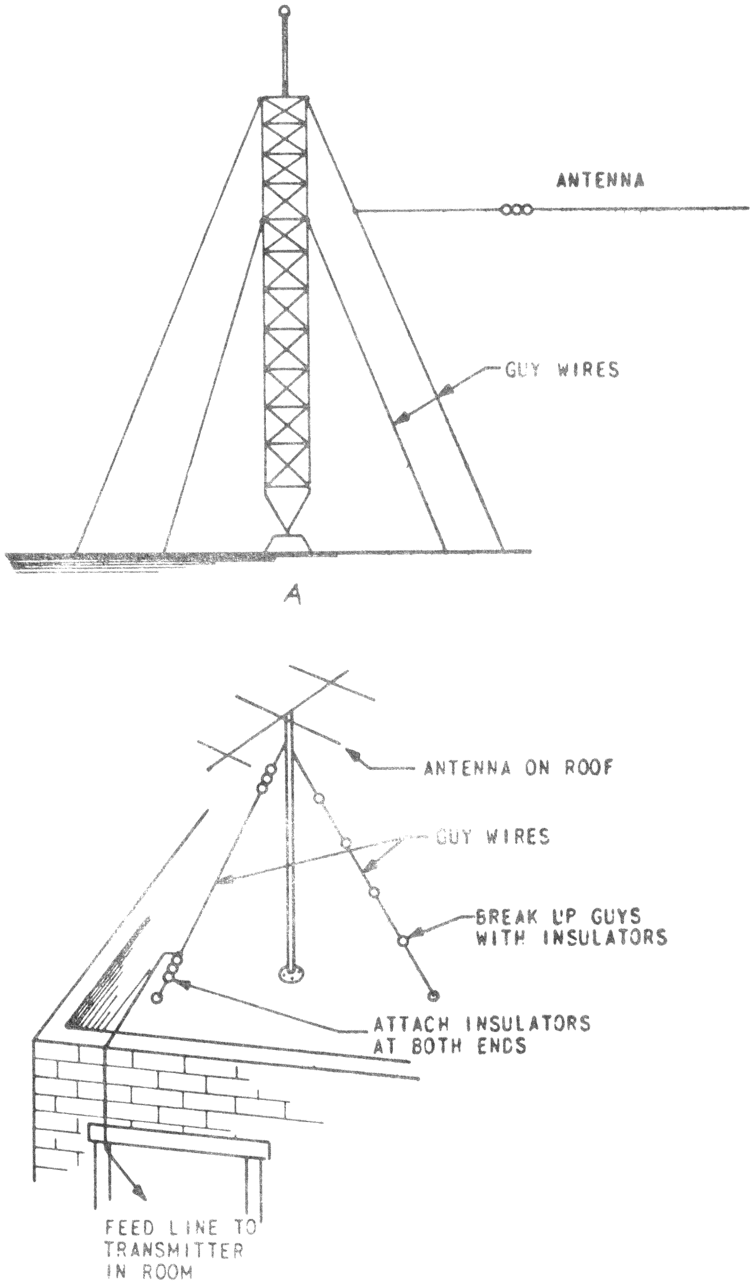

ANTENNA
GUY WIRES
A
ANTENNA ON ROOF
GUY WIRES
BREAK UP GUYS WITH INSULATORS
ATTACH INSULATORS AT BOTH ENDS
FEED LINE TO TRANSMITTER IN ROOM

Figure 6-6

Finding a suitable ground in urban locations may present a problem. However, if earth is accessible, a ground system such as illustrated in figure 6-7 may be buried, for example, in a garden. A permanent ground system may be installed at a small house by ringing it with a heavy copper wire buried a few inches below the surface of the ground. Radials should be run out a distance of 20 to 30 feet from this wire if that much space is available. The ground connection is then made to any point along the wire encircling the building. This ground system could be used to advantage with a quarter-wave vertical antenna such as a downspout or lightning rod system.

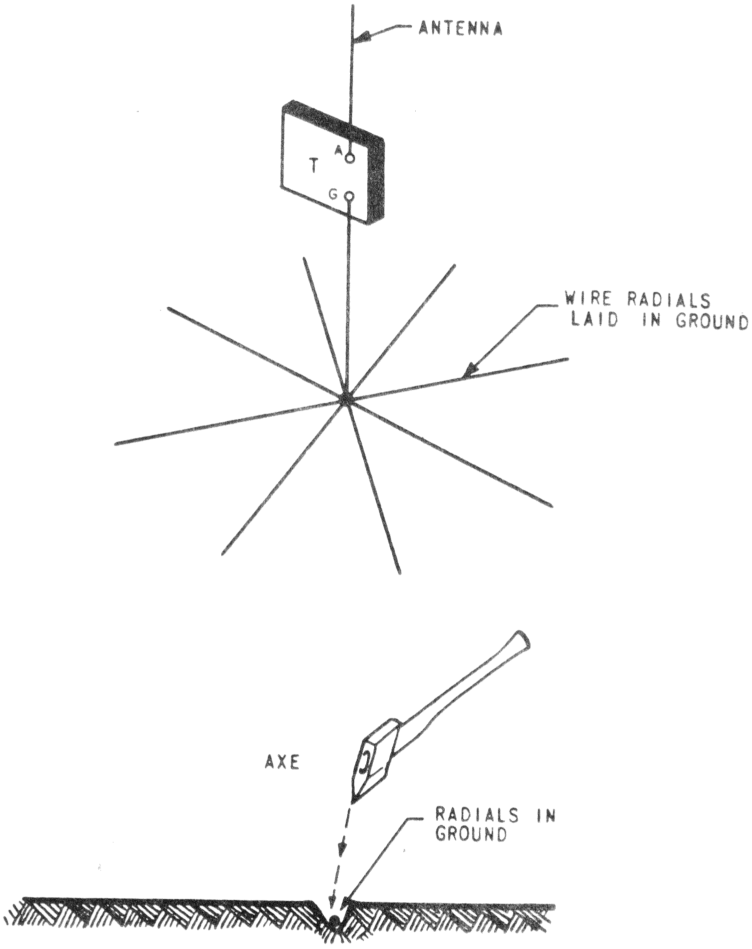


Figure 6-7

A good ground may be obtained by throwing the ground lead from the transmitter into a pond, stream or river as shown in figure 6-8.

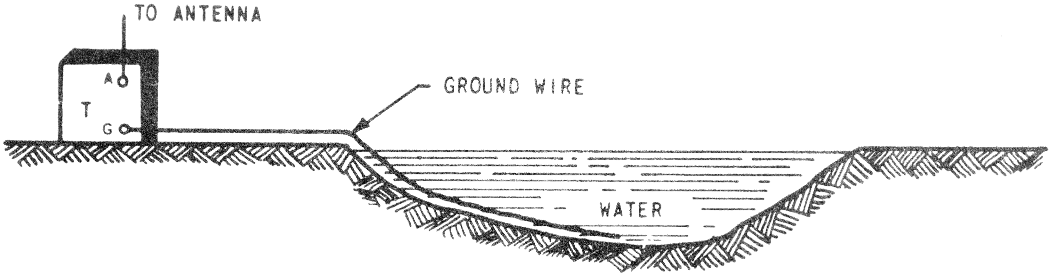


Figure 6-8

6.2 INSTALLATION OF OUTDOOR ANTENNAS.

Before setting up the antenna, the operator should make sure that the proposed run is clear of obstructions and that the antenna will be lined up to provide proper directivity toward the base station. The antenna feedline, if used, and all insulators can be assembled in seclusion. As in figure 6-9, the end of the antenna should be spaced at least 6 feet from structural supports such as buildings.

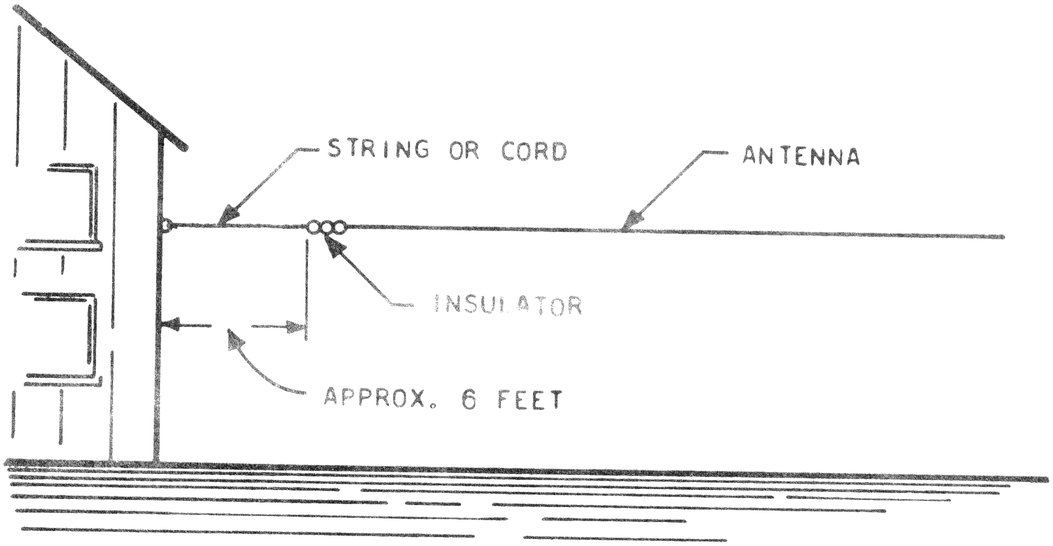


Figure 6-9

A leader may be easily thrown into a tree if a stone is tied to its end. If necessary the stone may then be lowered to the ground and a heavier rope pulled up into position. Figure 6-10 shows how a short, lightweight antenna may be supported at its far end by the stone and limb.

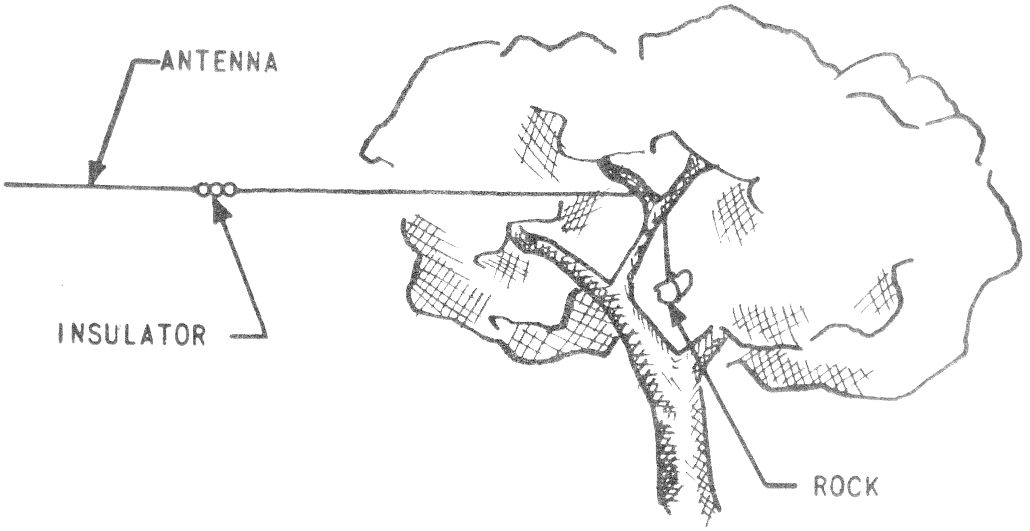


Figure 6-10

In countries where amateur radio operation is allowed, it may be possible to erect fairly good antenna systems which may be left in place indefinitely. The operator would do well to familiarize himself with the local operating practices.

A typical outdoor horizontal antenna installation is shown in figure 6-1. The length of wire between the insulators should be a half-wavelength at the operating frequency. The direction of the antenna wire should be at right angles to the bearing to the base station since the radiation of a half-wave antenna is strongest at right angles to the wire. It should be installed as shown and fed with a single-wire feeder as illustrated in figure 4-2G of chapter 4. It may be convenient to connect the feeder by an alligator clip to simplify installation. The feeder should be allowed to fall at right angles to the wire toward the ground for at least one-third the length of the horizontal portion of the antenna. The feeder in this type of antenna, it will be remembered, connects a short distance "D" from the center of the antenna. The value of "D" is one-seventh (fourteen percent) of the total length of the antenna.

With a frequency of 15 megahertz, a half-wave antenna would be

$$\frac{(1-.05)\ 150}{15} \text{ or } 9.5 \text{ meters}$$

(This value can be found from figure 4-1B of chapter 4.) Figure 1-16 of chapter 1, indicates that if the distance to the base station is 2000 miles, a low angle of radiation should be used. This would be accomplished by mounting the half-wave antenna at a height of one-half wavelength, as indicated in figure 2-19 of chapter 2. As previously noted, this results in an antenna height of 10 meters.

The single-wire feeder might be brought into the basement of the house where a short direct ground could be attached to the transmitter. The feeder wire may have to be supported by string to insure that it leaves the antenna at right angles without touching the ground or other conducting objects. It is important to keep the feeder wire as clear of surrounding objects as possible.

We may also consider an operator located on one of the upper floors of a tall apartment building. A slant-wire antenna may be constructed and fixed at its lower end as shown in figure 6-2. The wire should slope in the direction of the base station. The antenna should make an angle of about 30 degrees with the earth. This angle will be 30 degrees when the distance along the floor between the transmitter and the insulator is exactly twice the length of the vertical lead. Thus if the height of the insulator is 2 meters above ground, the height to the fourth floor window ledge location of the transmitter is 12 meters, the vertical reference height of the transmitter unit above the insulator will be 10 meters. A length of antenna equal to 20 meters will then make an angle of 30 degrees with the ground and be optimum for low-angle radiation in the desired direction.

An end-fed, 60-foot wire will be suitable for use at frequencies for which it is one-eighth to two wavelengths, providing feed points do not fall at half-wave points. Thus if 20 meters are equal to one-eighth wavelength, a wave-length is 160 meters. This corresponds to a frequency of 300/160 megahertz or something less than 2 megahertz. Where 20 meters are equal to three-eighths of a wavelength, the wavelength is equal to approximately 8/3 x 20 = 53 meters. This corresponds to a frequency of 300/53 megahertz or approximately 5.7 megahertz. When 20 meters are equal to two wavelengths, the wavelength is 10 meters. This corresponds to a frequency of 30 megahertz.

No attempt should be made to end-feed such a wire at 7.5 megahertz, its half-wavelength frequency, since the end impedance of a half-wave is too high to be matched without special equipment. To operate this wire at its half-wave frequency, the operator must revert to off-center feed operation.

The ground terminal of the transmitter should be connected directly to a water pipe ground, or any large metal mass available.

6.3 SELECTION OF POSSIBLE ANTENNAS.

The operator searching for antenna supports has considerably more freedom of choice outdoors than indoors. He should examine his physical surroundings to determine whether a slant-wire, vertical, horizontal, or inverted "L" antenna could be used. The amount of space normally available to the operator within a city would probably not permit the installation of long-wire or inverted "V" antennas.

For short communication paths of a few hundred miles, a horizontal antenna is best because of its high-angle radiation. This antenna should be fed by a single-wire feeder. If necessary for concealment purposes however, the half-wave antenna may be cut in the center and fed directly from the transmitter by connecting one side to the antenna terminal and the other side to the ground terminal. As much of the wire as possible should be in the clear. For frequencies above 7 megahertz, a horizontal antenna provides good, low-angle radiation (for long-distance operation) if it is placed at least one-half wavelength above the earth.

On the higher frequencies a vertical antenna should be used when there is insufficient room for a horizontal wire. A rainspout or a dummy drop wire from a telephone line may be used. Insulated wire may be used for the antenna, and the insulated webbing may extend beyond the actual antenna for concealment purposes.

A slant-wire or "V" antenna could be installed along the trim boards running up to the peak of the roof for operation on frequencies above 15 megahertz.

6.4 CONCEALMENT OF OUTDOOR ANTENNAS.

If absolutely necessary, antennas may be attached directly to an outside brick, wood, or cement wall and they will radiate fairly well. Figure 6-11 shows an antenna made less conspicuous by concealment in the grooves of brickwork. The lead from this antenna may be kept out of sight between transmissions and reached with a clothes hanger when needed. If space permits, a number of well-concealed antennas cut for different frequencies may be installed. An alligator clip at the end of a 6-foot lead provides a convenient method for quickly connecting and disconnecting the transmitter from concealed antennas.

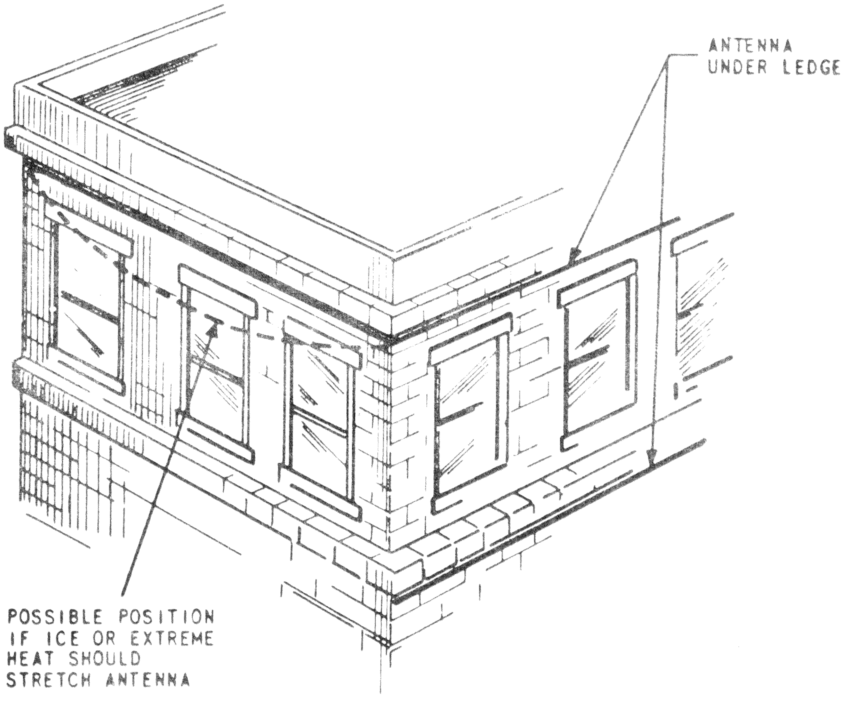


Figure 6-11

Where a large wall area is available, a full-wave, closed loop should be considered. It will be recalled from chapter 4 that the maximum radiation from such a loop occurs perpendicular to the loop, and therefore it should be placed on the side of the building toward the base station. If the loop is arranged with disconnect sections (one in the vertical arm and one in a horizontal arm), either vertical or horizontal polarization may then be selected. Vertical polarization is best for long-distance transmission when the bottom of the loop is not very high above ground. The transmitter may be connected to the side of such a loop through a second-story window for vertical polarization, or the loop may be fed in the top or bottom arm from a first floor or third floor window for horizontal polarization.

CHAPTER 7

INDOOR ANTENNAS IN RURAL AREAS

7.1 INDOOR ANTENNA CONSIDERATIONS IN RURAL AREAS.

In rural areas an indoor antenna is used when security precautions prevent the construction of an outdoor antenna. While it will not radiate quite as well as its outdoor counterpart, the losses of an indoor antenna are not too great, especially when used in widely separated wooden structures.

All rural buildings follow roughly the same structural pattern. Steel is not usually used for reinforcement, and for this reason almost any rural building can be used for indoor radio work. The operator should be cautious, however, of metal roofs or corrugated metal walls sometimes encountered.

The rural dwelling offers many possibilities for the concealment of an antenna. It may be run in hundreds of ways, a few of which are illustrated in figures 7-1A through 7-1D. The best antenna location is the attic of the main dwelling, since it is so high above ground.

The operator looking for a suitable antenna installation should follow the four steps outlined below:

(1) Determine the bearing to the base station.

(2) Determine what antenna runs, supports, and materials are available.

(3) Determine what possible antennas may be set up.

(4) Select the antenna which looks best and build it.

From the illustrations in figure 7-1, it is seen that an antenna can be set up to produce a major radiation lobe in any desired direction. However, an indoor antenna, even in a very large dwelling, will rarely be longer than a half-wavelength, so it is important to remember a few rules about directivity of short antennas.

(1) An antenna whose major length is horizontal, as in figure 7-1A, will radiate well at right angles to the direction in which the wire is run.

(2) The slant-wire antenna shown in figure 7-1B radiates well in the direction toward which it is tipped. The transmitter should be directly in line with the base station, and the wire should make a 30-degree angle with ground if possible.

(3) End-fed, "L"-shaped antennas with sides of equal length radiate best in the direction of the bisector of the angle formed by the wire. (See figure 7-1C.) Never end-feed a half-wave antenna. To use the antenna at its half-wave frequency, cut it in the exact center and connect the two halves directly to the antenna and ground posts of the transmitter.

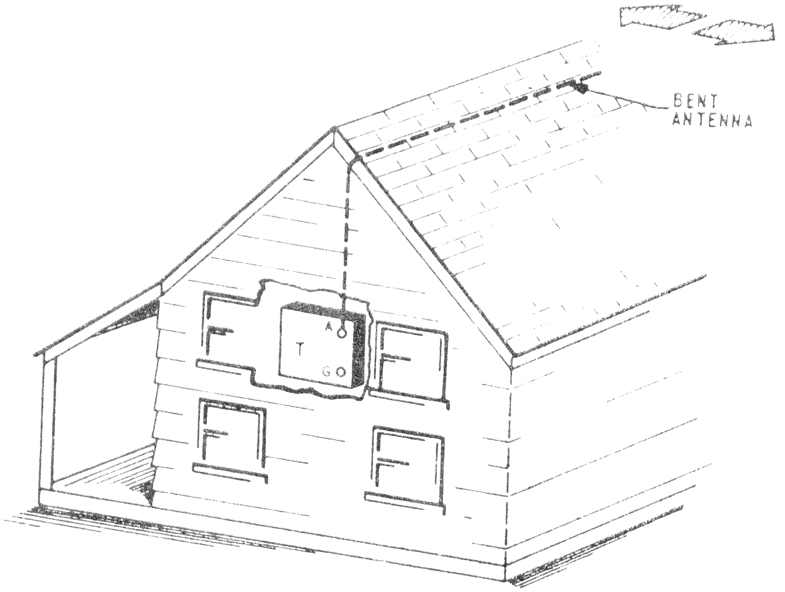


Figure 7-1A

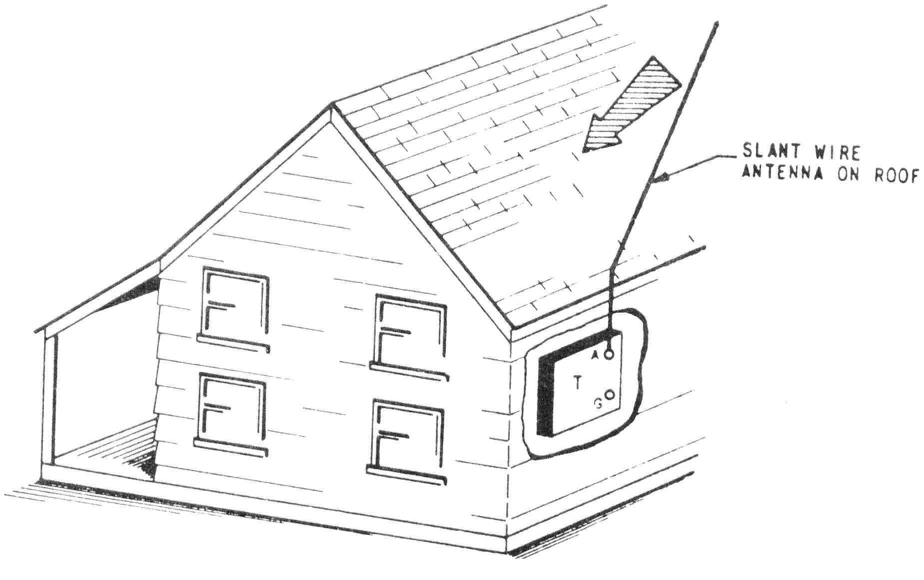


Figure 7-1B

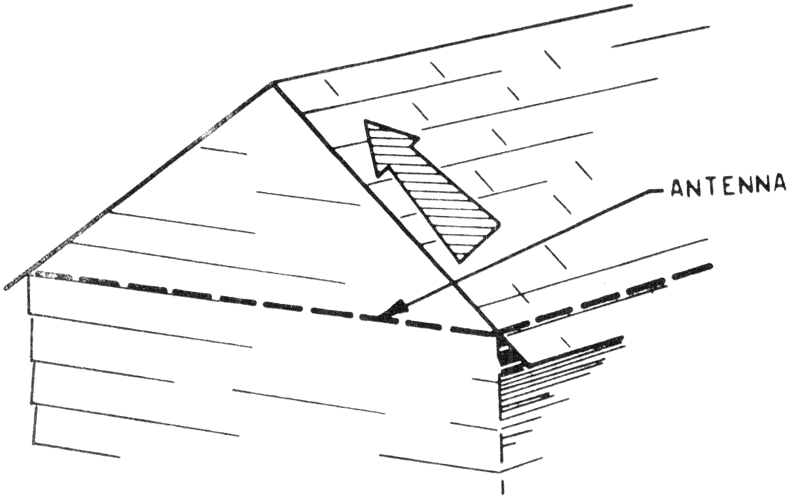


Figure 7-1C

(4) Half-wave loops radiate best in the plane of the loop, while full-wave loops radiate best at right angles to the plane of the loop. A half-wave loop must be fed at one side of the loop, and the opposite side of the loop must be left open. Maximum directivity will be toward the side of the loop in which the transmitter is inserted.

The signal polarization of a half-wave loop will be the same as the plane of the loop. In other words, if the loop lies flat on an attic floor it will have horizontal polarization. If it hangs from the center pole of the roof, it will have vertical polarization.

As shown in figure 7-1D, a full-wave loop should always be mounted vertically. If the loop is fed on one of its vertical sides, as illustrated, it will have vertically polarized radiation. If it is fed in one of the horizontal arms its radiation will be horizontally polarized. The choice of polarization will depend upon the distance to the base station and the height above ground. When the bottom of the loop is a half-wavelength above the ground, horizontal arm feed may be used. If it is necessary to use the loop when the bottom of the loop is near the ground, vertical side feed should be used. In either case maximum radiation occurs at right angles to the plane of the loop.

It should not be difficult to secure a good ground system in rural areas. Copper radials buried beneath the family garden can be carefully placed to provide excellent contact with the earth. Where a well with a metal casing is available, an excellent ground can be secured by connecting to this casing, as shown in figure 7-2.

Lightning rod grounds may be used as good grounding points, as shown in figure 7-3A. The antenna and ground terminals may be inserted directly in the break shown.

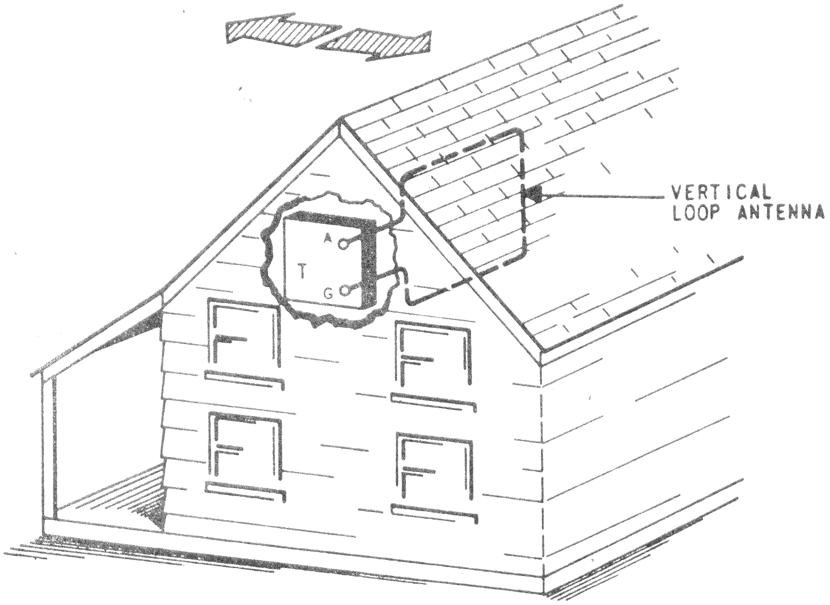


Figure 7-1D

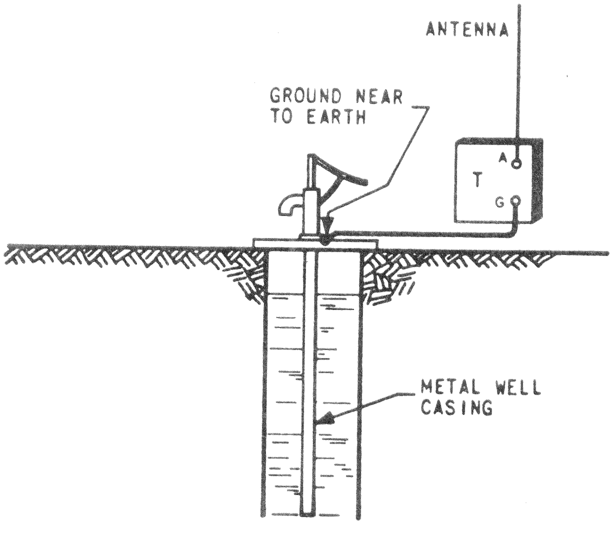


Figure 7-2

Figure 7-3B illustrates a variation on this installation wherein the break in the lightning rod system is made as usual but a separate vertical antenna is run from the antenna terminal of the transmitter up inside the dwelling. With this method we have a directive parasitic array as discussed in chapter 9. With proper proportioning of the lengths of the lightning rod system and the active antenna element, a pronounced directive effect can be produced. As in all directive arrays, the proper horizontal spacing between them must be observed. The lightning rod may be used as either a director or as a reflector, depending upon its length and spacing from the antenna.

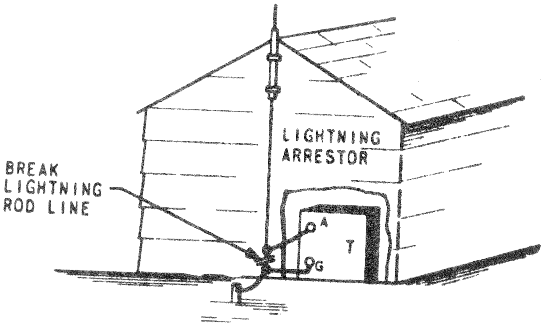


Figure 7-3A

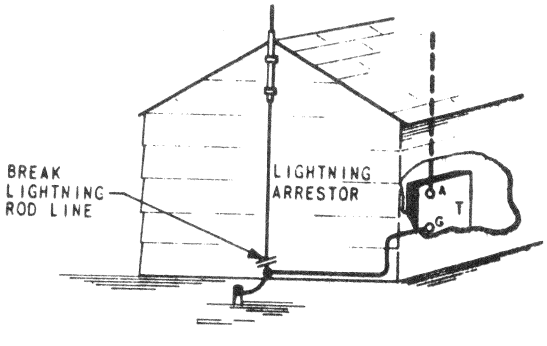


Figure 7-3B

The largest structures in rural areas are usually barns. Their size is normally great enough to allow a wide choice of antenna locations. Several techniques for installing antennas in barns are shown in figures 7-4A, 7-4B, 7-4C, and 7-4D. In general, the antenna should be kept as high as possible. By putting the transmitter in the hayloft as shown in figure 7-4A, the lead from the antenna terminal can be kept mostly horizontal.

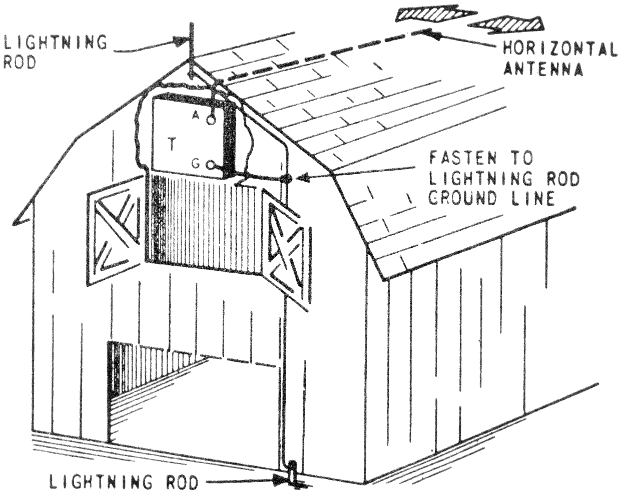


Figure 7-4A

If horizontal directivity is desired, it would be well to keep the vertical part of the antenna shown in figure 7-4B short in proportion to the length of the horizontal portion running along beneath the barn roof. In all the figures, the barn is assumed to be several times longer than it is wide so that the wires run greater distances than are implied by the illustrations.

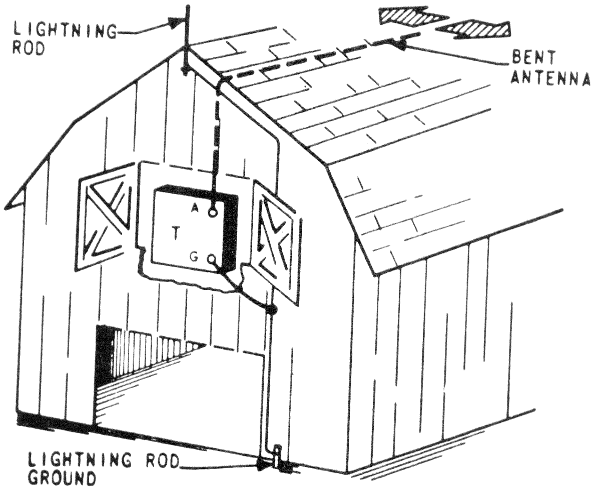


Figure 7-4B

Figure 7-4C shows a one-wavelength, loop antenna installed around a hayloft opening. Its radiation is horizontally polarized and is greatest in directions at right angles to the opening. In the example shown, the loop is surrounded by relatively open space, so it will tend to be bidirectional. It will have a lobe coming straight out of the barn, and another going back into it.

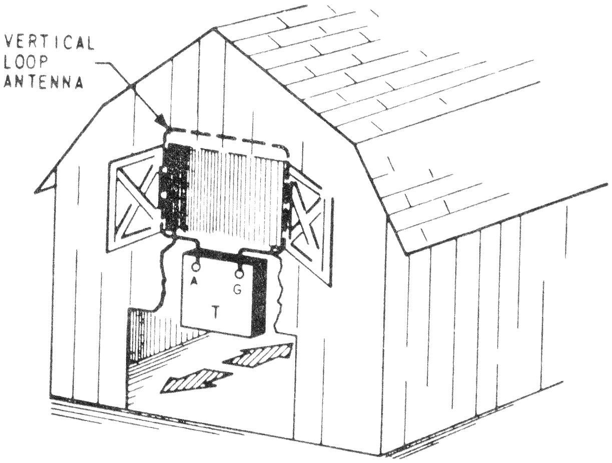


Figure 7-4C

The horizontal "V" antenna shown in figure 7-4D performs best when at least one wavelength of wire is run parallel to the earth from each terminal of the transmitter. The angle between the wires should be a right angle (90 degrees). The radiation will be horizontally polarized and strongest at about 30 degrees above the earth. This angle is suitable for medium distance propagation if the antenna is about a half-wavelength above ground.

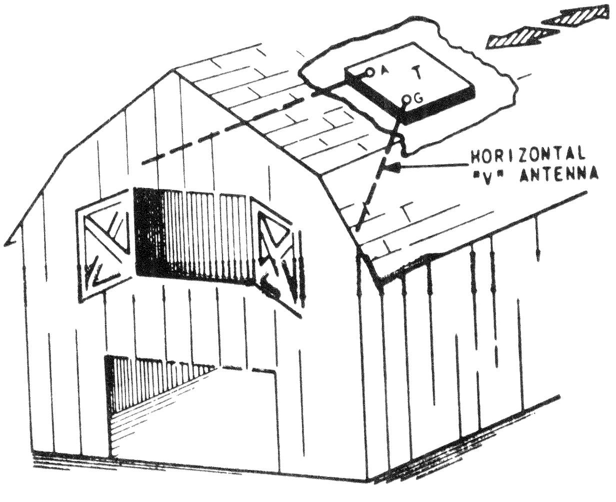


Figure 7-4D

A good ground can be obtained by connecting to lightning rods or to stakes in the ground. Piles of animal refuse saturate the ground with nitrates which provide very good contact for a ground stake.

Figures 7-5A and 7-5B show antenna installations in farm silos. Before making an installation in a silo, the operator should check to be sure the silo structure does not contain steel reinforcement or hoops. If metal reinforcing is used, the silo should be avoided.

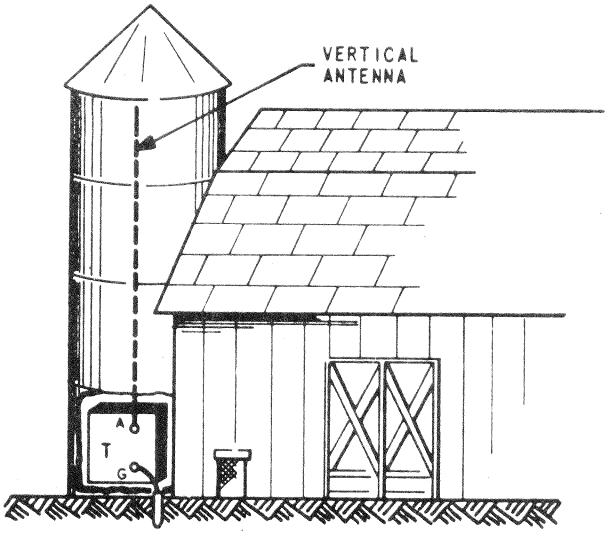


Figure 7-5A

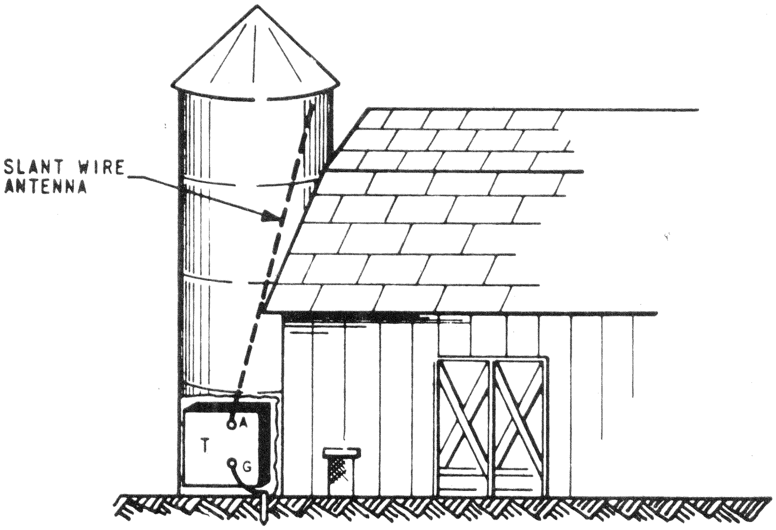


Figure 7-5B

If the silo roof is metal, the operator can attach a vertical radiator to the inside center point of the metal roof by extending the antenna as illustrated in figure 7-5A. This technique will lengthen the antenna considerably by providing a much higher capacity to ground. A wire 33 feet (10 meters) long, for example, might have an apparent electrical length of as much as 40 feet (12 meters) when connected to such a top loading device.

Since the silo is usually a tall structure, vertical antennas will ordinarily be best. However, there may be instances when the half-wave loop will be suitable. The amount of slope available for a slant wire is not very great, as shown in figure 7-5B. It may be well to experiment with positions between those shown in Figures 7-5A and 7-5B to secure the optimum vertical radiation.

Animal shelters and machinery sheds are normally small structures built low to conserve material. The operator should be careful to get his antenna as high in the building as possible. Two methods of construction are illustrated in figures 7-6A and 7-6B. Sheds which are used for the storage of farm machinery should not be used when the machinery is in them since the large metal masses may seriously affect the radiation pattern of the antenna.

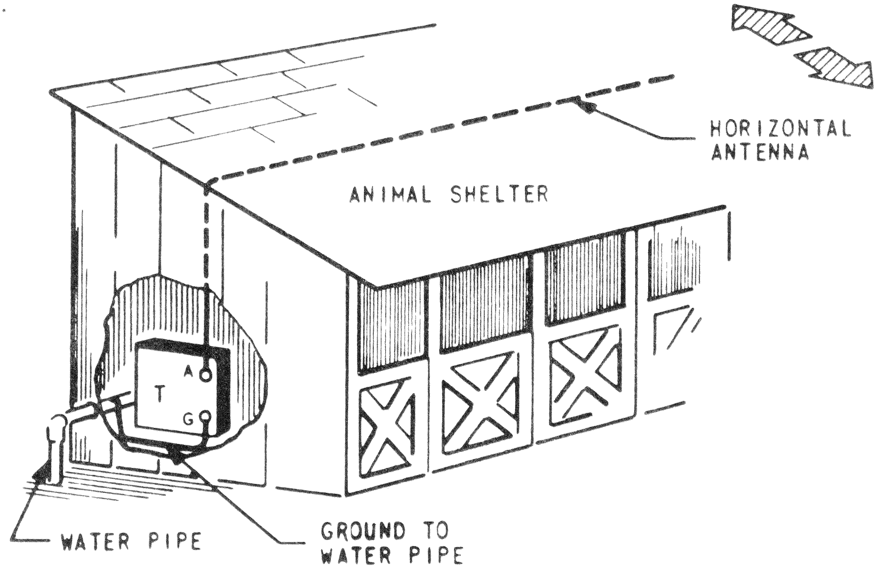


Figure 7-6A

Grounding in such sheds may present a problem. In livestock sheds, plumbing for supplying water may be used if available. The next best thing may be a rod driven into the ground under a manure pile.

7.2 INSTALLATION OF INDOOR ANTENNAS IN RURAL AREAS.

The operator should carefully consider the best locations available, and avoid buildings having metal roofs. The operator may increase the space available in the building selected by running his antenna through rooms and hallways of the house. Within rooms, it may run from floor corner to opposite ceiling corner to secure maximum length.

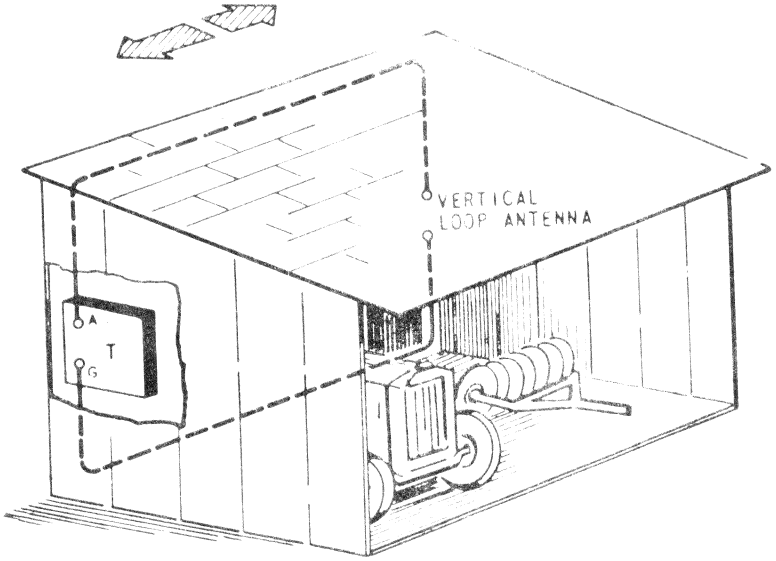


Figure 7-6B

Barn walls often have large openings such as cattle doorways and haylofts. Antennas constructed across them are almost equivalent to outdoor antennas.

If there is no danger of close inspection, a semipermanent antenna may be constructed. Where concealment is not paramount, the antenna wire should be run about 3 feet away from the building in order to reduce energy losses in the roof and walls.

A directional antenna suitable for installation in a large barn is shown in figure 7-4D. The length of each wire should be one wavelength. One leg of the "V" should be attached to the antenna terminal of the transmitter and the other to the ground terminal. The angle made by the two wires should be about 90 degrees.

The strongest radiation from this antenna is shown in the sketch; it is bidirectional along an imaginary line bisecting the angle between the wires.

Let us assume that the operator's base station is 1500 miles to the south. A horizontal "V" antenna a half-wavelength above ground would be most suitable for this installation since it has good radiation at a vertical angle of about 30 degrees.

Figure 1-17 of chapter 1 shows that this is the correct angle for this distance, using double-hop propagation. It also indicates this type of antenna would be suitable for a 700-mile path, single-hop.

If the assigned frequency is 20 megahertz, a full wavelength wire is 48 feet (14.6 meters) long, and each leg of the "V" is cut to this length. The correct height for this antenna is one-half wavelength or 25 feet (7 1/2 meters). The bisector of the angle formed by the two wires should run due south. In other words, the transmitter could be located at the north end of the system, and the wires run at angles of 45 degrees to the west and 45 degrees to the east of a due south center line. All transmitter power wires should be run downward at right angles to the plane of the two wires.

Other suitable antennas for rural dwellings or barns would be similar to those previously discussed in the chapter on indoor antennas in cities. The greater size of the buildings often found in rural areas will make possible the efficient use of somewhat lower radio frequencies.

7.3 SELECTION OF POSSIBLE ANTENNAS.

Once the operator has determined the direction to the base station it might be well for him to make a list of possible antennas with their characteristics. The list in a typical rural situation could include the following:

(1) Bent wire in attic well concealed, may be oriented to base station. Some energy loss by absorption in roof.

(2) One and one-quarter wavelength horizontal long wire in barn — may be well concealed and has a fair amount of gain.

(3) Inverted "V" antenna over roof of barn (similar to figure 4-18 of chapter 4) — good radiator assuming barn roof is sufficiently high. Will be bidirectional. One wavelength long on each leg.

(4) Vertical half-wavelength loop on barn wall — relatively low gain but easy to feed if a good ground system is not available. Fed on vertical side for best, low-angle radiation.

(5) Simple vertical antenna — may be installed in the silo and preferably one-quarter wavelength long.

(6) Two and three-quarter wavelength slant-wire antenna in barn — good gain toward base station. But requires considerable height at high end, possibly extending outside through barn roof ventilator.

If it were possible to install each of the above antennas, they may be rated in the following order of preference. A communication path of 600 miles is assumed. It will be seen from figure 1-17 of chapter 1 that good radiation at a vertical angle of 35 degrees would be required.

(1) Best — "V" antenna — best directivity and gain among possibilities outlined.

(2) Two and three-quarter wavelength slant-wire antenna — simple construction and good gain.

(3) The quarter-wave vertical antenna — assumes that a good ground system is available preferably consisting of buried radial copper wires in immediate vicinity of vertical antenna.

The shorter horizontal antenna and the loop antenna would be rated as less efficient than the ones listed above. The radiation from the horizontal antennas would be concentrated mainly at vertical angles above those required for the length of the communication path.

The half-wave antenna would be last choice since its gain in the most favorable direction is somewhat less than a half-wave antenna installed at the proper height.

7.4 CONCEALMENT OF RURAL, INDOOR ANTENNAS.

Any antenna should be built for rapid removal if necessary. Where possible, the materials used to connect the antenna insulator to the supports should be weaker than the antenna so that a quick pull will remove the antenna assembly.

Where possible, parts which must be abandoned in an emergency should be made to look like the normal surroundings. Dirty, old string is preferable to clean new string as an antenna support. A special ground rod could appear to be a part of the lightning protection system.

Antennas may sometimes be installed to appear as though they were a part of structural reinforcement. A wire, for example, might appear as a toolholding wire in the hayloft, or as part of a system for opening or closing loft air vents.

Antenna loops may be attached to large barn doors, to enable the operator to change the directivity of the loop. The optimum bearing to the base station could be determined by orienting the door for best reception of the base. Directivity could also be checked by listening to international broadcast or amateur stations. Only frequencies near the assigned transmitting frequency should be used in checking directivity of an antenna, since the radiation pattern of an antenna will change as the frequency is changed.

A few basic rules about concealment of indoor antennas should be remembered:

(1) The antenna and ground structures should appear as part of a building element (possibly a reinforcing wire or lightning rod ground system).

(2) The antenna should be placed in an area of poor visibility to make discovery more difficult.

(3) The operator should try to decide where he would least expect to find an antenna, and then put it there.

While antenna wire may be camouflaged in the dry hay of a barn loft, it should be remembered that wet material will increase the losses in the antenna system. Burial of a wire in fodder material, such as in a silo, is therefore not recommended. A false partition could be used to separate the wire and the fodder.

* * * * * * *

DO'S AND DON'TS FOR RURAL INDOOR ANTENNAS

DO determine bearing to the base station carefully.

DO use an antenna which has good radiation at the proper vertical radiation angle.

DO consult chapters 2 and 4 for variations in radiation in both vertical and horizontal planes when designing antenna.

DO NOT forget to return transmitter each time frequency is shifted or antenna is modified.

DO NOT neglect to construct the best ground system possible, especially for use with vertical Marconi antennas.

DO NOT allow wiring and transmitter-receiver harnessing to come into contact with antenna wires. Keep such wiring at right angles to the antenna system.

CHAPTER 8

OUTDOOR ANTENNAS IN RURAL AREAS

8.1 OUTDOOR ANTENNA CONSIDERATIONS FOR RURAL AREAS.

Outdoor antennas in rural areas can be made more efficient than any of the other antenna installations discussed in this text. The number of different antenna arrangements possible on the average farm, for example, is almost unlimited since most farm structures provide a suitable end support for an antenna. Where room is available, a minimum of half-wavelength spacing between the antenna insulator and the supporting structure should be maintained.

Figure 8-1, part (A), shows how the antenna wire, insulator, and rope or string leader should be prepared. In this case, a stone has been attached to the end of the leader preparatory to tossing it over a high tree limb as indicated in part (B) of the figure.

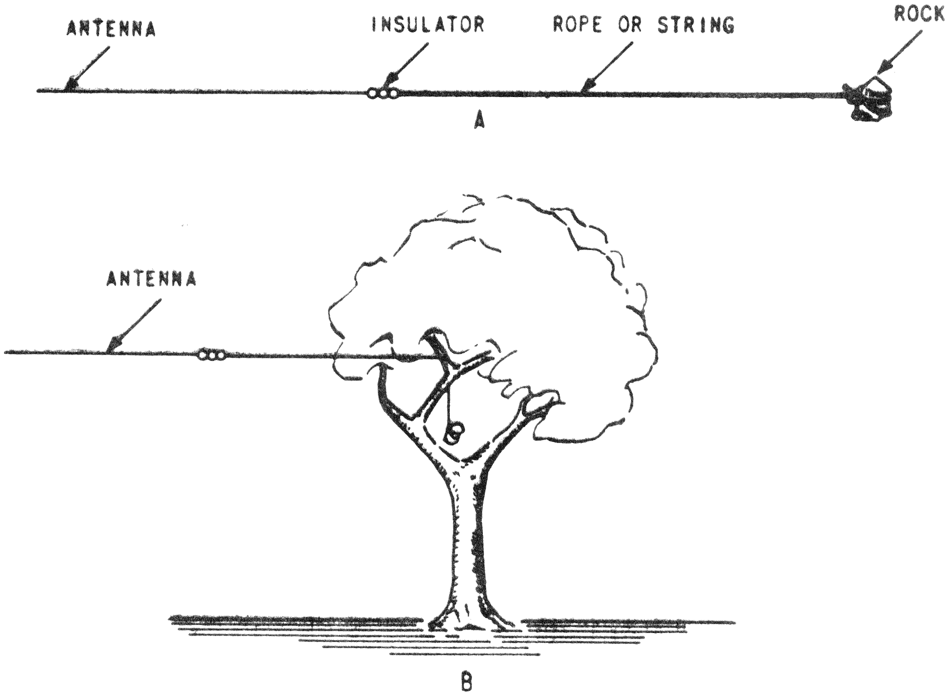


Figure 8-1

Figure 8-2 shows a complete installation of an inverted "L" antenna. If both the horizontal and vertical portions of the antenna are 25 feet long, this antenna can be used over the range of frequencies shown in figure 4-15 of chapter 4 for the inverted "L" antenna. As illustrated, a space has been selected where the radiating portions of the wire are kept clear of trees and other objects.

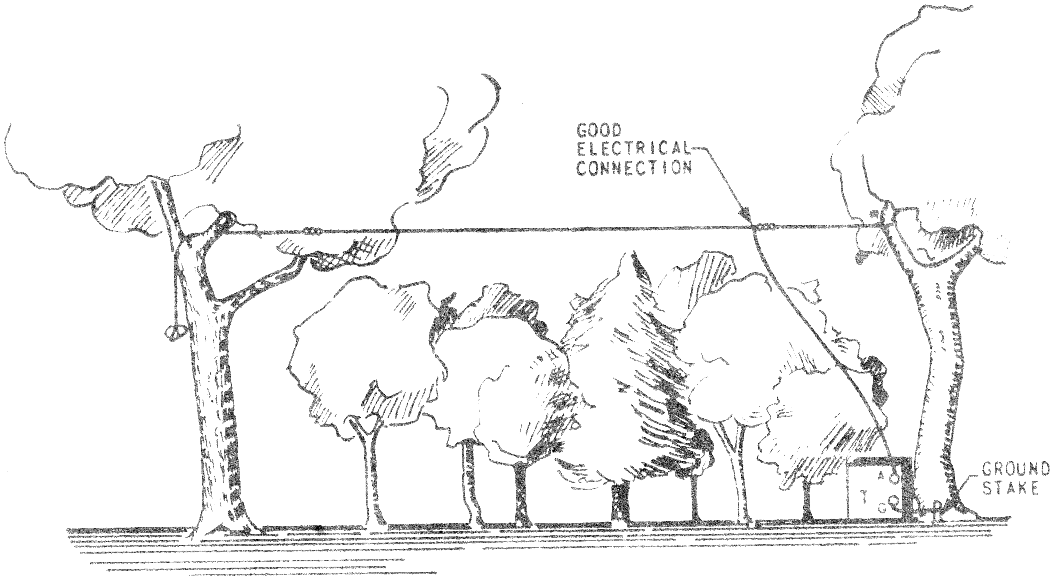


Figure 8-2

In a semipermanent installation, counterweights as shown in figures 8-3A and 8-3B may be used in the installation. Pulleys are used to keep the antenna wire straight when arrangement of figure 8-3B is especially convenient since it permits quick removal of the entire system except for the raising portion of the leader.

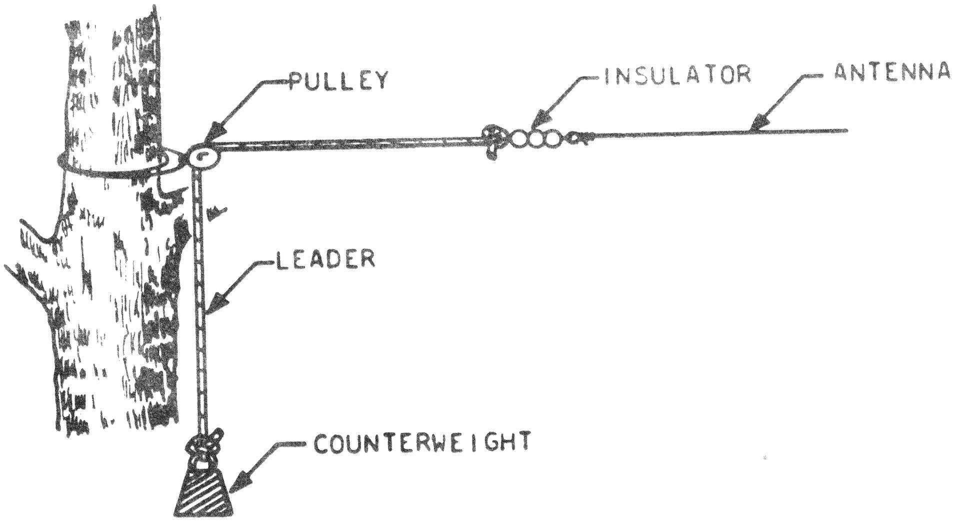


Figure 8-3A

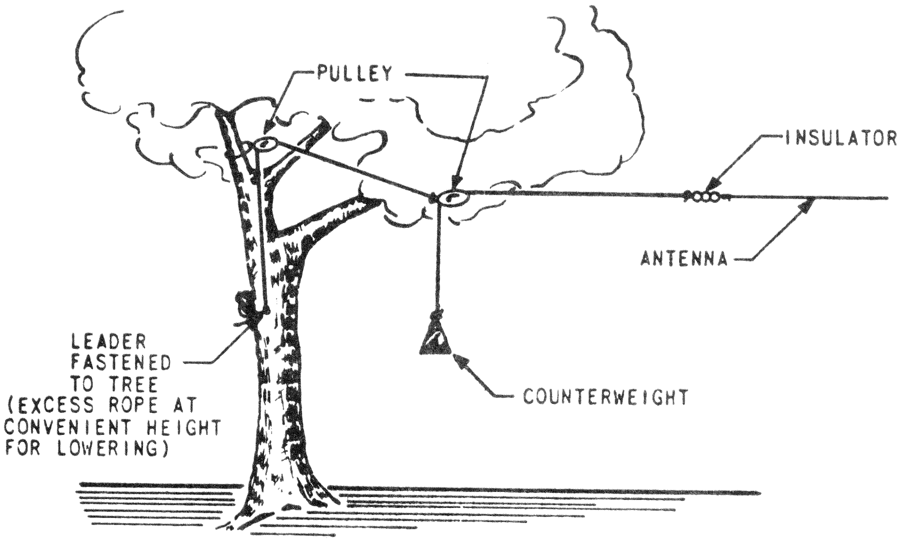


Figure 8-3B

The combination of fence post and tree provide convenient supports for the slant-wire antenna illustrated in figure 8-4. If the length of the slant wire, including the transmitter lead-in wire, is made 25-feet long, this antenna may be used over the frequency ranges indicated in figure 4-15 of chapter 4.

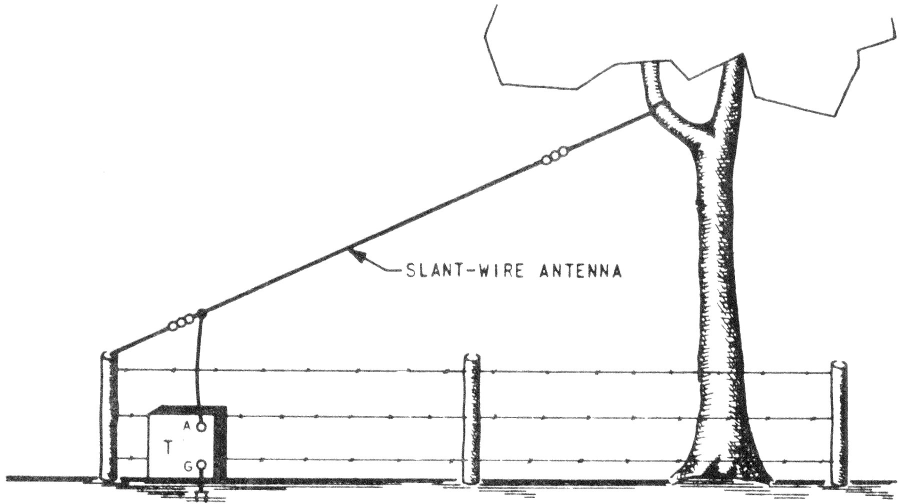


Figure 8-4

The lead between the bottom insulator and the transmitter antenna terminal should be kept as short as possible since a short wire is easier to keep clear of surrounding objects. The lead from the slant wire to the antenna terminal will become a part of the radiating system, and should be kept well separated from the wire fence.

The transmitter may be installed at either the high or low end of a slant-wire antenna. Figure 8-5A shows an installation in the top floor of a windmill from which the slant-wire runs to a fence post or stake in the direction of the base station. If the angle the wire makes with the earth is maintained at approximately 30 degrees, this radiating system will be fairly efficient.

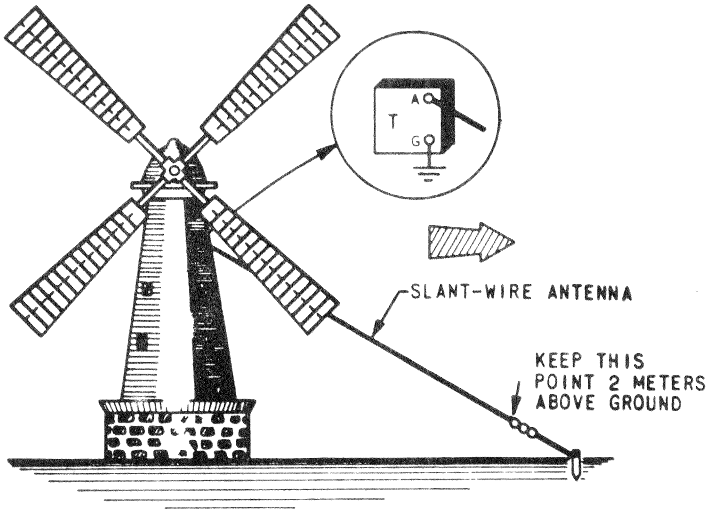


Figure 8-5A

If a tree is located at a proper distance and direction from a windmill, the installation shown in figure 8-5B may be used. Here the transmitter is located inside the building, and the transmitter lead-in wire becomes a part of the radiating system. In this case, even multiples of a half-wavelength should be avoided for the overall length of the radiating system. If a short antenna is used, one which is slightly more or less than a half-wavelength, it should run at right angles to an imaginary line between the antenna center and the base station.

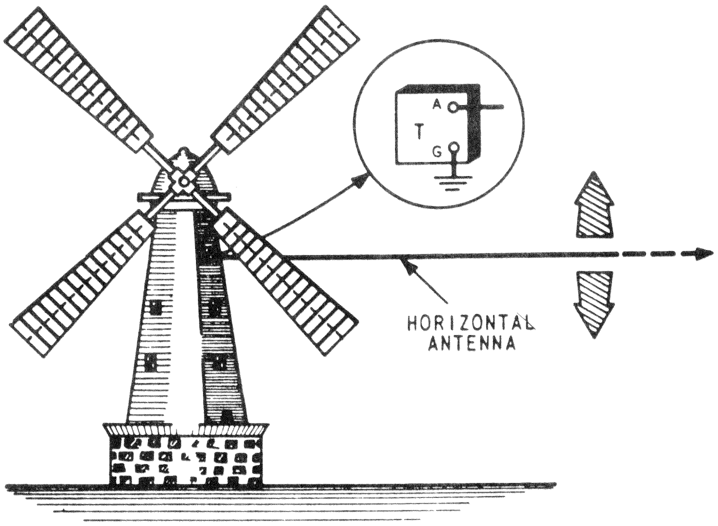


Figure 8-5B

If a more distant tree is used which requires a wire length considerably greater than a half-wavelength, the direction in which the wire is run should be determined from figure 4-16 of chapter 4. This figure gives the angle between the wire and the maximum lobe of radiation.

Figure 8-5C shows a windmill-supported, slant-wire antenna which is fed from the ground end. The direction of maximum radiation is along the slope of the wire as in figure 8-5A.

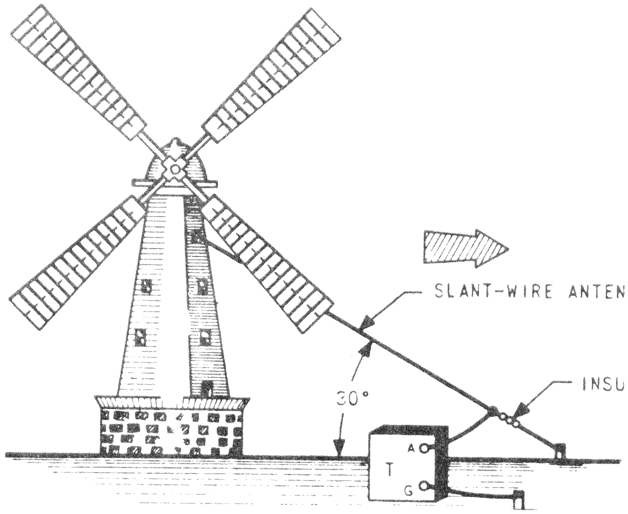


Figure 8-5C

Where metal buildings are found, the antenna should be run at right angles to the building as shown in figure 8-6. A minimum separation of at least 15 feet should be maintained between the side of the building and the insulator at the end of the antenna.

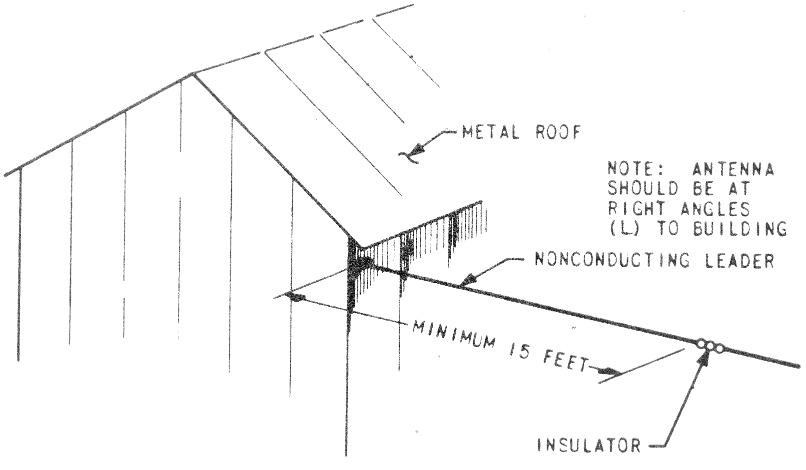


Figure 8-6

Figure 8-7A shows a suitable method for hooking onto an existing long-wave receiving antenna such as may be found between a house and a barn. The horizontal portion of the antenna should be long compared to the vertical lead-in portion. The antenna should be carefully oriented to make sure that the major lobe radiation is in the desired direction. The lead-in to the farm receiver should be disconnected at the point shown at the top of the chimney.

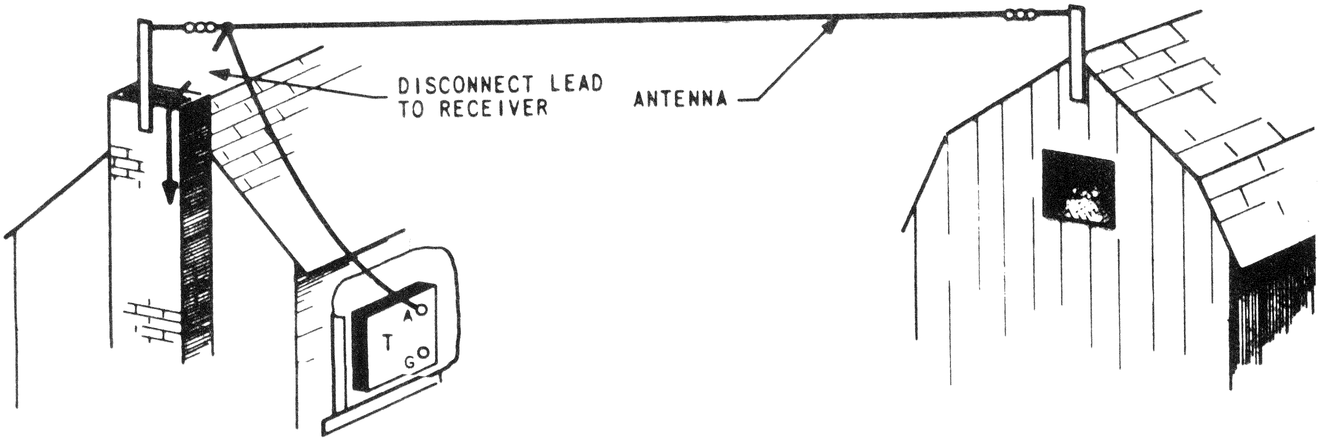


Figure 8-7A

If the existing system does not provide the required orientation, it may be used as one support for a slant-wire arrangement as shown in figure 8-7B. Figure 8-7C shows another possible arrangement when the existing antenna has been mounted between the ends of the farmhouse roof. Here again, the operator must make certain that his orientation is correct. It may be possible to use the existing system as one leg of an inverted "L" antenna.

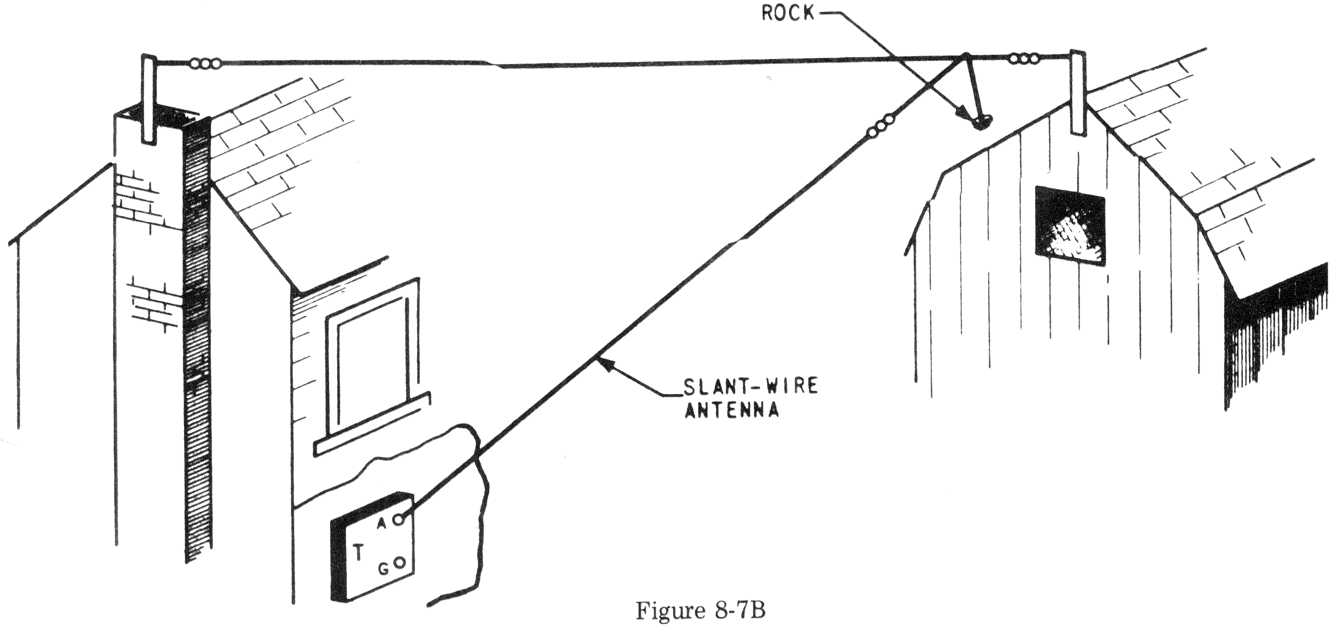


Figure 8-7B

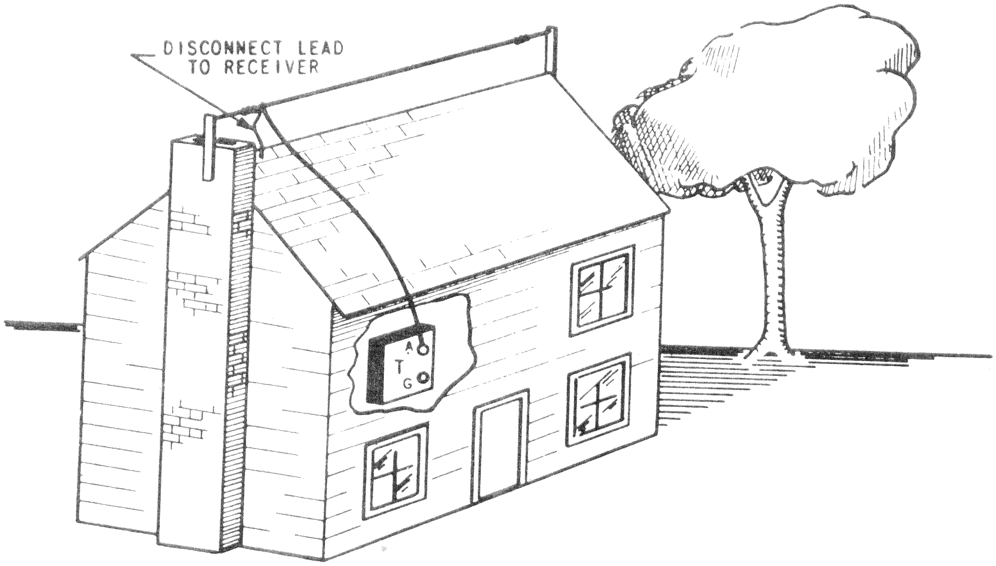


Figure 8-7C

High frequency FM or television antennas can sometimes be used to advantage as shown in figure 8-8. Where a vertical ground lead has been used as lightning protection for a high frequency antenna as shown in part (A), it may be broken and fed from the transmitter. The high frequency antenna can also be used to support a slant-wire radiator. In some cases, the ground lead from the high frequency antenna may be used to form the actual slant-wire antenna as shown in part (B). When used as a part of the transmitting antenna, the high frequency antenna cannot be used as a receiving antenna.

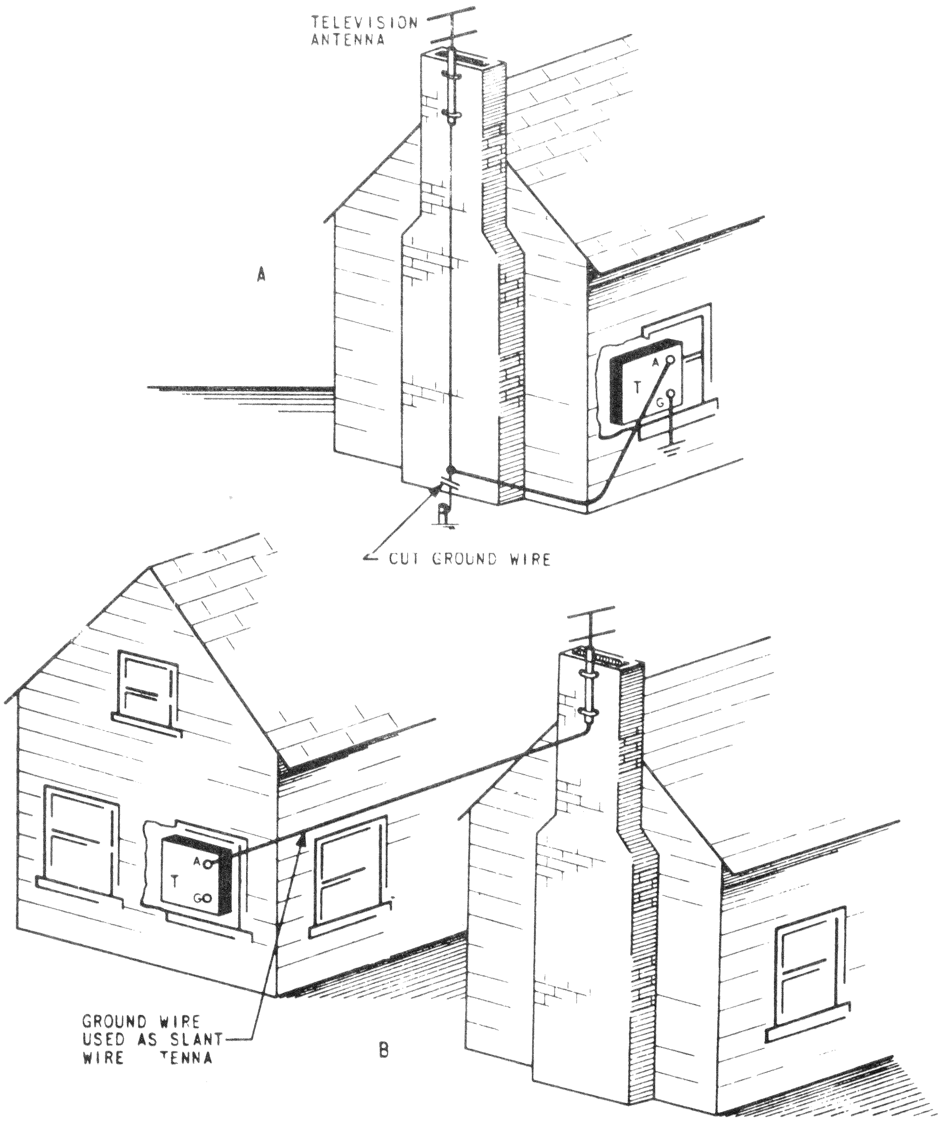

TELEVISION ANTENNA
A
A
T
G
CUT GROUND WIRE
A
T
G
GROUND WIRE USED AS SLANT WIRE TENNA
B

Figure 8-8

The rain gutters and downspouts of farm buildings can be used to form all or a part of the radiating system as suggested in figures 8-9A and 8-9B. The arrangement in figure 8-9A results in a vertical antenna while that in figure 8-9B forms an "L" antenna. As indicated in figure 8-9B, a jumper can be used to provide either type. All orientation considerations previously discussed apply to this type installation. In addition, the antenna should be located on the side of the house toward the base station to avoid unnecessary losses in the building materials.

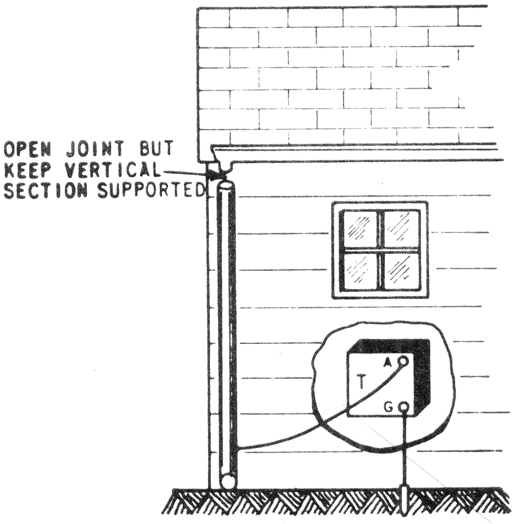


Figure 8-9A

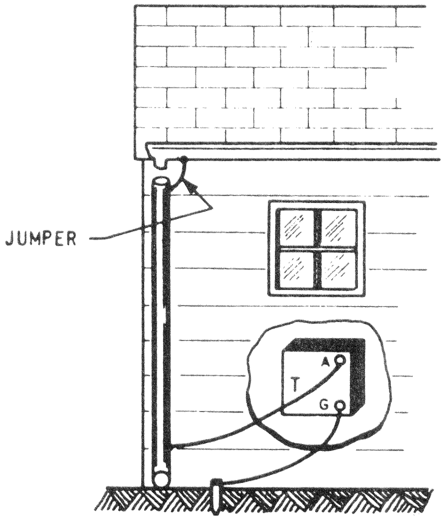


Figure 8-9B

Figure 8-9C shows a rain gutter used as a horizontal antenna, and includes a suggested method of connecting the wire to the spouting. A self-tapping metal screw should be inserted into a small pilot hole, and tightened around the wire.

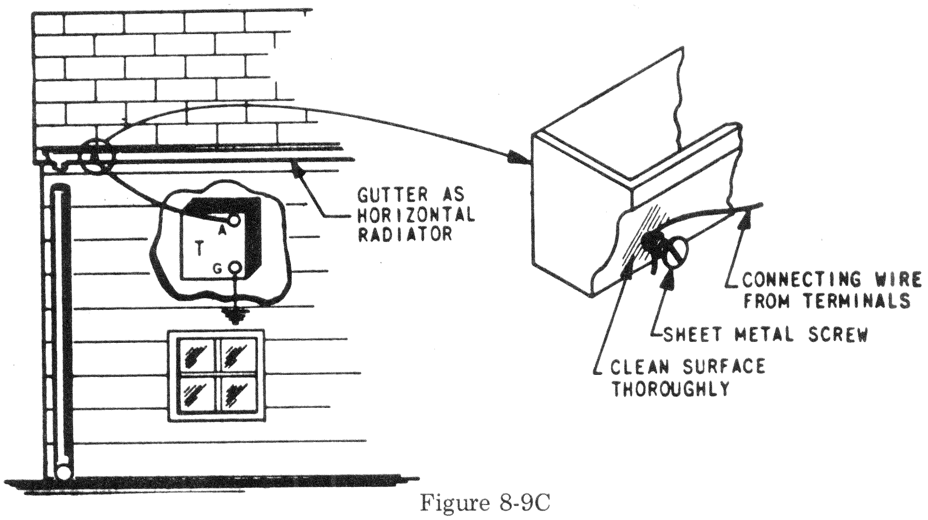


Figure 8-9C

Figure 8-10 shows how a building lightning rod system can be used to form a vertical antenna. Where time is available, and a long period of operation is planned, the ground system could be improved in accordance with suggestions made in chapter 3.

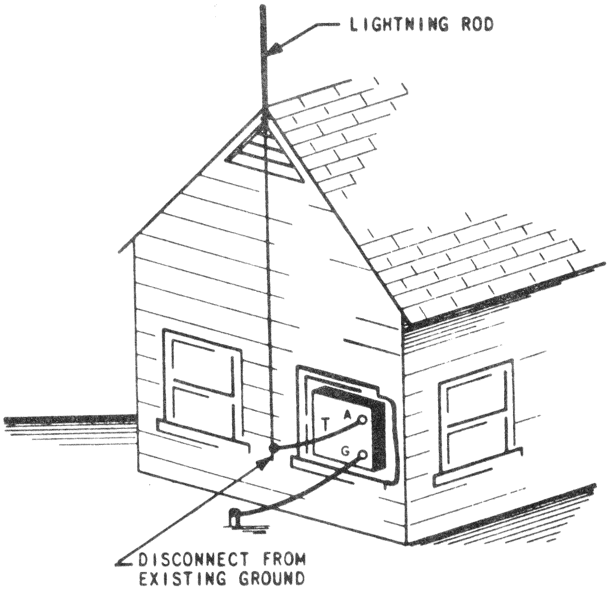


Figure 8-10

Figure 8-11 shows several antenna suggestions for use in rural field areas. Where the antenna is close to earth, it must be at least six wavelengths long to achieve low-angle radiation.

The operator planning the antenna installation should again follow the four basic steps:

(1) Determine the bearing to the base station.

(2) Determine what antenna directions, supports, and materials are available.

(3) Determine what possible antennas may be set up.

(4) Select the most desirable antenna and build it.

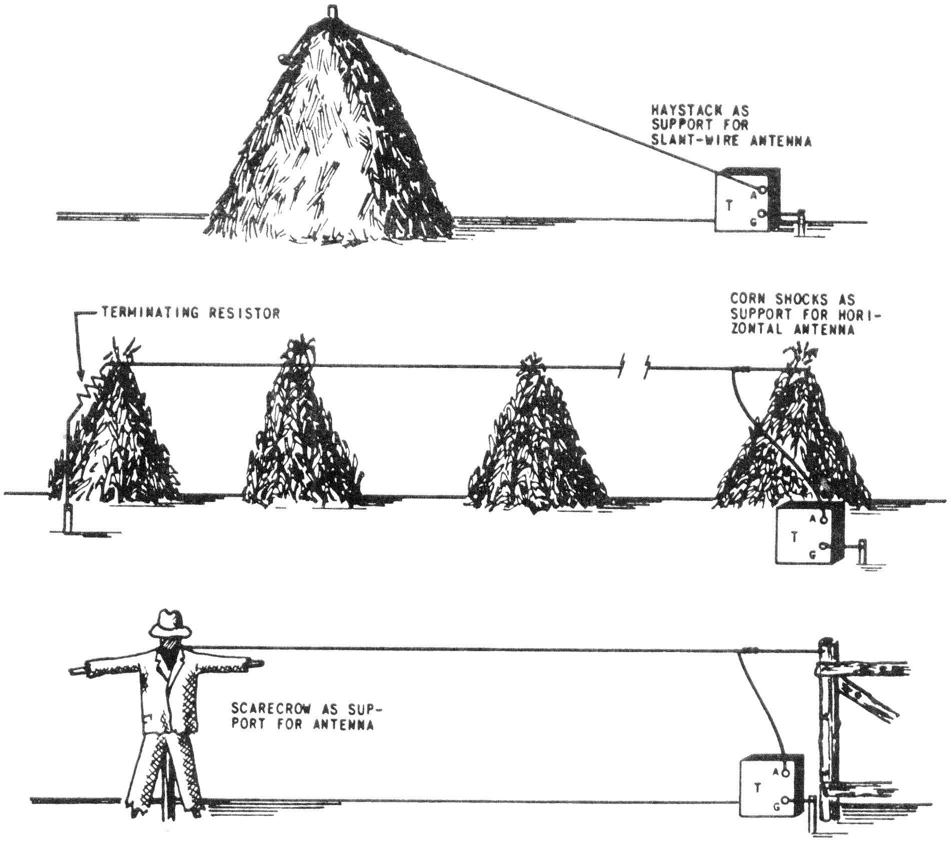
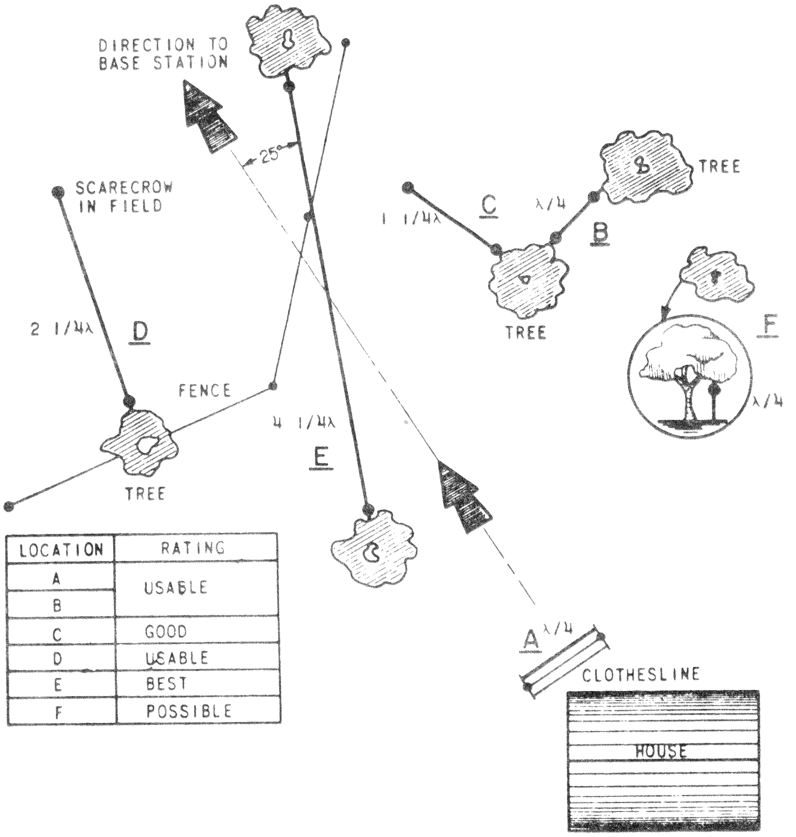


Figure 8-11

8.2 INSTALLATION OF OUTDOOR ANTENNAS IN RURAL AREAS.

When evaluating a typical farm layout, the operator should carefully consider all the facilities available for the erection of an antenna. Figure 8-12 shows a plan view of a farm area in which six possible antenna arrangements are illustrated. The direction to the base station is the same for each arragement and is indicated by the large, shaded arrows. A table which gives the rating for the various antennas is contained in the figure. The major radiation lobe for each antenna has been properly oriented with respect to the base station. It is assumed that the necessary antenna gounds can be made in accordance with suggestions contained in chapter 3.

The advantages and disadvantages of the various antennas may be summarized as follows:



LOCATION	RATING
A	USABLE
B	
C	GOOD
D	USABLE
E	BEST
F	POSSIBLE

Figure 8-12

(A) A horizontal quarter-wave wire 7 feet above the ground supported along a clothesline — this antenna will have no gain and can only be used when there are no wet clothes on the line. It is easy to install but will radiate most of its energy at high angles. It is good for a 200- to 400-mile operation.

(B) A quarter-wave bent wire installed between the two trees in the form of an inverted "L" — this antenna will have low gain. It will develop some vertically polarized signal if the vertical down lead is of appreciable length. Its radiation angle will be fairly high.

(C) A one and one-quarter wavelength wire run from high up in the tree down toward ground — this antenna has more gain than the first two and is almost as easy to set up. If the angle between the wire and ground is about 30 degrees, it will have good directivity toward the base station when sloped in that direction.

(D) A two and one-quarter wavelength wire from a tree to the scarecrow in the field — if installed as a slant-wire antenna, the wire will have somewhat more gain than that shown for condition (C). Its orientation as shown in the drawing, however, is not properly lined up to make proper use of the major radiation lobes. It should be reoriented, possibly by moving the scarecrow around in the field so that one of the major lobes of radiation lies along the direction to the base station.

(E) A four and one-quarter wavelength wire installed horizontally at a height of 35 feet between the two trees — the ground level feed point impedance must be kept low. The antenna tuning indicator will glow brightly when a low impedance feed is obtained. The length, and the slope of the vertical down lead can be varied to obtain a low impedance feed as evidenced by the tuning indicator. This antenna has the highest gain of any considered. It also has good, low, vertical-angle radiation. If it can be securely mounted by using weights, it will not need much maintenance.

(F) A quarter-wave vertical antenna this antenna is vertically polarized and needs a high support. Some radiation from the antenna would be lost during the foliage season, particularly when leaves are wet.

Assuming an 800 to 2,000 mile communication path, with no possibility of discovery existing, these antennas would be rated as follows:

Best — Four and one-quarter wavelength horizontal wire between two trees. This antenna has the highest gain, and for this reason, should be used in preference to all the others. When possible, the longest length of wire feasible should be used to increase the apparent effective radiated power providing communication path lengths of greater than several hundred miles are involved.

Good — The slant-wire antenna discussed in (C) would be fairly good. The longer wire discussed in (D) would not be used because of the existence of large vertical null areas with this type radiator.

Poor — The antennas shown at (A), (B), and (F) are usable but should not be selected where longer wire radiators can be installed. In the case of the vertical quarter wave shown in (F), care must be taken to run the antenna up through the clearest part of the tree, or the energy absorbed by the trees will reduce the power radiated. In contrast to the other antennas shown at (A) and (B), the vertical antenna shown at (F) will have good, low-angle radiation. It will give better results than types (A) and (B) if a good ground system is installed. It is especially desirable where rapid removal may be necessary.

8.3 SELECTION OF POSSIBLE ANTENNAS.

When installing outdoor antennas in rural areas, every possible method should be used to erect long lengths of wire. Figure 8-11 shows an antenna installation in which a number of corn shocks have been used as supports. This antenna will be directive along the wire toward the base station from the transmitter end, if it is terminated in a 400-ohm noninductive resistor as shown. The ground system for the terminating resistor should be equivalent to the ground system provided for the transmitter unit. If the terminating resistor is not used. The antenna will radiate in two directions, forward and backward along the length of the wire.

Such an antenna should be between six and eight wavelengths long. For this length, the major lobes would occur at slight angles to the wire in accordance with figure 4-16 of chapter 4.

Horizontal wires, approximately four wavelengths long, would also provide excellent results if properly oriented. Where a rural swelling is primarily of wood construction, such an end-fed antenna may be run from a distant tree into a second story or attic window. A ground for the transmitter may be secured by tying directly to a lightning rod down lead. Care should be taken to prevent the wire from being an even number of wavelengths long. This is necessary to insure a reasonably low impedance at the transmitter terminals.

Vertical antennas may be considered where tall structures are available. For example, figures 8-13A and 8-13B show a vertical antenna installation which utilizes a wooden water tank as support. If there are metal bands about the wooden tank, the wire should be brought away from the side of the tank as shown in figure 8-13A. Where the steps up the tank are metal, the ladder may be adapted for use as an antenna if a good connection can be made to it. If the ladder is rusty and the joints are corroded, it will be better to avoid the structure entirely.

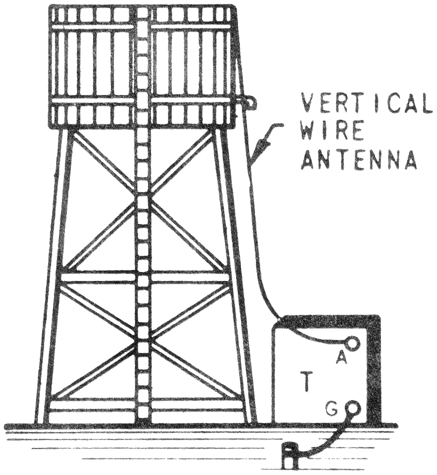


Figure 8-13A

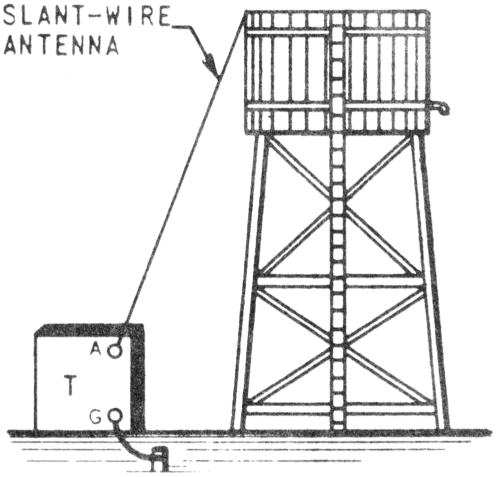


Figure 8-13B

8.4 CONCEALMENT OF OUTDOOR RURAL ANTENNAS.

When necessary, rural areas afford a number of possible sites for antenna concealment. Figure 8-14 shows how an antenna wire might be wrapped around a clothesline to provide the length of antenna required. If a wire clothesline were used, a connection could be made directly to the wire itself. However, if dual metal clotheslines are used as in figure 8-15, one of the lines should be removed, and the other one used for the antenna.

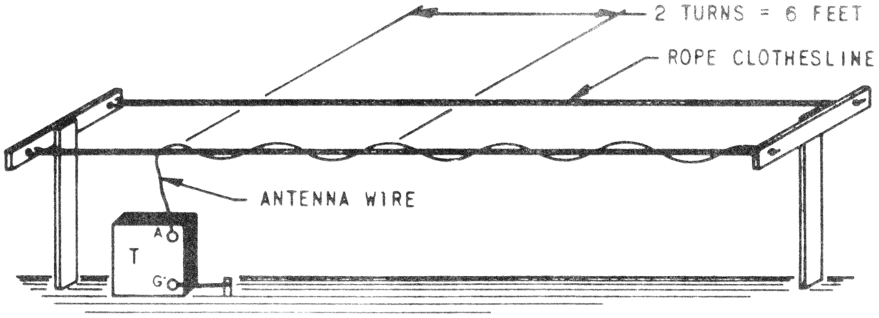


Figure 8-14

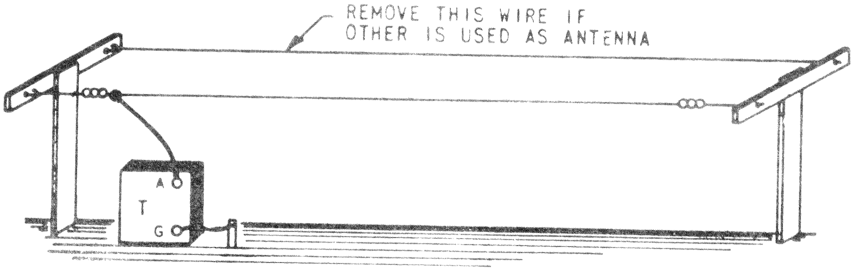


Figure 8-15

Figure 8-16 shows how a wire may be concealed by inserting it into a hollow, plastic clothesline. Figure 8-17 illustrates a typical installation of this type. For some of the lower frequencies, several clotheslines may be used to obtain the length of wire required for a terminated long wire antenna similar to that shown in figure 8-11. In general, where wires must be kept low to the ground, long wire terminated antennas should be used, if at all feasible.

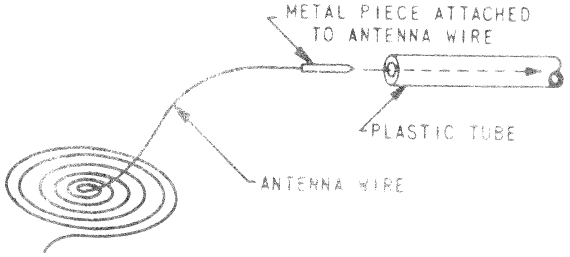


Figure 8-16

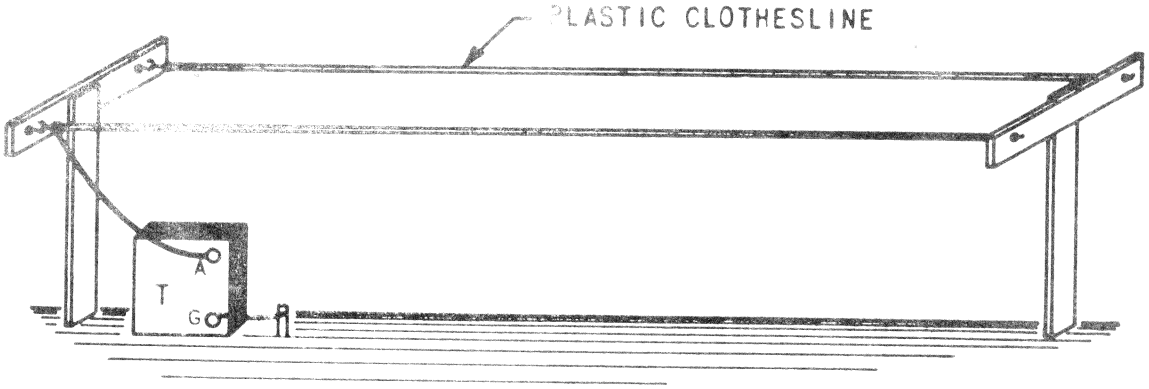


Figure 8-17

Figure 8-18 shows how a horizontal antenna may be installed and made to appear as part of an outdoor lighting system. The transmitter can be located near the power fuse box for the swelling, and connected to either a wire made to look like an electrical powerline, or in some cases, to the powerline itself. If the powerline is used, arrangements must be made to disconnect it from the supply voltage during transmission. This can be most easily accomplished by removing the fuse. Under circumstances where a powerline is run to provide light for a chickenhouse or barn, several poles may be installed to provide an excellent long wire system.

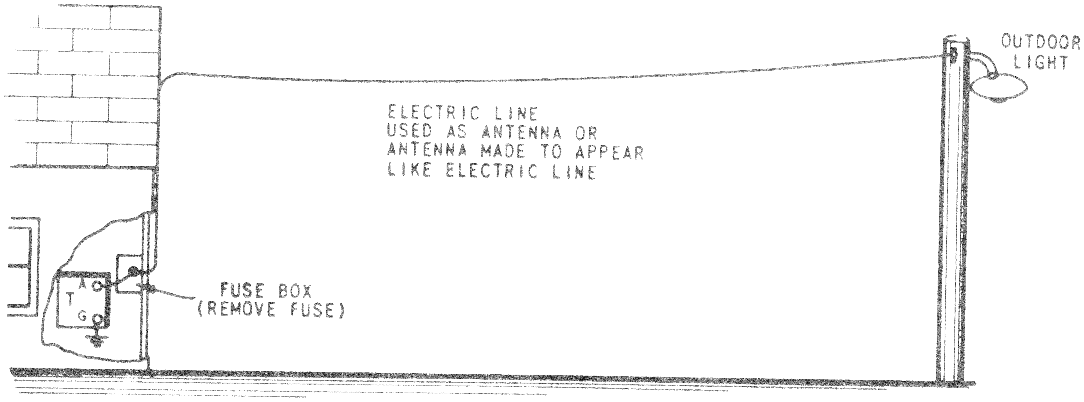


Figure 8-18

Parts of rural heating systems may sometimes be used as all or part of the radiating system. Figure 8-19 shows how a stovepipe is used to make up a part of the antenna. In some cases, particularly at higher frequencies, a tall smokestack for a two-story house serves as a very efficient vertical radiator. When parts of heating systems, such as stovepipes are used, the operator should either solder the joints in the stovepipe or screw them together with sheet metal screws. If this is not done, an excessive waste of power will occur in the high resistances present in the joints.

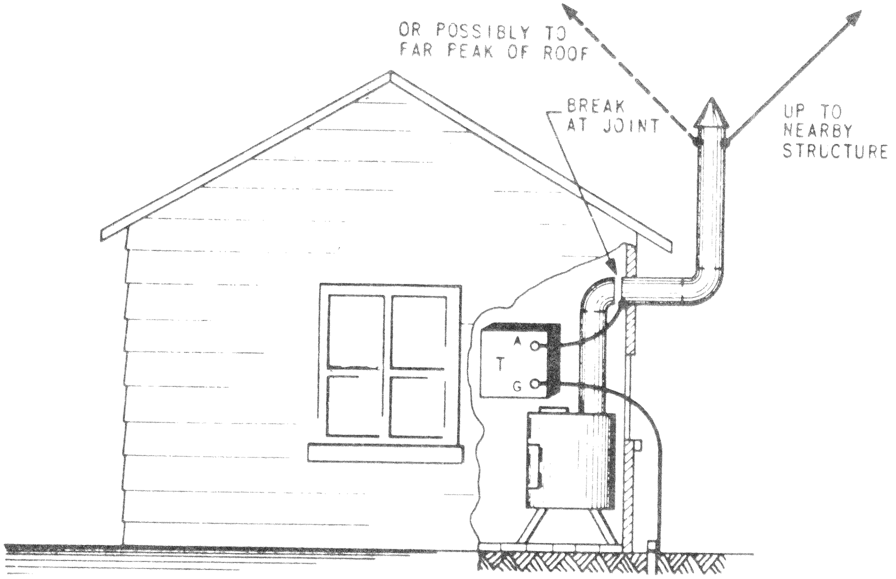


Figure 8-19

In areas subject to frequent observation and possible close scrutiny or subject to the explosive effects of weapons an antenna may be placed underground or buried. The degree of protection desired and the efficiency required of the buried antenna will determine the depth at which it may be placed beneath the earths surface. Generally speaking, the lower the operating frequency, the higher the efficiency and effective radiation of the antenna. For this reason, underground antennas are usually restricted to use with AM or SSB HF radio sets. The depth of burial will also have an effect on the radiation efficiency, therefore, a compromise must be reached on the radiation efficiency and the degree of protection desired. Generally, 15-30 cm (6-12 inches) will provide acceptable radiation and protection, however, the antenna should not be buried any deeper than absolutely necessary. The radiation pattern of buried antennas remains practically the same as above ground antennas, so they should be oriented in the same manner.

Although more elaborate, higher gain antennas may be buried, only the long wire and doublet will be discussed here because of their simplicity and relative ease of construction. All buried antennas must be insulated from the ground. This can be accomplished by using insulated wire and sealing the ends and all connections with some type of sealing material (e.g., rubber tape) or by inserting the wire in an ordinary garden hose or other rubber or plastic tubing and sealing it before burial.

The doublet is cut to frequency the same as an above ground doublet, sealed, and buried to the desired depth. It is advisable to bury the transmission line, also, insuring that all connections are sealed and water proof.

Depending upon the amount of space available, a long wire antenna, preferably 2 or 3 wavelengths, may be used. As with the doublet, the length will be the same as for an above ground long wire for the same frequency. Insure that the orientation is correct for the length of antenna constructed.

Keep in mind, when constructing underground antennas, that any metallic objects (underground pipes, telephone lines, etc.) which are in close proximity may have an adverse effect on the radiation efficiency. If at all possible, bury the antenna in dry soil. If buried in sandy soil, care must be taken to insure that the antenna does not work its way to the surface due to the normal activity in the vicinity.

Underground antennas, when constructed properly, provide an excellent alternate antenna system which will be protected from weapons effects, or provide excellent concealment, if the situation requires.

DO'S AND DON'TS FOR RURAL OUTDOOR ANTENNAS

DO use as long an antenna as possible if a clear outdoor area is available.

DO be careful to orient a long wire antenna correctly by observing the angle of maximum radiation from the wire.

DO keep the antenna as high as possible.

DO figure antenna length to avoid end feed at half-wavelength points.

DO make the best ground system possible by burying a long ground wire under a long wire antenna.

DO solder antenna joints if the antenna is to be used for more than one or two days at the same location.

DO NOT wrap antenna wire around tree branches. Use a leader rope or insulator, and keep the radiating portion of the wire away from trees.

DO NOT install an antenna in the woods unless no other arrangement is possible.

CHAPTER 9

DIRECTIONAL ANTENNAS

9.1 GENERAL DISCUSSION – DIRECTIVE PROPERTIES OF ANTENNAS.

As we have seen, single-wire antennas have directive properties in both the horizontal and vertical planes. No antenna (with the possible exception of a simple vertical antenna) radiates its energy equally well in all horizontal directions. The various combinations of half-wavelength wires produce maximum radiation at right angles to the wire. However, the directivity effect is not always pronounced since the antenna is usually influenced by nearby objects which affect the radiation pattern.

Long wire antennas are made up of a series of half-wavelengths and produce significantly greater radiation in some directions at a sacrifice of radiation in other directions. The directive pattern of a long single wire is the result of the combination of two or more half-wave patterns.

Figure 9-1 shows a long wire used to create a pronounced directional pattern with transmission or reception gain maximum in one direction and minimum in another. In part (A) of this figure, a single wire 25 meters long is excited at 30 megacycles, a frequency that results in five half-wavelengths of radio frequency current on the antenna.

When this wire is supported horizontally above the ground at a height of 5 meters, it exhibits the directional properties illustrated in part (B) of the figure. This lobe structure is a rather complicated one because of the half-wave current distribution along the wire. Part (A) of the figure shows that the direction of the current at each half-wave point on the wire is opposite to that in the preceding section. We may, therefore, state that the current in section "2" of the wire is out of phase with the current in section "1," and similarly, that the currents in section "2" and "4" of the wire are out of phase with the currents in sections "1," "3," and "5."

The 25-meter length of wire can be made more directive at a frequency of 30 megacycles if it is bent into the shape shown in part (C) of figure 9-1. In this case sections "2 " and "4" of the wire have been doubled back upon themselves. If the current distribution in the various sections of the antenna is analyzed in accordance with the illustration shown, there will be three sections of wire spaced closely together in which the currents are all in the same direction (or inphase).

It is also apparent that the currents in the so-called phasing sections composed of sections "2" and "4" of the wire are flowing in opposite directions, or are out of phase with respect to one another. When sections "2" and "4" are close together (about 4 inches), these currents will tend to cancel. The resulting directivity for this type array is illustrated in part (D) of the figure.

In effect, the radiation from three half-waves inphase is maximum at right angles to the direction of the array. Increased radiation from the maximum lobes results in reduced radiation from the minor lobes. As illustrated, the array is bidirectional, and if it can be properly oriented for the desired direction, will provide considerable gain over the single half-wave element shown in part (E).

Directive antennas are advantageous because they increase the effective power of the transmitter by increasing the energy radiated in the desired directions and reducing it in the undesired directions. (A reduction of radiation in undesired directions is useful in avoiding detection by direction-finding stations.)

In directive systems, the phase relationships of antenna radiating elements are controlled to increase radiation in the desired direction. Greater signal strength in the desired direction, at the expense of cancellation in other directions, can be obtained by proper phasing of the radiating elements.

As in all antennas, the impedance of directive arrays is of major importance. We know, for example, that it is desirable to feed power to an antenna at a point of low impedance. For this purpose, it is important to visualize the r-f current and voltage patterns which are present on the antenna.

As discussed in chapter 2, minimum current and maximum voltage must exist at the end of a wire antenna, while the reverse is true at the center point. Figure 2-6 of chapter 2 shows that the center point impedance, which is defined as the ratio of the instantaneous voltage to the instantaneous current, is a minimum. Thus for a half-wave antenna, the low-impedance center point is the best feed point.

Part (A) of figure 9-2, illustrates an antenna similar to that shown in part (C) of figure 9-1. The dotted line represents current distribution along this antenna. The voltage distribution is represented by the dashed line. Points "A," "B," and "C" of figure 9-2, part (A), represent points of low impedance, and would therefore be the most appropriate feed points. Since it is desirable to have equal currents in the various sections of the antenna, point "B" would be the preferred feed point as shown in part (B) of figure 9-2.

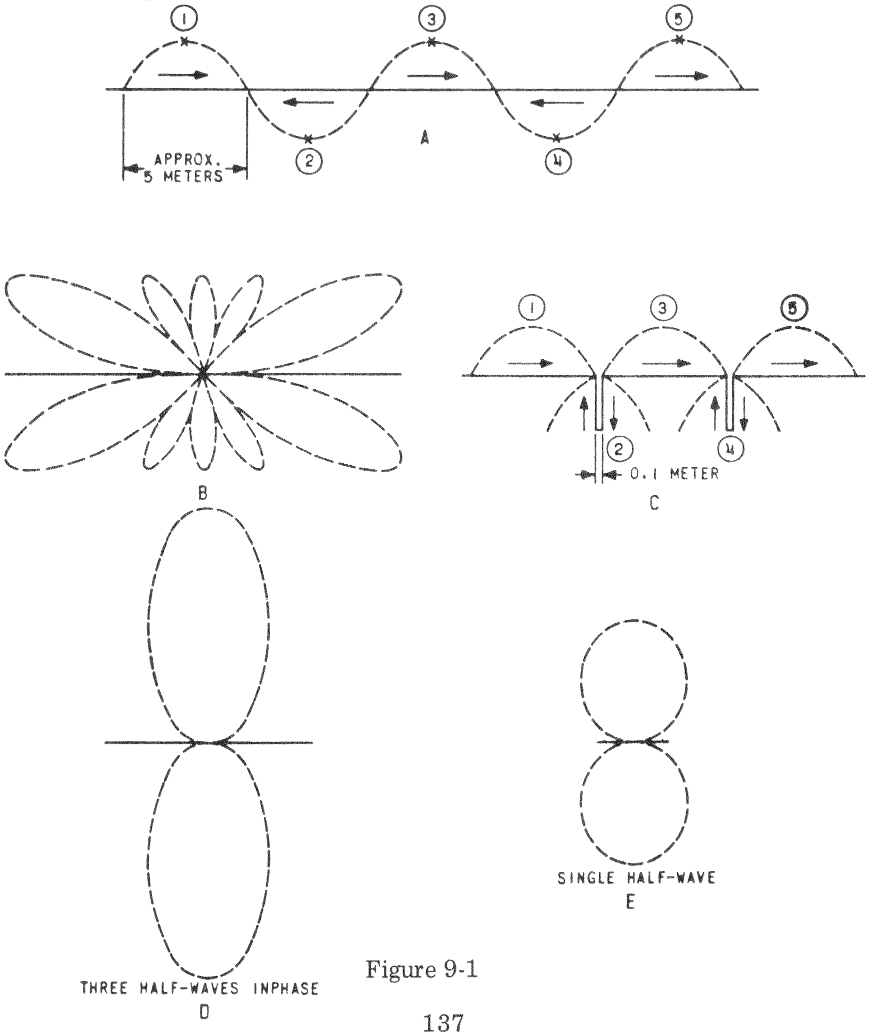


Figure 9-1

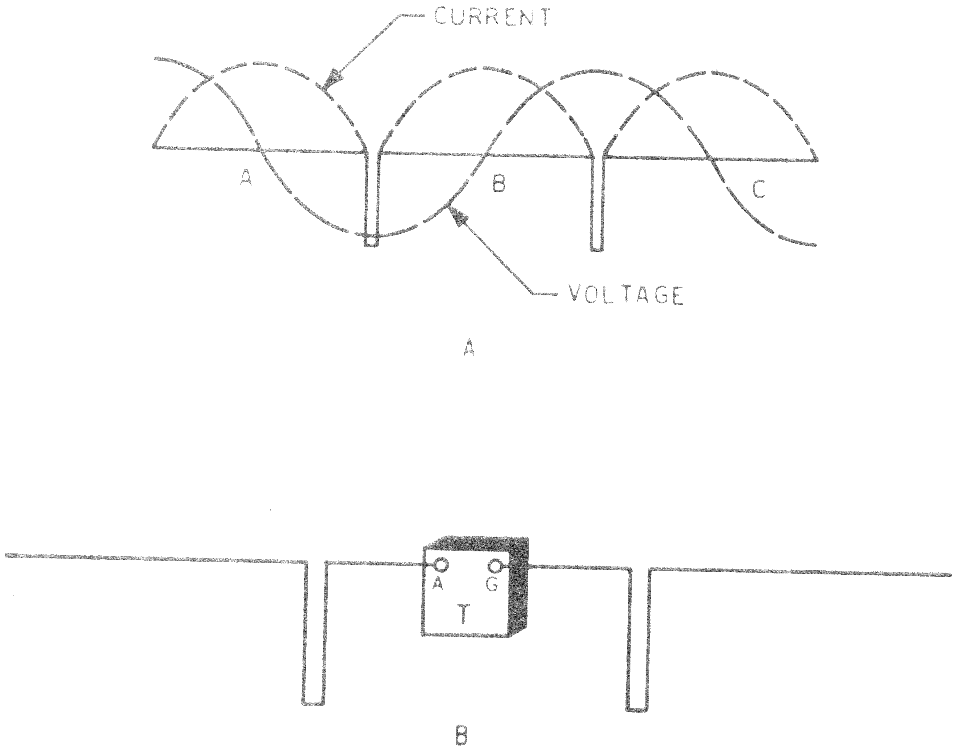


Figure 9-2

Feeding the directional array at position "A" or "C" could be tolerated if absolutely necessary for concealment purposes. A feed point other than point "B" would be used only under the most adverse conditions since the residual resistance of the antenna wire would not be distributed symmetrically about the feed point.

9.2 TYPES OF DIRECTIVE ARRAYS.

Directional antennas may be either driven or parasitic arrays. In driven arrays, all antenna elements are supplied with radio frequency power directly from the transmitter as shown in figures 9-1 and 9-2. Parasitic arrays contain certain elements which do not receive power directly from the transmitter but which are energized by a nearby driven element.

In parasitic arrays, antenna elements which are near resonant length are placed in the immediate vicinity of the antenna element to which power is supplied. The directive characteristics of such an array are largely determined by the spacing between the parasitic and power-driven element.

An example of a driven directional array, is two vertical half-wave antennas spaced a half-wavelength apart. If equal inphase radio frequency currents are fed into the antennas, the currents reach their maximum in the same direction at the same instant. Figure 9-3 shows the horizontal directivity pattern of such an array.

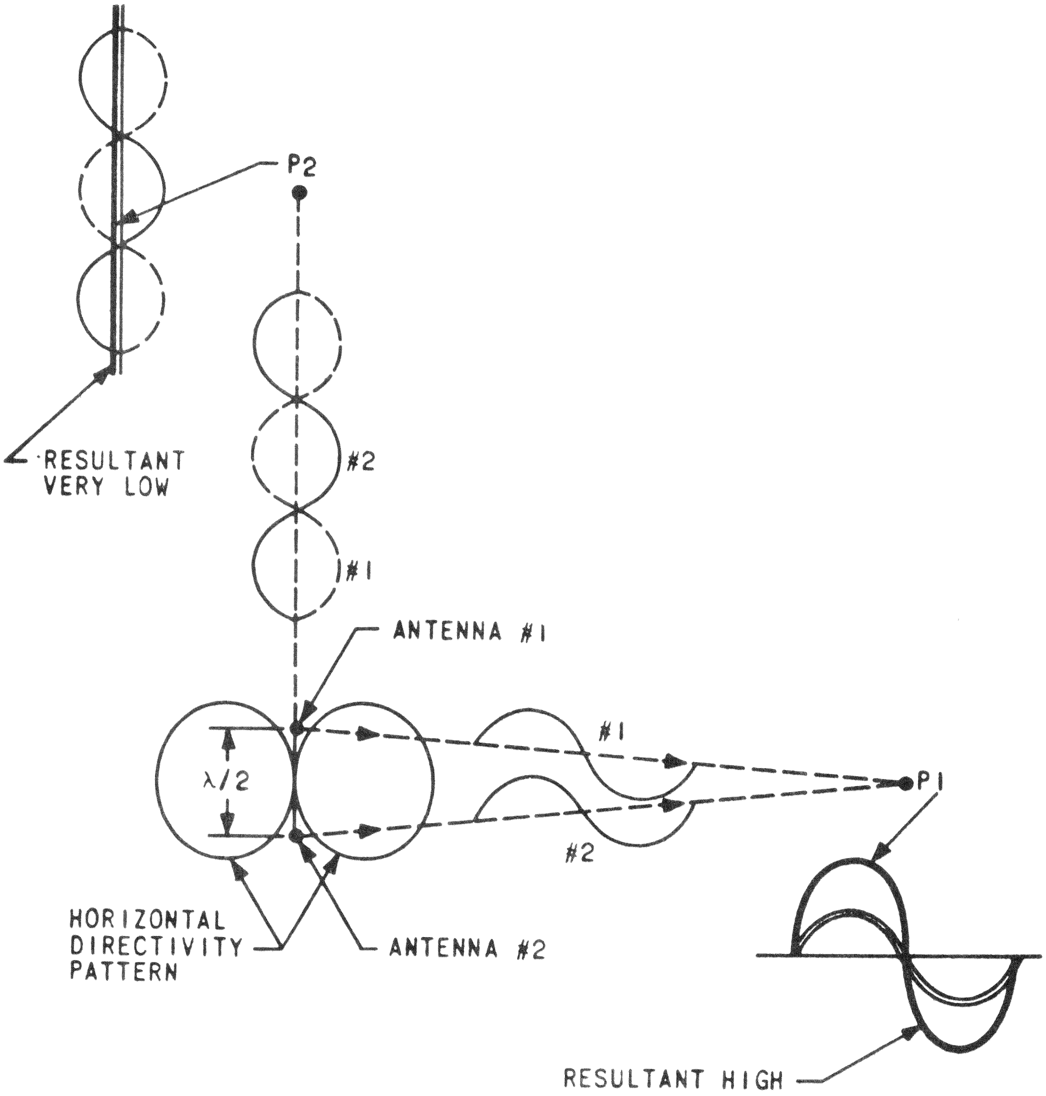


Figure 9-3

Another type of driven directional system is the loop antenna discussed in chapter 4. Where some directivity is desired in a confined space, the loop antenna will provide the most practical solution.

A parasitic directional array is one in which only one element of the array is directly coupled to the transmitter and the other elements are energized by the electromagnetic field of the driven element. A parasitic element may either direct energy from the driven radiator by reradiation, or reflect energy from the driven radiator.

Figure 9-4 shows two types of parasitic arrays. The parasitic element is used as a director in one array, and as a reflector in the other. When the parasitic element is approximately 5 percent shorter than the driven element and within a tenth-wavelength of it, it will act as a director. When it is approximately 5 percent longer than the driven element and placed more than a tenth-wavelength away, it will act as a reflector. Thus action of a parasitic element depends upon both its length relative to that of the driven element, and upon its spacing with respect to the driven element. The directions of maximum signal radiation for both the director and reflector-type parasitic arrays are illustrated in figure 9-4.

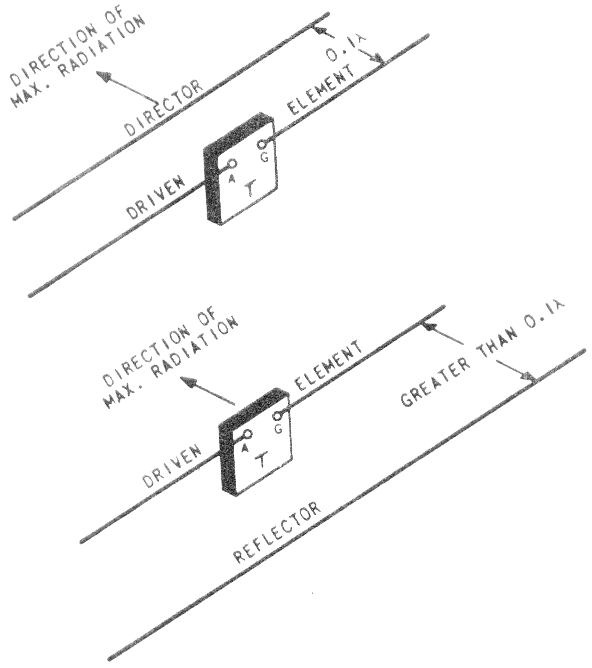


Figure 9-4

Figure 9-5 shows spacing requirements for director and reflector elements. As shown on the graph, the array will have maximum gain when the director parasitic element is spaced a tenth-wavelength from the driven element.

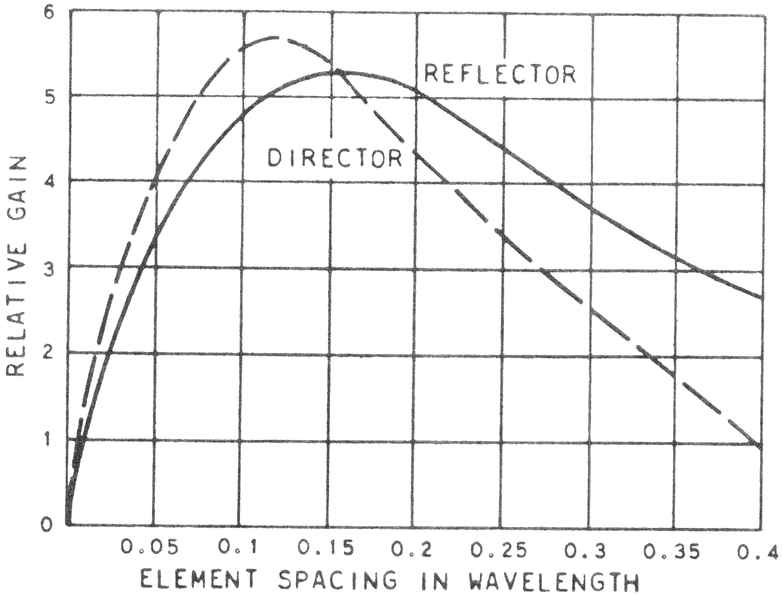


Figure 9-5

Similarly, a reflector parasitic element spaced be spaced about twice this distance from the driven element if reflection. When used as a reflector, the signal will be reinforced in the direction away from the reflector and toward the driven unit.

More complex beams having a greater gain in the forward direction may be constructed by utilizing both director and reflector elements as shown in figure 9-6. Where the array must be portable, the use of this type of beam will be limited. As additional parasitic elements are added, the radiation resistance of the driven element begins to decrease. The driven element alone is a simple dipole and has a radiation resistance of about 70 ohms. Its radiation resistance with either a single director or single reflector drops to approximately 20 ohms.

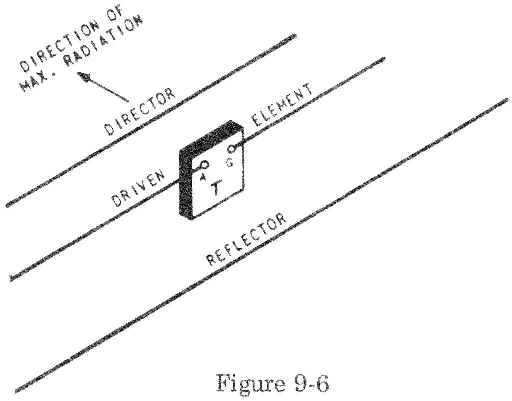


Figure 9-6

In the three-element array illustrated in figure 9-6, the driven element has a radiation resistance of approximately 10 ohms. As additional parasitic elements are added, the radiation resistance continues to decrease. Special feed techniques must then be employed to compensate for this low resistance, and match the array to the transmitter.

When operated on harmonics of their resonant frequency, long wire radiators exhibit directional and gain characteristics, although the gain of long wire antennas less than two wavelengths long is not appreciable. Figure 9-7 shows the gain in the main lobes of a long wire antenna as a function of its length.

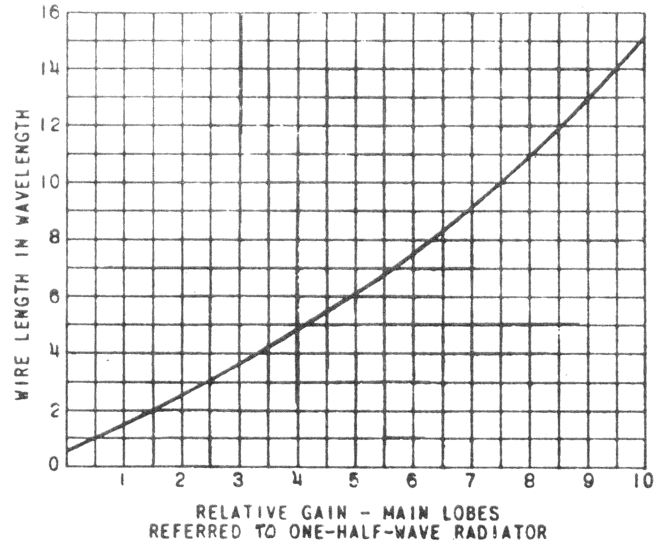


Figure 9-7

If the wire length is greater than four wavelengths, the maximum radiation at vertical angles up to approximately 20 degrees occurs along the direction of the wire rather than at right angles to it.

With the limited amount of power available, wire lengths greater than 10 wavelengths are not practical, especially at the lower frequencies. In general, the maximum wire length should be about 200 meters which would correspond to approximately 10 wavelengths at a frequency of 15 megahertz.

As the length of the antenna is increased beyond a few wavelengths, the tuning of the antenna matching system becomes quite broad. For frequencies where the long wire exceeds 10 wavelengths it works almost equally well over a wide range of frequencies. The directional characteristic of such a broad band antenna varies with the operating frequency. Since the impedance of a long wire antenna is very high at its end, it should be broken and fed at a point of current maximum. Figure 9-8A indicates how this is accomplished.

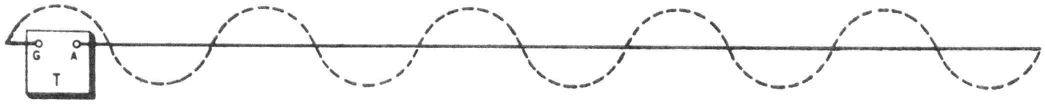


Figure 9-8A

The directivity pattern shown in figure 9-8B varies with the length of the antenna. The pattern illustrated is for a five-wavelength antenna. The pattern illustrated is for a five-wavelength antenna. For this antenna, the maximum radiation occurs off the two ends of the wire at the angles indicated. Figure 4-16 of chapter 4 should be used to determine the horizontal angle at which maximum radiation occurs for the length of wire used.

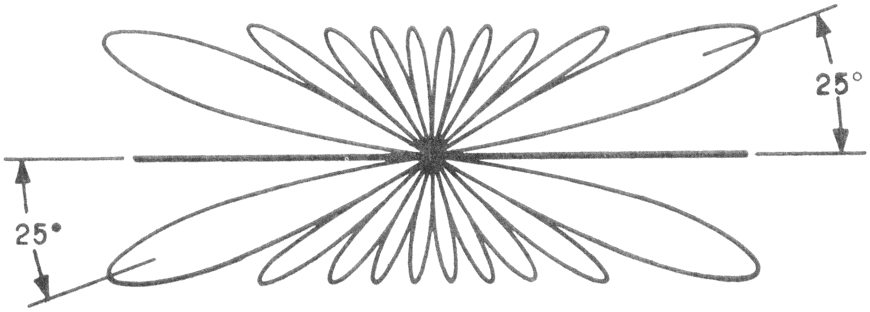


Figure 9-8B

Such a system can be made unidirectional if it is terminated in the characteristic impedance of the system. The terminating resistor should be noninductive and have a value of approximately 400 ohms. It should be capable of dissipating about one-half of the transmitter output power. This power loss represents the power previously dissipated in the opposite direction. The ground points at each end of the antenna should be the best possible to obtain maximum system efficiency.

Figure 9-9A illustrates a 10-wavelength antenna terminated in a 400-ohm noninductive resistance. If this antenna is operated without the 400-ohm termination, it will have the bidirectional radiation pattern shown in figure 9-9B. When terminated, the pattern is the right half of that shown in figure 9-9B, and is directive away from the transmitter.

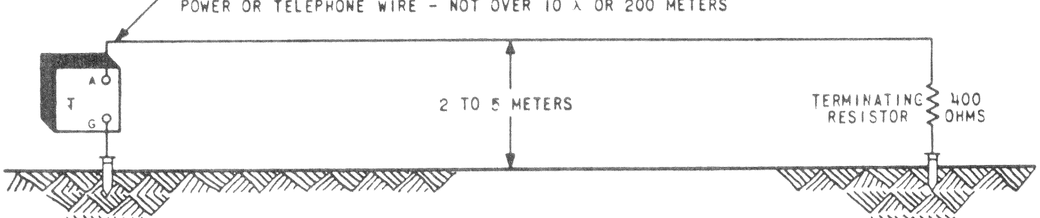


Figure 9-9A

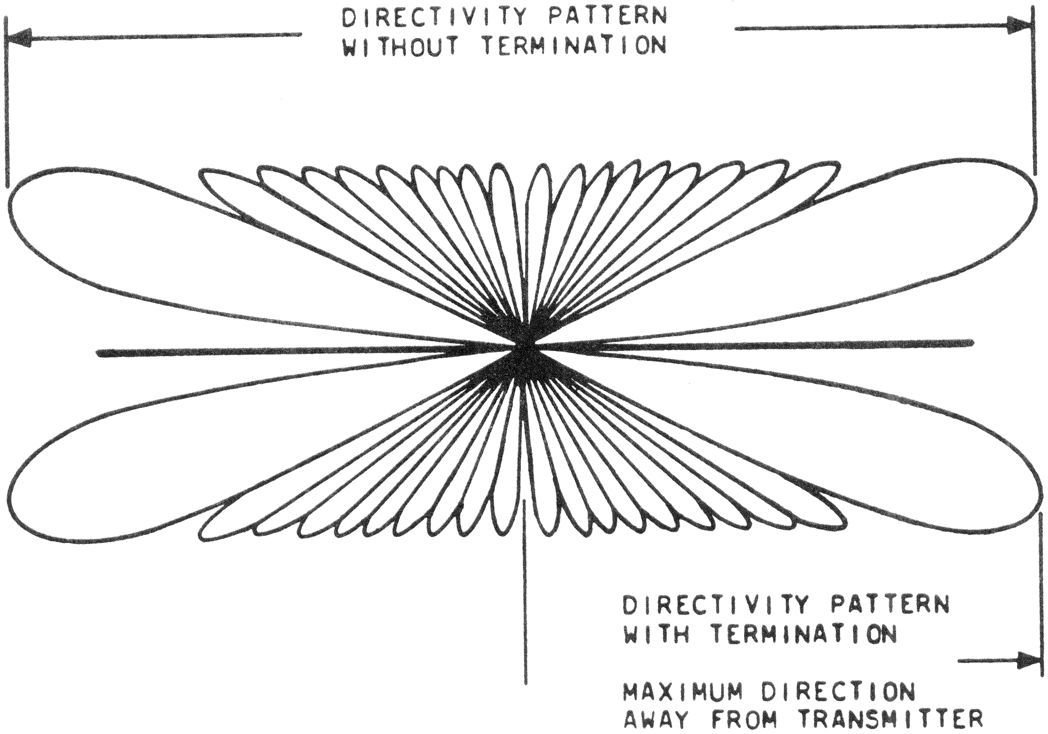


Figure 9-9B

This antenna may be used with some success where the antenna height above ground is limited to a few meters. If the operator plans to transmit with such an antenna, he should compare its efficiency as a receiving system with that of a conventional antenna.

In general, this type antenna requires long lengths of wire which makes concealment difficult. Plans for installing this type antenna could include arrangements to make the wires look like telephone, communication, or powerline elements.

CHAPTER 10

COMMUNICATIONS SECURITY

10.1 INTRODUCTION.

The previous chapters have dealt with the theory, design, and construction of antennas. This chapter will deal with a subject which has a great deal of bearing on the selection and siting of antennas used within the UWOA.

The field of communications security (COMSEC) includes physical, transmission, and cryptographic security. All three of these components are extremely important to the Special Forces detachment in an unconventional warfare environment. Although the siting and selection of antennas comes under the heading of transmission security, the other two aspects of communications security will be discussed because of their importance and close relationship to the subject matter.

10.2 COMMUNICATIONS SECURITY (COMSEC).

Communications security is the protection resulting from all measures designed to deny to unauthorized persons information of value which might be derived from the possession and study of telecommunications, or to mislead unauthorized persons in their interpretation of the results of such a study.

Communications security is broken down into three components. These three components are physical security, transmission security, and cryptographic security.

10.3 PHYSICAL SECURITY.

Physical security may be defined as that element of communications security which results from physical measures taken to safeguard equipment, material, documents, and personnel.

Although we are just as concerned with this component in an unconventional warfare environment, it is more difficult to achieve due to the limited amount of equipment taken in with an operational detachment and the high state of mobility required.

A physical compromise may take place by loss, theft, capture, salvage, defection, or receiving.

The greatest danger in loss of signal equipment, CEOI's, codes, and ciphers lies not in the loss itself, but in the fact that the loss is not reported.

The safest, best, and the only course of action open to you if you cannot lay your hands on material you are supposed to have, is to immediately report them as lost. To continue to use CEOI's, codes, and ciphers of which you are not sure is an extremely rash course of action. Each committed detachment will normally have an alternate CEOI and cryptosystem which is committed to memory to be utilized in the event the primary system is lost or compromised.

Material may also be stolen. In a denied area, we will not be able to safeguard our codes and ciphers in the usual manner, that is by storing them in a safe place or storage cabinet within a secure building. The best we can do is provide guards or keep the material on our person and carry a weapon.

CEOI, codes, ciphers, signal equipment, and personnel may also be captured. In an unconventional warfare operation, we may be forced to leave an area with less material than we brought into it. This, consequently, is provided for in most manuals on signal equipment, in which there is a section on deliberate destruction of the equipment. A good way to destroy the AN/GRC-109 radio is to throw away the covers, chop holes in the soft metal face plates, pour gasoline on the radio, and ignite it. Codes, ciphers, CEOI's, and other material made of cardboard or paper may be destroyed by burning.

A reliable method to accomplish this is to prepare a canvas or plastic pouch for these documents, and equip the pouch with an incendiary charge.

In June 1944, an American submarine-hunting task force with the escort carrier Guadalcanal as its flagship attacked a German U-boat. The German captain, believing his ship to have suffered irreparable damage, gave orders to abandon ship and to open the valves that would scuttle it; however, a specially trained handful of Americans succeeded in boarding the sinking sub and captured it almost intact, with all its codes and ciphers aboard.

Imagine a C-130 aircraft flying over a denied area with an operational detachment aboard, being shot down, and crashing but not burning. The salvage value that could be obtained from such an unfortunate situation would be enormous; codes, ciphers, intact radio equipment, documents, CEOI's — all waiting to be policed up. This is something we hope will not happen, but it might.

Codes and ciphers may be physically compromised by defection. One recent coup on this field, by the Soviet Union, was the defection of two young mathameticians who worked for the National Security Agency. They went on vacation to Mexico, made their way to Cuba, and embarked on a Russian submarine. When next heard of, they were seeking Soviet citizenship.

Another way a physical compromise may take place is by viewing. Some of us, the lucky few, are able to read very rapidly and remember what we read. Some people are able to view plans, charts, or blueprints and reproduce these at a later time. As you know, cameras are TO&E to the operations detachment, and can be used, with accessories, to reproduce documents.

It does not require a photographic memory or a camera to bring about physical compromise by viewing; the smallest individual pieces of information, when correlated and analyzed by experts, can cause compromise of our systems.

10.4 TRANSMISSION SECURITY.

The element of communications security on which most emphasis is placed by Special Forces is transmission security.

Transmission security may be defined as that component of communications security which results from all measures designed to protect transmissions from interception, direction finding, traffic analysis, and imitative deception.

Let's look at the following: interception, direction finding, traffic analysis, and imitative deception, and fingerprinting. What is interception?

By interception we mean listening to our transmissions by the enemy. When our own COMSEC units listen to our circuits to check communications security and discipline, we refer to it as monitoring.

A great deal of our efforts are directed against interception. If we could prevent interception, we wouldn't have to worry about any other factors. Unfortunately, the only absolute defense against interception is radio silence, and radio silence precludes communications. Therefore, in Special Forces we utilize methods in which there is judicious use of radio silence; we transmit as infrequently as possible. When we do transmit, we keep our transmission as short as possible, and we vary the frequency used as often as possible. These measures increase the period of radio silence, and of course provide radio silence on frequencies previously used.

The measures we apply in defense against traffic analysis include those for interception, since a transmission that is not intercepted cannot be analyzed.

Traffic analysis is the study of the external characteristics of signal communications for the purpose of obtaining information concerning the organization and operation of a communications system. Although cryptanalysis can be an aid to traffic analysis, traffic analysis is normally accomplished without cryptanalysis, without breaking the codes and ciphers used. Now, if we know what the traffic analyst looks for, we can prevent the traffic analyst from obtaining the information that he wants. Let's see what he does look for and what we can do about it.

First of all, the traffic analyst wants to know who is talking to whom. How can we deny him this information? The principal method we use is the blind transmission broadcast, which we abbreviate as "BTB." The Navy uses this system, in which they send "foxtrot" messages. This is a message for which no acknowledgement is made, at the time of the transmission, by the receiving station. In fact, it may be several days before a receipt is sent. The Navy uses this system for a very good reason. When they broad cast to their ships from land stations, they don't want the ships to answer, because if they do their position at sea can be plotted. The disposition at sea can be plotted. The disposition of ships is a valuable bit of information for an enemy. Special Forces utilizes the BTB system principally to prevent identification of our detachments with their supporting bases. If individual detachments can be linked to their base station, an enemy can obtain valuable intelligence simply by monitoring the base station. The base station, with its high-powered transmitters operating from a fixed position, is much more accessible than the elusive, low-powered detachment radio.

On the technical side, if an enemy knows the distance existing between a detachment and its supporting base, then a radio propagation curve can be plotted to narrow the frequency band that must be searched for interception.

The present concept of the blind broadcast is similar to that used in World War II; i.e., the message is sent repeatedly, each contact, until it is receipted for. The message may be sent in the same cipher groups each time, if transmitted by the base station, or re-enciphered if transmitted by a detachment. Since the major purpose of the BTB is to disassociate the detachment from the base, the receipt is always contained within the cipher text of a return message. Obviously, if any outward sign of receipt of the blind broadcast was made, association of the two stations could be easily confirmed.

The BTB is probably one of the most valuable communications security measures that can be employed by a clandestine radio station. Unfortunately, the BTB does not provide the most reliable system, since the transmitting station cannot immediately determine if the receiving station copied the message or even heard the broadcast at all. In spite of this principal disadvantage, in the initial stages of Special Forces operations the BTB is the best possible transmission security measure we can employ.

Another technique that can be employed is called duplex operation. In its simplest form the duplex technique consists of two stations transmitting on different frequencies and utilizing different sets of call signs. If the intercept station picks up only one of these frequencies, he hears only half of the conversation. The traffic analyst is again unable to link the two stations together.

The big advantage of duplex operation over blind broadcast is that the transmitting station knows when his message has been received. This technique, in its simplest form, is not subtle enough to fool the intercept operators or traffic analyst for very long; however, a more sophisticated version of the duplex technique can be employed that will provide desired security.

If the traffic analyst cannot determine who is talking to whom, and have some idea when and on what frequency, he is stymied before he begins. There are other things the traffic analyst looks for. One of these is call will continue to identify the unit even though other characteristics (to include location) may change. Coupled with a direction-finding program, the unit can be plotted in its movements. When particular units are singled out for traffic analysis, they are typically singled out by their call sign. In Special Forces, so that we will not be continually identified by call signs, we change call signs with each transmission.

Another thing the traffic analyst tries to pick out are the peculiarities of the operator. Each operator has a distinctive way of sending, which we call a "fist." Most operators also have one or more bad habits which further identify them. In conventional operations this is a dangerous fault, since the radio operator can be identified in spite of changing call signs, frequencies and location — and once identified with the unit, he is the unit to the traffic analyst. In Special Forces operations, the same fate awaits our operators, so we must attempt to eliminate individual characteristics through extensive training. Despite this extensive training, all radio operators still retain a signature which should be recorded at SFOB to prevent imitative deception. This identification of a radio operator through his characteristics is sometimes referred to as operator fingerprinting.

Another technique which may be utilized by the enemy is that of fingerprinting the radio transmitter. Each transmitter has slightly different characteristics (electrically) than the next radio has, even though the radios may be of the same model and basic design, such as the AN/GRC-109. Experts, with the use of certain electronic equipment, can distinguish the difference between 10 different radio sets in operation even though the 10 radios used are of the same model and design. This again would be extremely helpful in the enemy's efforts to ensure that, even though a station has changed call signs, frequencies, and locations, it is still the same station.

Some of the countermeasures against radio fingerprinting are (1) change radio operators if possible, and (2) change radios or components within radios. Again, the best countermeasure available is to avoid detection on the air to begin with.

Now let's look at direction finding. Radio direction finding (RDF) is the science of locating the position of a radio transmitter by interception and plotting the azimuth of an incoming radio wave. This is done with directional antennas that can be rotated so as to receive maximum signal strength from a given direction.

There are certain precautions an operator can take to minimize the danger of detection by radio direction finding (RDF). Before outlining them, however, let us review a few principles of RDF and determine the magnitude of hazard it presents. As we shall see, the monitoring services of most large countries have the capability of getting a fix on a clandestine transmitter within minutes after it goes on the air. This fix, however, since it is taken at long range, merely locates the transmitter within an area about 50 miles square. Mobile DF teams operating in trucks or with hand-carried equipment then take over and reduce the suspected area to about a half-dozen blocks. (An operator who spends 10 or more seconds tuning up his transmitter, or practices sloppy sending techniques, has pronounced personal "fixed" characteristics, which make the job of the mobile DF team much easier.)

From this point on, the team concentrates on finding the operator by looking for transmitting antennas, suspicious persons, broadcast interference, or other clues. An operator who has been on the air more than half a dozen times must be especially careful about his physical security. He should operate from batteries whenever possible, avoid turning lights on and off just before or after a transmission. He should also change location whenever he can. Under all circumstances the operator who stays on the air the shortest length of time is the safest.

The fact that radio signals travel in a straight line across or around the earth permits a properly equipped receiving station to determine the direction of the signal source. For example, the location of a ship at sea can be determined if the signals are received at two fixed receiving stations far enough apart to permit cross-bearings.

The ship shown in figure 10-1 transmits signals which are received by stations at points "A" and "B." The directions from which these signals arrive can be determined by means of special direction-finding antennas. By plotting the directions of signal arrival on a map, the ship location is found to be point "X."

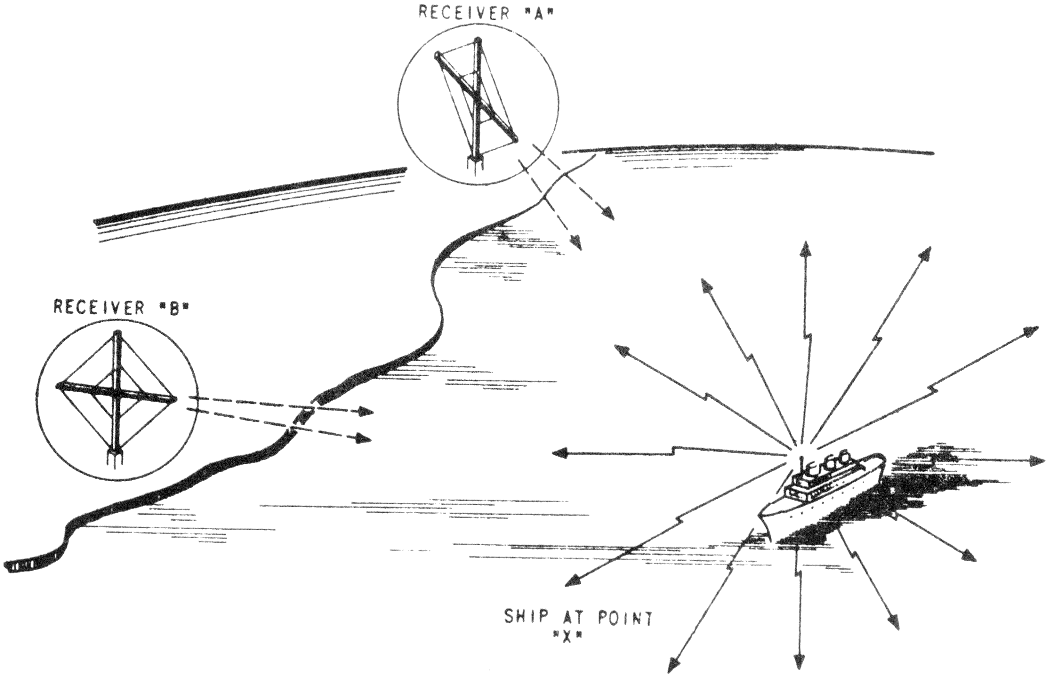


Figure 10-1

Over short ranges, the direction of arrival of the radio signals is usually determined by some form of rotatable loop antenna. A vertical loop antenna has a highly directive response pattern similar to that shown in figure 10-2. The signal is strongest when the loop points toward the transmitting station, and weakest when the direction of the loop is broadside to the station. By adjusting the receiving loop on a compass scale, the null, or direction of minimum response, can be determined within a few degrees, and the direction of the transmitting station established.

A minimum of two bearings on an unknown transmitter is necessary to determine its distance from the receiving points. In practice, three or more bearings from different receivers are made whenever possible. The signal is received at point "A," as in figure 10-1, and the bearing is determined and plotted on a map. A similar bearing is taken at point "B" as illustrated. The combination of the two readings and the point of intersection of the two bearings the approximate area from which the unknown signals originate.

This method of direction finding is successful only if signals are received at both fixed receiving points. For example, in figure 10-3, the location of the transmitting station at point "X" is unknown to the receiving station at point "A." If the unknown transmitter leaves the air before the direction-finding equipment is put into operation at the second position, point "B," the location cannot be satisfactorily established. The use of special antennas, however, makes it possible to determine the general location of a transmitting station from data obtained at a single receiving station.

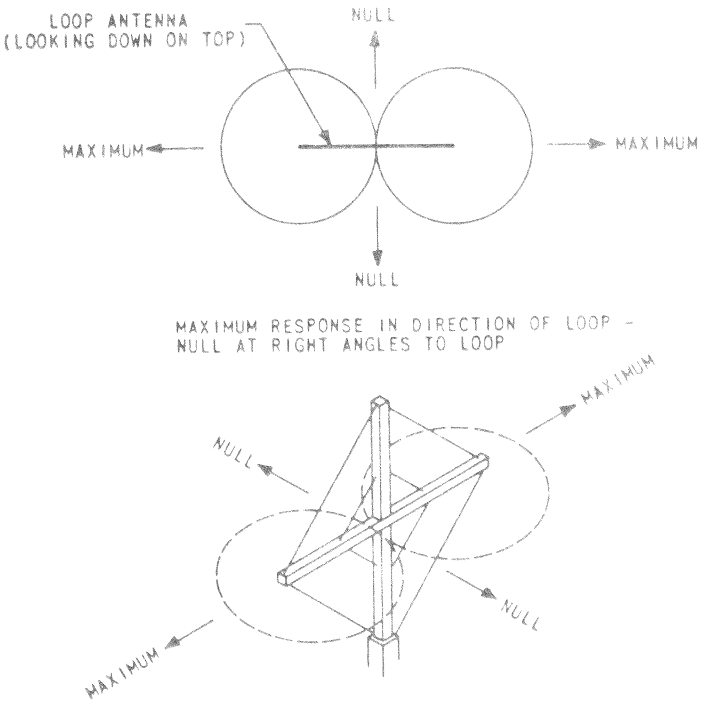


Figure 10-2

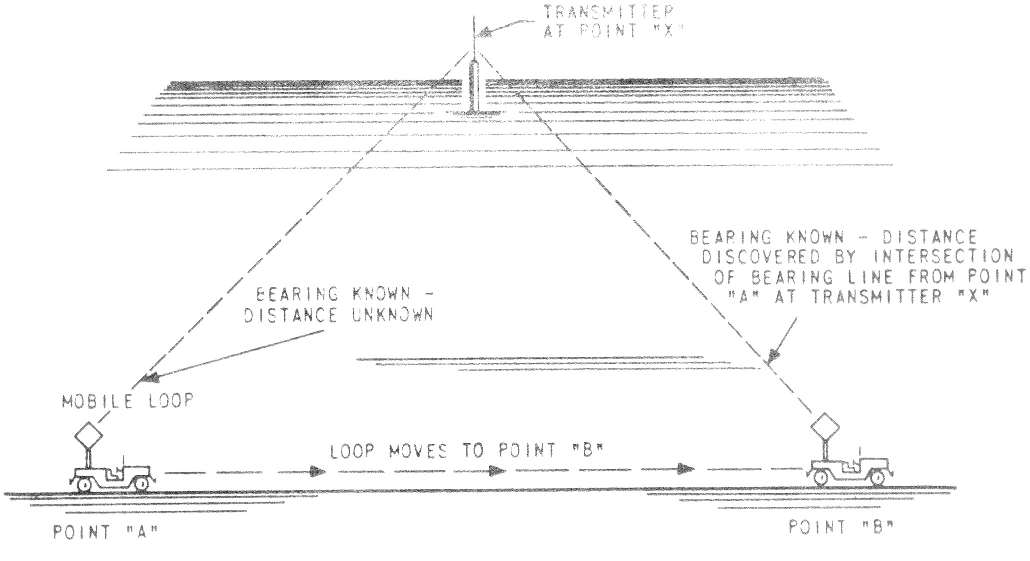


Figure 10-3

The bearings obtained from a vertical loop antenna rotated about its axis will be correct only if the radio waves received from the unknown transmitter are ground waves. If horizontally polarized signals are present, some portions of the loop will respond to these signals and the resulting null will be broad. This usually causes some difficulty in the interpretation of a true bearing. Airborne direction finders are susceptible to errors of this type, particularly in areas where the terrain is rough or mountainous.

The accuracy of directional loops decreases as the distance from the transmitter increases. They are more accurate during the day than at night when sky-wave propagation may be a confusing factor even at very short distances, as shown in figure 10-4. At frequencies of 3 megahertz and above, loop direction finders become increasingly difficult to use. Strong intensity sky-wave signals which are present both day and night within a few miles of the transmitter, give false indications on the direction-finding equipment.

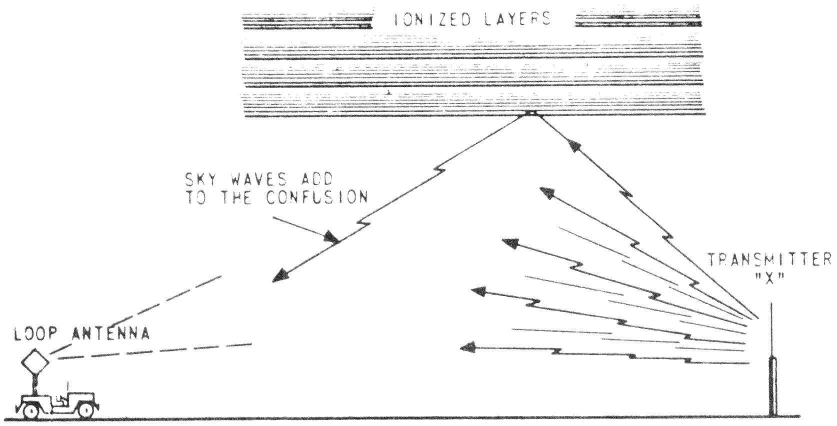


Figure 10-4

Most governments maintain a number of large direction-finding stations. These are expensive installations covering many acres with as many as 36 antennas to the station. The best station of this type was designed by the Germans for use in World War II and was called the "Wullenweber."

The Russians have several such installations which they designate "Krug." Under ideal conditions these stations can take a bearing in less than 30 seconds which is accurate to within two degrees, even on the sky wave.

If three of these stations can be tuned to the unknown transmitter frequency, and each takes an accurate bearing of the transmitter, this information can be plotted on a map. The lines from each direction finding (DF) station to the transmitter will intersect in a six-sided figure covering approximately 50 square miles as shown in figure 10-5.

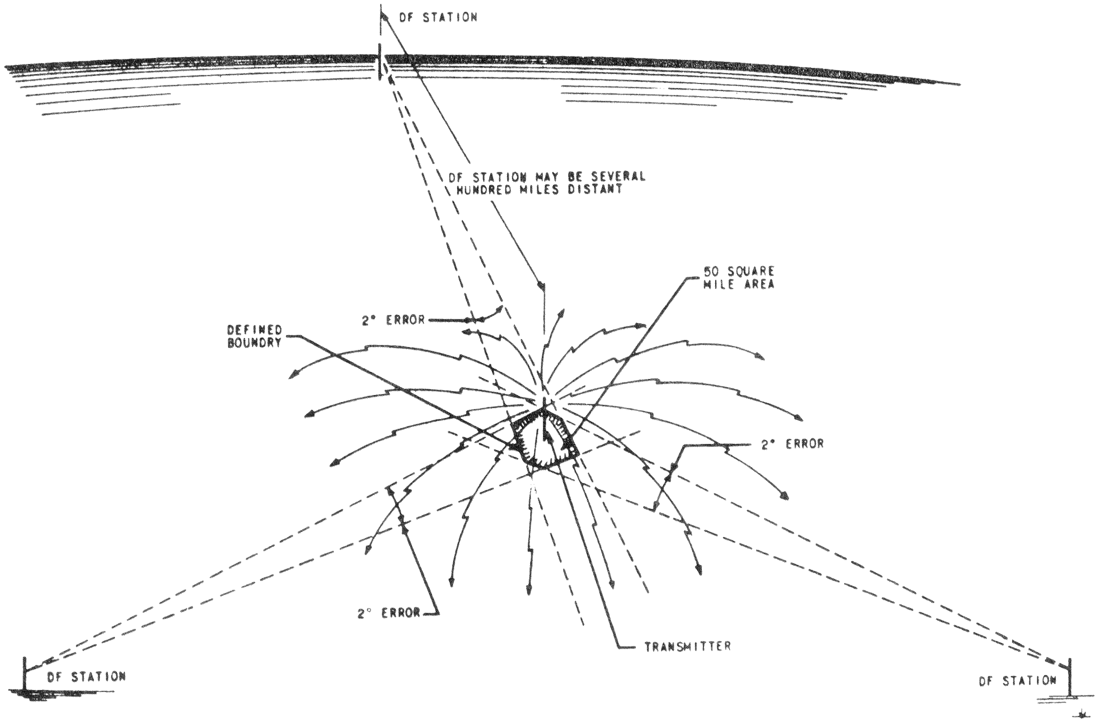


Figure 10-5

It should be noticed at this point that none of the stations can be in the skip zone, and all of the stations must, of course, be tuned to the correct frequency. For this reason it is important to change frequencies constantly and to keep transmissions as short as possible. The base station knows the time and frequency of the scheduled transmission, the DF team does not.

After the "Krug" stations locate the transmitter within a 50-mile area, the DF team sends truck-mounted direction-finding receivers into that area, as shown in figure 10-6. These truck-mounted DF stations have an accuracy of 5 degrees at best. They can encounter greater errors in hilly terrain or if an appreciable amount of energy comes to them by sky-wave reflection rather than ground wave.

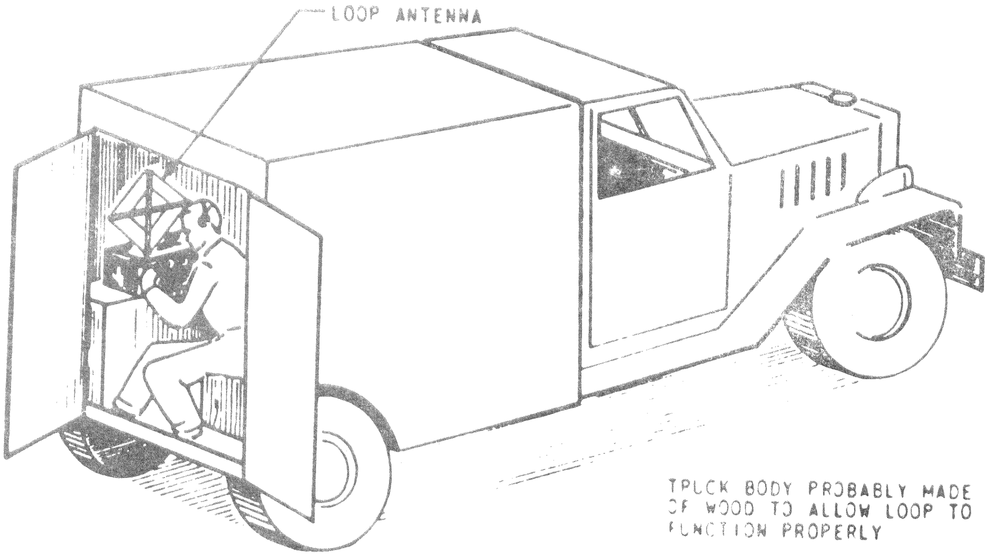


Figure 10-6

If the mobile station receives pure sky wave, its direction indication will be 90 degrees in error. If the mobile station receives purely ground wave, the direction-finding error will be approximately 4 degrees. If the mobile station receives both sky wave and ground wave, the error will be somewhere between these two extremes. It can, therefore, be seen that mobile stations are useless unless they are close enough to the transmitter to receive practically pure ground-wave signals.

The ground wave of a 10-watt station will not extend much more than 5 miles from the transmitter. Therefore, the mobile DF station will have to search the 50-square mile area for some time before coming within 5 miles of the transmitter. Horizontally polarized antennas have much less ground-wave radiation than do vertically polarized antennas and the DF team's job can, therefore, be made much tougher by using horizontally polarized antennas.

After several truck-mounted DF stations have gotten within ground-wave distance of the transmitting station and have taken bearings, they can determine the transmitter's location to within an area of 5 to 10 city blocks. See figure 10-7.

If there is a single dwelling within the 10-block area, the DF team has practically located its man. If there are a thousand apartments within the area, its work has just begun. This is one reason why it is better to operate in cities if the greatest protection from DF teams is desired.

If the transmitting station is in a city, every piece of metal within the 10-block area will reradiate some of the energy transmitted by the antenna. If the signal from a reradiating object is considerably stronger than that from the transmitter due to the DF team's proximity to the reradiating object, the DF indicator will point to the reradiating object. When the DF indicator is close to the transmitter, it will point to the transmitting antenna. When the team is somewhere between, the indicator will also point somewhere between.

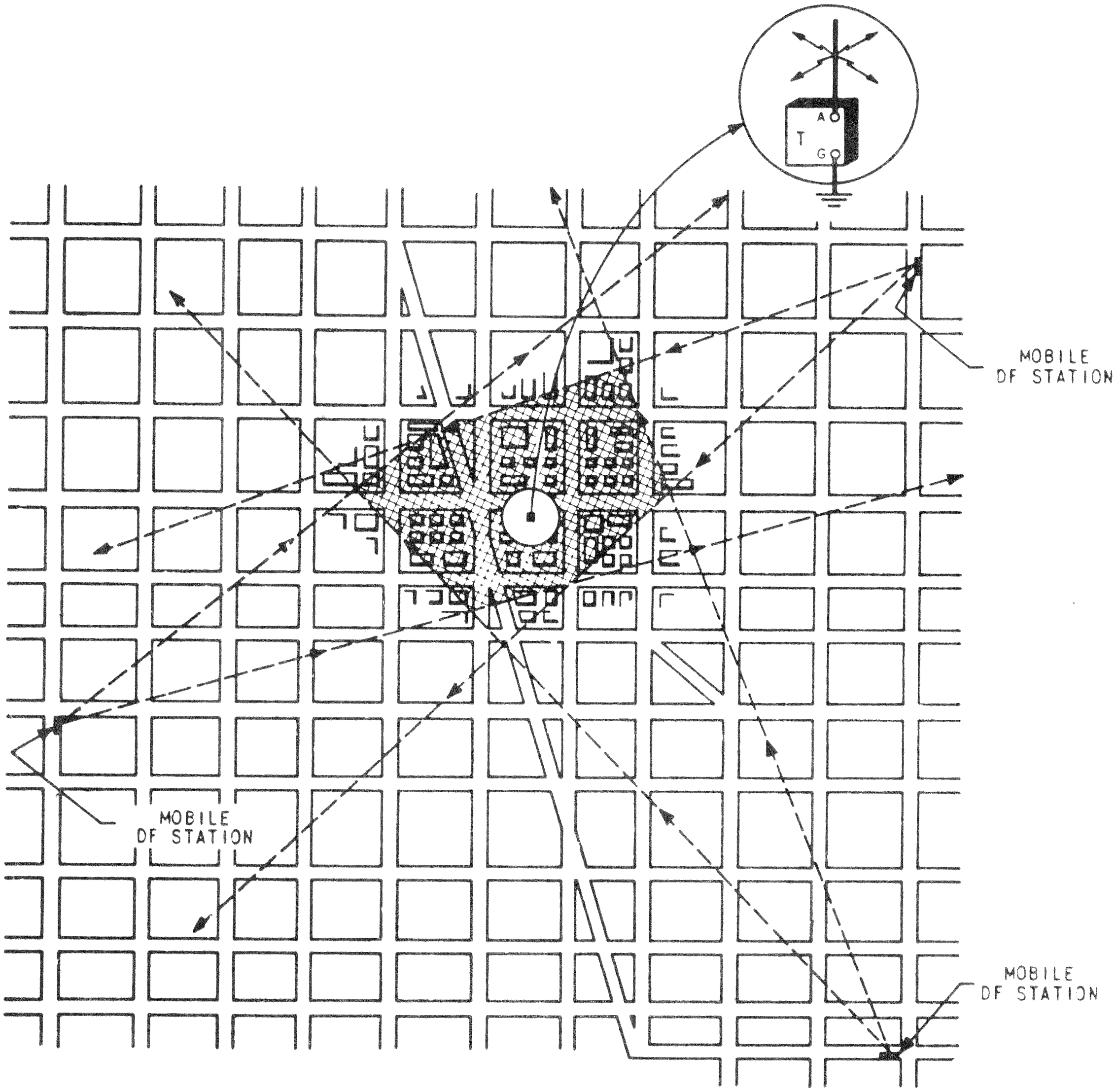


Figure 10-7

Thus, every lamppost, fence, and pipe in the area can give false indications to the cruising DF team. When the transmitting antenna is considerably above street level, the effect on the DF team antenna is just as if it were receiving a sky wave, and the indicator will point 90 degrees away from the antenna. These are some of the reasons why it often takes weeks to find a clandestine transmitter even after several mobile trucks have located the area to within 10 blocks.

After the DF trucks have located the block which contains the transmitter, the team starts going through the buildings wearing concealed receivers and direction-finding antennas. These sets are plagued even more by false indications from reradiation. Even as the team walks down the corridor of the correct building it still finds many false indications.

Because their work is so difficult, the mobile DF teams depend heavily on nonradio methods of finding the station. They carefully examine the 10-block area for suspicious antennas. They watch the wattmeters in the basement of each building to see if the power consumed by one apartment varies during the transmission. They will watch the lights of the apartment houses to see if the lights in one room go out shortly after a transmission is concluded. See figures 10-8A, 10-8B, and 10-8C. They will question apartment house residents concerning interference on their radio or television sets. Many more clandestine radio stations are discovered by these methods than by truly radio direction-finding methods.

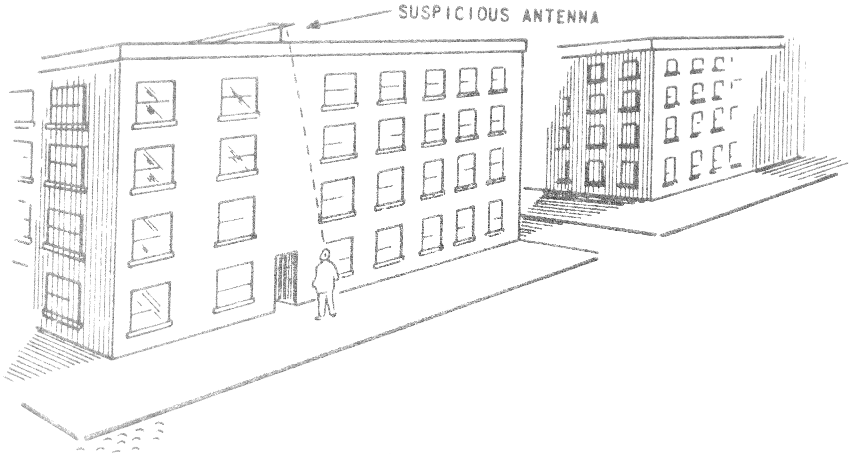


Figure 10-8A

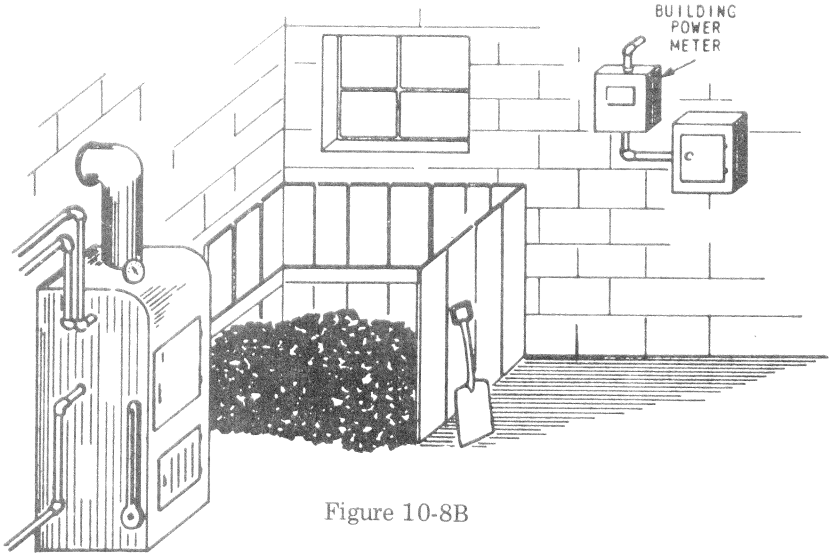


Figure 10-8B

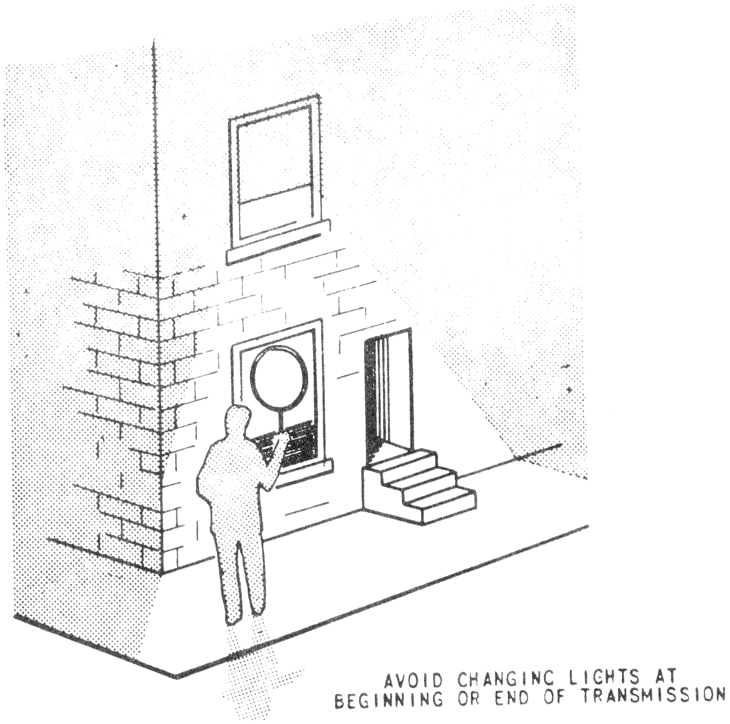


Figure 10-8C

10.5 PRECAUTIONS AGAINST RADIO DIRECTION FINDING.

We can now see the importance of taking the following precautions when detection by DF methods is a hazard:

(1) Change operating frequencies often.

(2) Change operating time.

(3) Keep transmissions short.

(4) Use horizontal antennas where possible.

(5) Operate from thickly populated areas.

(6) Locate antennas well above street level.

(7) Operate from batteries.

(8) Change transmitter location as often as possible.

(9) Avoid long tuneups and distinctive operating characteristics.

Given sufficient time on the air, any transmitter can be located by direction-finding methods. However, if the transmitter is operated at different times and frequencies, limits its transmission time, and changes its location every transmission, it is extremely difficult for the DF team to locate the transmitter.

In the event that a radio operator were to fail to send his security check, or he omitted to send his cryptocheck as instructed, this would naturally alert the base personnel. This is not to say, however, that they would automatically sever all contact with this station. A means must be devised to question the radio operator and get a positive confirmation that he has been compromised. This is accomplished through the use of a security recheck. A question is asked of the radio operator which would not arouse the suspicion of his captors, but in essence would ask the radio operator: "Are you captured?" There are numerous methods of doing this. One method is to the radio operator a simple question such as: "Do you need any radio batteries?" In the radio operator's reply, any mention of the batteries would imply that he had, in fact, been compromised and was operation under duress. The proper reply for him in the event he was not captured would be something like: "No, I just ate a bar of soap." This is the answer he would give if he had not been compromised.

If you are ever surprised while transmitting, and capture is imminent, there will not be sufficient time to explain your situation by drafting and sending a message. There is a way, however, in which you can let the SFOB know that your capture is imminent. This is through the use of danger signals. These signals are nothing but very short messages such as TSTSTS, which would alert the base personnel of your capture. The use of these danger signals is similar to the use of the international distress signal SOS. All of these techniques must meet at least three prerequisites. They must be (1) positively recognized, (2) easily transmitted, and (3) committed to memory.

Imitative deception is an attempt by the enemy to imitate one of our radio stations; e.g., an operational detachment. In clandestine communications we refer to this as a playback. Imitative deception may include the use of our own radio equipment, CEOI, codes, ciphers, and even our own radio operators (under duress). Remember the C-130 that was shot down for our illustration of salvage? Any enemy intelligence agency worthy of the name would attempt to use the radio, CEOI, codes, and ciphers aboard and pretend to be the missing operational detachment.

In Special Forces operations this is a distinct possibility, and we must be alert to it. There are various measures which can be taken to ensure that the enemy is unable to perform a playback operation without the cooperation of the radio operator.

The first measure we will discuss involves the use of the cryptosystem. At a predetermined position within the message, a code word is inserter within the message. The omission of this word from a message would alert the base station of a possible compromise. There are a number of variations of this system. Another way of doing it would be to always omit using a certain group of the cryptosystem. Then if you were ever compromised you would encipher the message in normal fashion. This again would alert the SFOB personnel of your capture. These crypto checks would not be found within the CEOI but would be committed to memory.

The use of a security check is nothing more than an operator authenticating himself by some prearranged method which again must be committed to memory. One way of doing this would be always to make a mistake within the call sign while transmitting. If the call sign which is found in the CEOI were ever transmitted correctly, it would again alert the SFOB operators.

10.6 CRYPTOGRAPHIC SECURITY.

Cryptographic security may be defined as that element of communications security which results from the provisions of technically sound cryptosystems and their proper use. Even the most technically secure cryptosystems can be broken if enough clues are available to the cryptanalyst. These clues are most often provided by violations of the rules of the system. The definition, points out that the two necessary elements of cryptographic security are (1) the provision of technically sound cryptosystems, and (2) their proper use. Either of these elements is valueless, unless complemented by the other.

Further discussian of cryptographic security would cause this text to be classified, therefore, additional information must be obtained by the reader from other sources.