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FIELD ENGINEERING FOR THE ARMED FORCES AND INDUSTRY

PHILCO TRAINING MANUAL on ANTENNAS

Antenna Series
VOLUME I

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PHILCO TRAINING MANUAL

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ANTENNAS

Antenna Series
VOLUME I

L. J. Wadsworth. SP2
NG 28228634

PHILCO CORPORATION
PHILADELPHIA, PA.

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TEACHING SUGGESTIONS

The success of any training course depends largely upon the methods employed by the instructor. As an aid to the instructor, the following suggestions are offered:

Know the subject thoroughly and be able to answer questions.

Enunciate clearly and speak loudly enough, using a voice amplifier if necessary, to be heard by every member of the class.

Emphasize by gestures and voice inflections the main points of the subject under discussion.

Always face the class when speaking.

Observe the students' reactions and expressions to see whether the students are interested, and whether more detailed explanation of the subject is necessary.

When discussing the electrical and physical characteristics of any subject before a large group, some large writing surface should be available so that complete or partial sketches may be drawn. Conventional parts of an electronic system, such as the transmitter, may be drawn in block-diagram form; the subject under discussion, such as the antenna matching section, should be sketched in detail.

At appropriate times during the lecture, question various students concerning the topic under discussion. (Choose especially those individuals who do not seem to be paying attention.) However, request that the students wait until the discussion of a particular subject is completed before they ask questions.

Keep an open mind; although a student's thinking process may be different from yours, his ideas may be just as correct as yours. Teach the student to be open-minded, and to think before asking questions.

Each student must have a notebook, in which notes on the main points of the lectures should be written, especially if sufficient copies of this manual are not available. Even if a copy of this manual is given to every student, the student should supplement this reference material by taking notes during lectures. Adjustment procedures and construction details should also be written in brief form by the students. The notebooks will then serve as a reference for future work with antenna systems in the field. If the notebook work is carefully done, it will be a valuable aid to installation crews or maintenance men. The notebooks must be checked weekly, by the instructor, for accuracy of content.

If the time allotted for a lecture begins to run short while there is still a considerable amount of subject material to be discussed, do not attempt to hurry, and skip over details. Break the discussion at some appropriate point, and continue from that point in the next lecture period. Five or ten minutes should be reserved at the end of each lecture, for a brief review of the main points discussed. If the students apparently understand the subject covered, and ask no questions, ask a few questions yourself.

There should be a short break, or rest period, after each hour of lecture, to allow students to relax.

The schedule presented in conjunction with the lecture outline is flexible, and should be modified to meet the conditions at hand. If, for example, it is possible to provide laboratory and field experiments for the students, allowances in time must be made in the lecture periods. Taking this into account, the last two weeks of the course have been scheduled so that sufficient time will be available for the undertaking of practical work. The instructor will be able to determine the necessary time allotments when he has had sufficient experience in conducting the course.

Before the weekly examination is given, the instructor should arrange a review for the class. The purpose of the review is to prepare the students for examination. Emphasize the important points of the past week's lectures, and clear up any points which may not be fully understood. If these questions do not consume all of the available time, the instructor should supplement his review material by asking pointed questions.

All of the examinations included in the course are designed to require one hour's time for completion. If this manual is employed by the students, these examinations are not to be used. In this case, similar ones should be prepared.

After the completion of the examination, a review of the questions should be conducted.

LECTURE OUTLINE AND SCHEDULE

LECTURE OUTLINE AND SCHEDULE (Cont.)

LECTURE OUTLINE AND SCHEDULE (Cont.)

LECTURE OUTLINE AND SCHEDULE (Cont.)

SAFETY PRECAUTIONS

IT IS THE DUTY of all personnel engaged in the INSTALLATION, OPERATION, and MAINTENANCE of electronic equipment, or engaged in the TRAINING OF OTHER PERSONNEL on electronic equipment, to become familiar with the following SAFETY PRECAUTIONS:

1. DO NOT RELY on safety devices.
2. USE RUBBER GLOVES when applicable.
3. KEEP YOUR FEET CLEAR of objects on the floor.
4. STAND ON A GOOD RUBBER MAT.
5. Whenever possible, KEEP ONE HAND BEHIND YOU, or in your pocket.
6. HAVE ANOTHER PERSON, qualified in FIRST AID FOR ELECTRICAL SHOCK, present at all times.

REMEMBER that men are always injured or killed by HIGH-VOLTAGE EQUIPMENT which is ASSUMED TO BE OFF. TAKE NOTHING FOR GRANTED. Make certain that the POWER IS OFF by securing the POWER-LINE SWITCH in its OFF position. Remove all fuses (including spares) from any circuits where switches might unintentionally be closed.

RESCUE OF SHOCK VICTIMS

1. PROTECT YOURSELF with DRY insulating material.
2. BREAK THE CIRCUIT by opening the power switch or pulling the victim free of the live conductor. DO NOT TOUCH THE VICTIM WITH YOUR BARE HANDS UNTIL THE CIRCUIT IS BROKEN.

FIRST AID

Do These Three Things First in Any Emergency Requiring First Aid

1. SEND FOR A DOCTOR OR CARRY THE VICTIM TO A DOCTOR.

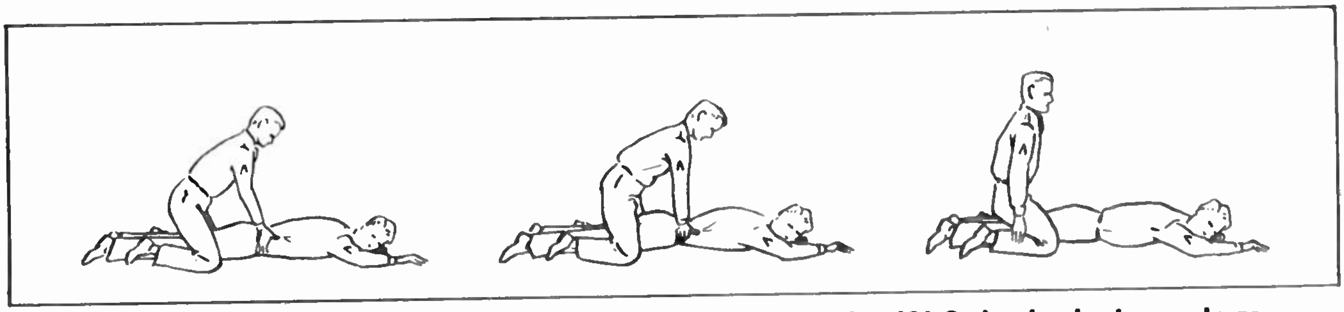
2. KEEP VICTIM WARM, QUIET, AND FLAT ON HIS BACK.

3. IF BREATHING HAS STOPPED, APPLY ARTIFICIAL RESPIRATION. STOP ALL SERIOUS BLEEDING.

When, from any cause whatever, BREATHING HAS STOPPED, APPLY ARTIFICIAL RESPIRATION IMMEDIATELY and continue WITHOUT STOPPING until normal breathing returns, or a doctor pronounces the victim dead. SPEED IN BEGINNING ARTIFICIAL RESPIRATION IS ESSENTIAL.

ARTIFICIAL RESPIRATION

1. SPREAD DRY BLANKET ON THE GROUND, and roll victim to center of blanket with his arms extended over his head, so that he lies FACE DOWN on blanket.
2. BEND ONE OF THE VICTIM'S ARMS at the elbow and rest victim's cheek on the back of his hand.
3. REMOVE FALSE TEETH, gum, candy, tobacco, food, etc., from victim's mouth.
4. LOOSEN ALL TIGHT CLOTHING, such as belts or collars.
5. COVER VICTIM LOOSELY by wrapping the ends of the blanket around him.
6. STRADDLE VICTIM across thighs.
7. PLACE THE PALMS OF YOUR HANDS ON VICTIM'S BACK so that the little fingers of your hands just touch the victim's lowest ribs.



(1) Straddle victim across thighs. Place the palms of your hands on the victim's back so that the little fingers of your hands just touch the victim's lowest ribs.

(2) Keep your arms stiff and straight and swing your body forward, allowing your weight to bear down on victim. DO NOT PUSH OR USE FORCE.

(3) Swing back at once to relieve pressure, and then continue the rhythmic application of alternate pressure and release.

Blanket is not shown in above drawings for the sake of clarity.

8. KEEP YOUR ARMS STIFF AND STRAIGHT and swing your body forward, allowing your weight to bear down on the victim.
9. DO NOT PUSH OR USE FORCE.
10. SWING BACK AT ONCE TO RELIEVE PRESSURE.
11. REPEAT step 8.
12. REPEAT step 10.
13. CONTINUE as above, maintaining a steady rhythm until victim gains consciousness or is pronounced dead by a doctor.
14. CONTINUE ARTIFICIAL RESPIRATION even after victim begins to breathe, and until he becomes conscious.
15. IF BREATHING STOPS AGAIN, continue artificial respiration at once.
16. DO NOT GIVE UP HOPE of reviving the victim. Four hours or more of continuous application of artificial respiration may be required before consciousness returns.
17. NEVER TRY TO FORCE LIQUIDS down an unconscious person's throat. He will drown.
18. ALWAYS WAIT UNTIL CONSCIOUSNESS RETURNS before administering liquid stimulants.
19. RECOMMENDED STIMULANTS ARE: Hot, black coffee. Strong, hot tea. Aromatic spirits of ammonia, one teaspoonful to a glass of water.
20. GIVE ONLY ONE STIMULANT, which should be sipped slowly.
21. ALCOHOLIC DRINKS are not recommended, unless absolutely nothing else is available.
22. When VICTIM HAS RETURNED TO CONSCIOUSNESS, allow him to lie quietly where he is for at least one hour, taking care that he is well covered and free from worry.
23. IF POSSIBLE, CARRY, OR HAVE HIM CARRIED, TO A DOCTOR.

FOREWORD

The material presented in this manual has been prepared primarily for instructors, but may be used by students or other personnel. It will serve as a general reference for technical information concerning antenna systems in use today. If sufficient copies are available, the students should be permitted to keep their manuals for future reference.

The LECTURE OUTLINE AND SCHEDULE has been planned to provide approximately a 4-weeks' course of instruction for students already familiar with the subject of radio. The lecture material is the basis for lectures to be given, and is to be expanded or supplemented by basic radio fundamentals, as required. Unnecessary complicated calculations and mathematics have been omitted in the lecture material, and the material has been presented concisely, in the language of the radio serviceman.

In presenting so complex and varied a subject as that covered in this manual, it has been found that the material can be more clearly understood if certain analogies are drawn. Although a slight amount of technical accuracy is lost in the use of these analogies, increased clarity of presentation is achieved.

The main purpose of this course is to provide the student with a basic foundation for future work with antennas. An attempt to discuss all of the different types of antennas now in existence would be impossible; therefore, only the pertinent types have been treated. The course will aid the student in coping with any future antenna problem.

PRELIMINARY

The subject of antennas is an extensive one, and has been presented in various ways. A mathematical treatment is desirable from the engineering standpoint, but has little value for the average technician, whose background in mathematics may be limited. Generally, he has to cope with the practical problems involved in the maintenance and construction of communication antennas. By studying the basic facts of antenna theory and design, together with all of the related factors, the technician will gain a practical knowledge of the subject.

In this handbook practical antenna considerations are discussed. In addition, the mass of communication data obtained over a period of years (particularly the war years), are utilized to maximum advantage. Particular emphasis is placed on antenna systems employed in U.S. Military communications.

The United States Armed Forces radio installations in different parts of the world use various types of antennas. The use of different types is governed by necessity rather than by choice. For instance, in the polar regions where only low frequency ground waves can be relied upon for consistent communication, the prevailing types are the long-wire Beverage, crowfoot, flat top, etc. In other areas, the medium and high-frequency types are used. For broadcast work, the vertical Marconi, usually a single steel tower, is utilized, while the common high-frequency types, such as a horizontal half wave, a V, a rhombic, and a driven or parasitic array, provide long-distance communication by sky-wave transmission.

Some of the factors which must be considered in the selection and design of an antenna for a specific application are enumerated below:

1. Coverage (area and/or distance)
2. Type of service
3. Operating period (daytime, nighttime, or continuous)
4. Geographical location
5. Proximity to other communications
6. Frequency selection for reliable communication
7. Tactical limitations
8. Noise level

Each of these factors presents specific problems. For instance, the last item involves atmospheric noise, generated in tropical latitudes, which affects both high and low frequency communication in all latitudes.

In order to understand the limitations involved in antenna work, it is necessary to unravel the mysteries of antenna theory into tangible items. Close adherence to the sequence of material in this manual will be a great aid in gaining an understanding of antennas.

PROPAGATION OF RADIO WAVES

GENERAL

Radio waves propagated into space are considered to be a radiant form of energy, similar to light and heat. They travel at a speed of approximately 300,000,000 meters per second or 186,000 miles per second. Conventional concepts of how the waves are radiated impose a severe strain on the average person's imagination. Even rigorous mathematical explanations are not considered absolute.

The theory of wave propagation as presented in this text, although greatly simplified, has found general acceptance. Needless to say, an academic treatment of this subject finds no useful place in a practical approach to antenna problems. Our major concern is in showing how to make antennas operate efficiently, both for transmission and reception, under various conditions.

WAVE PROPAGATION

The radio-frequency spectrum, which extends from .01 megacycle (very low frequency) to 30,000 megacycles (super high frequency), is outlined in the following chart.

CHART 1
RADIO-FREQUENCY SPECTRUM

Frequency in Megacycles (Mc)	Description	Abbreviation
.01 to .03	Very Low Frequency	V.L.F.
.03 to .3	Low Frequency	L.F.
.3 to 3	Medium Frequency	M.F.
3 to 30	High Frequency	H.F.
30 to 300	Very High Frequency	V.H.F.
300 to 3000	Ultra High Frequency	U.H.F.
3000 to 30000	Super High Frequency	S.H.F.

If the speed of radio waves in free space (300,000,000 meters per second) is known, the wave length of any radio wave can be found by the formula:

$$\frac{\text{velocity}}{\text{frequency}} = \text{wave length or } \frac{300{,}000{,}000}{f\ (\text{cycles})} = \text{wave length in meters}$$

Thus a 10-kc. radio wave has a wave length of 30,000 meters, while a 30,000-megacycle radio wave has a wave length of .01 meter or 1 centimeter.

If an alternating current, within the radio-frequency range, is applied to a suitable conductor, such as an antenna, it will create changing electric and magnetic fields about the conductor. These periodic changes in field intensity produce a moving-field wave travelling away from the antenna. The components of this moving-field wave are the induction field and the radiation field. The induction field components are no longer de-

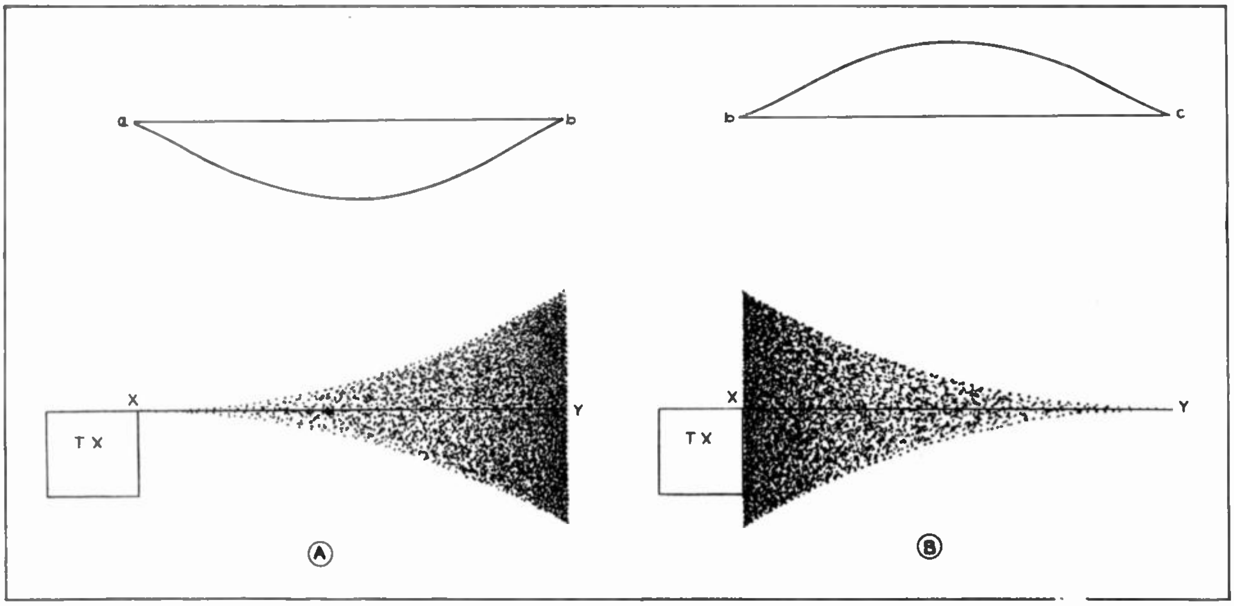


Figure 1. Development of Radiation Fields.

tectable beyond a distance of about two wave lengths from the antenna. However some of the energy of the induction field finds its way into distant space. This portion of the induction field which carries the signals, or intelligence, from the point of transmission to the point of reception is called the radiation field.

To better understand the actions involved in this phenomenon, let us examine figure 1, A and B.

Figure 1, A and B, shows a transmitter connected to an antenna, which in this case, is equal in length to exactly a half wave length at the frequency of the applied wave. When this wave is applied to the antenna, the actions listed below occur in the order given.

1. Electrons immediately begin to flow from point X at one end of the antenna to point Y at the other end of the antenna.
2. In the time which elapses during the first half cycle of the applied wave, a to b, most of the electrons from point X have crowded toward point Y.
3. Point Y, the open end of the antenna, forms a barrier to further travel of the electrons and they come to a complete stop.
4. As the alternating current goes into the second half cycle of its alternation, b to c, the electrons immediately start flowing back from point Y on the antenna toward point X at the input end.
5. All of the electrons from point Y on the antenna crowd toward point X during the time b to c of the second half of the a-c cycle.
6. The electrons have piled up at point X and they begin to travel back toward point Y, as soon as a new cycle of input wave a to b arrives at the antenna input point X.
7. This periodic action continues as long as the a-c power is applied to the antenna.

The useful radiation field results from the series of events above. Figure 1, A and B, helps to illustrate the apparent effects produced. The following series of events describe the production of the electric and magnetic fields around the antenna and the resulting wave motion.

1. In steps 1 and 2 above, maximum electron flow occurred at the center of the antenna (one quarter wave length from the end of the antenna), because the least average opposition (impedance) to the flow of current is offered at this point on the antenna.
2. Therefore, the greatest number of magnetic lines of force exist concentrically about the antenna at its center. Figure 2A shows the apparent magnetic-field distribution around the antenna.
3. There is a certain amount of capacitance between the ends of the antenna. Since the greatest number of electrons accumulates at the ends (the point of highest opposition to electron flow on the antenna), the maximum electric strain exists between the ends of the antenna. The apparent electric field around the antenna is shown in figure 2B.
4. At the end of the first half cycle when all electron flow ceases, the magnetic field dies out. At this instant the electric field is at a maximum. The two fields, therefore, are 90° out of phase in time.
5. When the electron flow from point Y to point X begins, as explained in steps 4 and 5 of the previous series, the magnetic field again builds up and the electric field again decreases in the opposite polarity.

By comparing figures 2A and 2B, it can be seen that the lines of force in the magnetic and electric fields are perpendicular to each other. Therefore, the two fields are 90° out of phase in space. In formal language, the electric and magnetic fields are, at all times, in space and time quadrature.

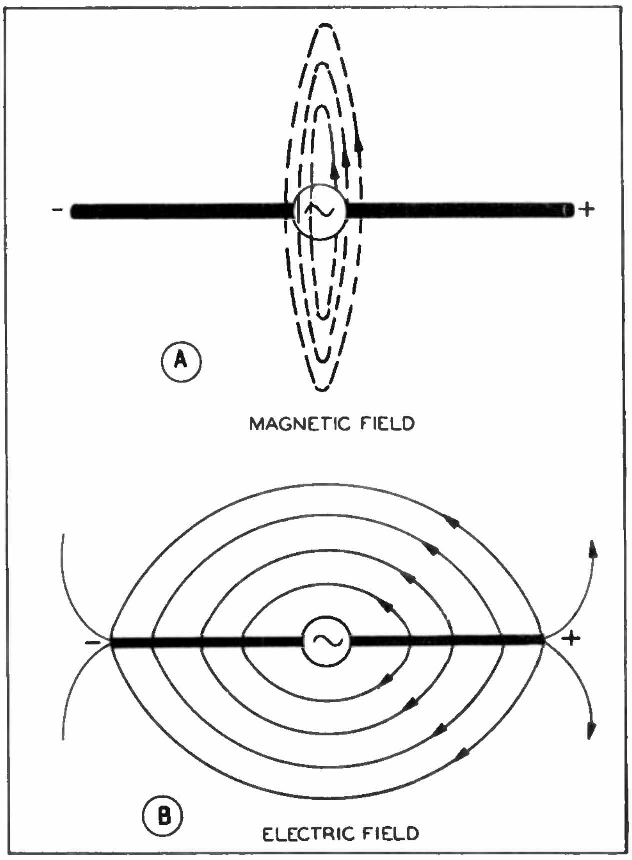


Figure 2. Magnetic and Electric Fields Around a Wire.

RADIATION

The periodic building up and collapsing of the electric and magnetic fields, commonly called the induction field, creates a wave motion around the antenna, which conforms to the frequency of the applied radio-frequency energy. As the induction field collapses every half cycle, the energy that left the antenna in the form of the electric and magnetic fields begins to travel back toward the antenna. The lines of force can be visualized as trying to shrink rapidly back into the core of the antenna, in the same order in which they left. However, all of the energy in the fields cannot return before the new induction field starts to move outward at the beginning of the next half cycle. The new induction-field components meet head-on with the tardy portion of the returning fields and shove the latter back and away from the antenna. This periodic action around the antenna produces a cumulative effect of the events described above, so that a steady flow of energy into distant space exists. This portion of the radiated energy that does not return to the antenna is called the radiation field. At a distance of 0.16 wave length from the antenna, the radiation field and the induction field are approximately equal in intensity, but beyond a distance of two wave lengths only the effects of the radiation field are apparent.

The intensity of the radiated wave depends primarily upon the amount of current flowing in the antenna and the antenna radiation resistance. The antenna radiation resistance depends upon the antenna size, shape, length, and height above ground and the frequency of operation. These radiation factors will be fully explained in subsequent discussions.

POLARIZATION

As previously mentioned, the magnetic and electric fields about a radiating conductor exist each in a particular plane as plane waves, and are perpendicular to each other. The polarization of an antenna is determined by the direction of the electric plane wave. An antenna erected horizontal to the earth's surface (see figure 3A) is said to be horizontally polarized; an antenna erected in a vertical position (see figure 3B) is said to be vertically polarized. The type of polarization to use in a specific antenna application will depend upon the type of transmission desired. The following factors should be considered before attempting to determine the desired polarization for a specific antenna installation.

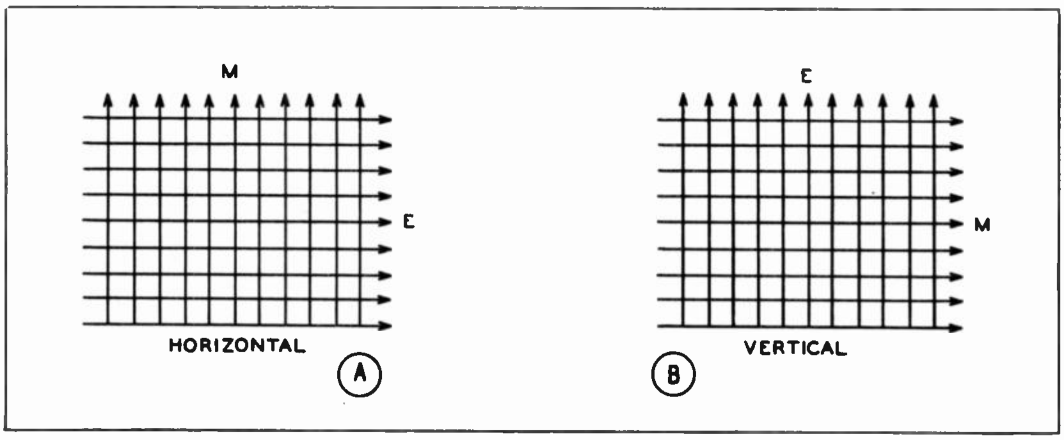


Figure 3. Representation of Magnetic and Electric Fields in Horizontally and Vertically Polarized Wave Fronts.

1. At low and medium frequencies (see chart 1) the radiated waves from a horizontally polarized antenna tend to have the characteristics of a vertically polarized antenna. This is true because at low and medium frequencies the earth below a horizontally polarized antenna has a shorting effect for the electric field parallel with it. At frequencies below 5 megacycles the ground acts like a conductor, but at higher frequencies it acts more like a dielectric.

2. At high frequencies (see chart 1) the transmitting antenna is generally horizontally polarized because most transmission is affected by high-angle sky-wave propagation. High-frequency receiving antennas, on the other hand, can be polarized in any direction because the transmitted wave undergoes all manner of convolutions in arriving at the receiving site.

3. At extremely high frequencies (see chart 1) maximum efficiency is obtained when the transmitting and receiving antennas are polarized in the same direction.

4. The physical dimensions of the antenna system must also be considered when deciding the type of polarization to be employed. (A long-wire, vertical antenna is not easily built.)

Other advantages and disadvantages of the different types of polarization will become apparent in the following discussion.

GROUND-WAVE PROPAGATION

The radiation-field waves from an antenna travel into space in all directions. Those waves which travel along the surface of the earth and are greatly affected by the earth's presence and its terrain features are called ground waves.

It was pointed out previously that the behavior of radio waves is similar to that of light waves. It is an established fact that light may be absorbed, refracted, and reflected, and that the degree of absorption, refraction, or reflection depends upon the medium involved and the frequency of the wave. These same basic facts are generally true of radio waves as will be shown in the following discussion.

Transmission Considerations

That part of a radiation-field wave which passes along the surface of the earth is called the ground wave. It is hampered in travel by many factors introduced by its proximity to the earth's surface, but is practically unaffected by changing conditions in the upper atmosphere. Therefore, the main considerations in determining the transmission characteristics of a ground wave are its frequency, the different surface conditions over which it passes, and the conditions of the lower atmosphere.

The ground wave consists of three components: a surface wave, a direct wave, and an earth-reflected wave (see figure 4). The surface wave, which is an earth-guided wave, is vertically polarized, and is independent of seasonal and day and night effects at frequencies above 1500 kc. Its transmission range depends upon the ground characteristics.

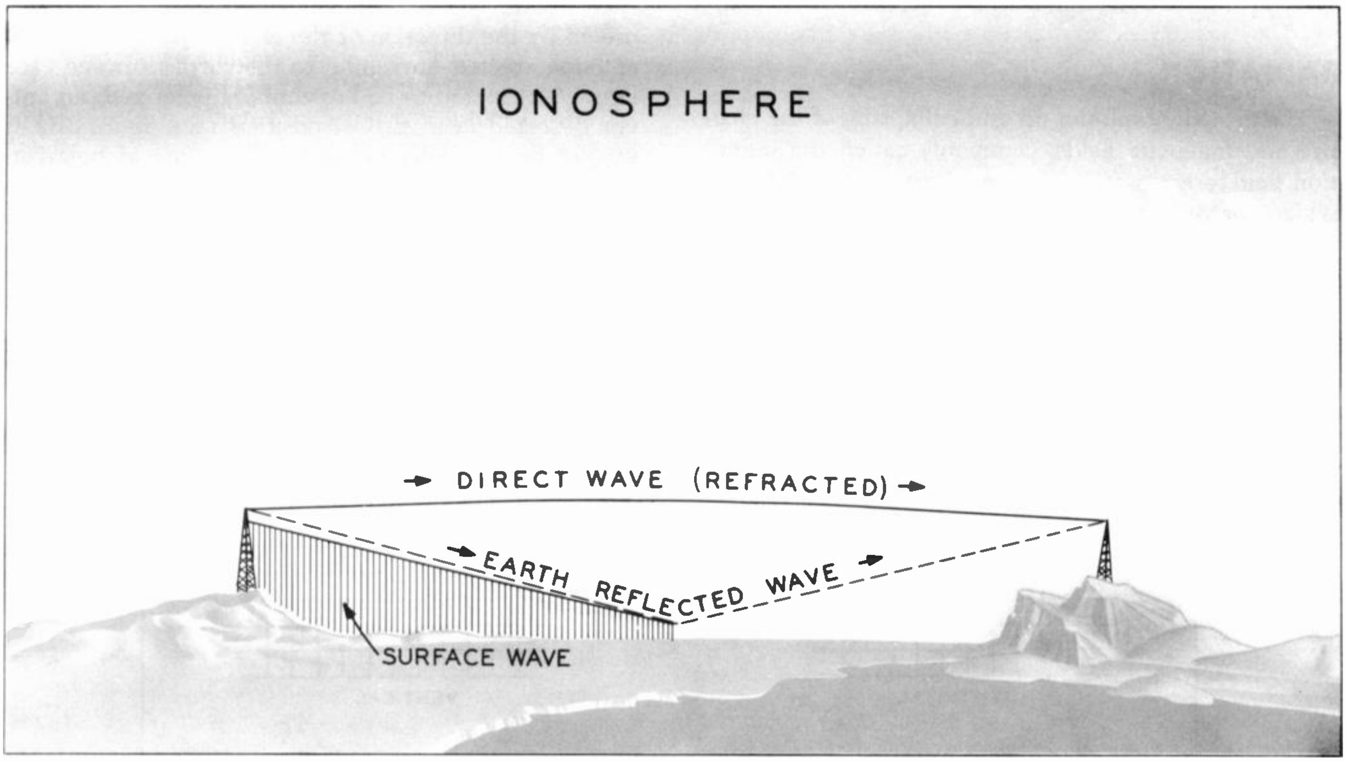


Figure 4. Components of Ground Waves. A radiated ground wave from an antenna located on the earth's surface follows three radiation paths—a direct path to the receiving site, a rebounding path from the antenna to the earth's surface, and a path along the contour of the earth's surface.

Attenuation of Ground Wave

First consider the earth's surface as a conductor. Since it is known that radio waves travel along a conductor, and that surface waves move along the earth's surface, it is evident that the earth's surface must have some degree of conductivity. The conductivity varies with the nature of the conducting path (see charts 2, 3, and 4). Attenuation of the surface wave due to absorption depends upon the relative conductivity of the surface over which it travels.

From the accompanying chart 2 it is apparent that the best ground-wave transmission will be over sea water. This point was proven early in the development of the art of radio communication when ground waves were first used extensively for overseas communication.

CHART 2

RELATIVE CONDUCTIVITY OF VARIOUS MEDIUMS

Medium	Relative Conductivity
Sea water	Good
Flat, loamy soil	Fair
Large bodies of fresh water	Fair
Rocky terrain	Poor
Desert	Poor
Jungle	Unusable

CHART 3

STRENGTH OF GROUND WAVE OVER LAND FROM A 1-KW. TRANSMITTER

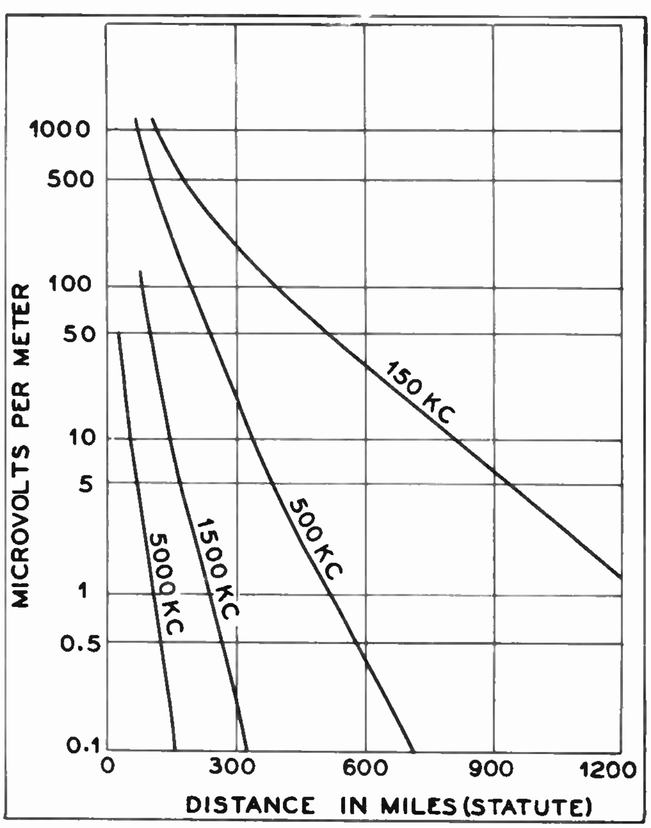


CHART 4

STRENGTH OF GROUND WAVE OVER SEA WATER FROM A 1-KW. TRANSMITTER

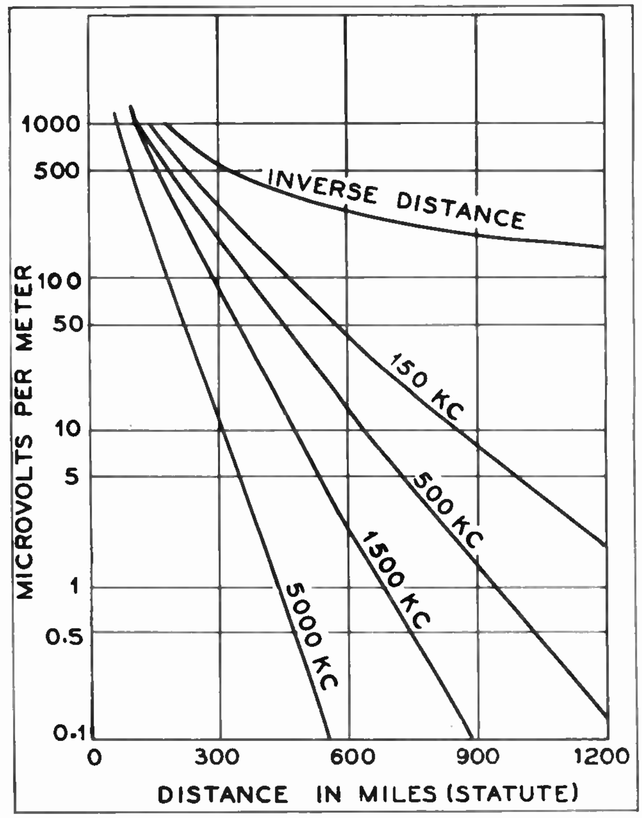


Figure 5 shows the relative effectiveness of ground-wave propagation over the Pacific Seaboard and the Pacific Ocean.

The highest degree of ground-wave attenuation is found in jungle areas. Recent wartime operating experience has shown ground-wave operation in jungle areas to be unfeasible beyond a one-mile radius, with the usual types of communication equipment.

Lower Atmosphere (Tropospheric) Refraction

The direct wave, which attempts to travel a line-of-sight path, will be refracted in the lower atmosphere due to the changes in density (hence, the refractive index) of air with altitude, and to the changes in the relative conductivity (dielectric constant) of the layers of the lower atmosphere. Refraction is often caused by the existence of large layers of warm and cold air masses near each other, water-vapor content of the atmosphere, and abrupt temperature differences at the surface of cloud banks due to direct heating by the sun's rays. The refraction due to changes in density and relative conductivity is also dependent upon the frequency of the wave; hence, low-frequency waves are refracted to a greater degree than high-frequency waves. This refraction factor offers one explanation for

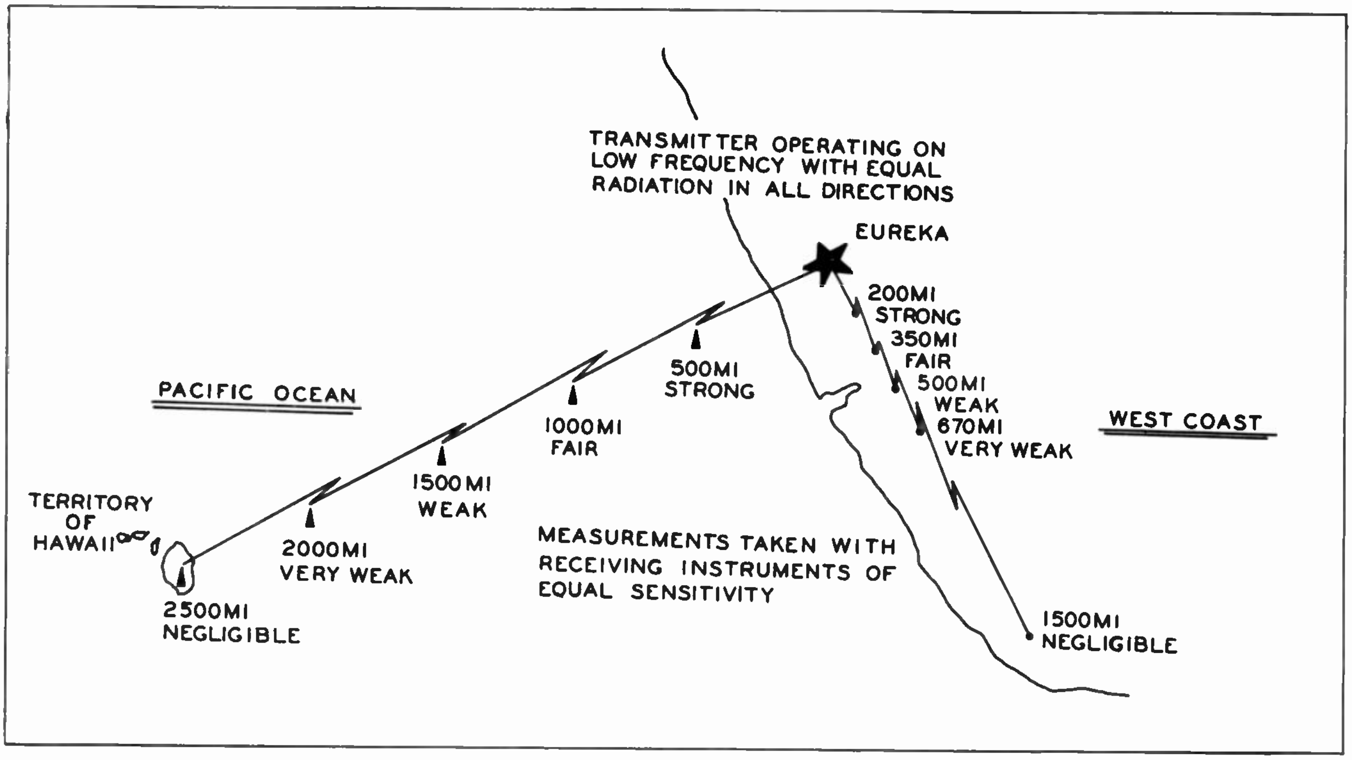


Figure 5. Effectiveness of Ground-Wave Propagation over Land and Sea Water.

the fact that at low frequencies greatly extended ranges on ground-wave transmission are realized, whereas at very-high and ultra-high-frequencies only slight extension of transmission range is possible. The lower of the two most important ionosphere layers, known as the "sporadic E layer," causes erratic reception at higher frequencies up to 60 mc.

V-H-F and U-H-F Considerations

At v-h-f and u-h-f frequencies, the direct-wave component of the radiated field tends to travel in practically "line-of-sight" manner (see figure 6), with minor refraction due to the lower atmosphere. However, a portion of the wave front strikes the earth at some distance from the antenna, and is reflected upward. The earth-reflected wave obviously lags behind the direct-wave component, in arriving at the distant point. At points where the reflected wave arrives 180° out of phase with the direct wave, a cancellation of signal energy results. See figure 7. For efficient v-h-f and u-h-f transmission, therefore, it is necessary to minimize the cancellation effect produced by the earth-reflected wave. It has been found that increasing the antenna height is the best practical method of solving this problem. Increasing the antenna height tends to decrease the phase angle between the direct and reflected waves, arriving at a distant point, from 180° to a lower value. This in turn reduces the degree of signal-voltage cancellation.

In general, at v-h-f and u-h-f frequencies the field strength increases directly as the transmitting and receiving-antenna heights increase, and as the square root of the antenna power. The field strength decreases as the square of the distances between the transmitting and receiving antennas.

Where refraction of the direct-wave component is not taken into account, a clear line-of-sight transmission to a distant point over level terrain can be obtained if the antenna height conforms to that determined by the following formula:

$$h=\frac{d^2}{1.51}$$

where h=height of transmitting antenna (feet)
and d=distance to distant point (miles)

If the antenna height is known, the line-of-sight distance it will be possible to cover, still neglecting refraction, will be governed by the following formula:

$$d=1.23\sqrt{h}$$

Introducing the factor of refraction alters the formulas slightly as shown:

$$h=\frac{d^2}{2} \text{ and } d=\sqrt{2h} \text{ or } 1.41\sqrt{h} \text{ (approximately)}$$

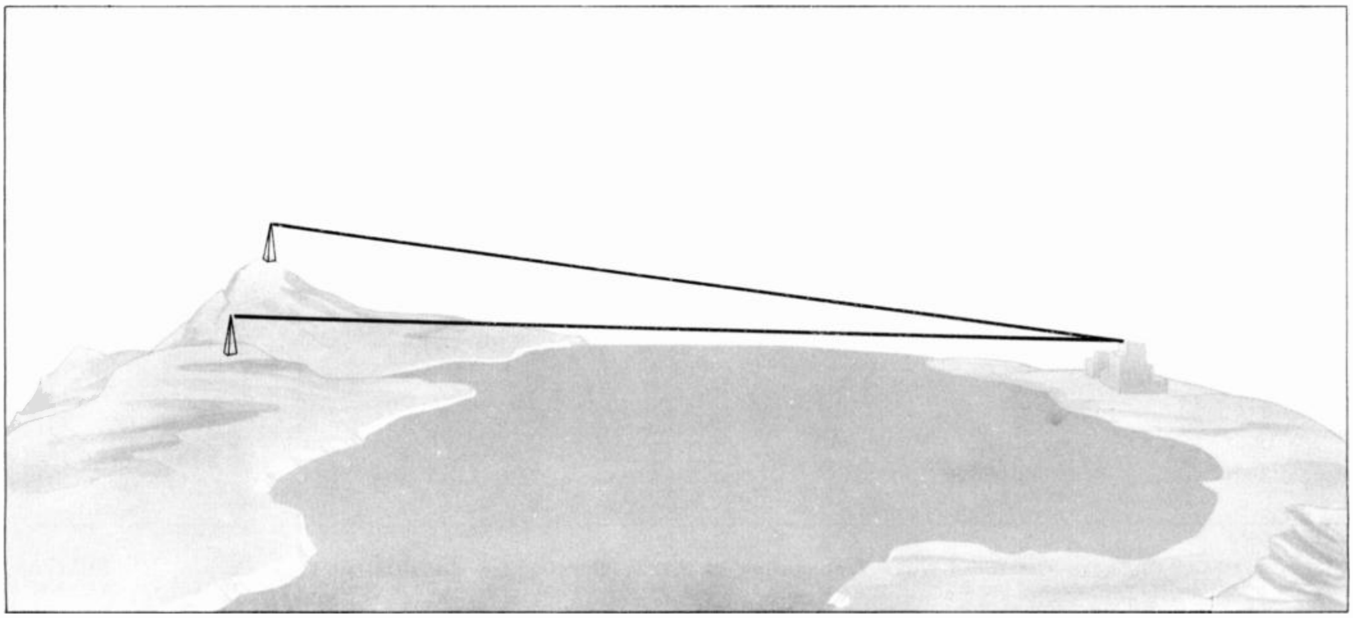


Figure 6. Line-of-Sight Communication at V.H.F. and U.H.F

When both the transmitter-antenna height and the receiver-antenna height are known, and considering the refraction factor, the formula for determining the possible range becomes:

$$d=\sqrt{2h_t}+\sqrt{2h_r}$$

where h_t=height of transmitting antenna
and h_r=height of receiving antenna

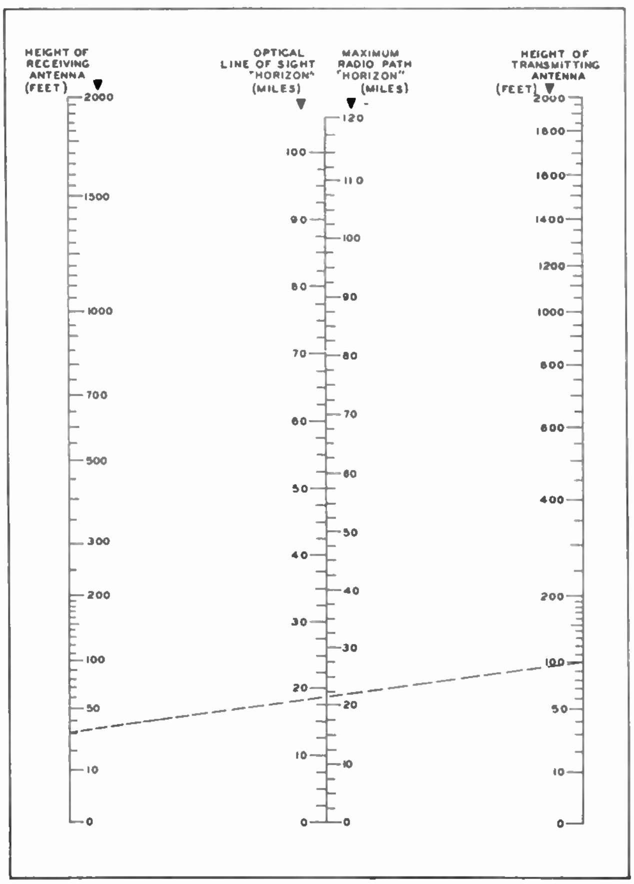
An approximation of the line-of-sight transmission range for frequencies between 30 and 3000 megacycles can be obtained from chart 5, without performing any mathematical calculations. Simply lay a straight edge on the chart so that it is aligned with both the receiving-antenna height and the transmitting-antenna height, which are found on the two outside vertical lines of the chart. The transmission range is then indicated, on the center vertical line, at the point where the straight edge crosses the center vertical line. An example is given on the chart: If the receiving-antenna height is 30 feet and the transmitting-antenna height is 100 feet, the line-of-sight transmission range is approximately 21 miles.

In general, most short distance field communication is carried on by means of vhf ground waves. For frequencies of 3 to 30 megacycles, ground-wave transmission is practical for ranges of 5 to 15 miles over land and about 75 miles over water.

In the line-of-sight transmission of v-h-f signals only the direct wave component is involved. In recent years the old theory that only line-of-sight transmission was possible at these frequencies has been disputed. Extension of v-h-f transmission ranges beyond the line-of-sight range has been found possible by means of the "sporadic-E-layer" skip of sky waves.

CHART 5

LINE-OF-SIGHT TRANSMISSION RANGES



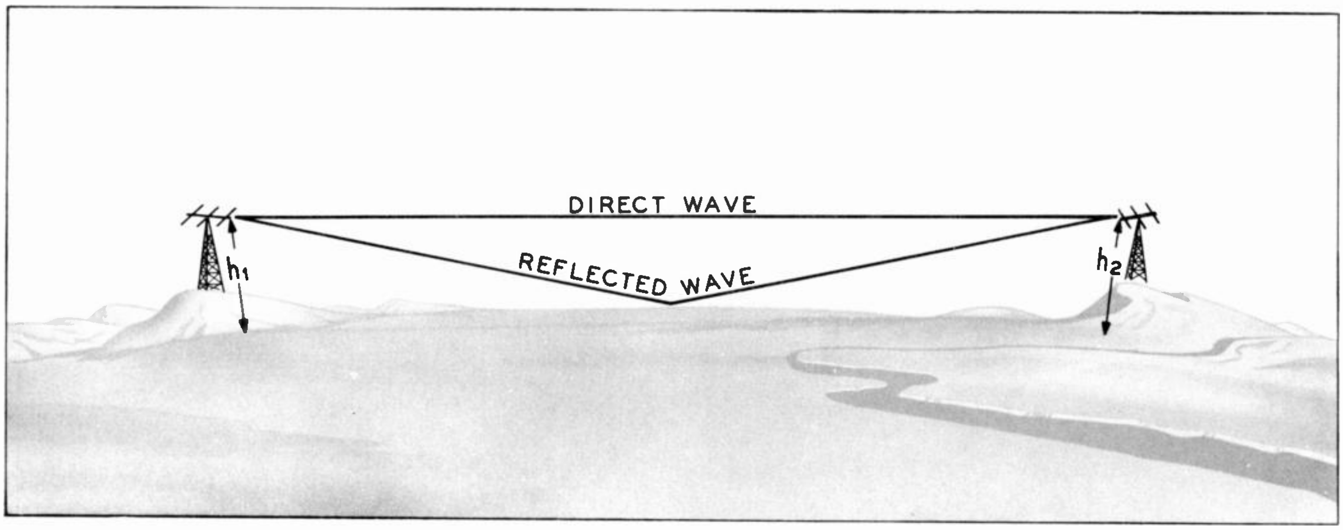


Figure 7. Ground-Wave Propagation at V.H.F., Showing the Cancellation Effect.

SKY-WAVE PROPAGATION

It was stated earlier in the discussion that when radiated energy leaves an antenna it travels in all directions. Thus far the transmission features of the ground wave have been discussed. In the following paragraphs, the transmission features of the sky wave are discussed.

Ionosphere

Composition and General Description

The earth's atmosphere is subject to ultraviolet radiation from the sun, so that considerable ionization of its constituent gases occurs. These gases are mainly oxygen, nitrogen, hydrogen, and helium. The oxygen and nitrogen mass extends to approximately 50 miles above the earth, and is highly rarified in the upper regions. Beyond the oxygen and nitrogen region lies the hydrogen and helium mass. The existence of the latter has been verified by spectrographic analysis of comets, set aflame in the earth's atmosphere.

Ionization begins at a height of approximately 20 to 30 miles above the earth. In the ionizing process, both positive and negative ions and also *free electrons* are produced. The density of the free electrons is believed to be the most important item affecting sky-wave transmission. Ordinarily, the maximum concentration of free electrons occurs at a height of about 250 miles above the earth.

Kennelly-Heaviside Layers

It is a generally accepted fact that the ionization is distributed in stratified layers. The D layer exists at heights of 30 to 50 miles above the earth during daylight hours. It has a tendency to absorb sky waves of frequencies less than 30 megacycles. The absorption effect is particularly pronounced at frequencies below 2 megacycles.

The E layer is the ionized region between 55 and 90 miles above the earth. Its highest electron density is attained at a height of approximately 65 miles. The E layer becomes highly ionized during daylight hours, so that considerable absorption of sky waves below 1.5 megacycles takes place. During hours of darkness, the electron density is reduced sufficiently to allow the passage of sky waves with minimum attenuation.

The F region extends from approximately 90 to 250 miles above the earth, with two well defined layers existing during daylight hours. The lower region is called the F_1 layer, while the upper region is called the F_2 layer. Over areas of the earth in total darkness, the F_1 and F_2 layers converge to produce a single layer, the maximum density of which occurs at a height of about 200 miles above the earth. This layer is referred to as the nighttime F layer. The F_2 layer attains the highest degree of electron density of any of the ionosphere layers. Figure 8 shows the relative distribution of ionospheric layers about the earth.

Ionospheric Variations

The ionospheric layers undergo considerable variations in effective altitude, electron density, and layer thickness, due mainly to varying degrees of solar ultraviolet radiation. See figure 9. These variations follow a daily and seasonal pattern and the 11-year sunspot cycle (maximum, 1948-1949; minimum, 1944). The electron density of the F_2 layer undergoes the greatest variation due to solar disturbances (sun-spot activity). There is a greater concentration of ultraviolet radiation in the earth's atmosphere during peak sun-spot activity.

The ionospheric layers are commonly referred to as the Kennelly-Heaviside layers, in honor of the two men who were the first to advance the idea of the existence of the ionosphere.

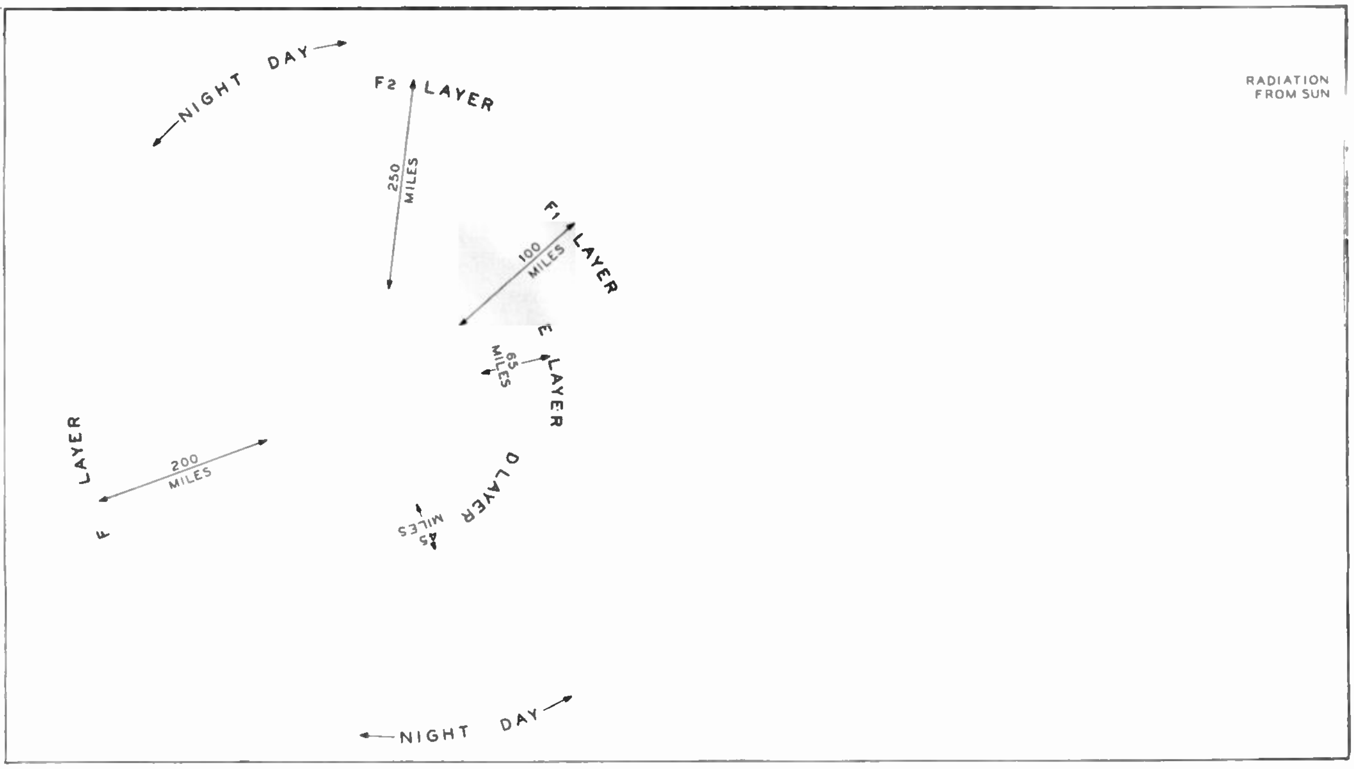


Figure 8. Relative Distribution of the Ionosphere Layers about the Earth.

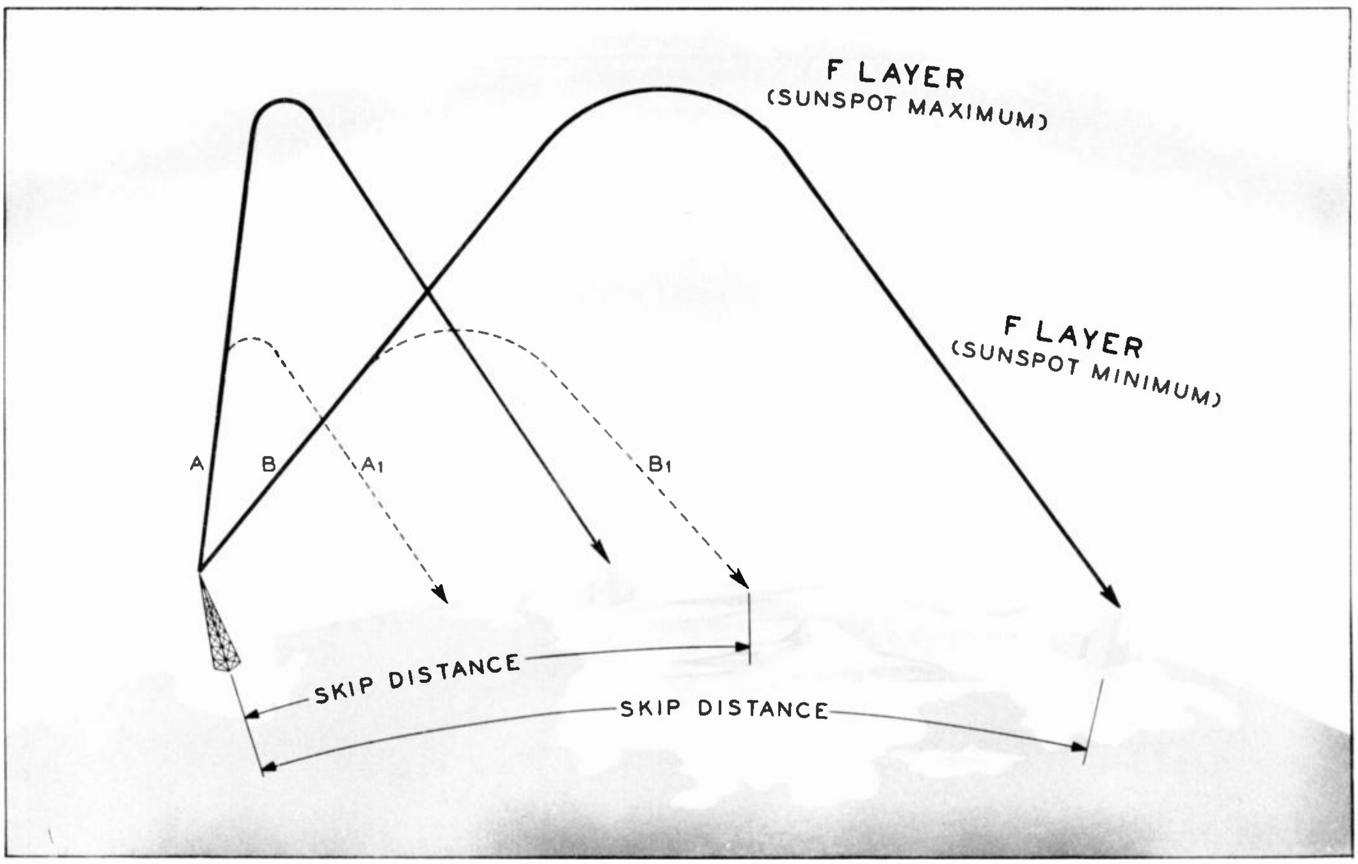


Figure 9. Effects of Sunspot Maximum and Minimum on Transmission of Radio Waves. Waves A and A_1, which are at 40 mc. and 22 mc., respectively, are propagated at the same angle under sunspot maximum and sunspot minimum conditions. These are approximately the maximum usable frequencies for these conditions. Waves B and B_1, which are also at 40 mc. and 22 mc., respectively, represent a lower angle of propagation. Note how the skip distance varies with sunspot conditions.

Sky Waves

Refraction

The above discussion gives some idea of the mediums encountered by radio waves travelling in free space. The waves propagated in free space travel in straight lines, so long as the medium through which they pass has constant electron density. Thus, as a wave front enters the D layer, its path is immediately altered. Lower frequency waves are readily affected by this layer, so that a scattering, or lateral dispersal, of the wave front results. Consequently, most of the signal energy is dissipated or absorbed.

High-frequency waves, however, are not so readily affected by the D layer, and hence they continue, along their original path, up to the E layer. As the high-frequency wave front penetrates the E layer, it begins to follow a gradual curved path. The influence of the free-electron field is such that the wave-front retardation results in a refracting process. Thus the path of the wave front is bent back toward the earth, so that considerable energy is returned to the earth as a usable signal.

If the frequency of the radio waves being transmitted vertically is gradually raised, a point will be found beyond which the waves will not be refracted sufficiently to curve their path back to earth. Consequently, these waves continue on up to the next layer, or in the case of the F layer, on out into space.

Critical Frequency

The highest frequency which will be returned to earth when transmitted vertically under given ionospheric conditions is called the *critical frequency*. The critical frequency will vary, of course, with the time of day, the season, the sunspot cycle, etc. The density of free electrons, the layer heights, and the wave length determine the degree of refraction. In general, the lower the frequency, the more easily the signal is refracted; conversely, the higher the frequency, the more difficult the refracting or bending process. See figure 10. The refractive power of the ionosphere increases with the density of the free electrons. The degree of ionization obtained is greater in summer than in winter, and is also greater during the day than at night. It follows, therefore, that the critical frequency will be the highest at noon, and the highest in midsummer. Abnormally high critical frequencies will result during times of peak sun-spot activity. Figure 11 shows the relationship of critical frequency to the path of the radiated wave.

Critical Angle of Radiation

Another item closely related to critical frequency is the critical angle. Above a certain frequency, waves transmitted vertically will not be returned to earth. However, by lowering the angle of propagation (the

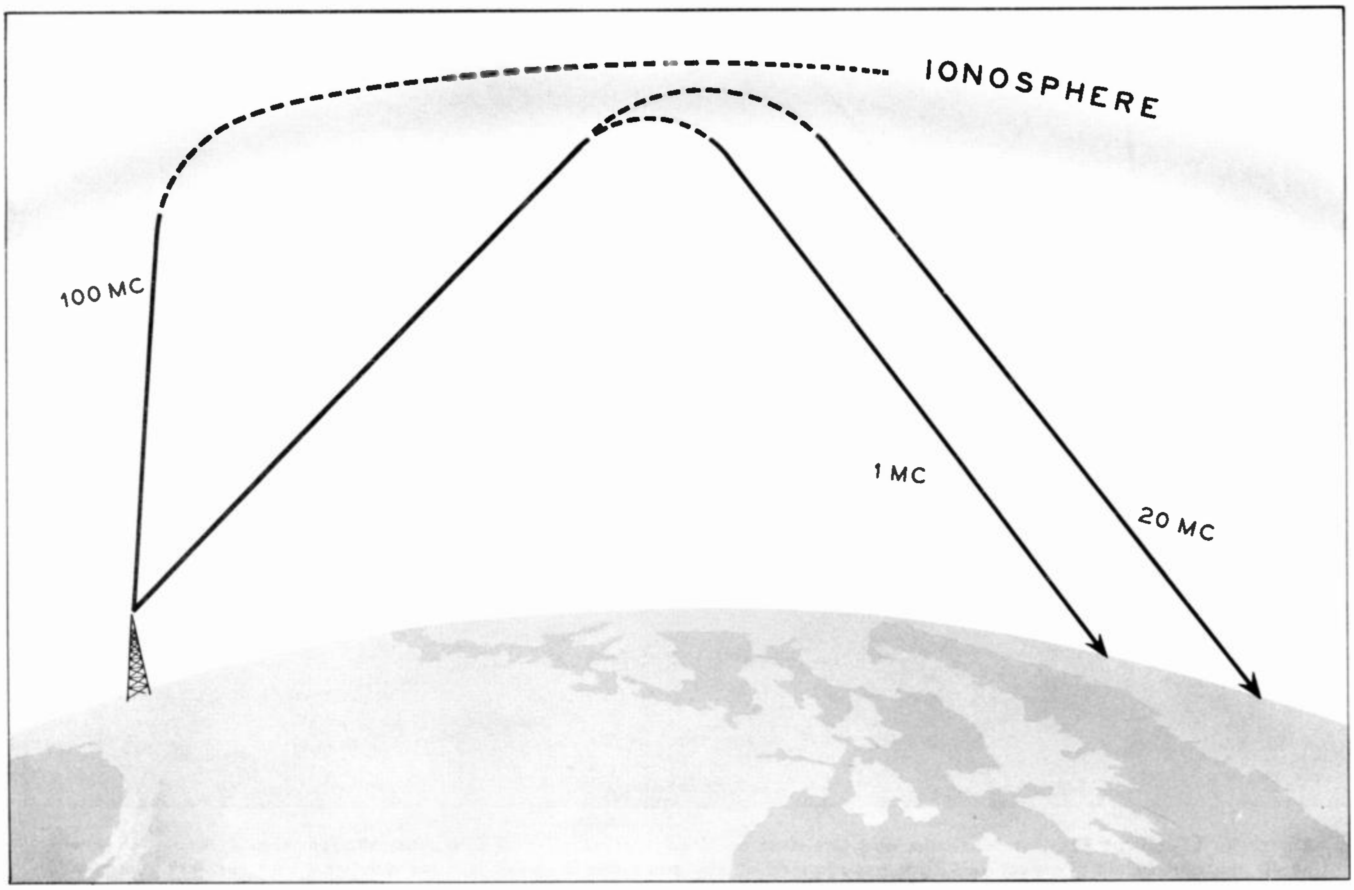


Figure 10. Relationship of Frequency of Radiated Wave to Refraction by Ionosphere.

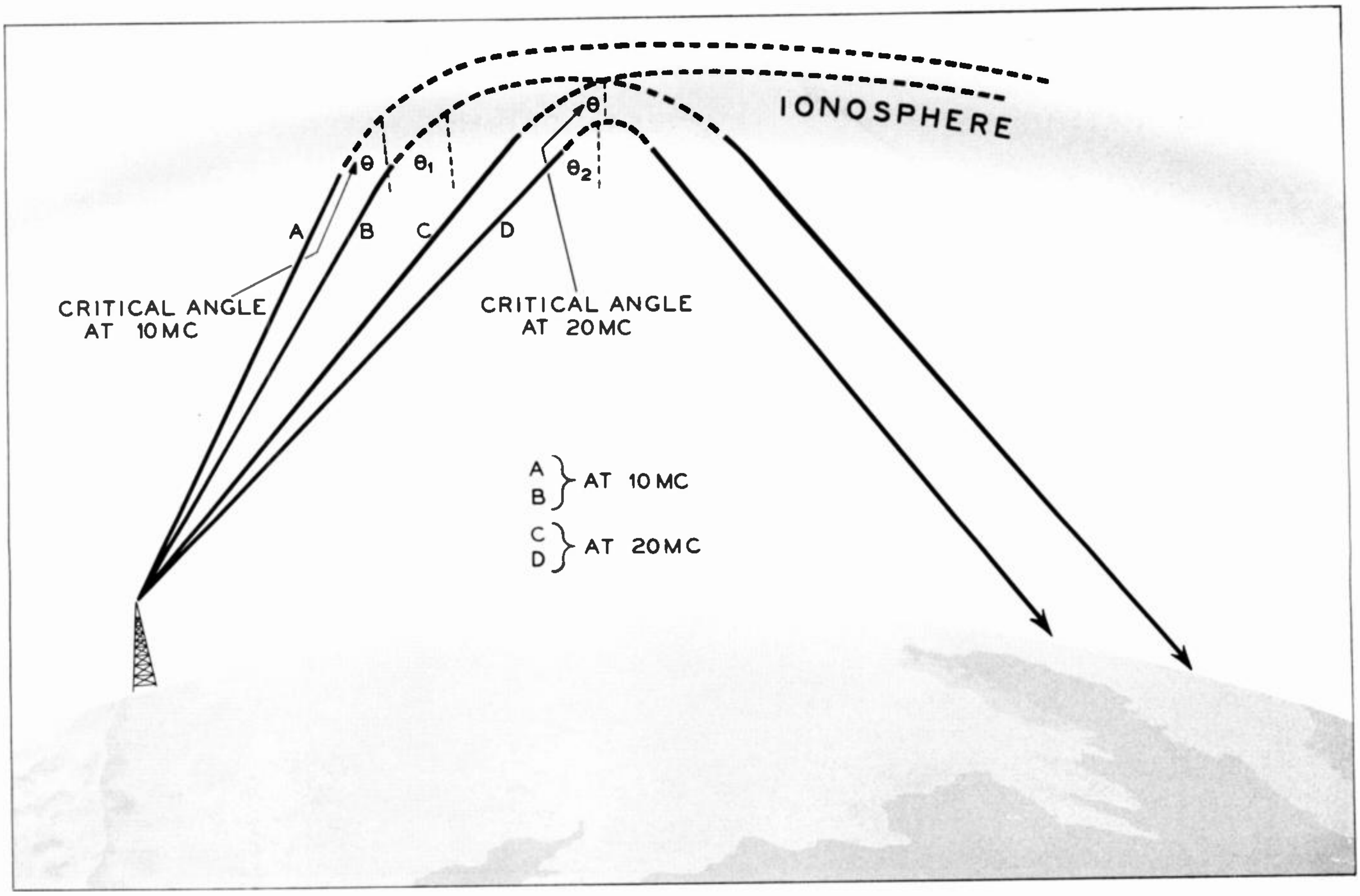


Figure 11. Relationship of Frequency to the Critical Angle, and the Resultant Path of the Radiated Wave.

angle the wave path makes with a line tangent to the earth at the transmitting point), a portion of the high-frequency waves will be returned to earth. The highest angle at which a wave can be propagated and still be returned to earth from the ionosphere is called the "limiting" angle for that particular frequency. For purposes of calculation, the "critical angle" is the angle which the wave front path, at incidence with the ionosphere, makes with a line extended to the center of the earth.

The light-beam analogy, in figure 12, demonstrates the critical-angle concept. Figure 12 shows a light source located well below the surface of a body of water. Light beam "A", in passing through the water, undergoes negligible refraction. Upon tilting the light source slightly to the right, light beam "B" is refracted a considerable amount and the beam skirts the surface of the water. Upon tilting the light source a little more to the right, light beam "C" is reflected back to the bottom of the container.

The action of a radiated wave from an antenna is very similar to that described above, in that when the electromagnetic wave front enters the ionosphere region it is effectively speeded up and follows a curved path due to refraction (dotted line in figure 13).

Maximum Usable Frequency (M.U.F.)

From the previous discussion it is apparent that for each communication problem there must be a "best frequency." Referring to figure 11, it can be seen that, with a given ionosphere condition, the distance between the transmitter and the point at which the wave returns to earth depends upon the angle of propagation, which in turn is limited by the frequency.

The highest frequency which is returned to the earth at a given distance is the maximum usable frequency (m.u.f.) for that distance and it has an average monthly value for any given time of the year. The optimum working frequency (o.w.f.) is that one from which most consistent communication can be expected. For transmission via the F_2 layer, the o.w.f. would be 85% of the m.u.f. For transmission via the E layer, the use of a frequency near the m.u.f. will result, in most cases, in consistent communication. Operation at frequencies near the m.u.f. will usually result in excellent communication over the greatest possible distance.

It was stated that waves above the critical frequency (f_c) entering the ionosphere at steep vertical angles (angles smaller than the critical angle) will not be returned to earth, but will continue on into space and will be dissipated there. However, it is obvious

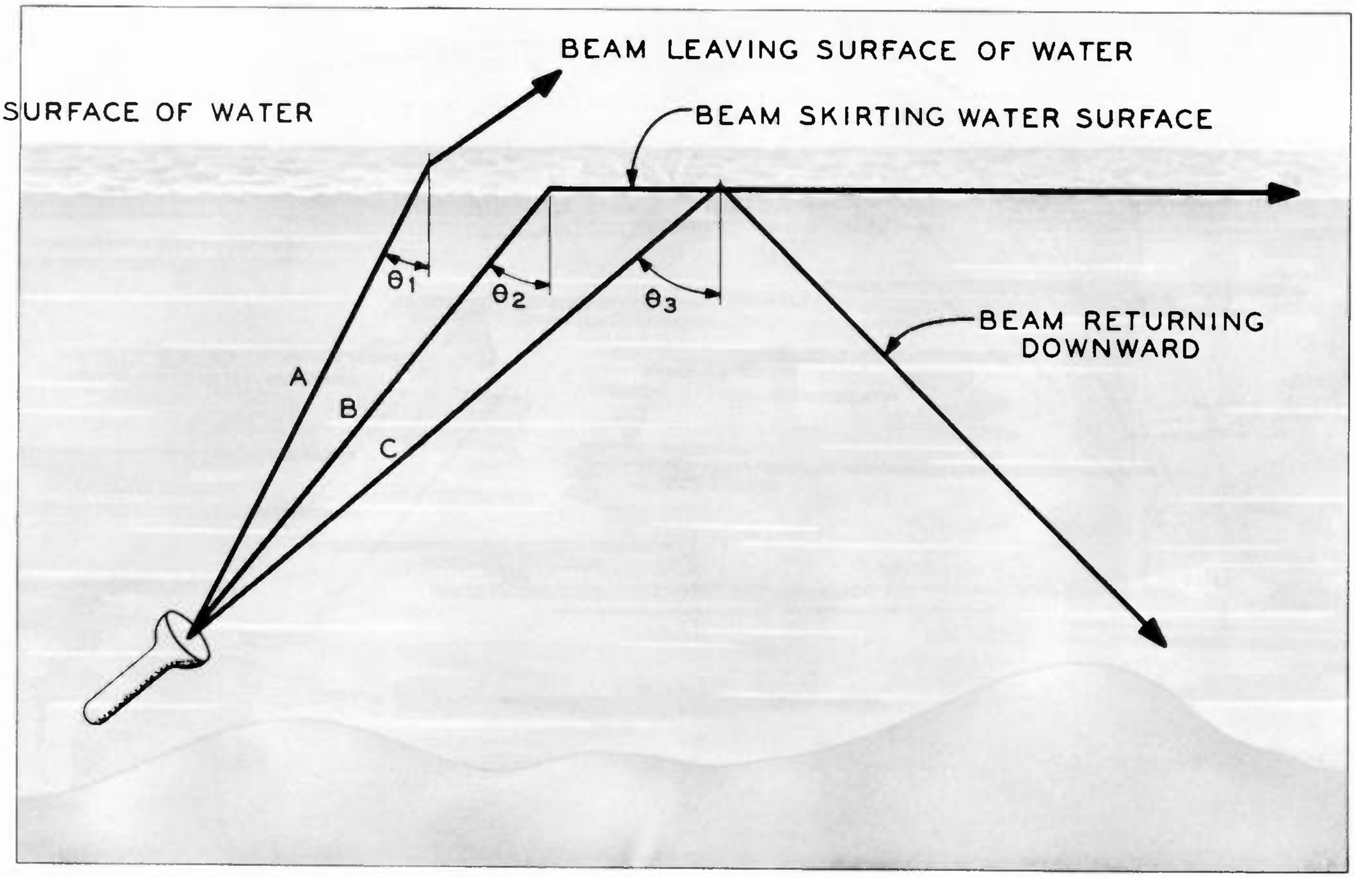


Figure 12. Light-Wave Analogy, Showing the Effect of Refraction and the Critical Angle.

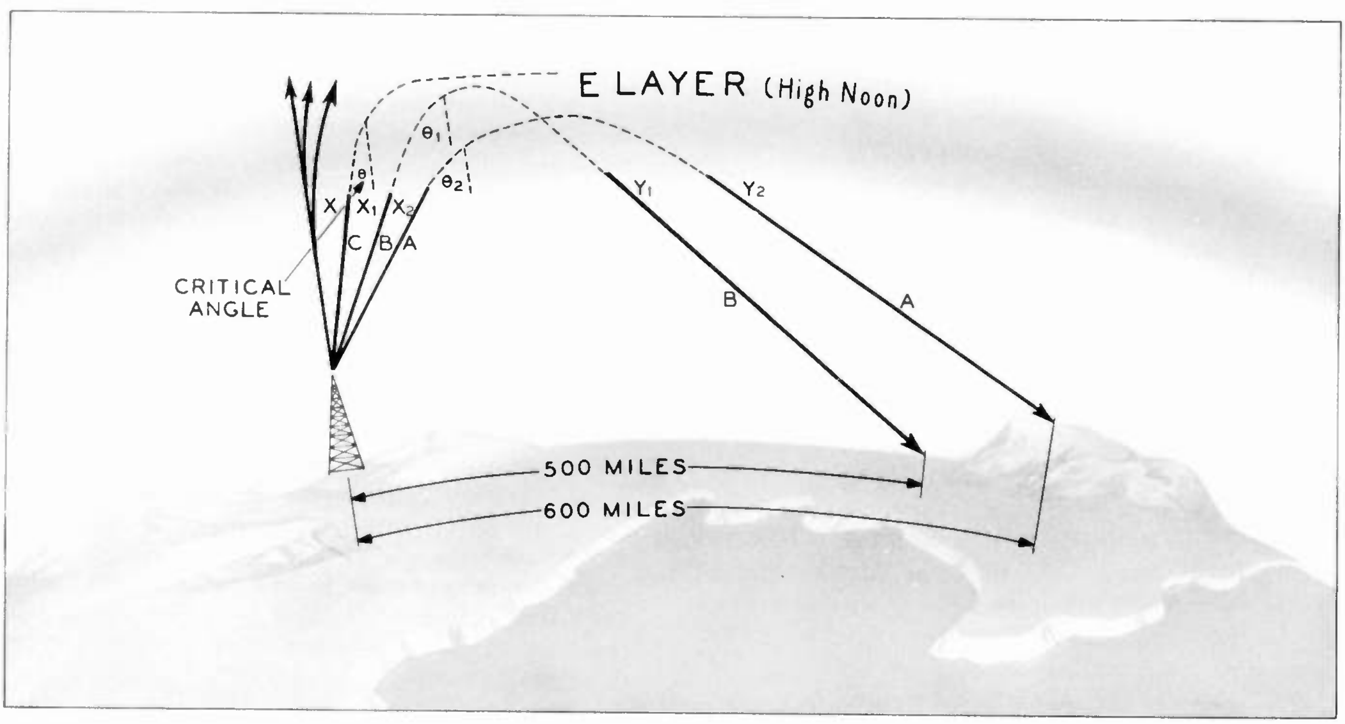


Figure 13. Radio Waves Entering the Ionosphere at Various Angles, Showing the Depth of Penetration and the Degree of Refraction. Notice that wave A was refracted (bent) more gradually than wave B. The waves are speeded up as they enter the ionosphere at points X, X1, and X2. Wave A travels through a greater arc and, consequently, returns to the earth at a more distant point than wave B.

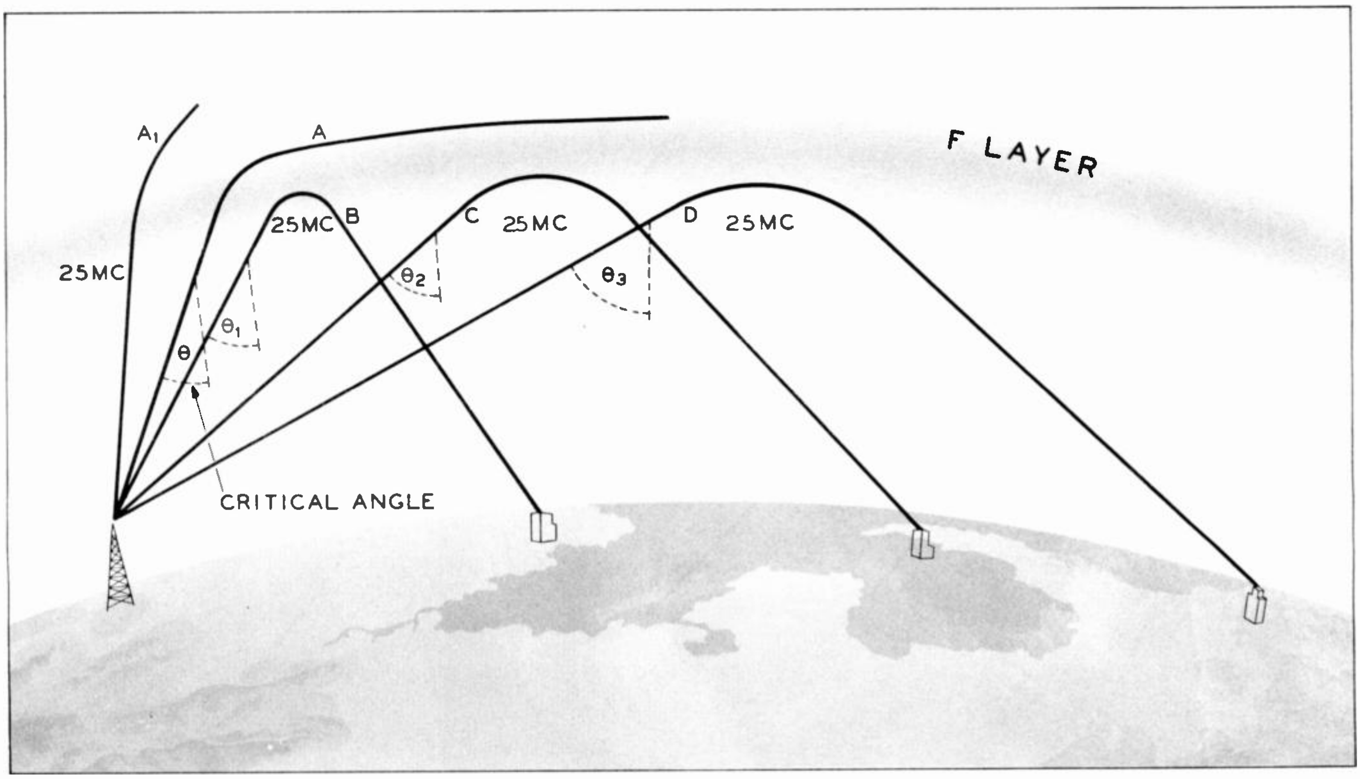


Figure 14. Radio Wave Entering the Ionosphere at Various Angles, Showing the Effect on Range.

that frequencies higher than the critical frequency can be returned to earth if they enter the ionosphere at an oblique angle, or at an angle greater than the critical angle. See figure 14.

The m.u.f. for the particular layer (E, F_1, or F_2) and the required operating range can be determined by the formula:

$M.U.F. = f_c \sec \theta$

f_c = critical frequency

θ = angle of incidence or angle at which wave front enters ionosphere region

Vertical Radiation Angle Vs. Frequency

Since most long-distance communication is carried on by sky-wave transmission methods, the vertical radiation angle used at a given frequency is an important factor.

The following tabulation indicates the approximate vertical angles of radiation most suitable for radio waves of different frequencies and for different distances between the points of communication.

1.5 to 3 mc.—Low-angle radiation for long distances. High-angle radiation may cause fading of ground-wave reception. Vertical antenna preferable.

3.0 to 6.5 mc.—Good sky-wave ground return at any angle of radiation. High-angle radiation can be used for short to moderate distances, but *low*-angle radiation should be used for long-distance communication work.

7.0 to 12 mc.—Angle of radiation of 45 to 30 degrees for short to moderate distances. Lower angles should be used for long-distance communication. Higher radiation angles can be used to overcome ionospheric variations at the height of sunspot activity.

13 to 30 mc.—Not useful for short-distance, sky-wave transmission. Maximum useful angle when operating on a frequency of 13 to 16 mc. is about 30°. As the frequency increases above 14 mc., the angle of propagation should be progressively decreased from 20 to 10 degrees. Above 28 mc., an angle less than 10 degrees should be used.

Skip Distance

It will be remembered that the ionosphere is composed of several layers, D, E, F_1, and F_2; the D and E layers are practically nonexistent at night and the F_1 and F_2 layers combine into a single layer at night, are effectively lower in altitude, and decrease in electron density. By referring to figure 15 it is seen that the points at which the waves traveling through the ionosphere return to earth will vary, depending on the existing layers, layer height, layer density, and angle of propagation. A wave of given frequency and propagation angle will be returned to earth at a more distant point if it is reflected from the F_2 layer rather than the E layer; see figure 15. For instance, if in the daytime a 6-mc. wave at a 20-degree propagation angle is returned to earth from the E layer at a point approximately 300 miles from the transmitter, the same wave under the same conditions may be re-

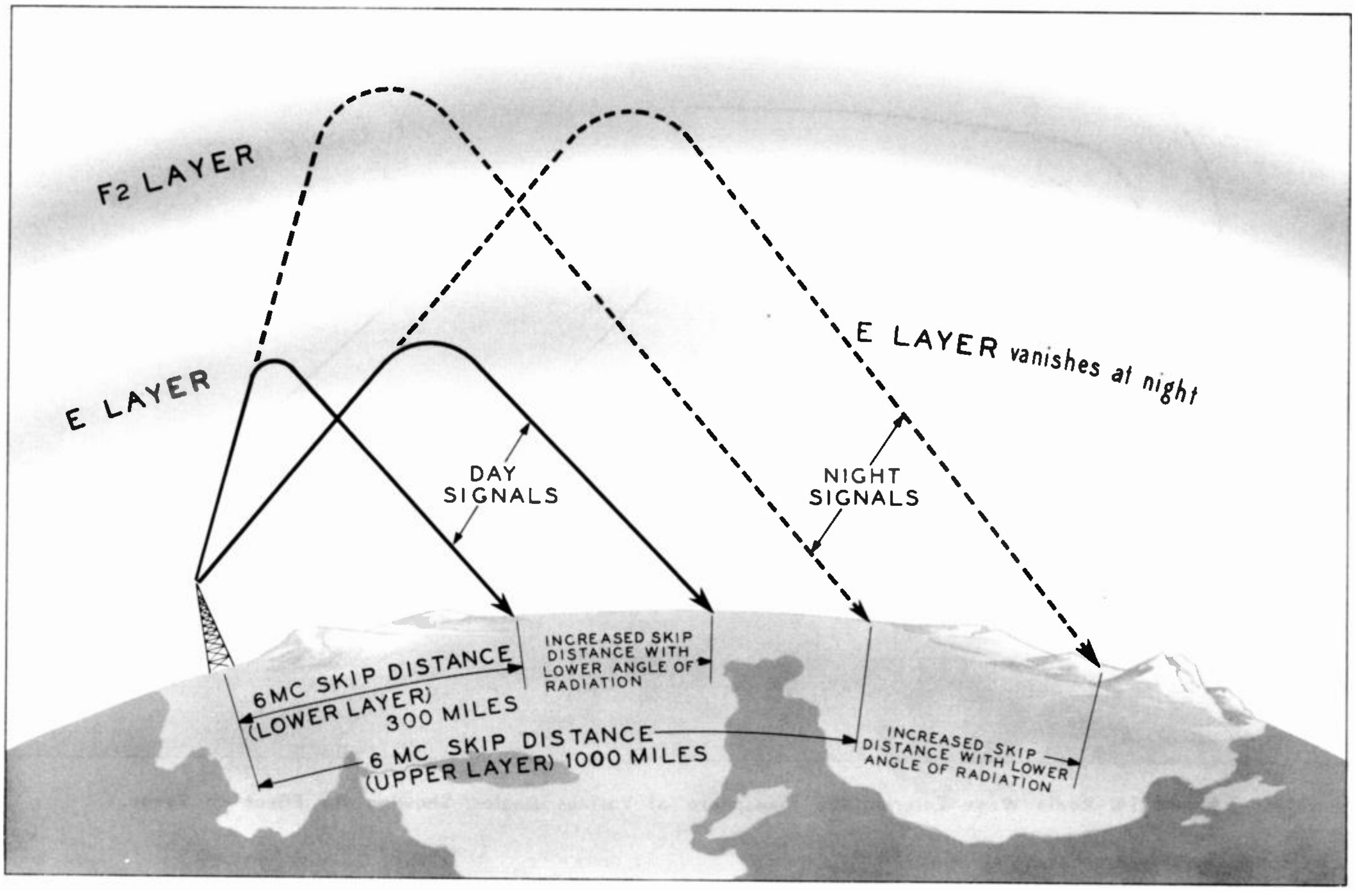


Figure 15. Day and Night Signals at Different Angles of Propagation, Showing the Effect on the Skip Distance.

turned from the F_2 layer at a point approximately 1000 miles away at night (assuming that the 6-mc. wave could not reach the F_2 layer in daytime because of absorption by the D and E layers). The distance between the transmitter and the nearest point where a usable refracted wave is returned to the earth is called the "skip distance." For an illustration of the variations in skip distance with frequency, see figure 16.

Skip Zone

Between the point where the ground wave is completely dissipated and the point where the first sky wave returns *no* signals will be heard; this is called the "skip zone." See figure 17. The skip zone for the lower high frequencies (roughly 3 to 9 mc.) will be greater at night than during the day. For instance, if signals transmitted on 6 mc. from Philadelphia, Pa., can be heard from 1300 to 1700 o'clock in Pittsburgh, Pa., but not in Chicago, Ill., transmissions from the same station may be heard from 1730 to 2200 o'clock in Chicago, but not in Pittsburgh. However, skip effect can be compensated for by utilizing lower frequencies for nighttime communication. For example, to maintain reliable communication from Philadelphia to Pittsburgh during the hours from 1730 to 2200, a frequency of 3 or 4 megacycles might be used.

When high-angle radiation is used with frequencies near the low end of the h-f band (1.75 to 3 mc.) little or no skip effect is encountered and complete coverage of an area considerably beyond the ground wave-coverage area is obtained. As a general rule, it can be said that as the frequency decreases the skip distance decreases.

Multiple-Hop Transmission

The sky-wave path of a signal propagated at two different vertical angles is illustrated in figure 18. When the vertical angle is ϕ_1, the signal is returned to earth at point "A", reflected back to the ionosphere and reappears at point "B." If the same signal is transmitted at the lower vertical radiation angle ϕ_2 it can reach point "B" in a single hop. The signal transmitted at angle ϕ_1, will suffer more ionospheric and ground-absorption losses than that transmitted at angle ϕ_2. In general, single-hop transmissions result in greater field intensities at a distant point than multiple-hop transmissions. By inspection of figure 18 it is evident that longer distances can be covered by multiple-hop transmission as the vertical radiation angle is decreased. The higher medium frequencies (9 to 30 mc.) are generally utilized for long-distance transmissions, and, in order to minimize the number of reflections of the

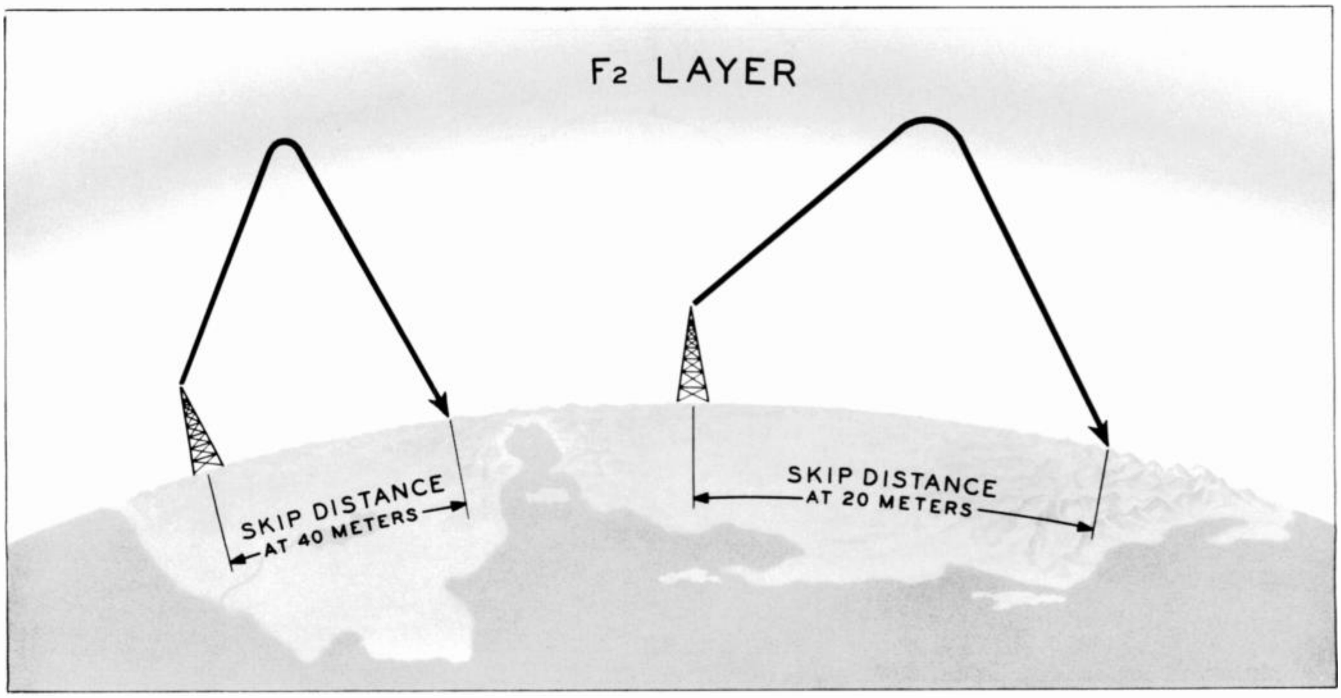


Figure 16. Variation of Skip Distance with Frequency.

signal in arriving at a distant point, lower vertical radiation angles are used. For example, a 20-mc. signal transmitted from Manila to San Francisco at a vertical radiation angle of 20°, arrives at San Francisco in three hops via signal path A, while the same signal transmitted at a vertical radiation angle of 10° arrives in two hops via signal path B; see figure 19. Signal path B will produce a stronger usable signal in San Francisco than signal path A. However, there is a limit to the improvement obtainable by low-angle radiation because absorption and other factors make operation on vertical radiation angles below 3 degrees impractical.

Fading

When a received signal varies in intensity over a relatively short period of time, the effect is known as *fading*, which may be one of the most troublesome problems encountered in a radio communication network.

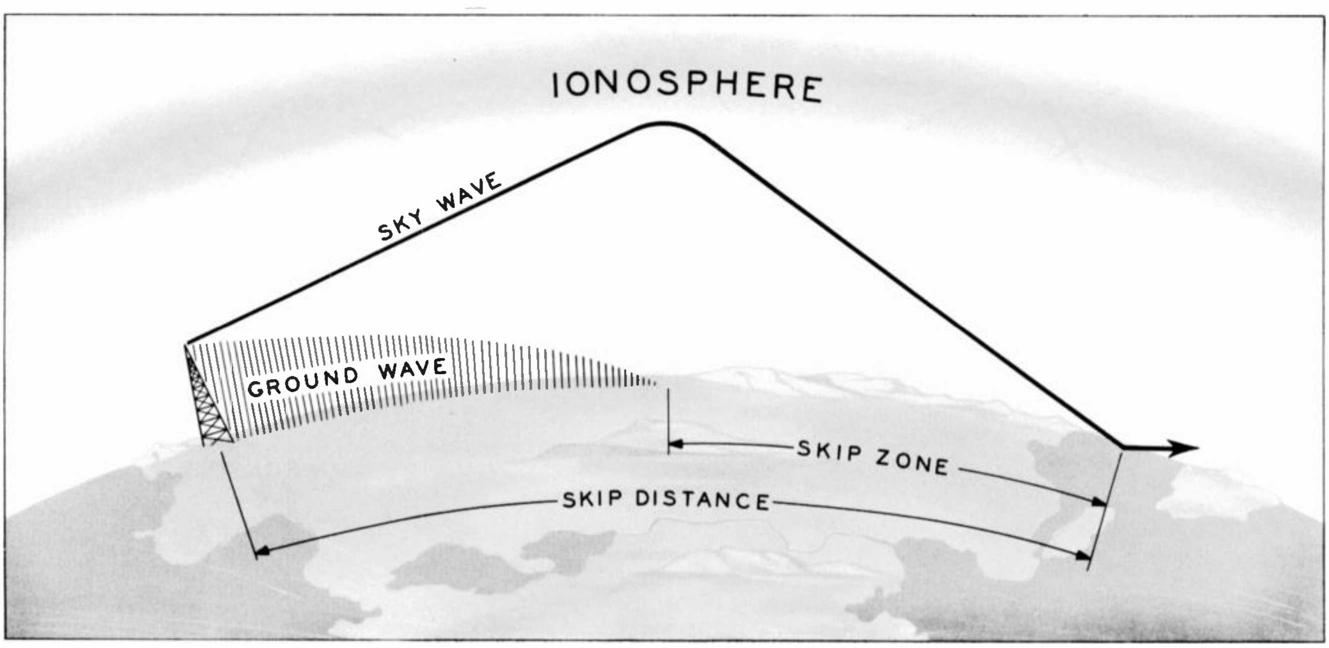


Figure 17. Skip Zone.

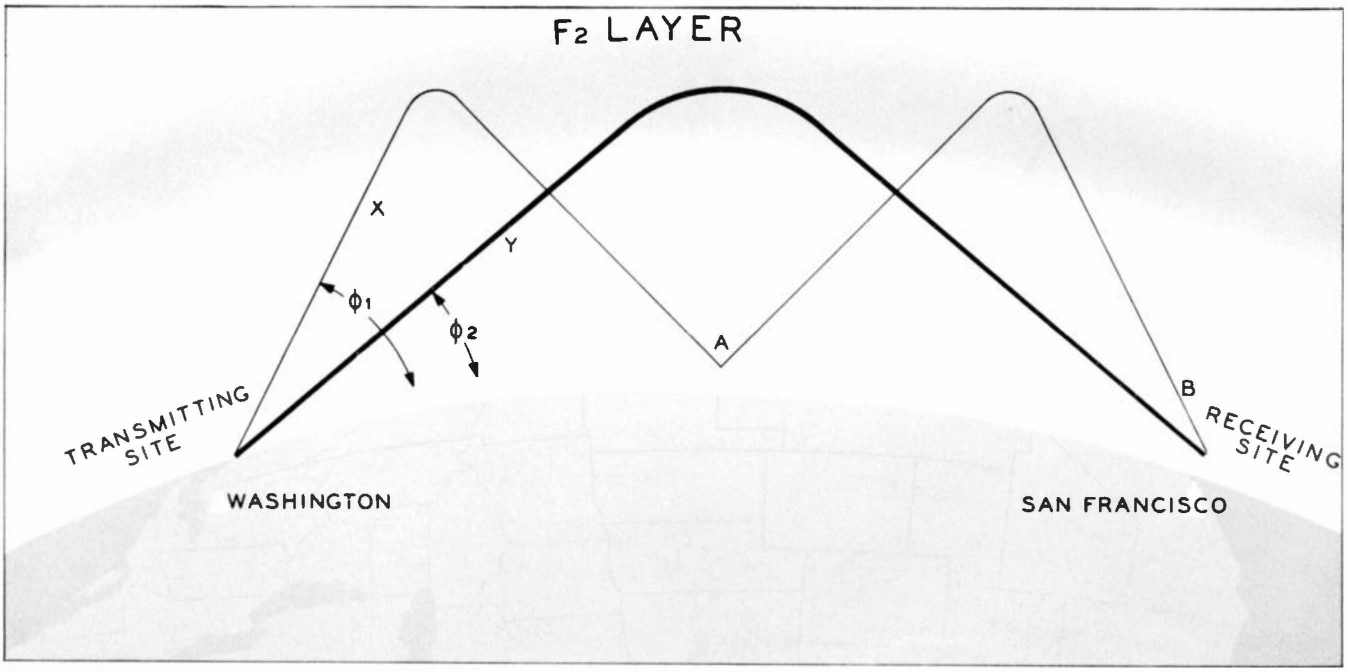


Figure 18. Path of a Sky-Wave Signal Propagated at Two Different Vertical Angles.

There are several possible conditions which can produce fading. Fading may occur at any point where both the ground wave and the first sky wave returns occur. See figure 20. The ground-wave and sky-wave signals may arrive at the same point out of phase, thus producing a cancellation of the usable signals. This type of fading presents a problem in Loran (long range navigation) operation over bodies of water. In some parts of the Pacific area, the ground-wave range extends to over 800 miles. As a result, signal variations from the 600-mile point to the 900-mile point interfere with normal Loran operation, which requires recep-

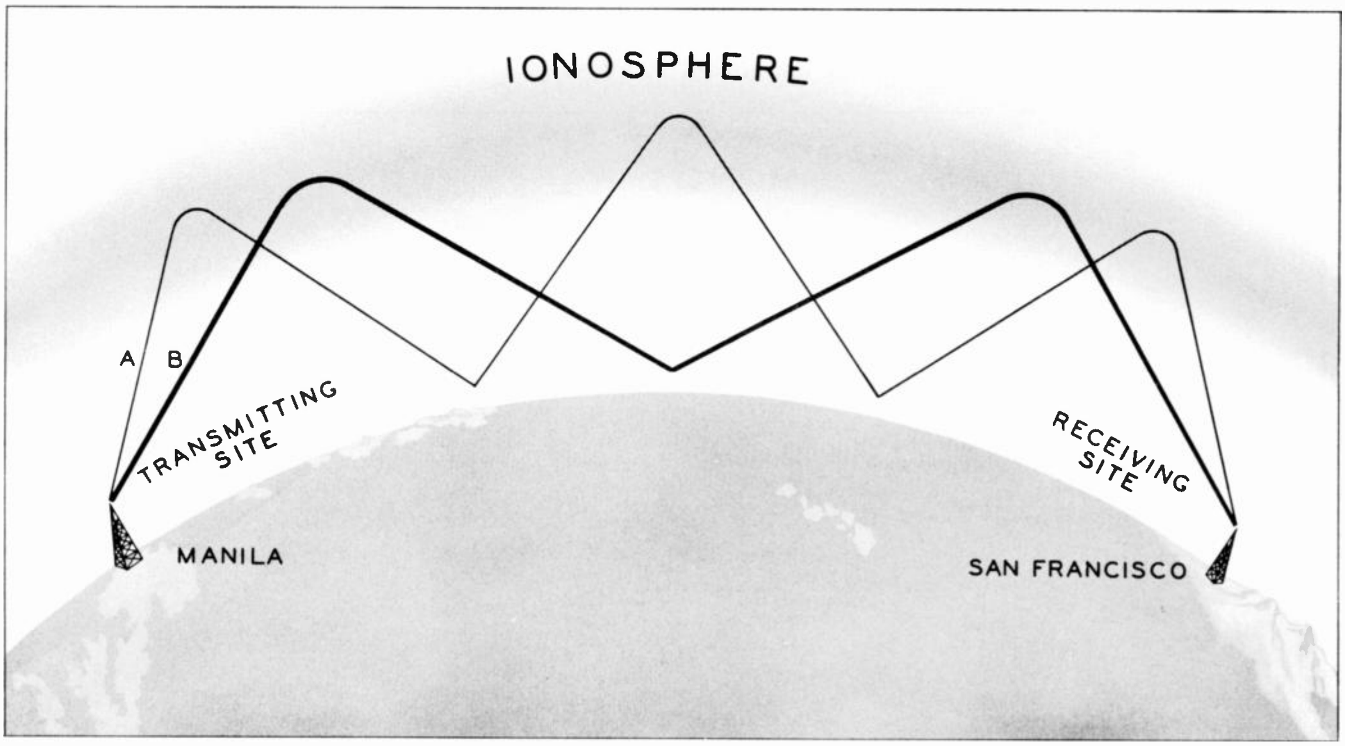


Figure 19. Multiple-Hop Transmission.

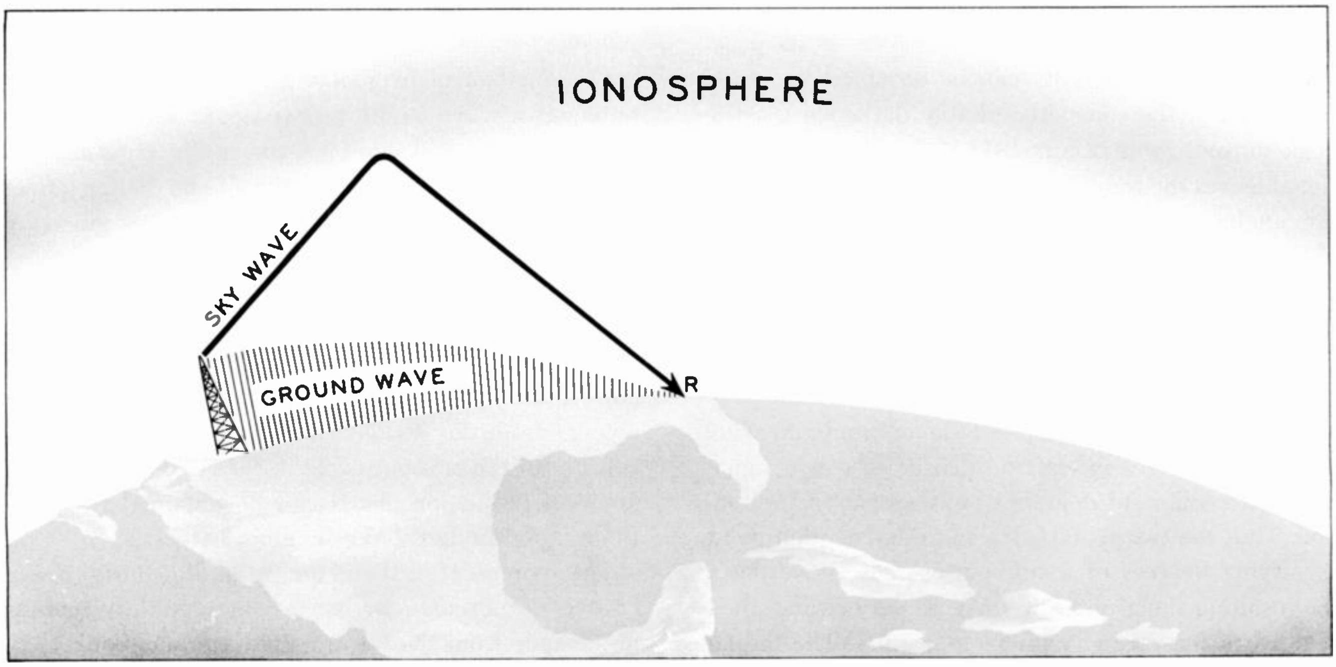


Figure 20. Fading Caused by Arrival of Ground Wave and Sky Wave at the Same Point (R) Out of Phase.

tion of either ground waves or sky waves, but not both at the same time. Loran operation involves frequencies within the 1750 to 2000-kc. band.

Another type of fading is prevalent in areas where sky waves are relied upon for communication. Figure 21 shows two sky waves traveling paths of different lengths, thereby arriving at the same point out of phase and thus producing a cancellation of the signal. For instance, if a portion of the transmitted wave front arrived at a distant point via the E layer and another portion via the F layer, a complete cancellation of signal voltages would occur if the waves arrived 180° out of phase and with equal amplitude. Usually one signal is weaker than the other and, therefore, a usable signal is obtained.

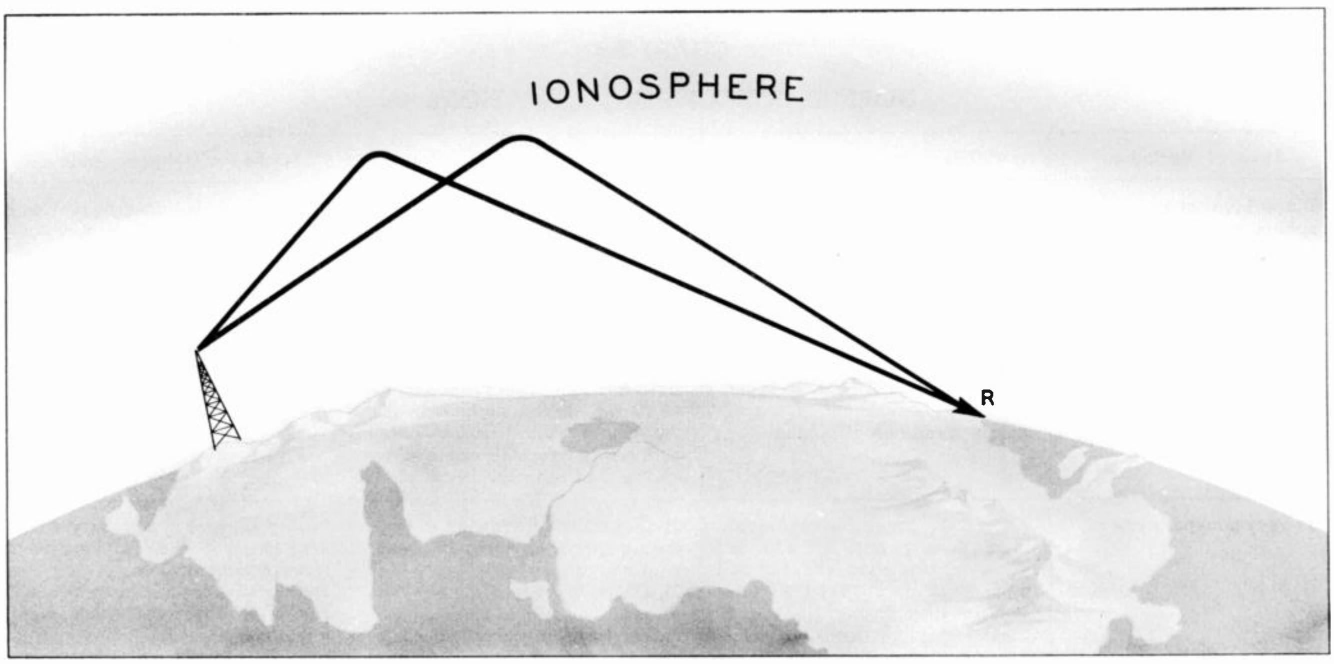


Figure 21. Fading Caused by Arrival of Two Sky Waves at the Same Point (R) Out of Phase.

An example of a typical fading situation is as follows: It is noon and sunspot activity is at its peak. (Relative sunspot activity can be observed by visual inspection of the sun with suitably darkened glasses; peak sunspot cycle occurs 1948-1949.) A 7-megacycle signal leaves the transmitting antenna at vertical radiation angles ranging from 10 to 40 degrees. The portion of the wave front between 10 and 12 degrees arrive at a receiving point 500 miles away via the E layer, but the portion between 38 and 40 degrees passes through the E layer, and is reflected by the F_2 layer before arriving at the receiving point. Due to the fact that during peak sunspot activity the ionospheric layers undergo wide and rapid changes in electron density, the two signal paths offer different degrees of absorption and refraction. Thus the two signals arrive at the reception point at varying degrees of in-and-out-of-phase conditions; the resulting signal intensity may be very strong, then very weak for several minutes at a time. The fading period may be of short or long duration. Fading effects are usually more pronounced on the higher medium frequencies (30-mc. signals often disappear completely). However, under critical conditions it is sometimes possible to establish satisfactory communication by raising the frequency to a higher value.

The type of fading which results in distortion of the audio side bands cannot be tolerated on important voice circuits or teletype circuits. This type of fading is called "selective" fading, and it results from the slight difference in transmission paths of the different frequencies within the side bands of the transmitted signal.

One method of overcoming fading is to place two antennas a wave length or two apart, feed two separate receivers, and combine the audio outputs; this is known as "diversity reception." The fading effect can be further minimized with diversity reception by the use of three antennas and three receivers.

Propagation Forecasts

The maximum usable frequency (m.u.f.) and the corresponding optimum working frequency (o.w.f.) change from day to day and from year to year, according to the sunspot cycle. Information in the form of m-u-f prediction charts can be obtained from the Bureau of Standards, Washington, D. C.

The pamphlet, called the *Monthly Basic Radio Propagation Predictions,* can be obtained three months in advance from the Central Radio Propagation Laboratories, National Bureau of Standards, Washington, D. C. The same information can be obtained from the Adjutant General's Office, War Department, Washington, D. C., under the nomenclature of TB11-499-( ) and TM11-499-( ).

The ionospheric variations can be classified into two main categories—normal and abnormal. The normal ionospheric variations with the general effects produced and the methods of compensation to maintain satisfactory communication, are given in chart 6; the abnormal ionospheric variations are given in chart 7.

CHART 6

NORMAL IONOSPHERIC VARIATIONS

Type of Variation	Effect on Ionosphere	Effect on Communication	Method of Compensation
Diurnal (variation of ionosphere with time of day)	Effective height and density of ionosphere layer vary as day progresses into night.	Skip distance varies in 1 to 30-mc. range.	Use higher medium frequencies in daytime and lower medium frequencies at night.
Seasonal variations	Summer period: Greater E-layer electron density and effective altitude. Little change in F layer with 250-mile height. Winter period: Lower E layer. F_1 layer nonexistent. F_2 layer height averages 185 miles.	Critical frequency about 4 mc. during daytime, and about 7 mc. during nighttime. Critical frequency about 3 mc. during daytime, and about 11 to 12 mc. during nighttime. Additional variations on intermediate frequencies expected in spring and autumn.	Use medium high frequencies for long-distance communication in winter. Use lower high frequencies for medium distances in winter.
11-year sunspot cycle	F_1 and F_2 layers attain maximum density and altitude in years of maximum sunspot activity (maximum, 1938-1939 and 1948-1949; minimum, 1934 and 1944).	Higher critical-frequency ranges during years of maximum sunspot activity. M.U.F. (sunspot maximum)—8 to 42 mc. M.U.F. (sunspot minimum)—5 to 22 mc.	During sunspot maximum years, use 19 to 35 mc. for long-distance communication. During sunspot minimum years, use 5 to 20 mc. for long-distance communication. Use TB 11-499 to determine m.u.f. and o.w.f.

CHART 7

ABNORMAL IONOSPHERIC VARIATIONS

Type of Variation	Effect on Ionosphere	Effect on Transmission	Method of Compensation
Sporadic E layer	Ionization irregularities in E layer for a large fraction of time each month raises critical frequency abnormally. Irregularities usually spotty in geographic extent and time.	Excellent transmission within normal skip zone. Occasionally, long-distance communication on frequencies above 60 mc. is possible.	Frequency may have to be lowered to maintain short-skip sky-wave communication. Occasionally, long-distance communication on abnormally high frequencies is possible via the E layer (consult TB 11-499).
Ionospheric storms	Disturbed ionospheric conditions, mostly above latitude of 60 degrees, causing radio black-outs on high frequencies. Lasts for few minutes to several hours, then disappears gradually in few days.	Limits the number of usable high frequencies.	Since these abnormalities are frequent above 60° latitude, low frequencies should be used for CONSISTENT communication. (Consult Radio Propagation Forecasts, Chief Signal Officer, Plans and Operations Division, Liaison Branch, Washington 25, D. C.)
Sudden ionospheric disturbance	Probably caused by magnetic storms, lasting for few minutes to hours. Results usually not as severe as ionospheric storm effects.	On frequencies above 1 mc., receivers appear DEAD, with lack of static and signals.	Raise working frequency above normal for short-hop transmission. Lower working frequency below normal for long-hop transmission.
Scattered reflections	Irregular reflections caused by scattering of waves; more pronounced during magnetic storms.	Unexpected signal reception on all frequencies.	Effects last for short time. No compensation required.

Considerations in Selecting Proper Transmission Method

Although ground-wave field strength decreases rapidly with increasing distance it usually does not vary with the time of day or the season of the year.

Sky-wave field strength decreases more slowly with increasing distance, but is subject to variations, due to all of the causes previously mentioned. Despite this fact, experience has shown that, by the use of the proper frequencies for certain periods of the day and night, season of the year, and sunspot cycle, consistent communication can be maintained over short, long, or intermediate distances. It must be emphasized however, that at distances where ground-wave transmission is adequate, it should be utilized instead of sky waves. Transmission by ground waves insures a steady signal, provides a wide choice of frequency ranges, and almost eliminates the effects of ionospheric disturbances.

The only limitations on ground-wave transmission are terrain conditions, static, and man-made noise. In v-h-f and u-h-f transmission, the antennas must be placed as high as possible. In mountainous country, ground-wave propagation may suffer from shadow effect; see figure 22.

Notice that the wave front is diffracted enough to reach point Y but that the shadow effect does not allow a usable signal to arrive at point X. In mountainous country or jungles areas, high-angle, sky-wave radiation should be used. For maximum ground-wave transmission efficiency over the ocean, the antenna should be located as close as possible to the edge of the surf. Locating an antenna as much as one hundred feet back on the beach considerably reduces the efficiency.

For ground-wave transmission in field work, the most suitable antennas are the whip type, for mobile equipment, and the inverted "L" and long-wire type for fixed installations.

For long-distance, low-frequency, ground-wave communication the Beverage antenna, crowfoot antenna, and various types of flat-top antennas are suitable.

For local, general coverage (5-to-25-mile radius) on the low, medium frequencies, the quarter-wave Marconi antenna consisting of a single steel tower, is often used.

For short-distance, sky-wave field communication the half-wave horizontal or sloping-wire antenna is convenient and efficient.

For long-distance, sky-wave transmission, the rhombic antennas, the collinear arrays, and the parasitic arrays are commonly used. These antennas have highly directional properties and, therefore, provide a power gain in a given direction as compared to a single-element antenna.

The horizontal antenna favors the reception of a high-angle signal and discriminates against the low-angle atmospheric static and local man-made noise, which are usually vertically polarized. Therefore, for general-coverage reception of high-vertical-angle sky waves, horizontal half-wave antennas should be used where the distance between the transmitter and the receiver is 200 miles or more.

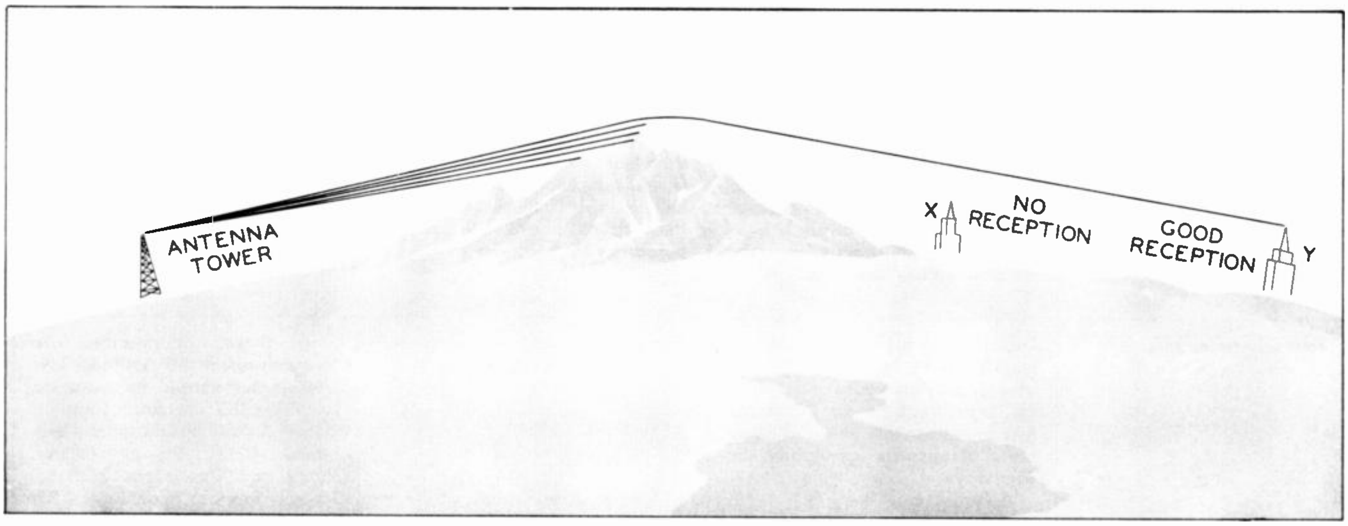


Figure 22. Shadow Effect Incurred at V.H.F.

NOISE CONSIDERATIONS

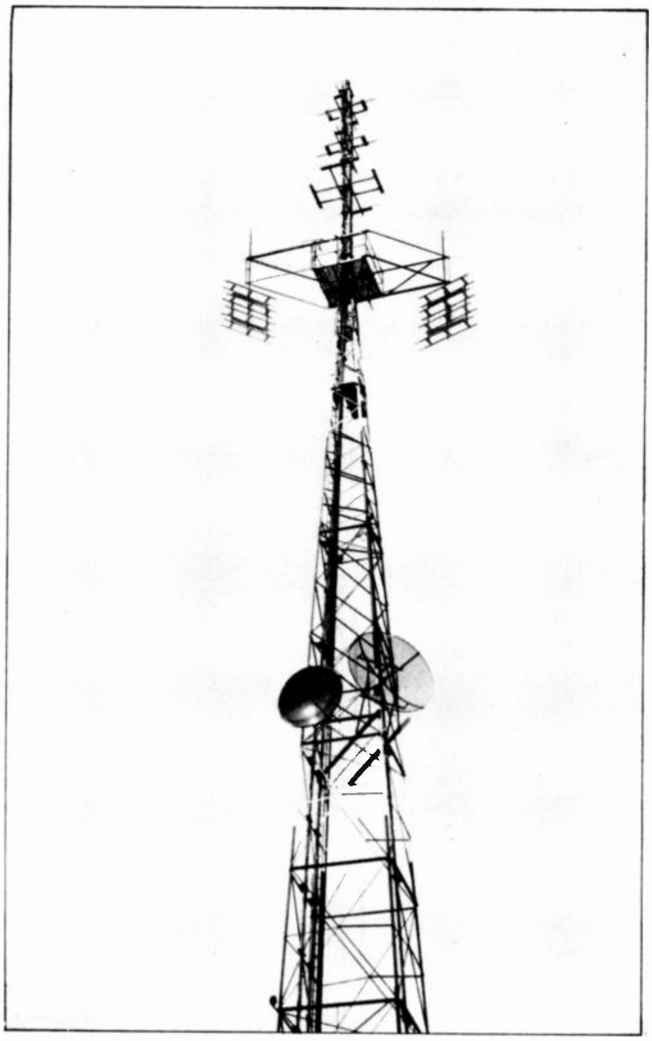
An important item to consider in connection with the reception of radio signals is noise propagation. In nearly all cases, the amount of antenna power required at a transmitting installation is partially governed by the magnitude of noise existing at the receiving site. Anyone in communication work generally has a passing knowledge of noise effects, but only a superficial knowledge of the complex nature of noise.

Types of Radio Noise

In order to gain a practical understanding of the ever present noise problem, and its solution, it is necessary, first, to recognize the nature of the different types of noise and their general effects and, second, to learn how the various noises find their way into the receiver.

The basic types of noise are man-made noise, and natural or static noise. Man-made noises are generated by high-voltage power lines, motors, electrical appliances, neon signs, diathermy machines, electronic heaters, etc. The frequency range and magnitude of the noise disturbance varies with the individual noise source. In general, man-made noise produces interference which extends over the entire communication frequency range. Certain types of noise sources can be readily identified by the periodic characteristics of the signal from the receiver. For instance an electric shaver produces a steady buzzing noise, and ignition noise produces a steady tapping sound.

Noises produced by ordinary household electrical appliances, motors, and neon signs are generally local in extent. Noise produced by electronic sources, on the other hand, may be radiated several thousand miles. An excellent example is a case that occurred recently. Noise was interfering with commercial airlines communications from the west coast to the North Atlantic. The noise source was finally located in a cabinet



Commercial Television Tower, Showing Turnstile, Broadside, and Microwave-Parabolic-Type Antennas.

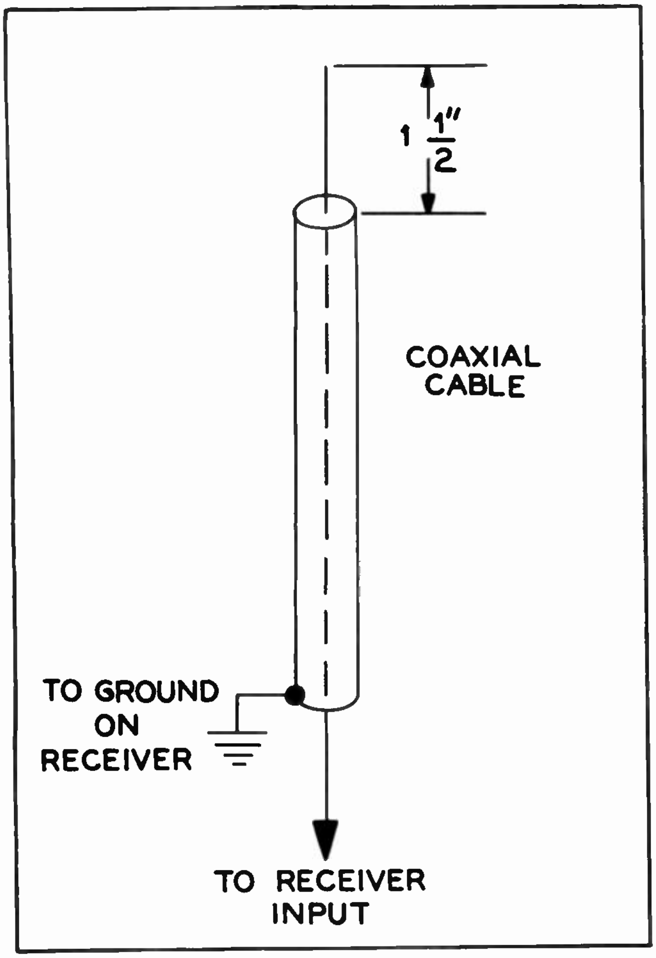


Figure 23. Details of Coaxial-Cable "Probe."

factory at Johnstown, Pennsylvania. In this case, an h-f electronic heater, used in the manufacture of plywood, was the offender. Considerable effort was required to track down this noise source.

Noise from diathermy machines produces havoc in h-f, u-h-f, and v-h-f reception, and is particularly troublesome in television reception.

Obviously man-made noise sources are more prolific in industrial areas. This accounts for the fact that precise receiving services, such as monitoring, transatlantic phone, and direction finding, are located in rural areas, at considerable distances from travelled highways, electric railways, and air lanes.

External noise may get into the receiver by way of the antenna, the antenna leadin, the ground lead, and the power-input cable. A poorly shielded receiver may pick up the radiated noise field directly through its own wiring. If the receiver input or output circuit is cabled in with wiring from other equipment, the receiver may pick up noise voltages existing on the other lines.

In military installations, local noise fields are generally caused by gasoline and diesel-powered generator units, keying circuits, motor vehicles, and reefers (refrigerating plants).

Methods of Localizing Noise

For the first step in tracking down any noise condition, disconnect the antenna from the receiver. If the noise output drops considerably, the noise source is external to the receiver. If the noise remains at approximately the same level, some component of the receiver is defective. A bad tube, particularly in the input r-f stage of the receiver, a bad resistor, a leaky capacitor, or a defective speaker may cause noise. In addition, it might be mentioned that every receiver has inherent noise, due to thermal agitation in the tubes and shot effect. At frequencies above 30 mc., these inherent noises are the limiting factors for proper reception.

If the check above indicates that the noise is external and man-made, the offending source should be tracked down systematically. Input power to each piece of suspected equipment should be removed, one at a time. If the area has extensive installations, some idea of the direction of the offending source may be determined by either of the two following methods:

The first method is based upon the fact that most man-made noise fields are *vertically* polarized. Remove about 1½ inches of the outside braid and insulation from a twelve-inch piece of coaxial cable to form a probe. See figure 23. Connect the center conductor of the cable to the input of a battery-operated receiver and ground the shielded braid to the receiver. Point the probe in various directions until a position is found where maximum noise is obtained from the receiver. When this position is found the bared end of the probe is pointing approximately in the direction of the noise source.

The second method requires a simple loop of about 2 or 3 turns about 1½ inches in diameter, made with rigid wire. Connect the loop to the receiver through a one-foot length of coaxial cable, and ground the braid of the coax to the receiver. Slowly rotate the loop for a null. When a null is obtained, the plane of the loop is at right angles to the direction of the noise source. For more accurate results, the loop may be provided with a split shield, similiar to that used on compass loops, to prevent capacitive pickup which tends to blur the null indication.

Methods of Reducing Man-Made Noise

After the noise source has been localized to a particular piece of equipment, steps should be taken to suppress it. The frames of motors should be grounded with a short heavy lead. All ground leads should be kept as short as possible.

The next step is the installation of noise-suppression devices. Some commercial electrical equipments are provided with integral suppressor units. Noise-eliminating circuits should be installed on all ingoing or outgoing power leads of the equipment. The usual type of noise suppressor for motors and generators consists simply of two capacitors, connected as shown

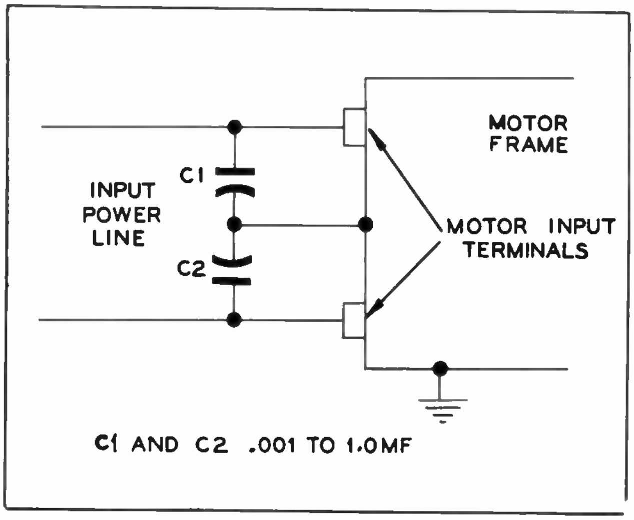


Figure 24. Simple Type of Noise Suppressor for Motors and Generators.

in figure 24. A more elaborate suppressor circuit is shown in figure 25.

The coils may consist of 10 to 30 turns of rigid #14 B. & S. enameled or double-cotton-covered wire. The turns of the coil should be closely spaced, and ¼″ or ¾″ in diameter. The wire size and coil dimensions will be greater for equipments using high current. A ceramic or wooden dowel may be used if the coil is layer wound.

Different coil and capacitor sizes should be tried for individual conditions. In any case, it is important to install the filter as close as possible to the terminals, with the short ground lead connected directly to the frame. The frame must be properly grounded to earth. The capacitors must have the correct voltage ratings, and the coil wires and leads must be large enough to carry a 150% current over-load.

The external wiring associated with the receiver should be thoroughly checked. If any remote lines, leadins, etc., are cabled in with other lines, they should be separated, to prevent noise pickup from the other wires in the cables.

The antenna input wiring of the receiver is in many cases a cause of noise pickup in the receiver. The usual type of connection to a receiver is shown in figure 26A. By using a balanced input to the receiver, as shown in figure 26B, considerable noise interference can be eliminated.

A balanced antenna is connected directly to the ungrounded terminals of the primary of the r-f transformer. A short ground lead is connected to the chassis. Some receivers are provided with an input terminal system which will accommodate this arrangement.

As a final resort, it may be necessary to modify a particular receiver, by decreasing its band-pass characteristics, or installing a noise-limiter circuit. Decreasing the over-all band width of the receiver minimizes interference from noise pulses of long duration.

In the v-h-f and u-h-f range, the use of narrow-band FM is universal for elimination of external noise effects.

In AM receivers, the use of a well shielded loop antenna helps to minimize local noise effects, provided that the received signal has sufficient intensity for intelligibility.

Methods of Reducing Natural Noise

Noise disturbances due to man-made devices are controllable to a great degree. Eliminating or overcoming the adverse effects of static, however, is, in most cases, a very difficult problem. In practical communication work, the main objective is to ascertain the extent and frequency of occurrence of static disturb-

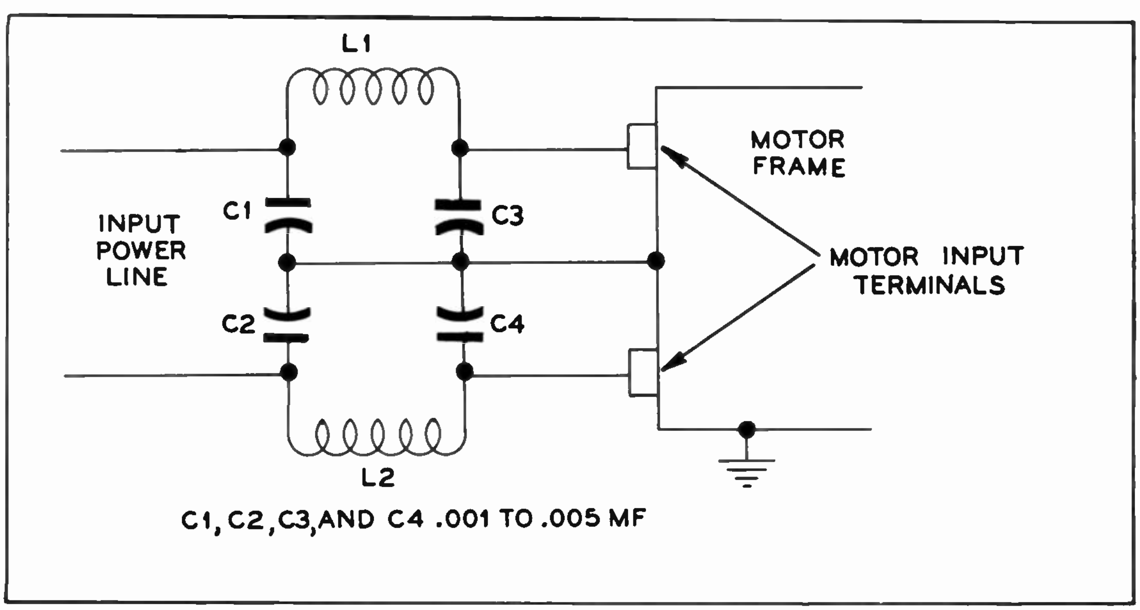


Figure 25. Double Pi-Type Noise-Suppressor Circuit.

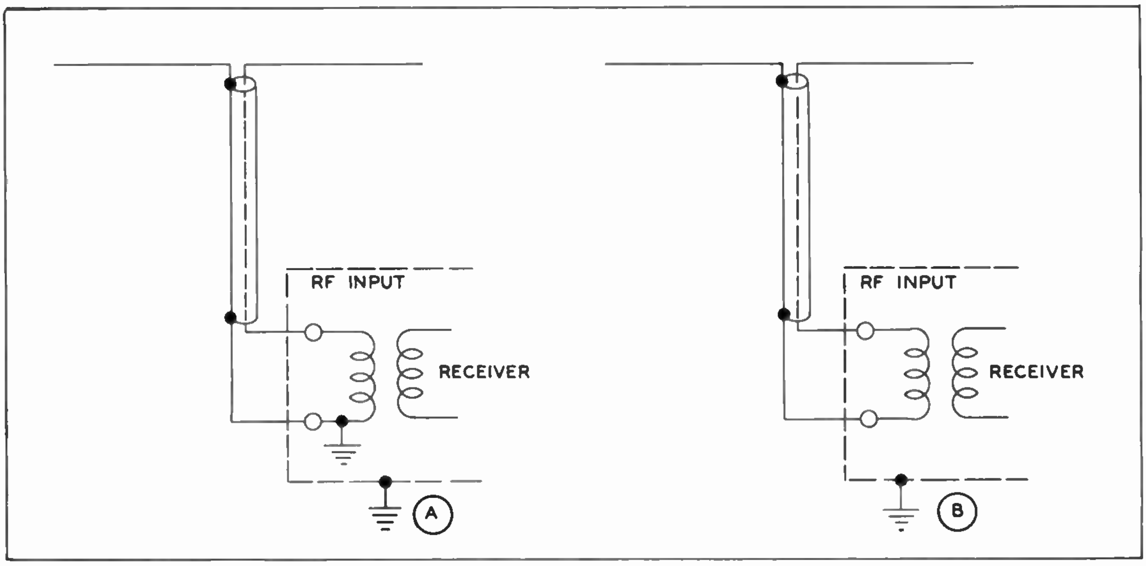


Figure 26. Unbalanced and Balanced Antenna-Input Circuits.

ances at a particular location, and then take steps to minimize their effects.

The most prolific sources of static energy in the atmosphere are lightning discharges during a thunderstorm. These static fields are most prevalent in the tropical zones of the earth. Figure 27 shows the general distribution of static noise fields in relation to their average magnitude. As these noise fields are generated they are propagated in all directions, in a similar manner to radio waves. Thus, the noise fields generated in the tropical zones travel by way of the ionosphere to areas in the northern and southern latitudes, and produce noise interference with communication services. In the tropical zones, radio reception over the h-f communication range is, in general, replete with static interference. Receiving services between a northern and southern latitude are affected, also, by the static fields originating in the tropics. For example, if a transmitting station in Buenos Aires beams its signal to a receiving station in New York, the path of the signal traverses the tropical zone. For maximum receiving efficiency, the receiving antenna (usually a directive receiving array) in New York is oriented directed toward Buenos Aires. Thus, the receiving antenna is very receptive to the noise fields generated in the tropics, as well as to the wanted signal. Fortunately, several factors exist which make it possible to solve this problem satisfactorily.

First, the intensity of the noise-disturbance effects produced in a receiver is roughly inversely proportional to the frequency. This means that the noise effects are less pronounced at 20 megacycles than at 5 megacycles. Conversely, the noise effects are most pronounced at the low frequencies.

Second, fairly accurate predictions of the maximum usable frequencies are obtainable, so that the proper choice of the highest frequencies can be made. The fact that the atmospheric noise effects *decrease* with the frequency clearly indicates why communication should be carried on at a frequency near the maximum usable frequency.

Signal-to-Noise Ratio

The vertical angles of departure and arrival of long-distance signals are very low (0 to 10°). In the example above, the transmitting station in Buenos Aires, beaming the signal to New York, operates on a frequency near the m.u.f., and propagates the signal at very low angles. If the noise energy in the signal path arrives at the receiving point at high angles, the ratio of signal to noise at the receiver is high. If the noise energy and the received signal are both maximum at the same angle of reception, the effectiveness of the directive receiving antenna is impaired, because the value of the noise signals approaches the value of the received signal. To insure a good margin of communication reliability, the transmitted signal must have sufficient magnitude to overcome the total noise at the receiver, which includes both the external noise and the inherent noise of the receiver.

The effective signal-to-noise ratio for reliable phone communication is usually 10 to 1. For reliable radio phone communication, the signal input should be ten times the noise input to the receiver. The signal-to-noise ratio for absolutely reliable communication should have a higher value because the modulation percentage is always less than 100 percent. This means that the energy in the side bands containing the signal intelligibility should always be great enough to overcome the noise energy at the receiver input. Therefore, when a communication system is contemplated, the first step is to determine the required *speech-to-noise* ratio at the receiving site.

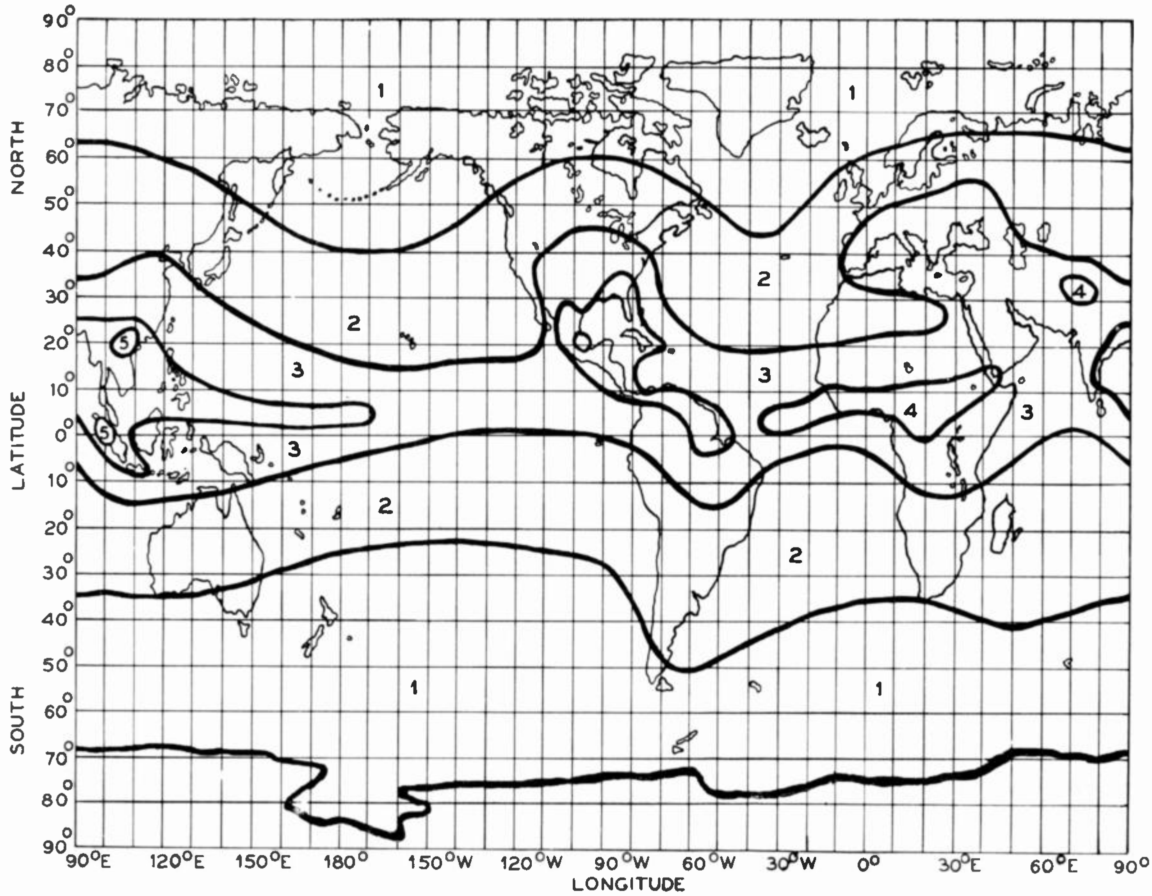


Figure 27. General Distribution of the Static Noise Field in Relation to the Average Magnitude. Designated as noise grade areas—high grade 5, low grade 1.

To determine the approximate required strength of the received signal for a particular location, use the following procedure:

1. Determine the over-all sensitivity of the receiving system (ratio of microvolts in to milliwatts out).

2. Eliminate or minimize all local man-made noises.

3. Connect an a-c output meter (r.m.s.) to the voice-coil terminals of the receiver; leave antenna connected. (Noise amplitude can be determined more accurately with an oscilloscope, if available.)

4. Tune the receiver to various frequencies until a point is found where the b.f.o. indicates that no radio signal is present.

5. With the b.f.o. and a.v.c. off and the volume control set to maximum, note the noise-voltage reading on the meter, and convert it to peak voltage by multiplying by 1.414.

6. Remove the antenna and feed in an unmodulated carrier from a good signal generator of sufficient power to give the same reading as obtained in step 5 above. The carrier input, in microvolts, should have a value at least 50% greater than the peak noise input in step 5 above.

7. Modulate the carrier with a 400-cycle signal at 30% modulation, and measure the peak voltage (peak voltage is 1.414 times r-m-s reading of meter).

8. The *speech-to-noise* ratio is the reading obtained in step 7 divided by reading obtained in step 5. The input voltage of the signal generator in step 7 is the required voltage input of received signal for intelligible phone communication. Due to the fact that the transmitted signal voltage will vary, the power estimate for the transmitter at the distant point should be based on a received signal voltage of about ten times that obtained in step 7 above, for a fair margin of reliability.

9. Ordinarily, radio-telephone operation requires considerably more power for reliability of communication than that required for c-w communication. If cost considerations are a major factor, c-w equipment should be used.

Noise Vs. Consistent Communication

In recapitulating, communication reliability as far as noise is concerned depends upon the following:

1. Transmitted power.
3. Signal-to-noise ratio for the type of antenna used
2. Inherent noise characteristics of the receiver.
   at the receiver.

To obtain the maximum transmitted power, use maximum directivity, the lowest angle of propagation, and the highest maximum usable frequency consistent with reliability. In some cases, where extremely long distances are involved, directivity will have to be sacrificed, because at times the signal wave front will not exactly follow the expected propagation path. The Sterba curtains, the rhombic, and the parasitic arrays, which are discussed later in the course, can be utilized for maximum transmission signal gain.

With regard to noise, it is necessary to eliminate all local man-made noises and to use receivers with low inherent noise. The over-all receiver band width should not be greater than that required for suitable reception of the type of signal involved (radio phone, radio teletype, television, etc.). Extreme care should be exercised in the construction of receiver feed lines and associated wiring.

In securing the highest signal-to-noise ratio, the type of antenna and its orientation are important factors. For reception of signals arriving at low angles, in a narrow horizontal plane, a rhombic, eight or ten wave lengths long at the highest frequency and erected $5/8$ wave length above the ground, is satisfactory.

If a margin of safety is allowed for the ionospheric deflection of a highly directive transmitted signal (vagaries of ionosphere may produce deflection of transmitted signal path), some sacrifice of the receiving antenna directivity may be necessary. This may be accomplished by the use of a rhombic antenna, six wave lengths long at the highest frequency to be received and three fourths to one wave length above the ground.

Another arrangement, although more costly, is the "Bruce" array. Figure 28 shows the schematic arrangement of this array. Currents induced in the horizontal sections are neutralized while the currents in the vertical sections are in phase. For maximum directivity the array can have a length not greater than 10 wave lengths. For good reliability the directivity may be reduced by shortening the length of the array to 6 or 8 wave lengths.

The array is generally constructed on a wooden frame, with the lowest horizontal conductors ten feet above the ground. Another identical array is suspended one quarter wave length behind the front array to act as a parasitic reflector. The Bruce array is highly receptive to signals arriving at low angles, in a narrow horizontal plane. It also favors noise at these angles, but rejects noise signals arriving at higher angles. It also rejects noise in all directions broadside to the path of the arriving signal. There is minimum reradiation of signals from this type of antenna.

The receiving antenna should be located at a considerable distance from the transmitting services with which it is associated. For example, a medium-powered transmitter should be located one to two miles from the receiving location, and remotely controlled from the receiving point or headquarters installation. For powers above 5 kw. this distance should be increased to at least 5 miles.

In general, noise conditions are less pronounced in communication facilities transmitting in an east and west direction in temperate latitudes than those in tropical areas or those whose signal path traverses the tropics. Noise conditions in the east-west direction are due to lightning discharges during local thunder storms. Thus extreme noise conditions are of a sporadic nature.

Noise from interstellar space has only a minor effect on receiving services below 20 mc., being highest at ultra high frequencies. This type of noise is caused by cosmic rays from all parts of the universe and by corpuscular energy from the sun.

Although cosmic rays are extremely potent (laboratory tests have shown that cosmic rays can penetrate 18 feet of concrete), they constitute only a minor source of trouble as far as radio communication is concerned. Minute quantities of cosmic rays have been detected in New York City subways, but maximum concentration has been found to occur at extremely high altitudes.

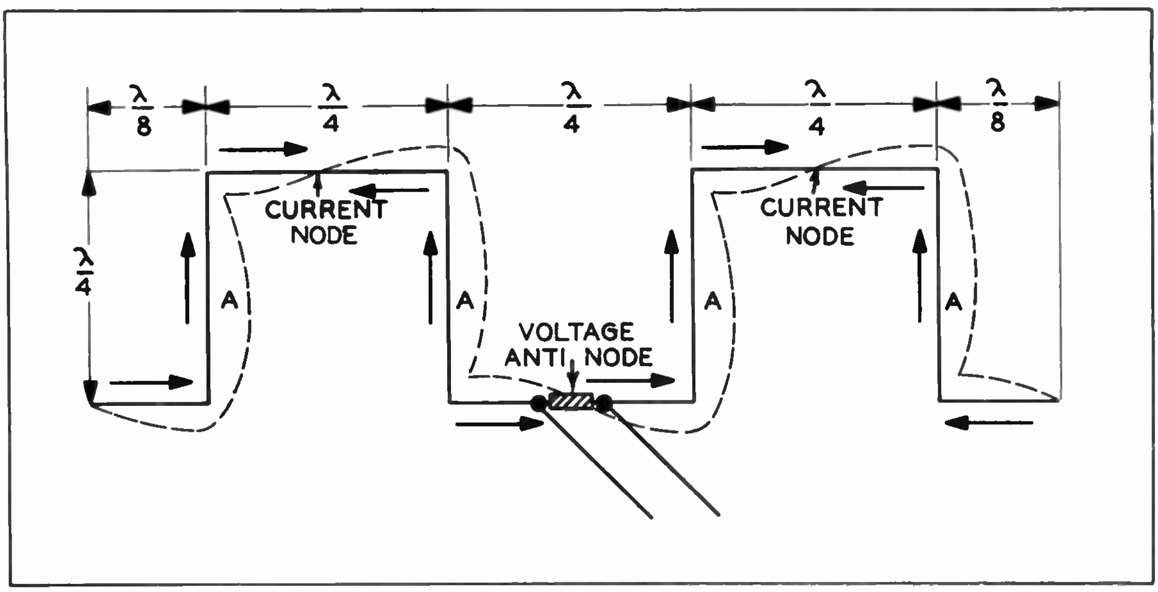


Figure 28. Simple Directive Receiving Antenna Known as a Bruce Array, Showing Dimensions and Current Distribution.

ANTENNA FUNDAMENTALS

The function of an antenna is to transfer, in the form of an electromagnetic wave, the radio-frequency energy generated by the transmitter to distant points on the earth. The radiated wave, in travelling through space, is intercepted by the receiving antenna, and a voltage is induced on the antenna.

The magnitude of the voltage induced on the receiving antenna depends, primarily, upon the intensity of the radiated wave, and the intensity, in turn, depends mainly upon the transmitting-antenna length and height, and the amount of current flowing in it. The current in the transmitting antenna, at a given frequency and power input, is the greatest when the antenna reactance at that particular frequency is approximately zero. The antenna is said to be resonant at the frequency of the applied wave.

LENGTH DETERMINATION

The shortest length of wire that can be made resonant is that which is just long enough to allow an electric charge to travel from one end of the wire to the other, and back again, during the time of one cycle of the applied radio-frequency wave. Since the charge travels with the velocity of light, or 300,000,000 meters per second, the distance covered in one cycle is equal to the velocity divided by frequency, or:

$$\text{Wave length } (\lambda) = \frac{300{,}000{,}000}{\text{frequency (f) in cycles}} \text{ meters}$$

$$= \frac{300{,}000}{\text{f (kilocycles)}} \text{ meters}$$

$$= \frac{300}{\text{f (megacycles)}} \text{ meters}$$

The shortest length of resonant wire, in wave lengths, is equal to one half of the value found by using the above formula. For example, the shortest length of wire that is resonant at 150 mc. is calculated as follows:

$$\text{Antenna length} = .5 \times \frac{300}{150 \text{ mc.}} = 1 \text{ meter.}$$

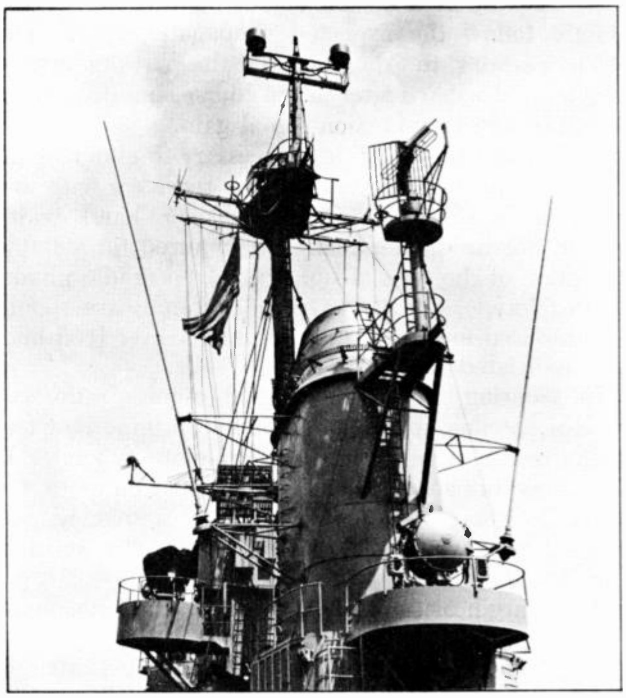
In other words, a wire one-half wave length long at 150 megacycles is 1 meter long. A more practical formula is evolved by considering the velocity of light in feet:

$$\text{Wave length } (\lambda) = \frac{984}{\text{f (megacycles)}} \text{ feet}$$

Using the formula, the length of wire in the preceding example is calculated as follows:

$$\text{Length of } \frac{\lambda}{2} \text{ antenna at 150 mc.} = \frac{.5 \times 984}{150 \text{ mc.}}$$

$$= \frac{492}{150 \text{ mc.}} = 3.28 \text{ feet}$$



Antenna Installations Aboard a Naval Vessel, Looking Aft.

ELECTROMAGNETIC WAVE THEORY

Suppose that a radio-frequency voltage is applied to one end of a half-wave antenna. See figure 30.

Arrow I_1 indicates the direction of current flow in the antenna for the first half alternation of the cycle, while arrow I_2 indicates the direction of current flow in the second half cycle. Since an antenna exhibits a reactive effect (capacitive or inductive reactance) similar to that in an ordinary coil and condenser tuned circuit, the voltage and current of the radio-frequency wave applied to the antenna are 90 degrees out of phase with each other. The result is a voltage and current distribution on the antenna as shown in figure 31.

At point P, the center of the half-wave antenna, the voltage is minimum and the current is maximum. If a neon bulb is moved along the excited half-wave antenna, maximum brilliance will be obtained at the ends (½ wave length apart). By inserting an ammeter at various points along the antenna, it will be found that maximum current occurs at the center. The maximum voltage points occur at the points (at the ends) where maximum impedance is offered to the flow of current, and, conversely, the high-current point is at the point of low impedance. The voltage change from minimum (theoretically zero) at the center of the antenna to maximum a quarter of a cycle away at the ends, follows a curve as shown. These distributions of current and voltage are referred to as standing waves of current and voltage; the point of maximum current or voltage is called a loop and the point of minimum current or voltage is called a null.

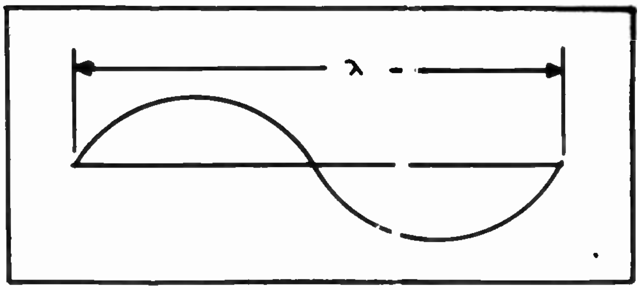


Figure 29. Sine Wave, Showing Wave Length.

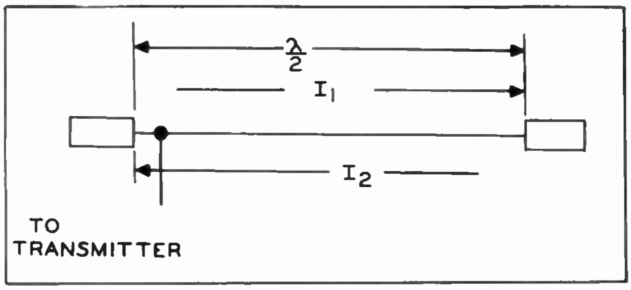


Figure 30. Direction of R-F Current on a Half-Wave Antenna for One Cycle.

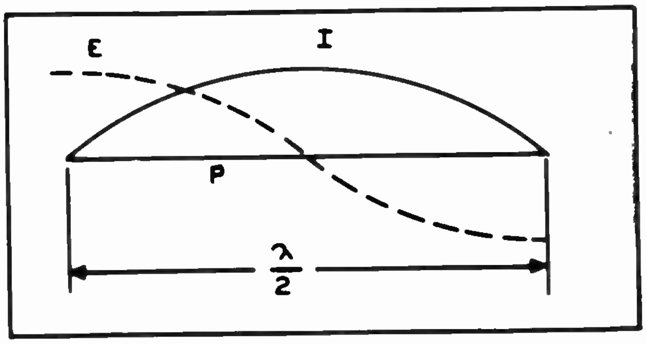


Figure 31. Standing Waves of Voltage and Current on a Half-Wave Antenna.

HARMONIC OPERATION

The half-wave antenna shown in figure 32A has one standing wave of current upon it at resonance. If the frequency of the applied wave is doubled, two standing waves will appear as shown in figure 32B, and the antenna is said to be operating at its second harmonic. An antenna can be resonant at harmonics several times the fundamental frequency, as long as the reflected wave is returned in step with the oncoming wave impulse from the transmitter. A resonant condition also results if the length of the antenna is doubled.

BASIC DESIGN

Transmitting antennas may be divided into two basic classifications, Hertz or Marconi. Hertz antennas generally are operated above 2 mc., are installed some distance above ground, and are polarized either vertically or horizontally. Figure 33 shows two examples of Hertz antennas. Marconi antennas operate at ground, that is one end is grounded either directly or through the coupling coil of the transmitter. Marconi antennas are utilized mostly, on frequencies below 2 mc., for vehicular and aircraft-transmitter installations.

Figure 34 shows the current and voltage distribution on a grounded quarter-wave Marconi. Effectively, the Marconi operates as a half-wave antenna, because the ground, acting as an image antenna, supplies a quarter wave to the length of the Marconi. By observing the standing-wave distribution, it is readily seen that for harmonic operation this type of antenna must be excited with *odd* harmonics (3rd, 5th, etc.) of the fundamental frequency. See figure 35.

Since radio-frequency waves are sine wave in character, wave length can be stated in degrees; thus, a full wave length is 360°, a half wave length is 180°, and a quarter wave length is 90°.

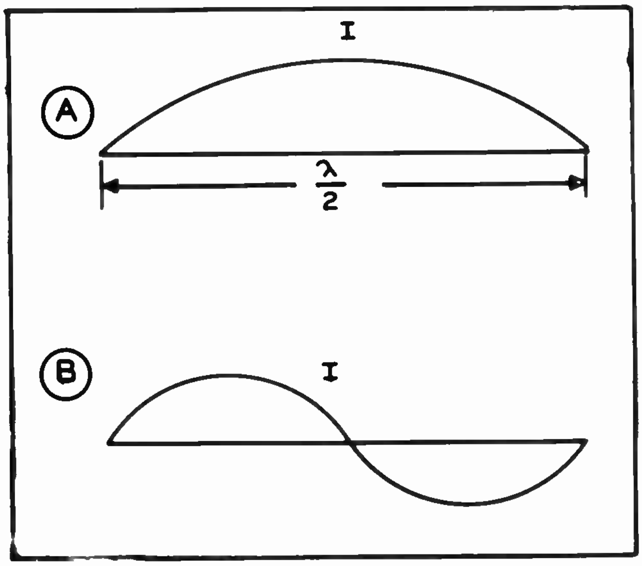


Figure 32. Standing Wave of Current on a Half-Wave and a Full-Wave Antenna at Resonance.

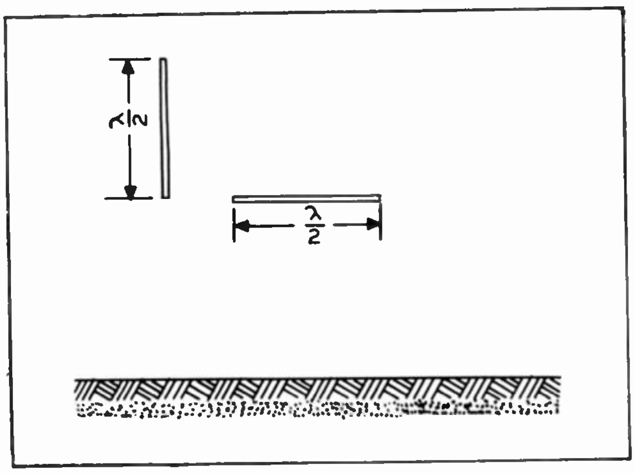


Figure 33. Examples of Hertz Antennas.

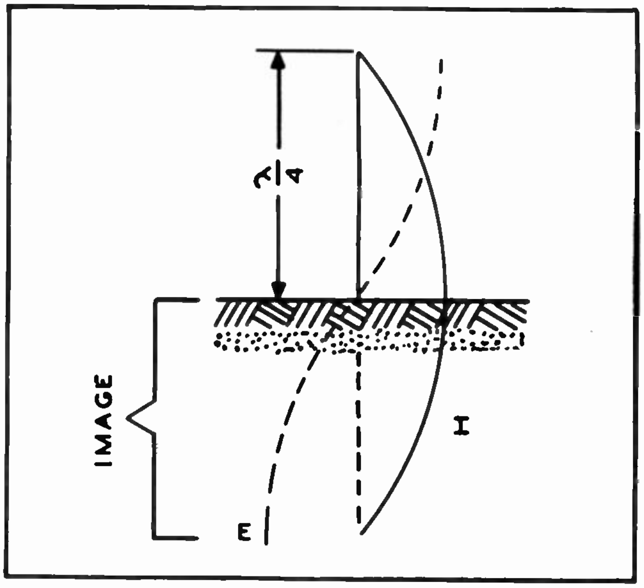


Figure 34. Voltage and Current Distribution on a Grounded Marconi Antenna.

COMPARISON OF ELECTRICAL AND PHYSICAL LENGTHS AND END EFFECT

The speed or velocity of a radio-frequency wave is the same as that for light in a vacuum or in free space, but in passing through other media of different dielectric constant the speed is decreased. The dielectric constant of air is 1. The capacity existing on an antenna due to insulators, etc., makes the dielectric constant greater than 1. Thus, for a half-wave antenna suspended in free space (theoretical), the electrical length is the equivalent of its physical length. Actually, however, the physical length is made about 5 per cent less, to compensate for the loss in the velocity of propagation.

In calculating the physical length of a half-wave antenna for frequencies up to 30 mc., the following formula is used:

$$\text{Length of } \frac{\lambda}{2} \text{ in feet} = \frac{492 \times .95}{\text{freq. in mc.}} = \frac{468}{\text{freq. in mc.}}$$

For frequencies above 50 mc., the capacitive "end effects" are more pronounced and the formula becomes:

$$\text{Length of } \frac{\lambda}{2} \text{ in feet} = \frac{492 \times .94}{\text{freq. in mc.}} = \frac{462}{\text{freq. in mc.}}$$

$$\text{Length of } \frac{\lambda}{2} \text{ in inches} = \frac{5550}{\text{freq. in mc.}}$$

The length of a long-wire antenna for harmonic operation is calculated by the following formula:

$$\text{Length in feet} = \frac{492\,(N - .05)}{\text{freq. in mc.}}$$

Where N=Number of half wave lengths in total length of antenna.

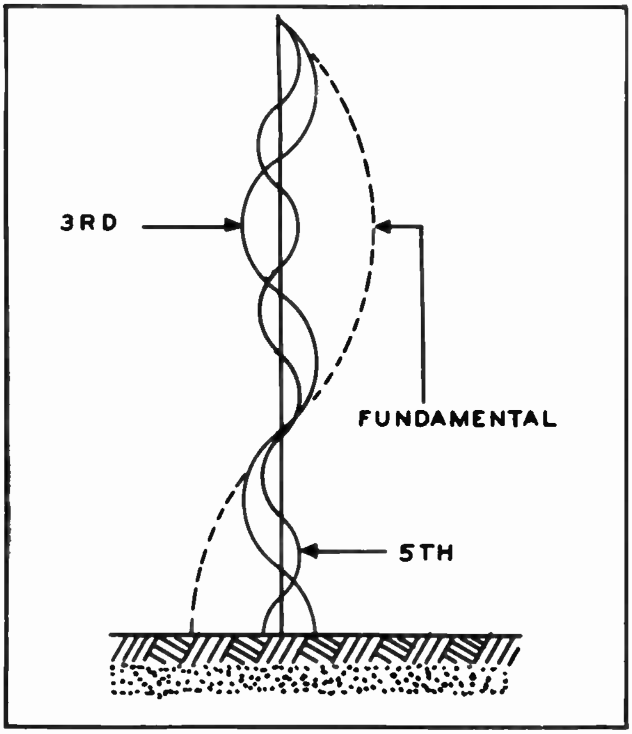
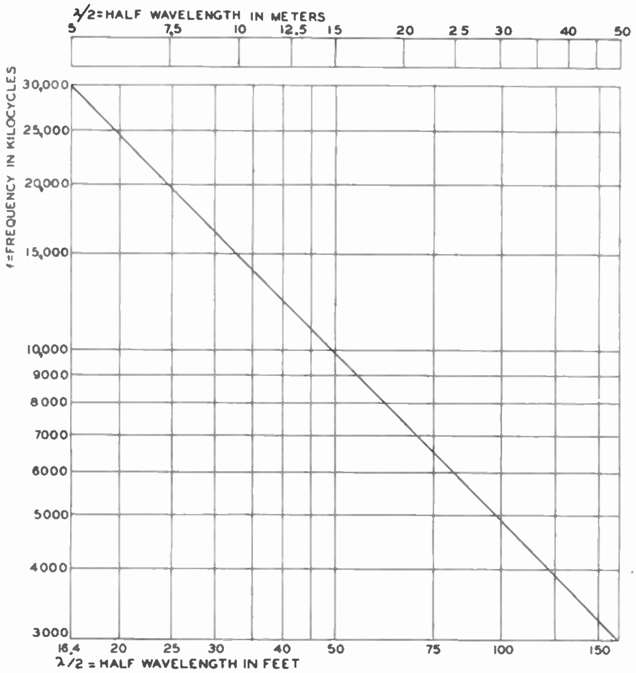


Figure 35. Standing-Wave Distribution on a Marconi Antenna at the Fundamental and Harmonic Frequencies. The antenna is three-fourths wave length long at the fundamental frequency.

The following chart is given to further simplify the conversion of frequency to wave length in feet or meters. End effect is not taken into account in this chart; therefore, the compensation designated above must be made to obtain accurate values.

CHART 8



Conversion Factors for Chart 8

For Frequencies of	Multiply f by	Multiply λ/2 by
30- 300 kilocycles	0.01	100.0
300- 3,000 kilocycles	0.1	10.0
3,000- 30,000 kilocycles	1.0	1.0
30,000- 300,000 kilocycles	10.0	0.1
300,000- 3,000,000 kilocycles	100.0	0.01
3,000,000-30,000,000 kilocycles	1000.0	0.001

ANTENNA RESISTANCE

Since current flows in an antenna, it is obvious that power is consumed, and that the system involved has resistance.

Antenna resistance is comprised of three distinct types of resistance, each of which is measured in ohms. They are radiation resistance, ohmic resistance, and dielectric absorption. Energy, in the form of heat losses, is dissipated by the pure ohmic resistance of the antenna and the leakage resistance of the dielectric components.

The energy dissipated by the radiation resistance produces a signal at a distant point. The formula for signal intensity, from a short vertical antenna, at a distance of one mile is $E = 186\sqrt{Pr}$, where E equals millivolts per meter of the receiving-antenna height and Pr is in kilowatts. Pr = the current in the antenna squared times the radiation resistance or $Pr = I^2 R$. If either the radiation resistance or the antenna current is changed, the field intensity or radiated power will change. The radiation resistance of an antenna depends upon its effective height and shape and the operational frequency.

If the radiation resistance of an antenna is known, the expected field strength under given conditions can be calculated. The following procedure can be used for determining the radiation resistance of either a short vertical antenna or a top-loaded vertical antenna.

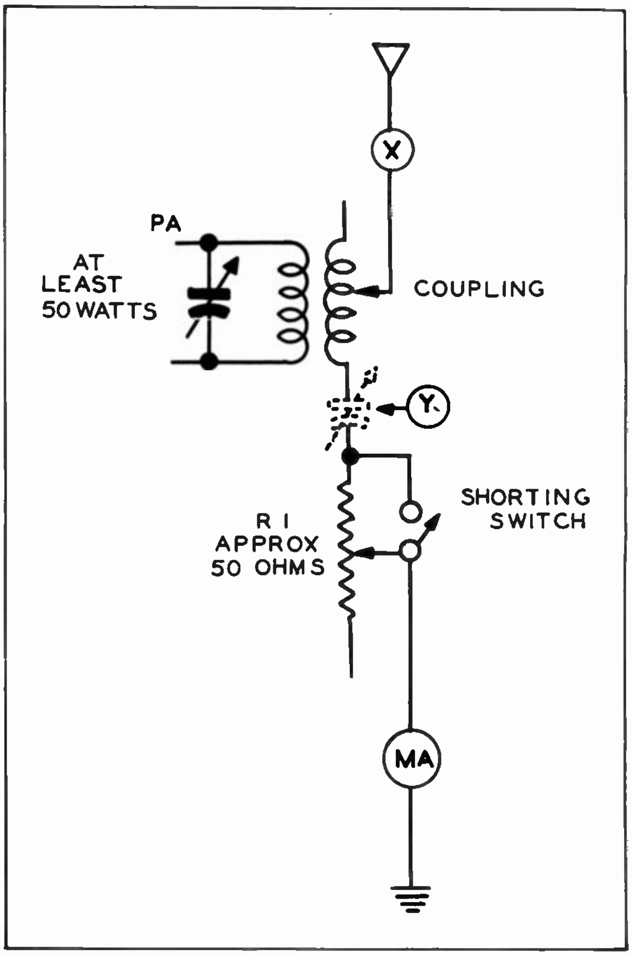
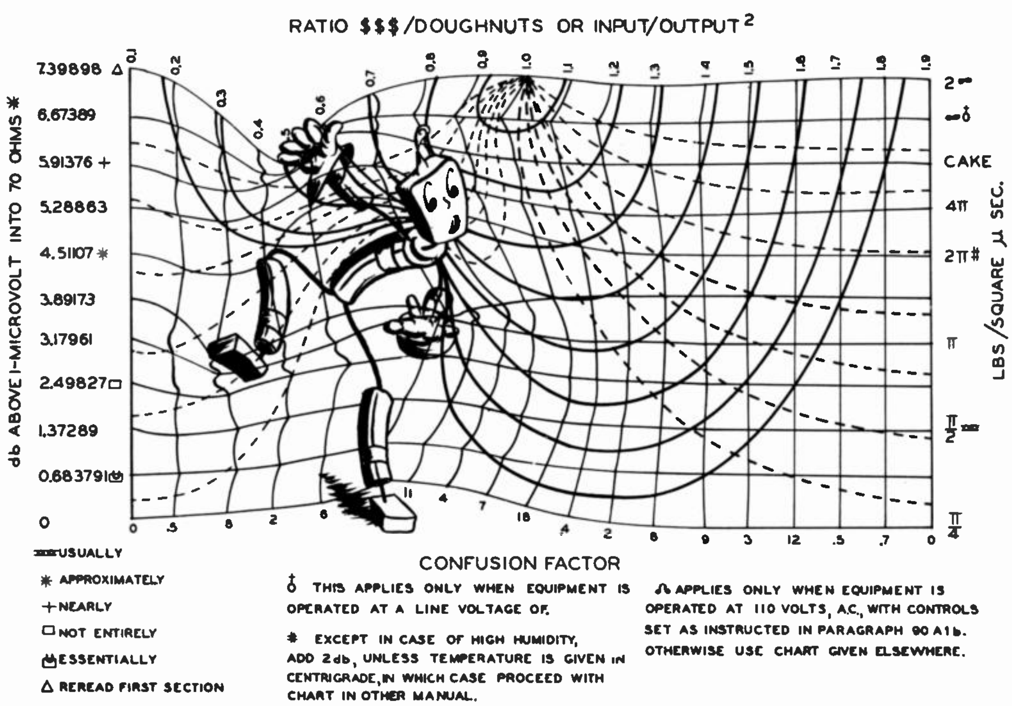


Figure 36. Test Setup for Determining Radiation Resistance.

Figure 36 illustrates a test set-up for determining the radiation resistance of such antennas, using at least a 50-watt power source as a driver.



Before beginning the antenna-radiation-resistance measurements, determine the natural wave length of the antenna by means of a suitable grid-dip oscillator. The procedure for doing this is given on page 179, under the subject Grid-Dip Oscillator Method.

The resistor R1, which is inserted in series with the antenna and ground, should be noninductive; its value depends upon the type of antenna to be checked.

The r-f milliammeter or galvanometer, which is used in this test, is inserted in series with the antenna and ground. It should be sufficiently sensitive to indicate distinctly the variations in current. For accurate determination of the radiation resistance, the resistance of the r-f milliammeter should be deducted from the calculated radiation resistance. If a current-squared galvanometer is used, the square root of the readings must be taken before substitution in the formula below.

To determine the radiation resistance, proceed as follows:

1. Close shorting switch.
2. Adjust antenna-circuit coupling and tuning capacitor (if used) to approximate settings for desired frequency.
3. Adjust power-amplifier tuning to approximate setting.
4. Apply power to antenna circuit.
5. With loose coupling of power to antenna circuit, resonate power-amplifier-plate tank for maximum dip on plate-current meter.
6. Alternately vary coupling of power to antenna circuit, and resonate for proper indication until nearly a full-scale reading is obtained on r-f milliammeter.
7. Make a record of r-f milliammeter reading. Do not change power or coupling to antenna.
8. Open shorting switch.
9. Successively adjust resistor R1 to obtain r-f milliammeter readings of approximately one fourth, one half, and three fourths of the reading obtained in step 7 above. In each case make a note of the milliammeter reading and the corresponding value of resistance.
10. Take the average of the milliammeter readings obtained in step 9 above, and also the average of the resistance values used. Substitute these values in the formula below:

$$R = \frac{R_1}{\frac{I}{I_1} - 1}$$

Where R = radiation resistance
R_1 = average value of resistance added to circuit
I = antenna current with resistance out of circuit
I_1 = average value of antenna current with resistance added to circuit

As an alternate to the method outlined in steps 1 to 10 above, the following procedure can be used to observe the over-all frequency and corresponding impedance characteristics of the antenna.

1. Open shorting switch and adjust resistor R_1 to obtain approximately one half of the reading obtained with resistor out of circuit.
2. Insert tuning capacitor at point Y (if not normally in circuit), and tune to resonance as indicated by maximum reading on r-f milliammeter.
3. Adjust power-input coupling for half-scale reading on r-f milliammeter.
4. Vary capacitor Y in small 5-kilocycle increments above and below resonant frequency and record r-f milliammeter readings for each change.
5. Draw graph of r-f milliammeter reading vs. frequency change.

If the radiation resistance of an antenna is known, the expected field strength or signal intensity, under given conditions, can be calculated. The method of calculation is given under the subject Field Strength Measurements on page 31.

It is interesting to note that the radiation resistance of an antenna, as measured at a current loop, becomes larger as the length of the antenna is increased. This fact is explained in the discussion of Basic Radiation Patterns.

ANTENNA IMPEDANCE

Any antenna at resonance presents a specific impedance at every point along its length. This can easily be seen by comparing the voltage and current values distributed along an antenna. See figure 37A. The impedance of an electrical circuit is equal to the voltage divided by the current. Therefore the highest impedance occurs where the current is the lowest and vice versa. Between the lowest and highest points of impedance, the impedance change follows a curve, as shown in figure 37B.

The voltage and the current distribution along an antenna in free space depends upon whether it is resonant or nonresonant at the frequency of the applied power. Since it is impossible to entirely isolate an antenna from ground, surrounding objects, etc., the voltage and current distribution are changed by the inductive and capacitive effects introduced. This, in turn, changes the impedance values along the length of the antenna; this change in impedance is an important factor when determining the method of coupling power to the antenna. Compensation must be made for this factor, and is discussed later under the subject of Transmission Lines and Coupling Circuits.

Figure 37 shows the impedance curve of a half-wave Hertz antenna in comparison with the voltage and current distribution. The low-impedance point at the center is approximately 73 ohms, whereas the high-impedance points at the ends are approximately 2400 ohms. The value of 73 ohms is generally accepted as the radiation resistance of a half-wave dipole in free space. This value varies with the antenna height, ranging from zero at zero height in wave length to about 73 ohms at $\lambda/4$ height, and to a maximum of about 97 ohms at $\lambda/3$ height. The low-impedance point (grounded end) of a Marconi antenna ranges from

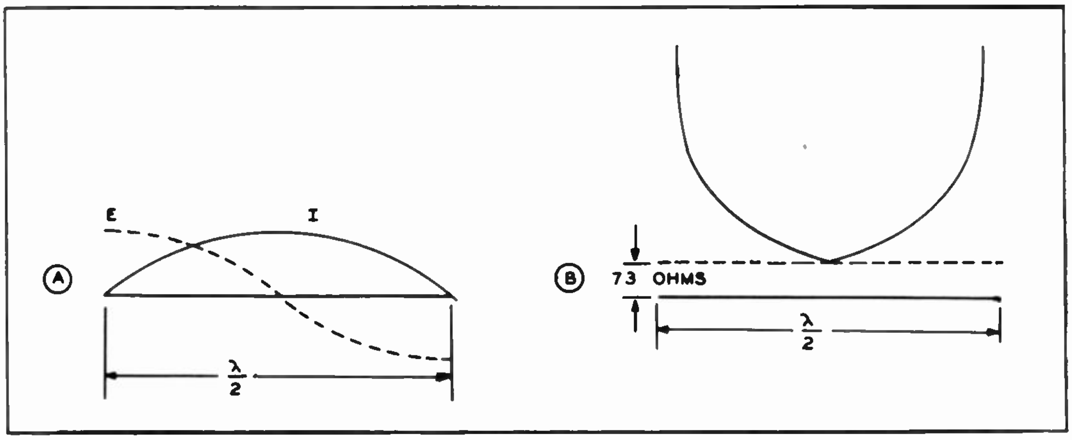


Figure 37. Voltage and Current Distribution and the Corresponding Impedance Curve for a Hertz Half-Wave Antenna.

approximately 36 ohms to 2 ohms, depending on the antenna length, whereas the high-impedance point (open end) is approximately 4800 ohms. See figure 38.

It is important to know the relative antenna impedances when the problem of coupling the transmitter output to the antenna arises, because the proper matching of impedances is an important requisite in obtaining efficient power transmission. For example, if the output impedance of a transmitter is low, a low-impedance transmission line should be used to couple into a low-impedance point on the antenna, and vice-versa for a high-impedance transmitter output. The various methods of coupling are discussed in a later lesson.

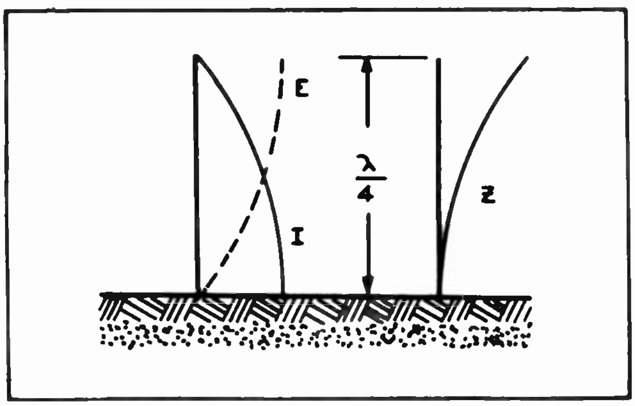


Figure 38. Voltage and Current Distribution and the Corresponding Impedance Curve for a Quarter-Wave Marconi Antenna.

FIELD-STRENGTH MEASUREMENTS

The following material deals entirely with field-strength patterns of the low-frequency ground waves of general-coverage-type antenna systems, because only these patterns have practical significance. The measurement of field patterns from directive arrays is discussed under directive-array theory.

The following information provides a means of calculating the field-strength pattern of an antenna. After the calculations are made, actual field-strength measurements should be taken and compared with the calculated data. Considerable variation from the proper pattern indicates a mismatch of impedances, nonresonance, uncompensated ground effects, etc.

After the radiation resistance of an antenna is determined and the antenna current under normal operating conditions is known, the expected field strength at moderate distances from a low-frequency antenna less than a $\lambda/4$ in height, can be calculated by the following formula:

$$E = \frac{377\,h\,I}{\lambda\,r} \text{ millivolts per meter}$$

Where h = effective height of antenna (meters)
I = current in antenna (amperes)
λ = operating wave length of transmitter (meters)
r = distance of point of measurement (kilometers)

The effective height, h, is defined as the height of a vertical wire having an even distribution of current throughout its entire length. In a vertical transmitting antenna with one end grounded, the current is maximum at the base and decreases almost to zero at the top. Due to this uneven current distribution, the actual physical height of the antenna cannot be used in the calculation, because maximum radiation, which occurs at points of highest current flow, takes place in the lower part of the antenna. Therefore, a mean value is arrived at experimentally, which in the case of a practical $\lambda/4$ vertical antenna is approximately 60 percent of the total physical height. In the case of a horizontal antenna (for example, a long flat top), the effective height equals 60 percent of the mean height at the point of maximum sag.

Using this formula for general-coverage antennas, a field pattern should be calculated for distances ranging from 0.6 to 6 miles from the radiator.

A field strength of one millivolt per meter means that the potential difference due to the field between two points, one meter apart on the same line of electric force, is one millivolt. If a transmitted wave produces a 5-millivolt signal on an antenna whose height is one meter at a distance of 3 miles, increasing the effective height to 5 meters produces a 100-millivolt signal.

Measurements of field strength can be taken in several ways. Usually, however, the actual voltage induced in a given receiving antenna is measured by the substitution method. In this method, a known, locally generated signal, identical in frequency to the received signal and of such magnitude as to produce the same receiver output, is substituted for the received signal.

For the actual taking of field-strength measurements, the use of a special field-strength meter is recommended. Basically, such a meter consists of a well-designed receiving device which detects and converts the r-f energy received into a relative value of measurable d-c voltage. Constructional details for such a device are given on page 181. A well-designed superhetrodyne receiver may be used in conjunction with a well-shielded local comparison oscillator of high accuracy and a signal-attenuator device. A loop-type antenna for the receiver is usually employed, and an output meter is connected to the receiver output.

To measure the field strength with such a setup, tune the receiver for maximum output meter indication, adjust the attenuator for a suitable reading, and note the reading. The output of the local comparison oscillator (which may or may not be a separate unit) is fed into the loop, with the loop adjusted to a null with respect to the received signal. With the b.f.o. on, tune the comparison oscillator to zero beat with the receiver, then turn off the b.f.o. Adjust the attenuator or gain control on the receiver until the receiver output is the same as that produced by the incoming signal being measured. The magnitude of the signal from the comparison oscillator can be determined by measuring the voltage drop across a small noninductive resistor placed in the center of the loop.

Stray pickup may possibly introduce errors in measurements made by this method. A rather complex but more accurate method of measuring the comparison signal when using a superhetrodyne receiving device has been devised; first, the output produced by the incoming signal from the distant transmitter is measured and noted. The loop is then disconnected and the comparison-oscillator signal is coupled into the last i-f stage, and is adjusted for the same output value as that produced by the incoming signal. The comparison oscillator must be factory calibrated for this method, so that the signal input can be read directly in microvolts or millivolts.

Both of these methods utilize the principle of comparing the magnitude of the unknown signal with one of known value. If the special equipment described above is not available, rough comparisons can be made by using the "S" meter of a communications receiver.

Radiation-field measurements should not be made at distances less than 0.6 wave length from the antenna, as the presence of the induction field in the vicinity of the antenna introduces errors. The strength of the induction field varies inversely as the third power of the distance from the transmitter.

For general-coverage-type antennas, field-strength measurements are ordinarly taken on a number of radials (usually 10 to 30) from the antenna, at distances ranging from 0.6 mile to 6 miles.

By comparing the actual field strength with the computed field strength, irregularities in the design of an antenna system may be detected. For instance, with a given antenna and radiated power a certain field strength may be expected at a given distance from the antenna. If measurements show a discrepancy of more than 20% or 30% between the estimated and the actual field strength, trouble in the antenna system is indicated.

The following formulas provide a means of estimating the field strength, at a point one mile distant and over level ground, for the indicated types of antennas.

Small L or T antenna $E = 25\sqrt{P_t}$ millivolts per meter at 1 mile

Vertical antenna .15 to .25 λ high $E = 150\sqrt{P_t}$ millivolts per meter at 1 mile

Vertical antenna .25 to .40 λ high $E = 175\sqrt{P_t}$ millivolts per meter at 1 mile

Vertical or flat-top antenna .40 to .60 λ high $E = 220\sqrt{P_t}$ millivolts per meter at 1 mile

Where E equals field strength in millivolts per meter and P_t equals the transmitter output power in kilowatts.

The nature of the terrain between the transmitter site and the measuring point affects the value of the signal strength at the measuring point; this fact should not be overlooked when making a comparison with the calculated value.

The power radiated from a resonant and matched antenna may be calculated in the following manner: measure the antenna r-f current under full-power operating conditions at the resonant frequency, square this value of current, and multiply the result by the surge impedance (Zo) of the transmission line; the result is equal to the power (P_t) supplied to the line.

BASIC RADIATION PATTERNS

The basic radiation pattern of an antenna depends primarily upon the current distribution throughout its length and the current, in turn, is affected by the antenna length, height, shape, polarization, etc. In the electromagnetic-wave-theory discussion, it was shown that there is a definite antenna voltage and current distribution for each type of antenna. Since the current distribution along the length of any antenna is uneven, the resulting electromagnetic wave distribution in space is also uneven, being of maximum intensity extending from points on the antenna where the

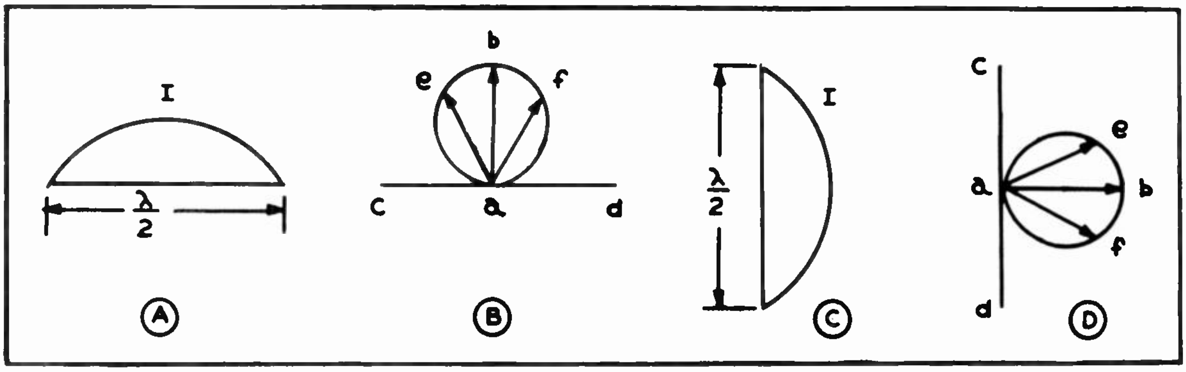


Figure 39. Basic Radiation Patterns.

current is a maximum and of minimum intensity where the current is a minimum. This accounts for the characteristic radiation pattern for each type of single-element antenna. For example, the radiated field intensity from a single-wire, horizontally polarized, half-wave antenna which is in free space, is maximum in the direction ab, broadside to the center of the antenna and minimum in the directions ac and ad off the ends of the antenna, corresponding to the loops and nodes of the current-distribution pattern. See figures 39A and B. Figures 39C and D illustrate the current distribution and corresponding radiation pattern on a vertically-polarized half-wave antenna in free space.

The relative intensity of radiation in figure 39 B and and D is proportional to the length of the line drawn from the center of the configuration to its perimeter. Lines ae and af, in both cases, indicate points of lower intensity than line ab.

It is important to remember that a simple transmitting antenna radiates in all directions, but with varying intensities in different directions. The radiation patterns shown in figure 39 are only a cross-sectional slice of the actual solid pattern produced. Figure 40 represents a cross-sectional view of the actual "solid" pattern, which takes the form of a doughnut. (Both illustrations neglect ground effects.)

Still considering the free-space condition, if the length of the antenna is increased to 1½ wave lengths, the radiation pattern evolves into the form shown in figure 41, due to the vector addition of the individual radiation components from all portions of the antenna. This creates a change in the angle of maximum radiation from that shown for the half-wave dipole.

Several important changes in the character of the field pattern become readily apparent; see figure 41. The so-called doughnut-shaped intensity pattern has developed into three distinct envelopes or lobes. Note the following significant changes:

1. The major lobes have shifted from directly broadside as in the half-wave antenna to a direction approaching that of the antenna wire. As the antenna length is increased, the angle between the major-lobe axis and the antenna becomes smaller.

2. The field-pattern envelope, or configuration, has been extended in the direction of the major axis oc, and the maximum width x′ of the major lobe has decreased. Thus the field intensity in the direction oc for

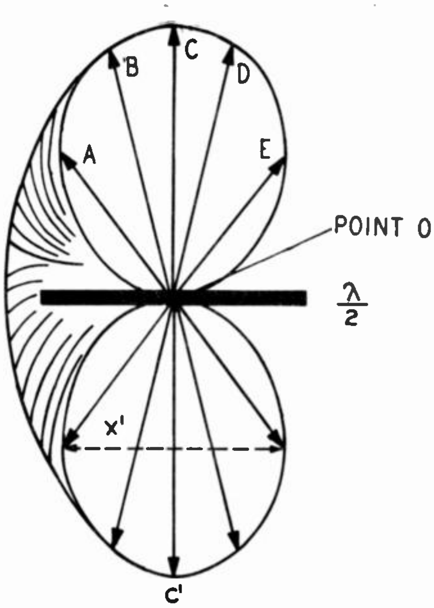


Figure 40. Cross Section of a Solid Radiation Pattern of a Horizontal Half-Wave Antenna.

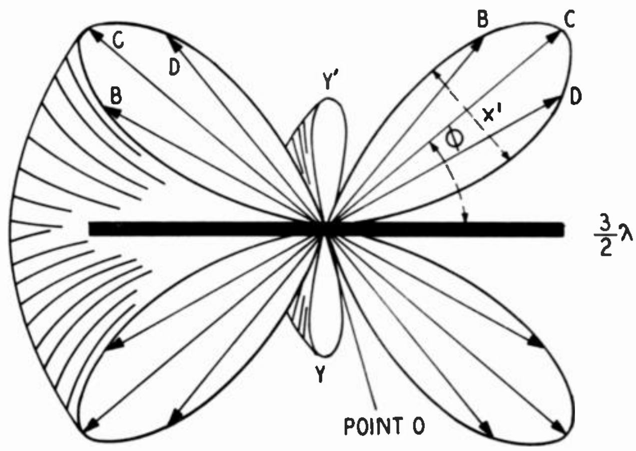


Figure 41. Cross-Section of a Solid Radiation Pattern, Showing the Effect of Increasing the Length of a Horizontal Antenna.

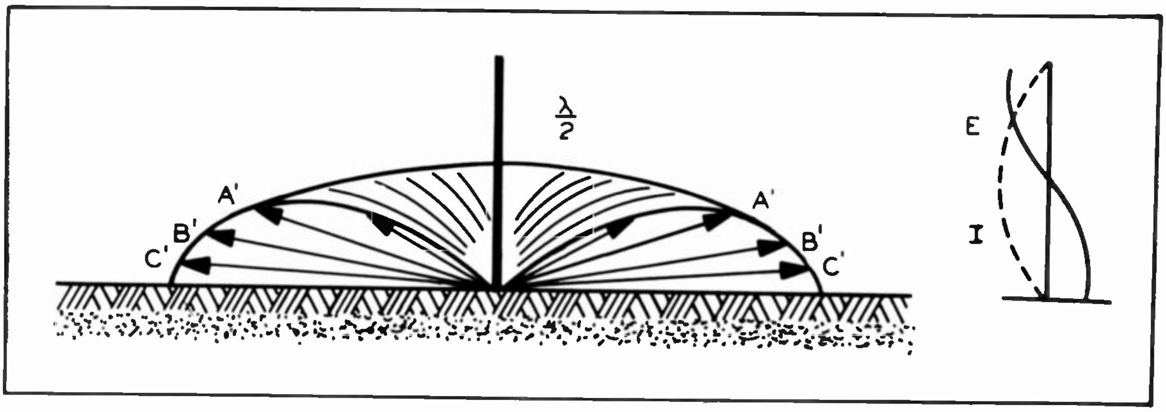


Figure 42. Cross Section of a Solid Radiation Pattern of a Half-Wave Vertical Antenna.

the 1½ wave length antenna has increased considerably in the line of the major axis oc, over that in the half-wave antenna. Broadside to the antenna, the minor-lobe pattern YY′ has appeared.

3. As the antenna length increases, the number of minor lobes YY′ increases and the power in the direction of the major lobe axis also increases.

4. Since a long wire may be considered as a series of short antennas, all tied together, it is reasonable to suppose that the radiation resistances of the individual antennas tend to add. Thus as the antenna length is increased, the radiation resistance increases as shown in figure 65. If the same amount of power were supplied to the two antennas discussed above, the total power in the lobes of each would be approximately the same, but the longer antenna would concentrate more power (thus effecting a gain) at angles nearer the axis of the antenna than the half-wave antenna radiated in a broadside direction. See figure 41.

The ability of an antenna to concentrate power in a given direction is called directivity. In general, the narrower the major lobe is at its maximum width (x′) the greater is the directivity of the radiated pattern. In radar transmission, lobe beam widths of less than 0.3 degree have been attained, thus concentrating a large amount of power in a given direction. Other methods of obtaining directivity are discussed later under Types of Antennas.

Figures 42 and 43 show the vertical radiation patterns of a half-wave and full-wave vertical antenna respectively. To get a clearer understanding of the field-pattern development of the vertical antennas, refer to figures 40 and 41 which show horizontally polarized Hertz antennas.

If the half-wave antenna of figure 40 is placed vertically on the ground, and the field pattern is visualized as being slid down the axis of the antenna until the two major-lobe axes C-C′ are flush with the ground, the relationship of a vertically polarized field pattern to a horizontally polarized field pattern becomes apparent. The resultant pattern, disregarding ground effects, is like that shown in figure 42.

Using the same approach for the 1½-wave length horizontal antenna, the resultant pattern is similar to

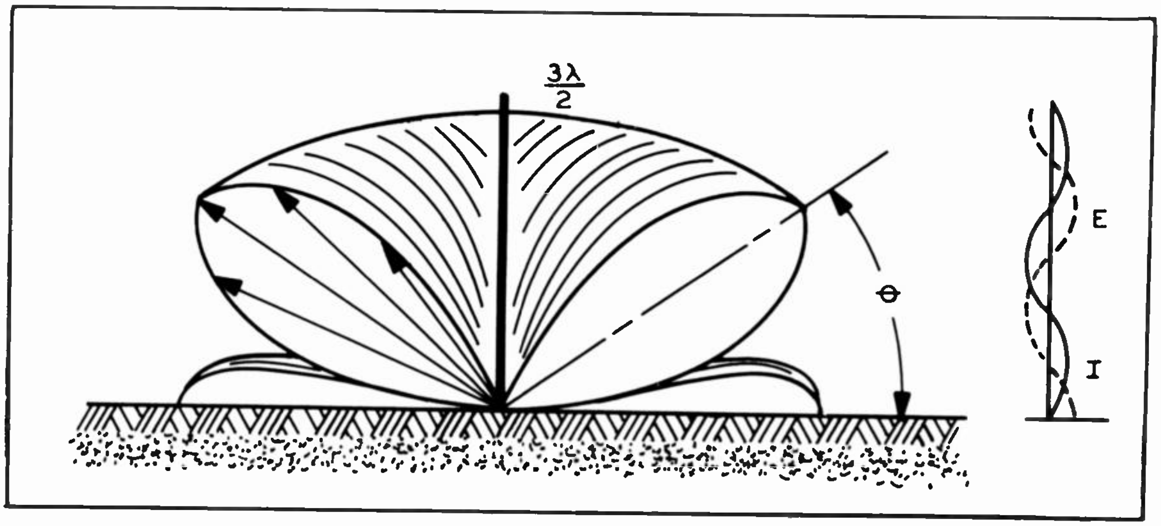


Figure 43. Cross Section of a Solid Radiation Pattern, Showing the Effect of Increasing the Length of a Vertical Antenna.

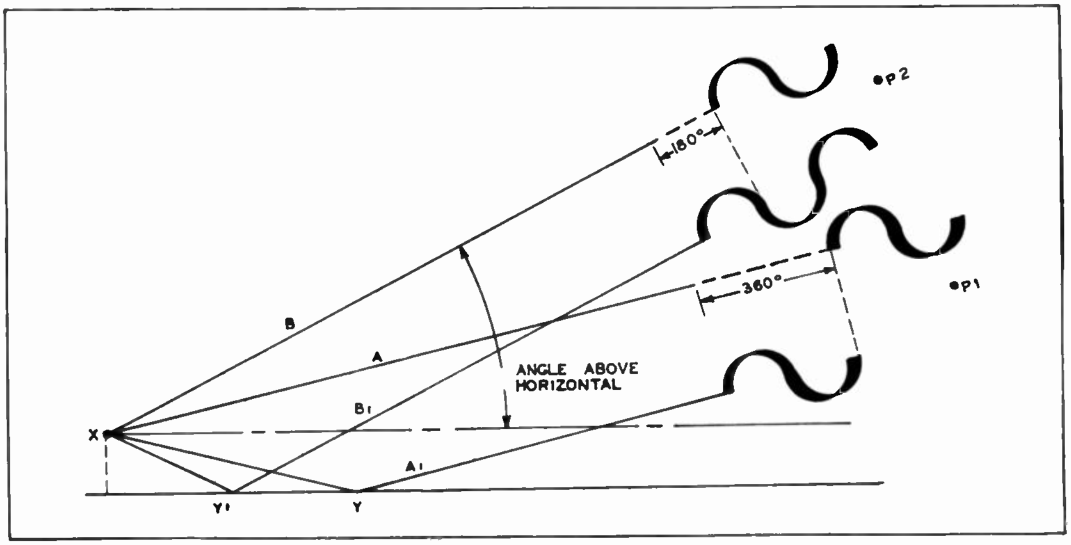


Figure 44. Signal Energy Travelling Multiple Paths, Showing the Possibility of Cancellation and the Resulting Variation in Field Intensity.

that shown in figure 43. Thus, it becomes obvious that if the length (height) of the vertical antenna increases, the vertical angle of major-lobe axis increases. In other words, as the vertical length of the antenna increases, the vertical angle of radiation increases.

GROUND EFFECTS

In the previous discussion of the development of basic field-intensity patterns, all descriptions were based on the assumption that the antenna was in free space. Obviously, an antenna cannot be suspended in free space, and is always relatively close to the ground. (In aircraft installations, the aircraft itself acts as the ground for the antenna.) The presence of ground modifies the free-space field-intensity patterns, due to the reflection and absorption of the radiated wave from the antenna.

Reflections take place because the electromagnetic waves leave the antenna at such angles that some of the radiation strikes the earth's surface. Figure 44 shows how wave A leaves the antenna at some vertical angle above the horizontal, while wave A′ leaves the antenna at a vertical angle below the horizontal. Both waves upon initial radiation travel in a straight line, but wave A′ strikes the ground at point Y where it is reflected upward and travels on into space. If the ground were a perfect conductor, the angle at which wave A′ is reflected from the ground would be exactly the same as that at which it strikes the ground. In other words, the angle of reflection is equal to the angle of incidence, just as it is in the case of light striking a mirrored surface.

The wave A′ travels in space virtually parallel to the direct wave A from the antenna, until at a distant point P_1 the two wave fronts converge. It is possible for them to converge before they hit the ionosphere, or they may travel almost parallel paths into the ionosphere and converge at some distant point on earth. Wave A′ will for practical applications always lag behind wave A, because it travels farther than wave A. If at the point P1 where the wave fronts of A and A′ converge, A′ lags A by 360°, the two waves will be in phase and reinforce each other, to produce an actual gain in signal intensity. A relative maximum gain of 2 is possible when the two signals arrive at the point of convergence, P1, in phase.

Referring again to figure 44, the waves B and B′ also converge at some distant point P2, but their wave fronts arrive at the point of convergence 180° out of phase, and an almost complete cancellation of the signal voltage occurs. Waves leaving the antenna at intermediate angles will produce corresponding degrees of addition and cancellation.

The height of the antenna above ground determines, to a large extent, the amount of distortion of the free-space pattern by the ground. A multiplication factor, called the "ground-reflection factor," is employed to represent the degree of change introduced by the ground. Figures 45 through 56 exhibit the "ground-reflection factors" for the field-strength patterns of horizontal antennas of any length, and of vertical antennas which are an even number of half waves long. Figures 57 through 62 apply to vertical antennas which are an odd number of half waves long.

These graphs exhibit multiplying factors representing the result of ground reflections for specific heights. When the value of relative intensity at a specific vertical angle of the free-space pattern is multiplied by the factor for that angle the resultant relative radiation intensity at this angle is obtained.

In order to determine the height required to obtain a reinforcement of field strength at a desired angle of radiation, refer to figure 63. For example, to obtain reinforcement at a wave angle of 30° for a horizontal or vertical antenna, which has a length of an even

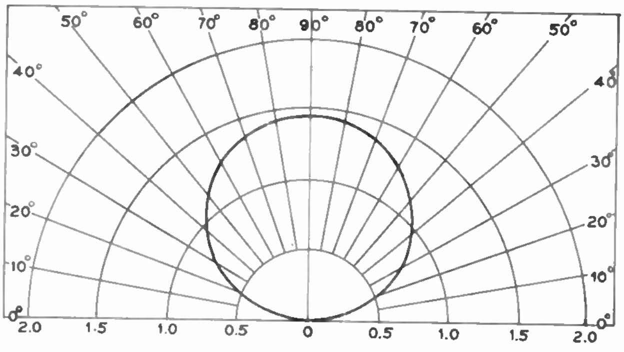


Figure 45. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed One Eighth Wave Length above Ground.

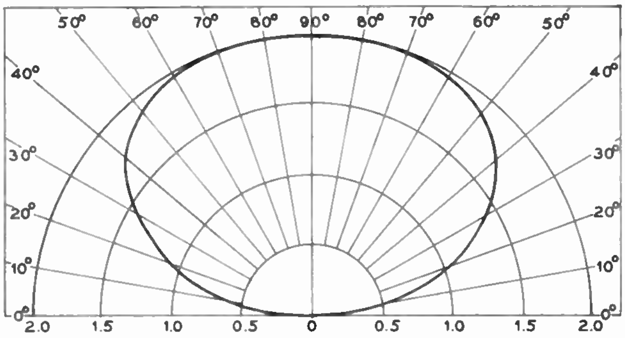


Figure 46. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed One Quarter Wave Length above Ground.

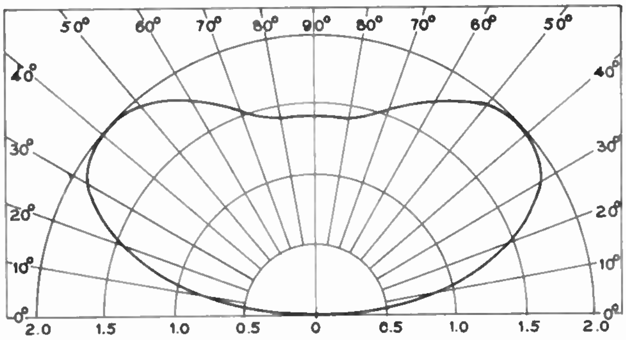


Figure 47. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed Three Eighths Wave Length above Ground.

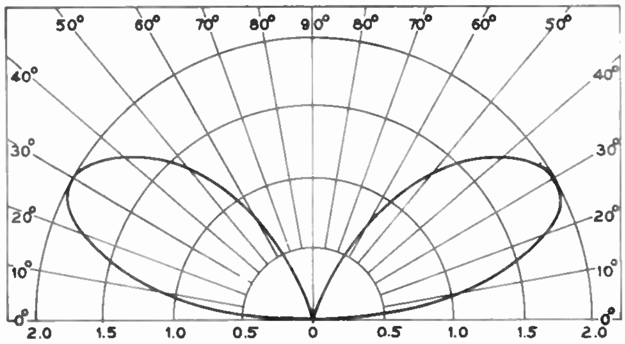


Figure 48. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed One Half Wave Length above Ground.

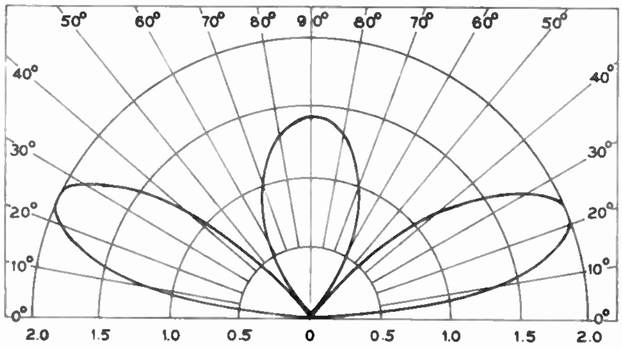


Figure 49. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed Five Eighths Wave Length above Ground.

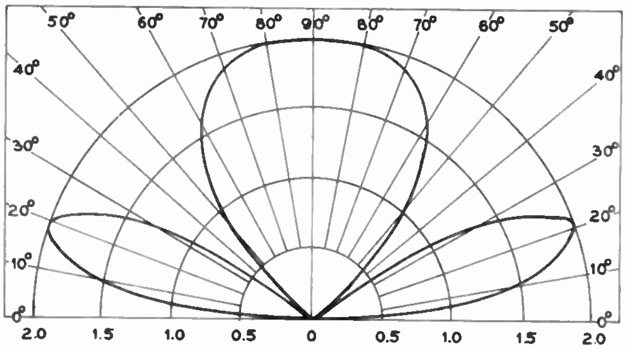


Figure 50. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed Three Fourths Wave Length above Ground.

multiple of one-half wave length, the required height above ground is one-half wave length; for a vertical antenna which is an odd multiple of one-half wave length long, the required height above ground is one wave length.

The angle of maximum radiation is usually called the wave angle or angle of propagation.

The preceding discussion of ground reflection and height effects, as well as the information in the graphs, are all based upon perfect ground conductivity. This assumption simplifies the explanation, but the actual ground losses greatly affect the radiation pattern.

In figure 44 the wave striking the ground was assumed to reflect without loss. When the two waves added at point P′, the result was effectively a doubling of the field intensity at that point. Any losses, due to absorption of the wave during reflection, result in a weaker reflection and, hence, a weaker total intensity at point P′.

Waves striking the earth at very small angles travel along the earth's surface for long distances and, therefore, are subject to much more than the normal ab-

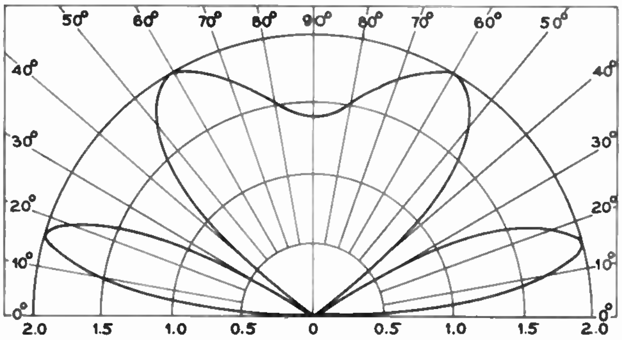


Figure 51. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed Seven Eighths Wave Length above Ground.

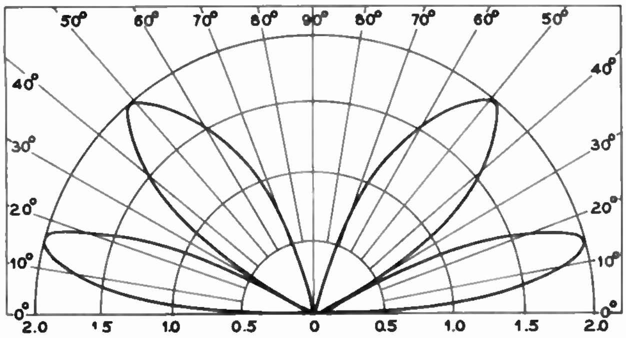


Figure 52. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed One Wave Length above Ground.

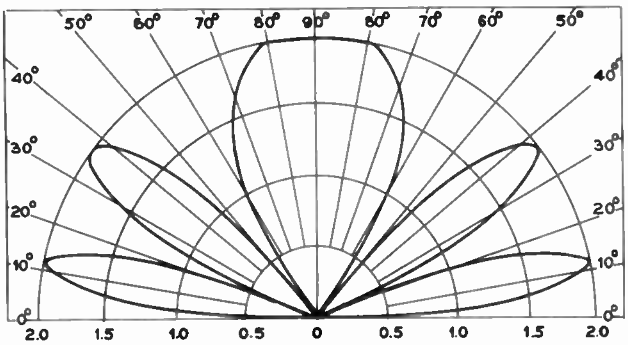


Figure 53. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed One and One Quarter Wave Lengths above Ground.

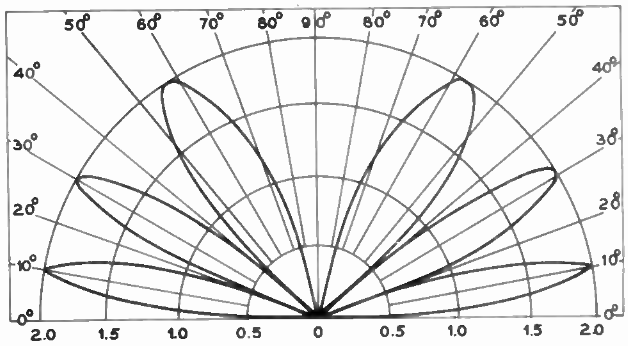


Figure 54. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed One and One Half Wave Lengths above Ground.

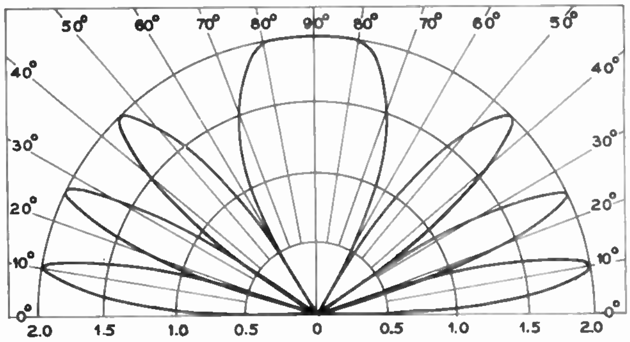


Figure 55. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed One and Three Quarters Wave Lengths above Ground.

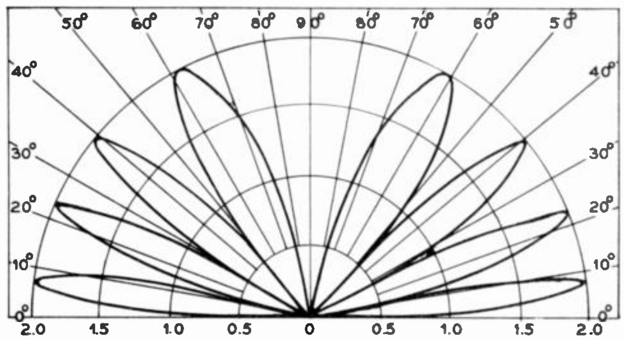


Figure 56. Ground-Reflection Factors for Horizontal and Vertical Antennas an Even Number of Half Waves Long and Placed Two Wave Lengths above Ground.

sorption losses. Therefore, the field intensity at low angles of radiation (below 5 degrees) is much less than that calculated by the multiplying factors given in figures 45 to 62; over normal earth's surface, practically all radiation below about 3 degrees is absorbed. Therefore, such low-angle radiation at point P1, in figure 44, is negligible, and the graphs are in error correspondingly.

A wave entering the earth is refracted; this alters the length of the path of the wave being reflected, and thereby changes its phase at point P1.

The over-all effect of these factors it to change the vertical distribution of the radiated energy, but not the horizontal distribution. This should be apparent from the fact that the radiated energy, at any particular height above ground, is affected equally in all horizontal directions by the presence of the ground. In other words, the ground adds to, or subtracts from the field intensity, equally, at points of equal height and equal distance from the antenna.

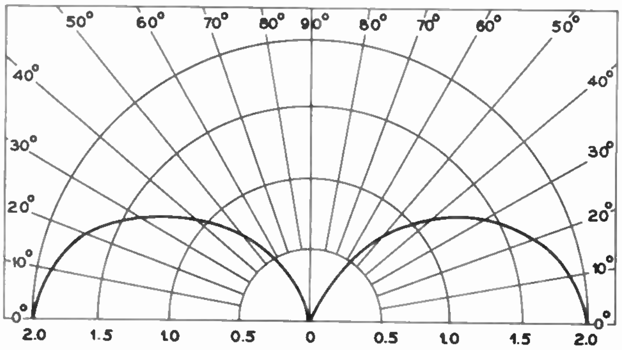


Figure 57. Ground-Reflection Factors for a Vertical Antenna an Odd Number of Half Waves Long, with the Center One Fourth Wave Length above Ground.

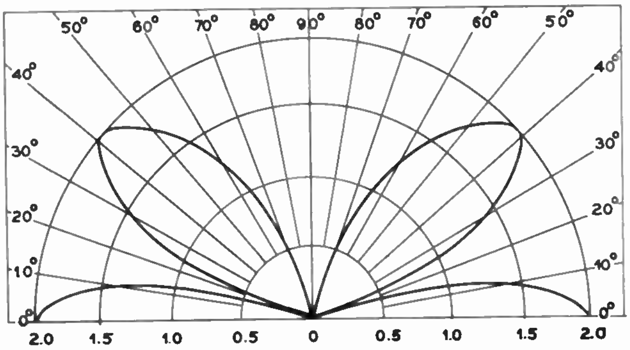


Figure 60. Ground-Reflection Factors for a Vertical Antenna an Odd Number of Half Waves Long, with the Center Three Fourths Wave Length above Ground.

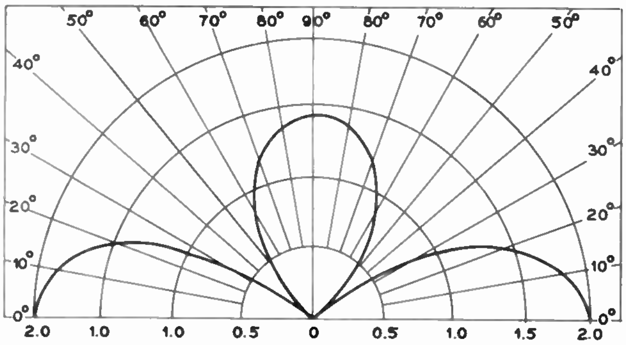


Figure 58. Ground-Reflection Factors for a Vertical Antenna an Odd Number of Half Waves Long, with the Center Three Eighths Wave Length above Ground.

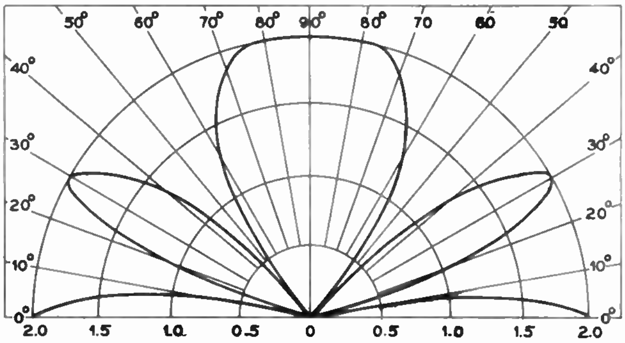


Figure 61. Ground-Reflection Factors for a Vertical Antenna an Odd Number of Half Waves Long, with the Center One Wave Length above Ground.

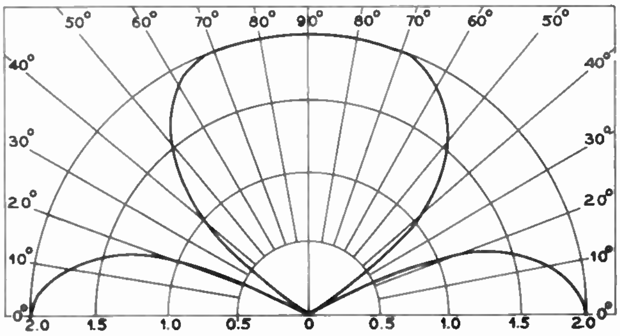


Figure 59. Ground-Reflection Factors for a Vertical Antenna an Odd Number of Half Waves Long, with the Center One Half Wave Length above Ground.

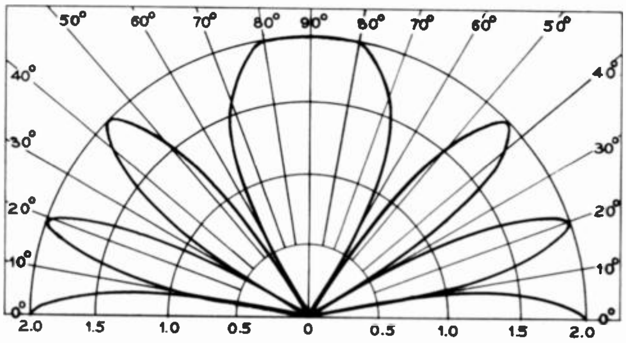


Figure 62. Ground-Reflection Factors for a Vertical Antenna an Odd Number of Half Waves Long, with the Center One and One Half Wave Lengths above Ground.

INDUCED CURRENT AND RADIATION RESISTANCE

Some of the waves leaving the antenna at a large angle with respect to the horizon strike the earth nearby, and upon reflection are intercepted by the antenna itself. Thus the field of this reflected wave induces a current in the antenna, which adds to, or subtracts from the total antenna current, depending upon the phasing of the two currents. This effectively changes the characteristic (free-space) radiation resistance of the antenna. The phasing condition or antenna-current change is a function of the antenna height. Figure 64 shows graphically the changes in radiation resistance in a horizontal half-wave antenna, due to induced current produced by ground reflection, when the antenna height is varied from zero to 2½ wave lengths. These changes in radiation resistance need be considered only when using a long-wire-type antenna, because the radiation resistance of a comparatively short antenna (half and quarter wave lengths) is not greatly affected.

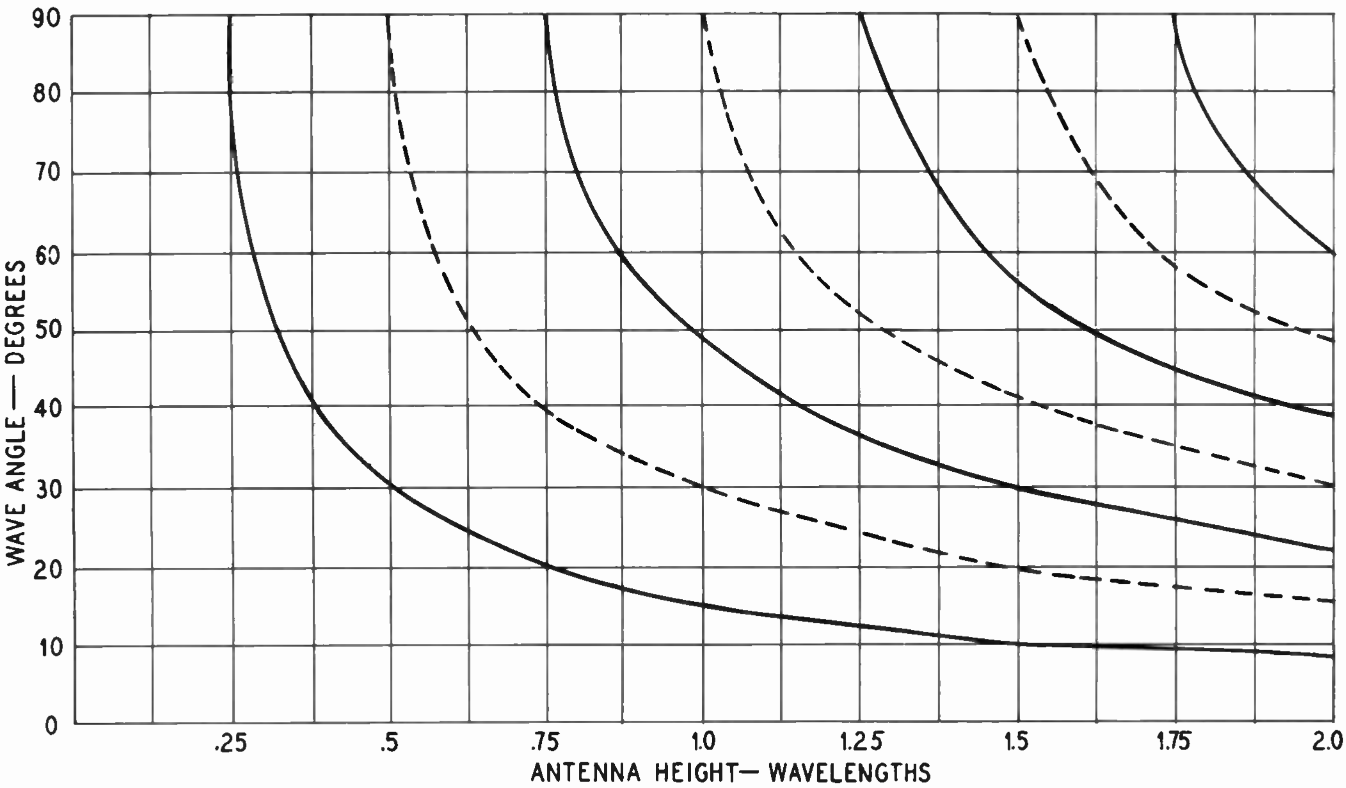


Figure 63. Angles of Maximum and Minimum Radiation for Antenna Heights up to Two Wave Lengths. For horizontal and vertical antennas an even number of half waves long, the solid lines are maximum and the dashed lines are minimum. For vertical antennas an odd number of half waves long, the dashed lines are maximum and the solid lines are minimum.

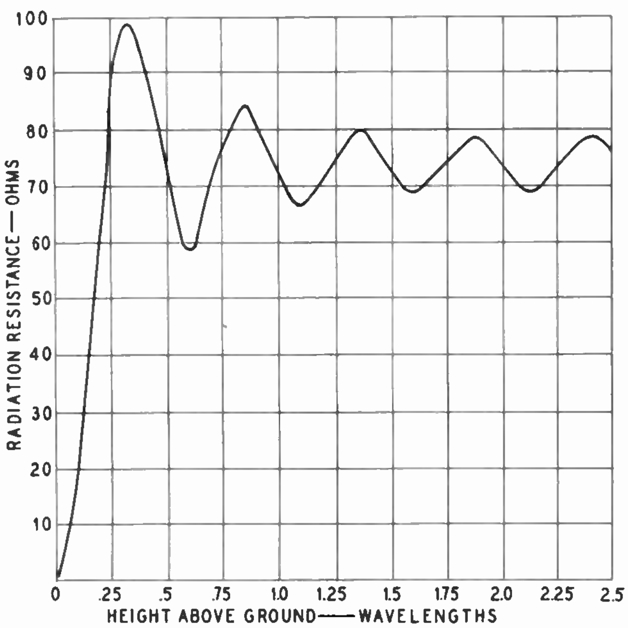


Figure 64. Variation in Radiation Resistance at the Current Maximum of a Horizontal Half-Wave Antenna at Various Heights above a Perfectly Conducting Ground.

It has been pointed out that the nature of the earth's terrain determines its conductivity. Therefore, it can be assumed that the greatest field-intensity gain, due to reflection, is obtained over the ocean or other bodies of water. By careful interpretation of the above graphs, a fairly good idea of the expected performance can be obtained before installation. Knowing that certain types of terrain have poor conductivity, a good ground plane should be used, to obtain maximum efficiency from induced currents due to reflection. The simplest way to construct a ground plane is to run wires a foot below the ground, and radially for a distance of at least 100 feet, or for a half wave length at higher frequencies. All the "spokes" should be interconnected and properly bonded. Best results are obtained at the higher frequencies by using heavy, bare copper wire.

If it is desired to set up an antenna system so that reliable and consistent communications can be maintained, the following factors must be considered and the following steps undertaken. From the M-U-F Propagation Prediction charts, the frequency and the wave angle which will provide the most reliable operation is selected. At this point, another important factor must be considered. If the charts indicate that a low frequency gives the optimum results, it must be realized that a wave length at this frequency is physically long. Therefore, it would be impractical to use a long-wire

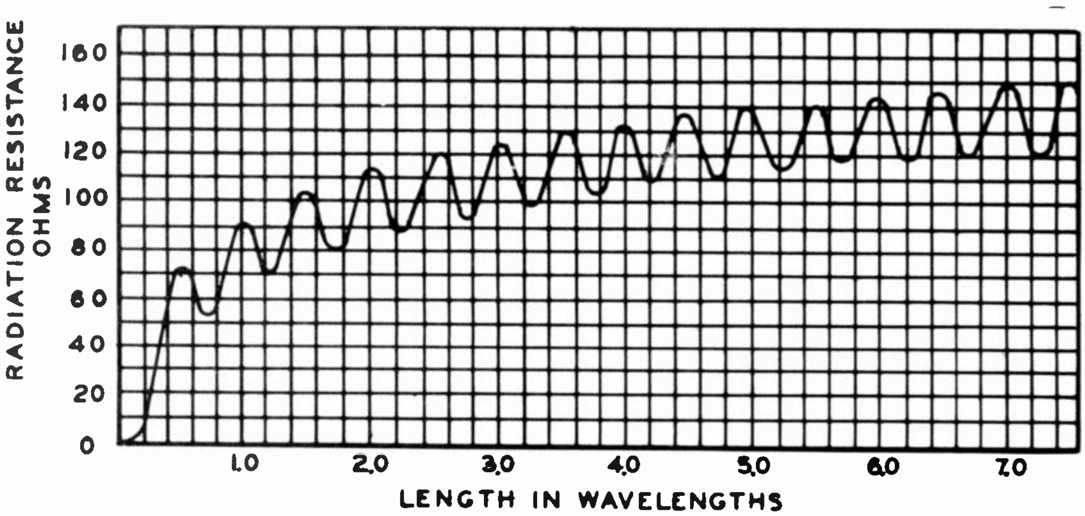


Figure 65. Variation in Radiation Resistance at the Current Maximums of Antennas of Various Lengths.

antenna or a similar antenna of multiple wave lengths since the tactical conditions usually limit the space and materials. In an application of this sort, it would be better to use some type of half-wave or similar submultiple-wave antenna. From the chart for the height of a half-wave antenna versus the angle of wave radiation (figure 63) the correct height of a half-wave antenna for a desired wave angle may be determined.

The charts referred to for the ground-reflection factors at different angles of radiation are made for a perfectly conducting ground. Thus they are not exactly accurate, and variations in height as compared to the theoretical value must be made in actual practice. Yet, the effect of a perfectly conducting ground can be simulated by installing a metal screen or mesh underneath the antenna, near, on, or below the surface of the ground. While it is most effective at higher frequencies, it helps to improve the performance of the antenna at lower frequencies by reducing losses in the ground in the vicinity of the antenna. When the screen is extended for about one half wave length, its beneficial effects are greatest.

When a high frequency is designated by the propagation charts, a different procedure is demanded. A wave length at a high frequency is substantially shorter than at a low frequency, therefore, a multiple wave-length antenna may be used if desired. In this case it might be wise to realize that the radiation resistance is affected by the length of the antenna, and also that an increase in length changes the directivity and radiation pattern of the antenna. Figure 65 gives an approximate indication of the radiation resistance with respect to the antenna length. Figure 66 indicates the angles of the major and minor power lobes of radiation, with respect to the wire axis, for different values of antenna length. Thus, the desired wave angle may be obtained and the maximum amount of power radiated in the desired direction.

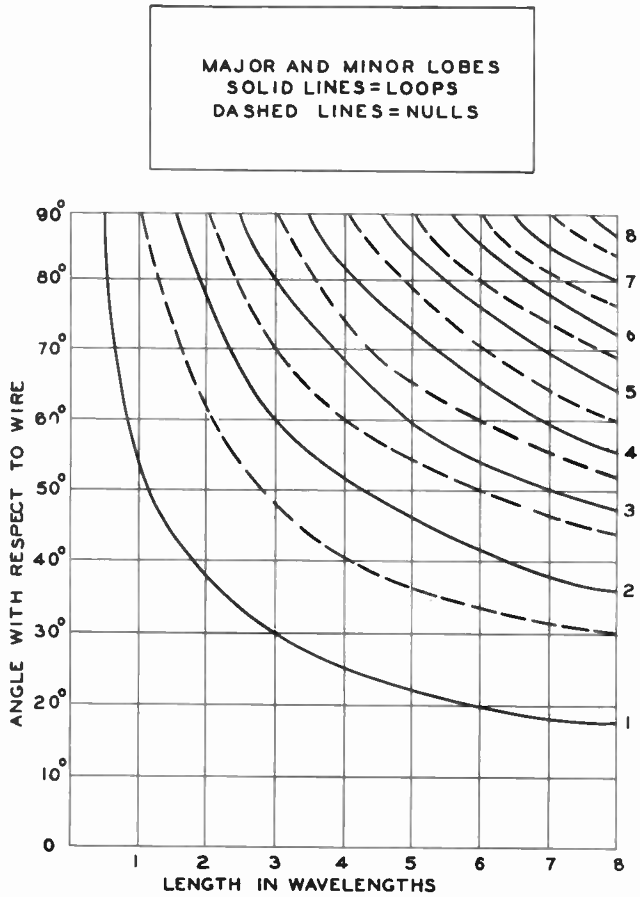


Figure 66. Angles which the Major and Minor Lobes of Radiation Make with Respect to the Axes of Horizontal-Long-Wire Antennas of Different Lengths.

EXAMINATION No. 1

True or False

1. If an alternating current in the radio-frequency range is caused to flow through a suitable conductor, it will produce a moving-field wave travelling away from the conductor. ....

2. The intensity of the radiated wave from an antenna depends primarily upon the length of the antenna. ....

3. The polarization characteristic of an antenna is determined by the direction of the magnetic field. ....

4. The main components of a ground wave are a surface wave, a direct wave, and an earth-reflected wave. ....

5. Best ground-wave transmission occurs over flat, desert terrain. ....

6. The factor of lower atmosphere refraction at lower frequencies explains the fact that greatly extended ranges on ground-wave transmission are realized at lower frequencies. ....

7. A condition of cancellation of ground waves can be improved by increasing the height of the transmitting antenna and/or the frequency of transmission. ....

8. It is an accepted fact that the atmosphere surrounding the earth is composed of layers, or strata, of a gaseous nature, with varying densities. ....

9. For a radiated wave at a given frequency to be refracted sufficiently to cause it to be returned to the earth, it must enter the ionosphere at an angle less than the critical angle. ....

10. A radio wave propagated straight up (at zero angle) into the ionosphere will not be returned to earth if its frequency is below a certain critical frequency. ....

Multiple Choice
(Underline the correct answer.)

1. The distance between the transmitter and the point where a usable refracted wave first returns to the earth is called the
   a. ground-wave-coverage distance.
   b. skip zone.
   c. skip distance.
   d. wave-front-expansive distance.

2. Greater distances can be covered with multiple-hop transmission by decreasing the
   a. vertical radiation angle of the antenna.
   b. length of the antenna.
   c. power applied to the antenna.
   d. mean height of the antenna.

3. Where ground-wave transmission is adequate, it should be utilized instead of sky-wave transmission, because it
   a. reduces power requirements.
   b. requires a small antenna array.
   c. is not affected by ionospheric disturbances.
   d. has highly directional properties.

4. The horizontal antenna favors reception of a high-angle signal and discriminates against low-angle atmospheric static and local man-made noise, which is principally
   a. unidirectional.
   b. vertically polarized.
   c. highly intense.
   d. horizontally polarized.

5. Standing waves on an antenna describe a condition of
   a. mismatch.
   b. heat losses.
   c. resonance.
   d. charges in motion.

6. Of the following types of noise, the chief disturbing component in the u-h-f range is
   a. atmospheric noise.
   b. cosmic noise.
   c. man-made noise.
   d. receiver and antenna noise.

7. Energy which produces a signal at a distant point is thought of as being dissipated by
   a. leakage resistance.
   b. antenna impedance.
   c. dielectric absorption.
   d. radiation resistance.

8. At resonance, the voltage and current distribution along an antenna depends upon its length and the
   a. size of the antenna wire.
   b. effects of the ground and surrounding objects.
   c. amount of power applied.
   d. type of coupling used.

9. An important prerequisite in obtaining efficient power transmission from a transmitter to an antenna is
   a. matching of impedance.
   b. proper method of balance.
   c. low ohmic resistance.
   d. high load impedance.

10. Radiation field measurements should not be made at distances less than 2 wave lengths from the antenna, because errors are introduced due to
    a. the capacitive effects of the metallic antenna towers.
    b. the fact that no signals exist within that space.
    c. the presence of the induction field.
    d. high-angle-radiation reflections.

Subjective

1. Name at least three factors which affect the basic radiation pattern of an antenna.

2. What is the shortest physical length (in feet) of a single wire that can be made resonant at a frequency of 1600 kilocycles?

3. Draw the characteristic standing-wave voltage and current distribution existing on a vertical quarter-wave and on a horizontal half-wave antenna at resonance.

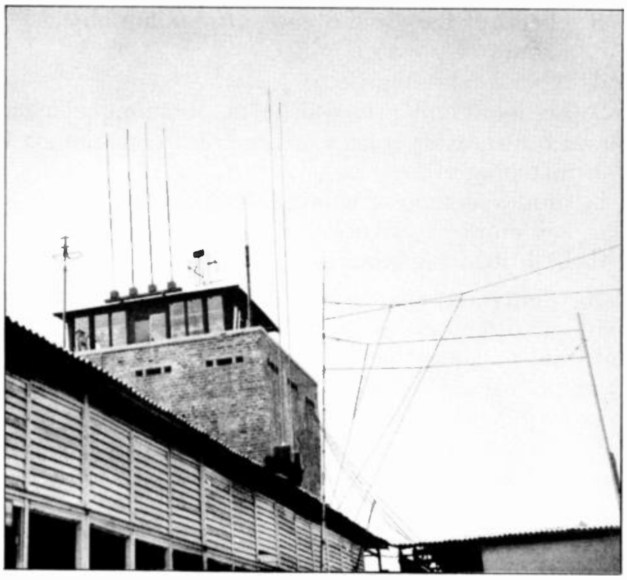
4. Name three factors upon which the radiation resistance of an antenna depends.

5. Outline a systematic method of locating the source of radio noise at a typical receiver site and give quick remedies.

TRANSMISSION-LINE THEORY

The amount of current flowing in an antenna is one of the most important factors affecting the efficiency of the antenna. Thus, in order to secure the maximum radiated power from a transmitter of given power, as much of the radio-frequency energy in the tank circuit as possible must be efficiently transferred to the antenna.

The device which transfers the r-f energy from the transmitter to the antenna is called a transmission line. Transmission lines may be divided into two main types —untuned or matched lines and tuned or unmatched lines. Untuned or matched lines are generally found in the form of concentric or coaxial cables, with one or more inner conductors. A hollow brass pipe or a copper tube, with an inner conductor insulated from the outer conductor by suitable ceramic spacers, can be used for very high and ultra high frequencies. A tuned line is usually in the form of an open-wire line, which is constructed of two exposed parallel conductors separated at intervals with suitable insulating spacers. A tuned line may be converted into an untuned line by properly terminating it into the load, which is the antenna.



Communications, Navigation, and Identification Antennas Atop and in the Vicinity of an Army-Airfield Control Tower.

CHARACTERISTIC IMPEDANCE

In antenna transmission problems, the transmitter output circuit is considered as the *generator,* the conducting path to the antenna as the *transmission line,* and the antenna as the *load.* See figure 67. All power sent down a transmission line will be absorbed by the load and none reflected back down the line if the load impedance is equal to the "characteristic impedance" of the line. Every transmission line has a certain characteristic impedance, usually designated Zo. An understanding of the meaning of Zo and how to calculate Zo for any particular type of line are important in practical antenna work.

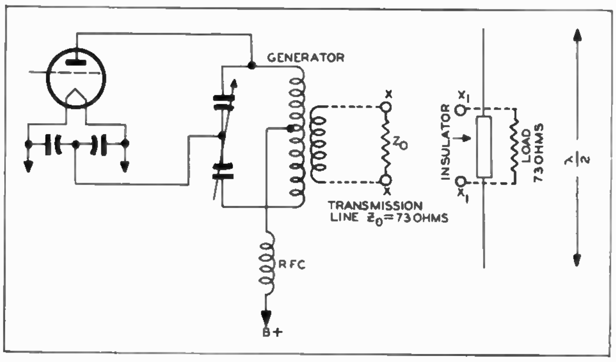


Figure 67. Matching the Impedance of the Transmission Line to the Load.

Perhaps the simplest approach to this problem is to recognize the fact that a pair of spaced conductors has resistance, inductance, and capacity; see figure 68A.

Figure 68C shows a generator connected to an infinitely long (no termination) open line. The total capacity, inductance and resistance of this line are shown integrated into small sections (1, 2, 3, etc.) in figure 68A, and the current paths that develop in each section are shown. Current flowing through each small section produces a voltage drop, due to the inductive and capacitive reactance and the resistance of the line. The

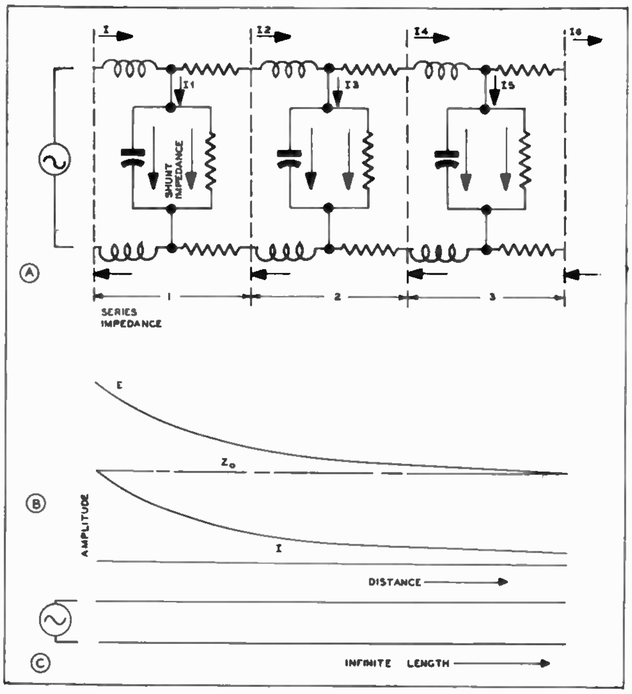
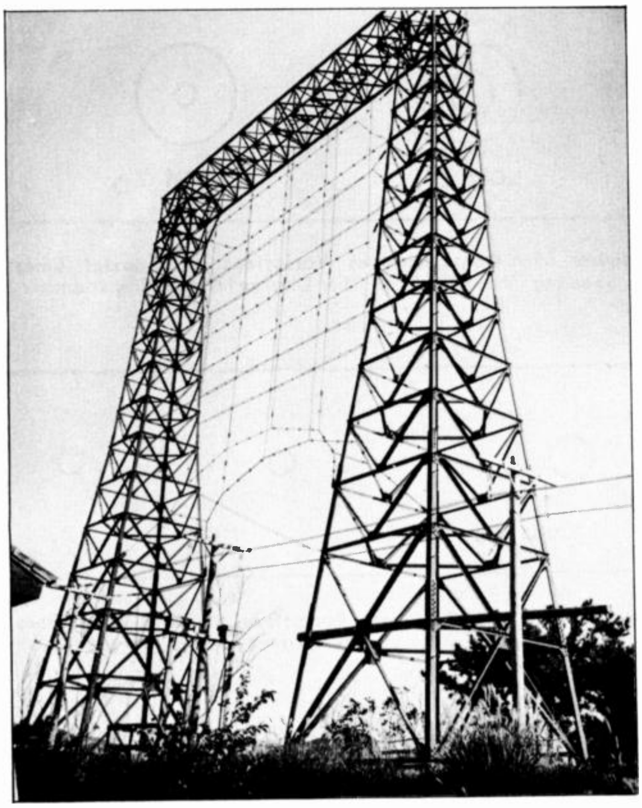


Figure 68. Equivalent Circuit of a Transmission Line and the Development of the Characteristic Impedance.



High-Frequency Receiving Antenna for a Radio-Telephone Link.

voltage drop in each succeeding section becomes proportionately smaller but a constant ratio of voltage to current is maintained. The current and voltage-drop curves both follow exponential paths, as shown in figure 68B.

In the infinitely long line, the impedance finally approaches a constant value. This final value of impedance, which is "seen" by a generator "looking" into an infinitely long line, is referred to as the characteristic impedance of the line. It must be understood that in actual practice the characteristic impedance of any line is a definite constant value.

The characteristic impedance of a transmission line can be determined by either one of two simple methods. In one method, the inductance and capacity of a short section of the line are measured with an inductance bridge and capacity bridge, respectively. In the other method, the physical dimensions of a cross section of the line are determined, that is, the diameter and spacing of the conductors. Inside and outside calipers are generally used to determine these dimensions. An ordinary rule, however, can be used for a rough determination. Both methods of determining the characteristic impedance require the use of simple formulas for obtaining the final result.

The procedure for determining the characteristic impedance of a line by the inductance-capacity method follows:

1. Using a capacity bridge, measure the capacity of a convenient length of an open-ended transmission line in micromicrofarads.
2. Short the open end of this same line and measure its inductance, in micromicrohenries, with an inductance bridge.

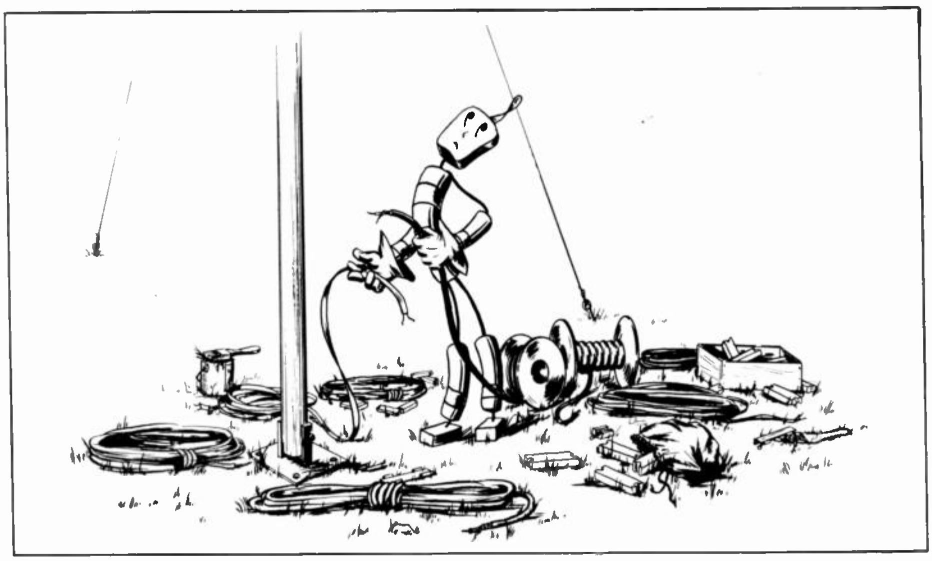
Then substitute the measured values in the following formula:

$$Zo \text{ in ohms} = \sqrt{\frac{L \text{ mmh.}}{C \text{ mmf.}}}$$

For example, assume that the following values of capacity and inductance are measured on a transmission line:

$$C = 29.5 \text{ mmf.}$$
(or approximately .00003 mf.)
$$L = 79{,}768 \text{ mmh.}$$
(or approximately .08 mh.)

$$\text{then } Zo = \sqrt{\frac{79{,}768}{29.5}}$$
$$Zo = \sqrt{2707}$$
$$Zo = 52 \text{ ohms}$$



If adequate test equipment for the above test is not available but measuring instruments such as calipers, are obtainable to measure the physical dimensions of the transmission line components, the following formulas can be applied to determine the characteristic impedance, Zo:

For coaxial or concentric cable lines

$$Zo = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d}$$

where D = inside diameter of outside conductor
d = outside diameter of center conductor
ϵ = dielectric constant of dielectric material

For example, if a concentric cable has a 2⅛″ hollow brass tube as the outer conductor and a ½″ copper tube as the inner conductor and air is the dielectric, the mathematical solution is as follows:

$$Zo = \frac{138}{\sqrt{\epsilon}} \log_{10} \frac{D}{d}$$

where D = 2″, inside diameter of 2⅛″ hollow brass tube
d = 0.5″, outside diameter of ½″ copper tube
ϵ = 1, dielectric of air

$$Zo = \frac{138}{1} \log_{10} \frac{2}{0.5}$$

$$Zo = 138 \log_{10} 4$$
$$Zo = 138\,(0.602)$$
$$Zo = 83 \text{ ohms}$$

For parallel-conductor lines, where D is much greater than d, which is standard construction procedure:

$$Zo = 276 \log_{10} \frac{2D}{d}$$

where D = distance between centers of conductors
d = diameter of conductor

The dielectric constant of the insulating materials commonly used in coaxial-type cables varies from approximately 2 to 5. For example, polyethylene has a dielectric constant of 2.25 and polystyrene has a dielectric constant of 2.53, both values being based upon the reference dielectric of air, which is 1.

A convenient rule to remember, concerning characteristic impedance of coaxial or concentric lines, is that when the inside diameter of the outer conductor is much greater than the outside diameter of the inner conductor the transmission line has a high Zo. Conversely, when the inside diameter of the outer conductor is not much greater than the outside diameter of the inner conductor, the transmission line has a low Zo. See figure 69.

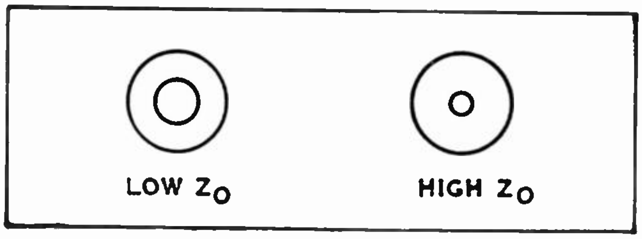


Figure 69. Constructional Variations of Coaxial Lines, Showing the Effect on the Characteristic Impedance.

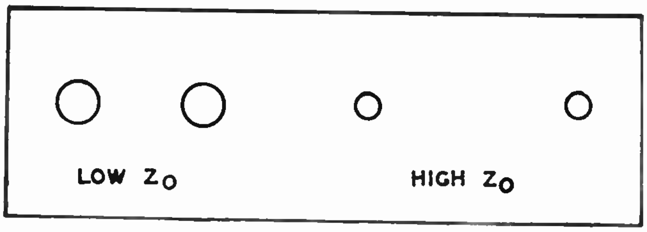


Figure 70. Constructional Variations of Open-Wire Lines, Showing the Effect on the Characteristic Impedance.

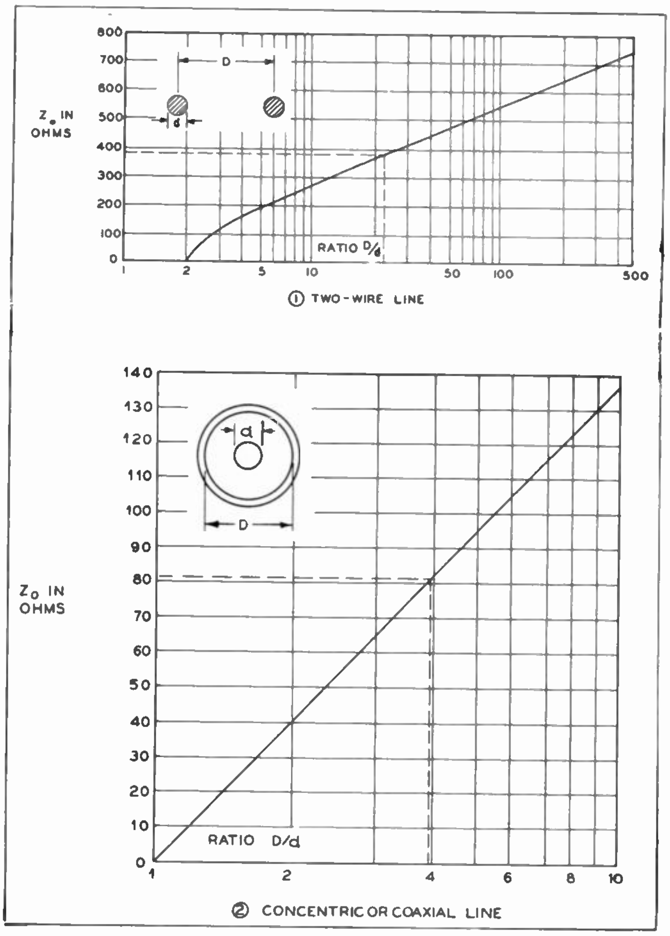


Figure 71. Graphs for Determining the Characteristic Impedance of Coaxial and Parallel Open-Wire Lines.

A general rule for open parallel-wire-type lines is that when the size of the wire is large with respect to the spacing between the wires the line has a low impedance; conversely, when the size of the wire is small with respect to the spacing between the wires the line has a high impedance. See figure 70.

For convenience in determining the characteristic impedance of concentric or parallel conductor-type line, the graphs in figure 71 are given.

It is important to have an idea of the relative voltage-handling capabilities of various types of coaxial cables. This and other pertinent information are given in chart 9.

STANDING WAVES

If a transmission line is terminated at any point along its length by a load, (such as an antenna), the impedance of which is equal to the characteristic impedance of the line, any radio-frequency wave sent down the line will arrive at the load with the same relative voltage and phase angle with which it left the generator.

If there is a mismatch, due to improper termination of the line, signal distortion in the form of phase distortion and phase delay will result, the effect being proportional to the difference between the frequency of the applied signal and the resonant frequency of the antenna. The most undesirable result of this condition is the appearance of standing waves on the line.

Standing waves are a result of the combination of the outgoing and reflected signal power on the line, and are similar to the standing waves which are produced on an antenna (previously described under the subject of Electromagnetic Wave Theory). The applied power, upon reaching the load end of a line, is opposed by an impedance different from that which the line presents, and is reflected. The degree of difference in the impedances is the factor which determines the amount of this power that is reflected. As the two waves travel in opposite directions along the length of the line, the reflected current or voltage either adds to, or subtracts from, the applied current or voltage. Since the impedance of an antenna changes with frequency, the resulting standing waves are also affected by changes in frequency of the applied power, and by changes in the electrical length of the line.

Reflections are always assumed to start from the load or termination end of the transmission line, therefore, in the case of an open-end termination, which presents a very high impedance, the voltage at that end is a maximum and the current, a minimum. With the shorted termination, which presents a very low impedance, the current at that end is a maximum and the voltage, a minimum. For the sake of simplicity, consider only the current distribution of the incident and reflected waves at one instant of time on a tuned line with an open termination, and of length L, corresponding to one wave length of the applied r-f power.

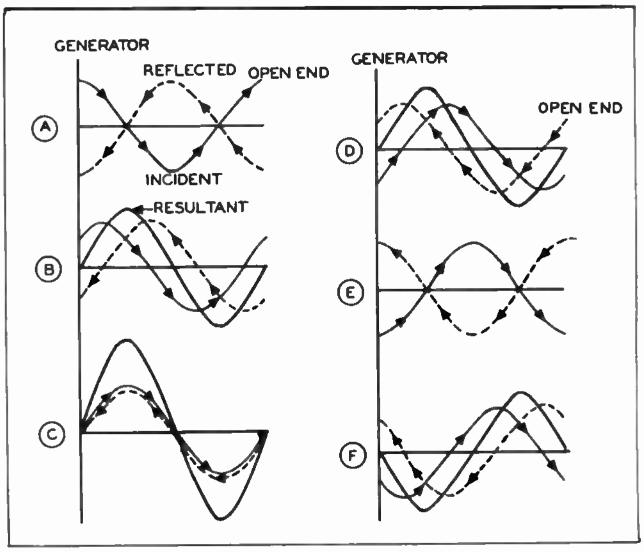


Figure 72. Formation of Standing Waves.

See figure 72A. Figure 72B shows the relationship of the incident and the reflected current waves at the instant of time one-eighth of a cycle later as they travel the same path in opposite directions. At each succeeding instant of time, the relative amplitude of the waves at any particular point change and the resultant changes accordingly. Figures 72C, D, E, and F show the relative amplitude of the resultant standing wave at one-eighth-cycle intervals. The voltage wave for the transmission line is affected in the same manner. Thus, on the same line, there are resultant standing waves of voltage and current.

The standing waves existing on a transmission line with a shorted termination are formed in the same manner as described above except that the loops and nulls are shifted by 90° in relation to those on a line with an open termination.

Since the impedance presented by an antenna is different for different frequencies a perfect matched condition is obtained at only one frequency. At this frequency, the transmission line is untuned, and is

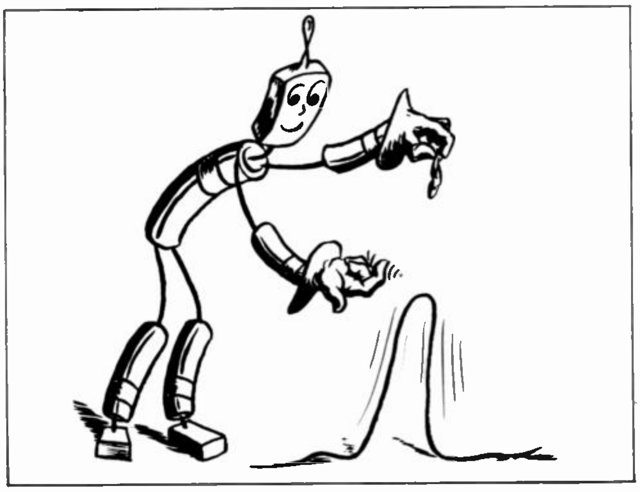


CHART 9

ARMY-NAVY STANDARD LIST OF RADIO-FREQUENCY CABLES

Class of Cables		Army-Navy Type Number	Inner Conductor	Nominal Overall Diam. (in.)	Nominal Imped-ance (ohms)	Maximum Operating Voltage (r.m.s.)	Remarks
50—55 ohms	Single braid	RG-58/U	20 A.W.G. copper	0.195	53.5	1,900	General-purpose, small-size flexible cable
		RG-8/U	7/21 A.W.G. copper	0.405	52.0	4,000	General-purpose, medium-size, flexible cable
		RG-10/U	7/21 A.W.G. copper	(max.) 0.475	52.0	4,000	Same as RG-8/U except armored for naval equipment
		RG-17/U	0.188 copper	0.870	52.0	11,000	Large, high-power, low-attenuation transmission cable
		RG-18/U	0.188 copper	(max.) 0.945	52.0	11,000	Same as RG-17/U except armored for naval equipment
		RG-19/U	0.250 copper	0.120	52.0	14,000	Very large, high-power, low-attenuation transmission cable
		RG-20/U	0.250 copper	(max.) 1.195	52.0	14,000	Same as RG-19/U except armored for naval equipment
	Double braid	RG-55/U	20 A.W.G. copper	(max.) 0.206	53.5	1,900	Small-size flexible cable
		RG-5/U	16 A.W.G. copper	0.332	53.5	2,000	Small microwave cable
		RG-9/U	7/21 A.W.G. silvered copper	0.420	5.10	4,000	Medium-size, low-level circuit cable
		RG-14/U	10 A.W.G. copper	0.545	52.0	5,500	General-purpose, semi-flexible, power-transmission cable
		RG-74/U	10 A.W.G. copper	0.615	52.0	5,500	Same as RG-14/U except armored for naval equipment
70—80 ohms	Single braid	RG-59/U	22 A.W.G. copperweld	0.242	73.0	2,300	General-purpose, small-size video cable
		RG-11/U	7/26 A.W.G. tinned copper	0.405	75.0	4,000	Medium-size, flexible video and communication cable
		RG-12/U	7/26 A.W.G. tinned copper	0.475	75.0	4,000	Same as RG-11/U except armored for naval equipment
	Double braid	RG-6/U	21 A.W.G. copperweld	0.332	76.0	2,700	Small size video and i-f cable
		RG-13/U	7/26 A.W.G. tinned copper	0.420	74.0	4,000	I-f cable
Cables of special characteristics	Twin conductor	RG-22/U	2 conductor 7/18 A.W.G. copper	0.405	95.0	1,000	Small-size, twin-conductor cable
		RG-57/U	2 conductor 7/21 A.W.G. copper	0.625	95.0	3,000	Large-size, twin-conductor cable
	High attenuation	RG-21/U	16 A.W.G. resistance wire	0.332	53.0	2,700	Special attenuating cable with small temperature coefficient of attenuation
	High impedance	RG-65/U	No. 32 formex F helix diam. 0.128 in.	0.405	95.0	1,000	High-impedance video cable. High delay
Low capacitance	Single braid	RG-62/U	22 A.W.G. copperweld	0.242	93.0	750	Small-size, low-capacitance, air-spaced cable
		RG-63/U	22 A.W.G. copperweld	0.405	125	1,000	Medium-size, low-capacitance, air-spaced cable
	Double braid	RG-71/U	22 A.W.G. copperweld	0.250	93.0	750	Small-size, low-capacitance, air-spaced cable for i-f purposes
Pulse applications	Single braid	RG-26/U	19/0.0117 tinned copper	(max.) 0.525	48.0	8,000 (peak)	Medium-size pulse cable, armored for naval equipment
		RG-27/U	19/0.0185 tinned copper	(max.) 0.675	48.0	15,000 (peak)	Large-size pulse cable, armored for naval equipment

ARMY-NAVY STANDARD LIST OF RADIO-FREQUENCY CABLES (Cont.)

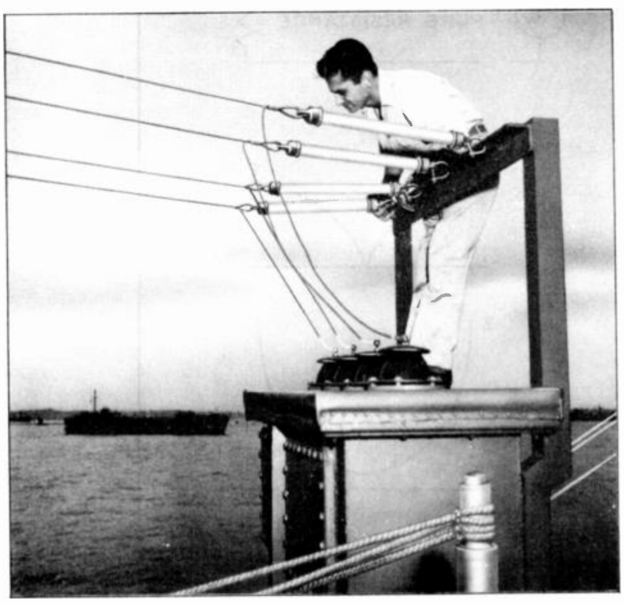
Class of Cables		Army-Navy Type Number	Inner Conductor	Nominal Overall Diam. (in.)	Nominal Imped-ance (ohms)	Maximum Operating Voltage (r.m.s.)	Remarks
Pulse applications (cont.)	Double braid	RG-64/U	19/0.0117 tinned copper	0.495	48.0	8,000 (peak)	Medium-size pulse cable
		RG-25/U	19/0.0117 tinned copper	0.565	48.0	8,000 (peak)	Special twist pulse cable for naval equipment
		RG-28/U	19/0.0185 tinned copper	0.805	48.0	15,000 (peak)	Large-size pulse cable
Twisting application	Single braid	RG-41/U	16/30 A.W.G. tinned copper	0.425	67.5	3,000	Special twist cable

very efficient because of negligible radiation; such lines are widely used for fixed-frequency applications.

The tuned type of transmission line is widely used for the following reasons: In comparison with the untuned line, it is simple to adjust, and provides satisfactory transfer of power over a relatively wide frequency band. However, the line length should not exceed one wave length.

The standing waves on a tuned line which is connected to an antenna conform to those on the antenna, that is, the transmission line acts like an extension of the antenna.

Standing waves on a conductor, due to an improper match of the line at either termination, cause losses due to unwanted radiation from the conductor and heat losses in the conductor, itself. In a properly terminated untuned line, all of the energy is absorbed in the load and, therefore, no standing waves are produced. In a tuned or unmatched line, standing waves are always present, but a simulated condition of match may be realized, as discussed later.



Inspection of Transmission Lines and Terminating Unit for Corrosion Caused by Salt Spray.

TERMINATIONS

It is interesting to note the impedance curves of an open-circuited and a shorted transmission line. The impedance curves conform to the standing waves of voltage. It is shown later in the discussion that specific lengths of transmission line can be used as impedance-matching transformers.

Figure 73 shows the impedance curve of a $\lambda/2$ open line, while figure 74 shows the impedance curve of a $\lambda/2$ line terminated in a short-circuit. These illustrations indicate the effect of standing waves at the extreme departures from a matched condition. When a

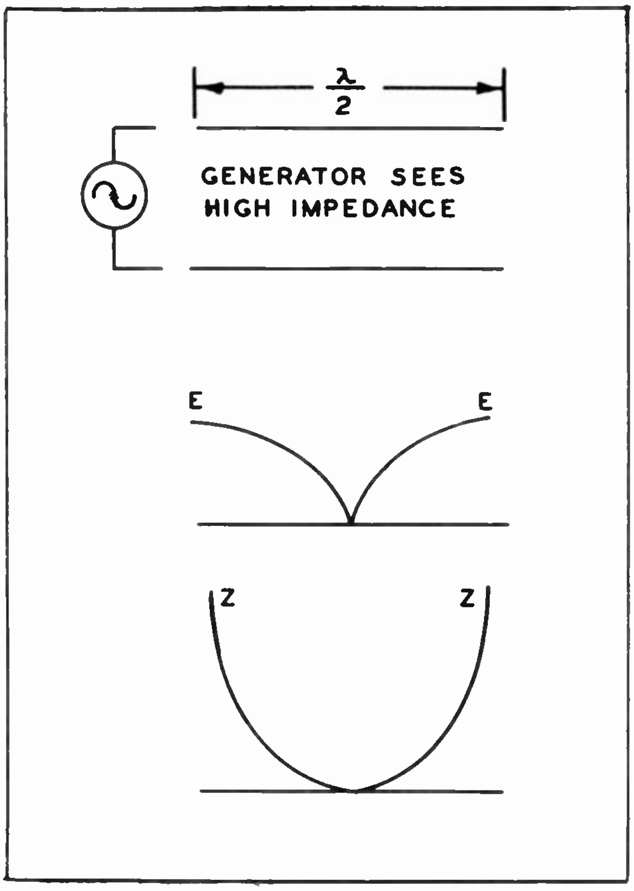


Figure 73. Voltage and Impedance Curves of a Half Wave Length, Open-End Transmission Line.

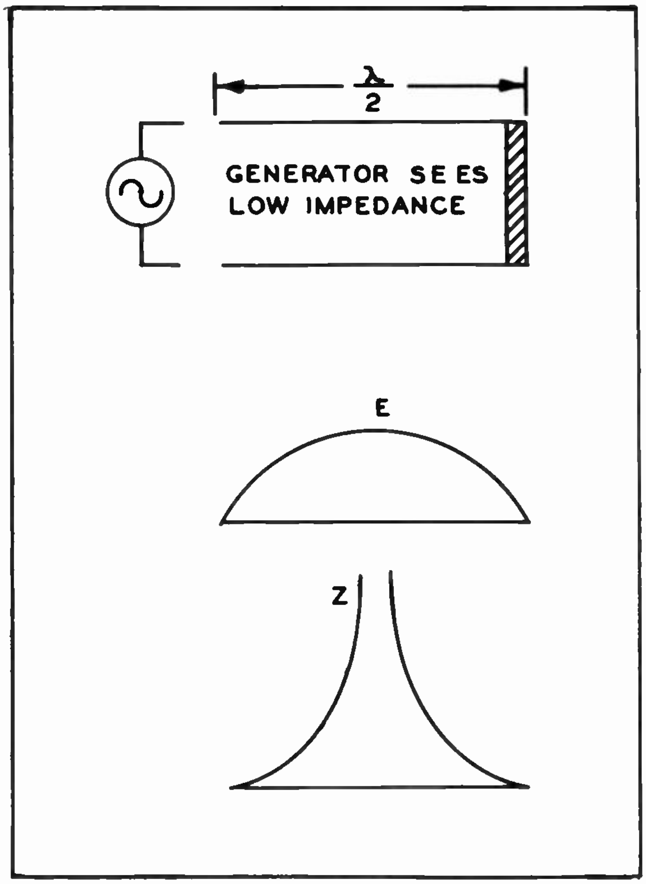


Figure 74. Voltage and Impedance Curves of a Half Wave Length, Open-End Transmission Line.

line is terminated with intermediate values of pure resistance, greater than or less than the characteristic impedance of the line, the loop or maximum point of voltage is less in amplitude and the null or minimum point of voltage is greater than zero. The voltage and impedance curves of these lines are shown in figure 75.

Transmission Line Terminated In Open Or Short

Figure 76A shows the standing-wave distribution on a one and one-half wave length shorted line and figure 76B shows the standing-wave distribution when the same line is open. In figure 76A, the points 1, 2, and 3 are called loops, while the points 4, 5, 6, and 7 are called nulls. In figure 76B, the points 1, 2, 3, and 4 are loops, and the points 5, 6, and 7 are nulls. Notice that the loops occur at points one-half wave length apart, and that the nulls also occur at points one-half wave length apart.

Transmission Line Terminated In Pure Resistance

Figure 77A shows the standing-wave distribution when a transmission line is terminated in a pure resistance of a value less than the characteristic impedance of the line. A comparison of this figure with figure 76A shows that the voltage loops and nulls occur at the same points as those on a shorted line, but the maxi-

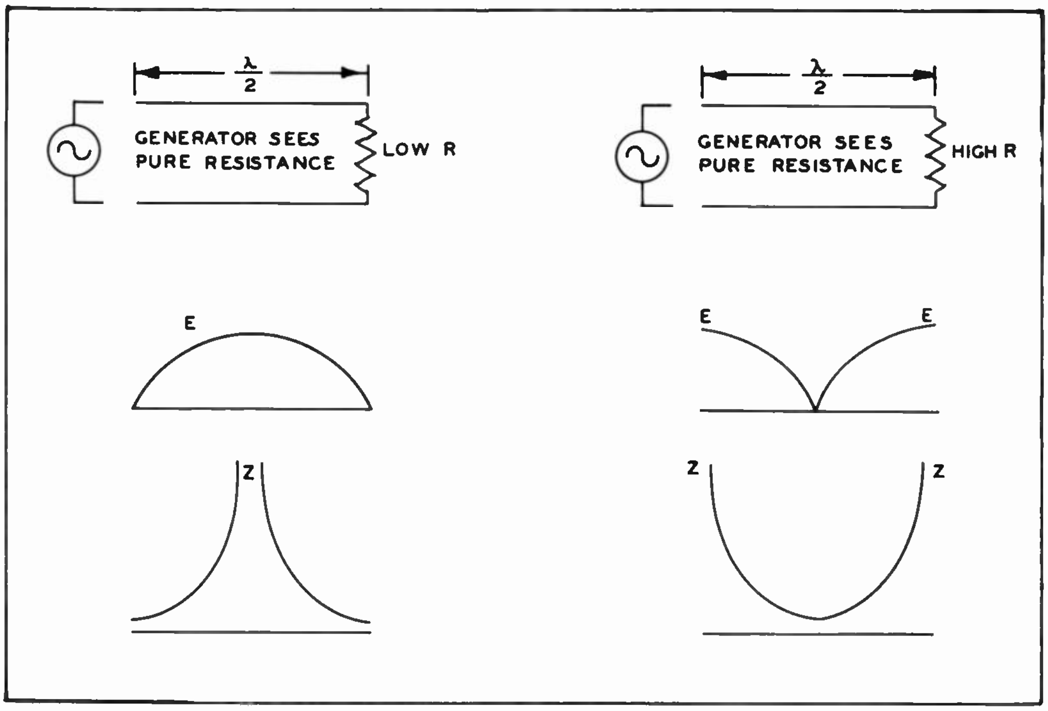


Figure 75. Voltage and Impedance Curves for a Half Wave Length Transmission Line Terminated in a Pure Resistance Having a Value Greater Than and Less Than the Characteristic Impedance of the Line.

mum and minimum amplitudes are different. Figures 77B shows the standing-wave distribution when a transmission line is terminated in a pure resistance of a value greater than the characteristic impedance of the line. A comparison of this figure with figure 76B shows that the voltage loops and nulls occur at the same points as those on an open line, but the maximum and minimum amplitudes are different.

Transmission Line Terminated In Reactive Load

If a transmission line is terminated in a reactive load, standing waves will be present on the line. The measurement of these standing waves involves factors not yet discussed.

Since, in practical applications, the antenna as a load usually offers some reactive component, this type of termination is discussed in detail. Figure 78A shows the standing wave of voltage (solid line) on a line terminated in capacity. Notice that the current (dashed line) leads the voltage (from termination end of line). The voltage loop approaches minimum (nearer the end of the line) as the capacitive load increases. The capacity increases the effective electrical length of the line.

Figure 78B shows the standing-wave pattern obtained when the line is terminated in an inductance; note that the voltage (solid line) leads the current

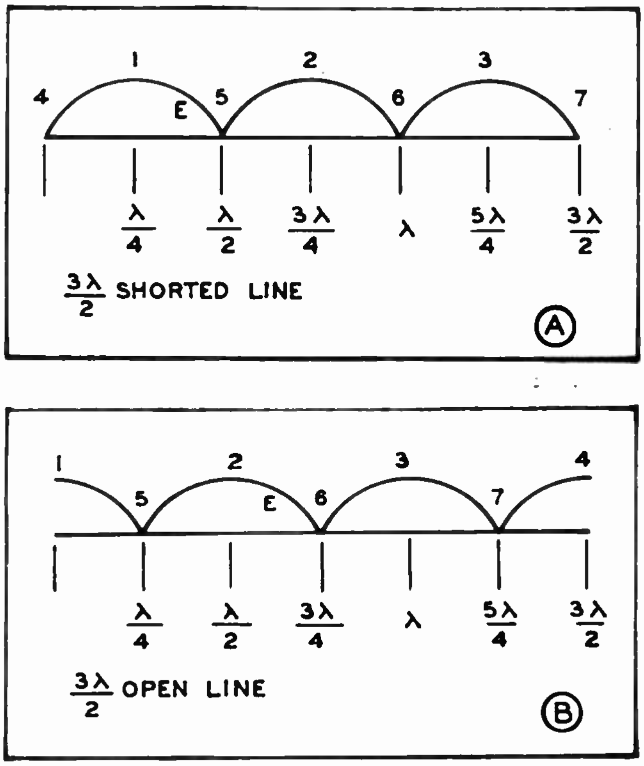


Figure 76. Distribution of Standing Waves of Voltage on a One and One Half Wave Length Section of Transmission Line Terminated in a Short and an Open.

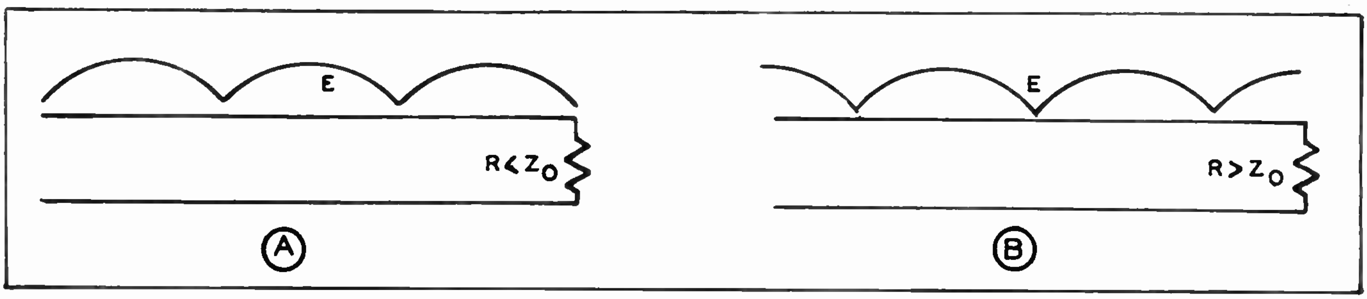


Figure 77. Distribution of Standing Waves of Voltage on a Section of Transmission Line Terminated in a Pure Resistance Having a Value Greater Than and Less Than the Characteristic Impedance of the Line.

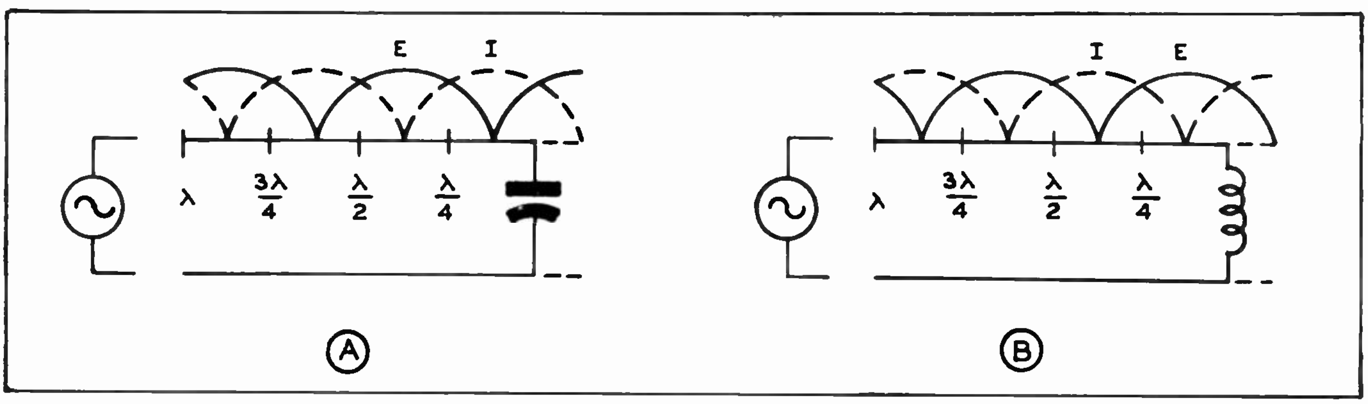


Figure 78. Distribution of Standing Waves of Voltage and Current on a One Wave Length Section of Transmission Line Terminated in a Capacitive Reactance and in an Inductive Reactance.

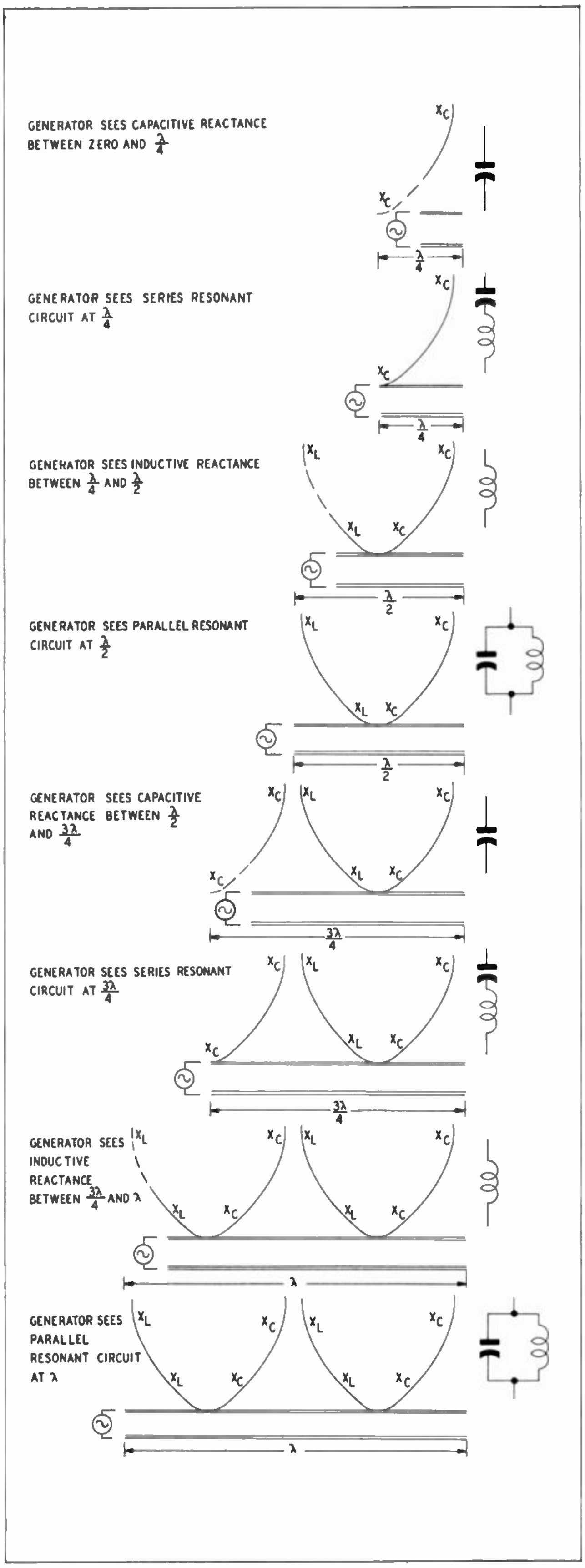


Figure 79. Effective Impedances Presented to a Generator by Various Lengths of an Open Transmission Line.

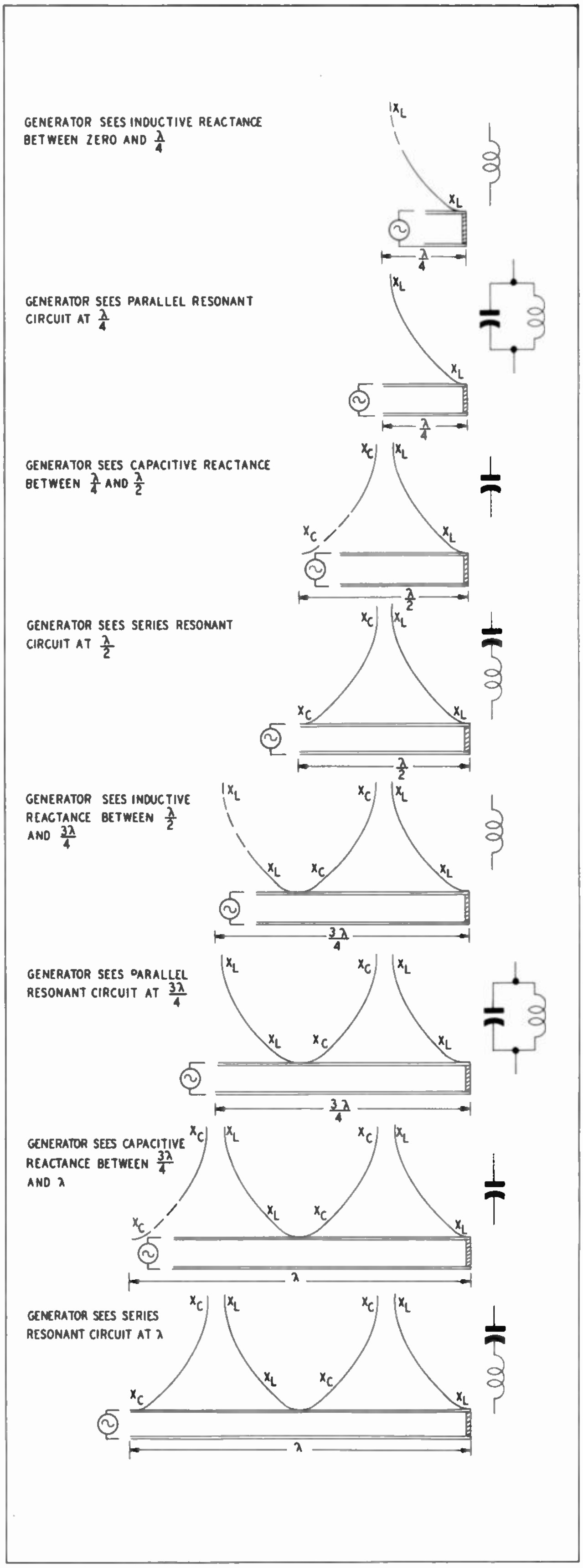


Figure 80. Effective Impedances Presented to a Generator by Various Lengths of a Shorted Transmission Line.

(dashed line). As in the capacitive termination, the effective electrical length of the line is increased. The larger the value of inductance, the nearer the end of the line the voltage loop occurs. Therefore, the effect of capacitive or inductive reactance in the load of a transmission line is to shift the standing wave one way or the other along the length of the line. This fact aids in determining which type of reactance is present in a load, and is discussed later. In both capacitive and inductive terminations, notice that the line is effectively chopped off at some value less than a quarter wave length. In general, therefore, a transmission line carrying radio-frequency energy exhibits reactive effects if it is terminated at any fraction of a quarter wave length, and exhibits resistance effects if it is terminated in some multiple of a quarter wave length. Figures 79 and 80 show the effective impedances for various lengths of transmission line. Applying this principle to the impedance curves of a one wave length transmission line terminated in an open circuit, it is easily seen that if a generator were connected at various points along the line it would see resistance, inductive reactance or capacitive reactance, depending upon the point selected. See figure 81. Thus, if the generator were connected to an open line ⅞ or ⅜ wave length from the open end, it would see an inductive reactance; if it were connected to an open line ⅝ or ⅛ wave length from the open end, it would see a capacitive reactance, etc. If the generator were connected to an open line an odd quarter wave length long, it would see the equivalent of a series resonant circuit. If it were connected to an open line an even multiple of wave lengths long, the generator would see the equivalent of a parallel resonant circuit.

Figure 82 shows the impedance curves of a shorted transmission line, one wave length long.

If a load is connected to a shorted quarter-wave section as shown in figure 83A, the line acts as a step-down transformer. Figure 83B indicates the current and voltage waves and figure 83C shows the equivalent circuit. Figure 84A shows a load connected to an open quarter-wave section; in this case the line acts as a step-up transformer. Figure 84B indicates the current and voltage waves and figure 84C shows the equivalent circuit.

STANDING-WAVE RATIO

First consider a line terminated in some finite value of pure resistance, greater than or less than the characteristic impedance, Zo, of the line. The degree of mismatch between the line and load is indicated by the ratio of the maximum value to the minimum value of voltage (or current), which is measurable along the length of line; this ratio is called the "standing-wave ratio". This can be more easily understood by referring to figure 85. The Zo of each transmission line is 50 ohms, while the load resistance of one line is 10 ohms

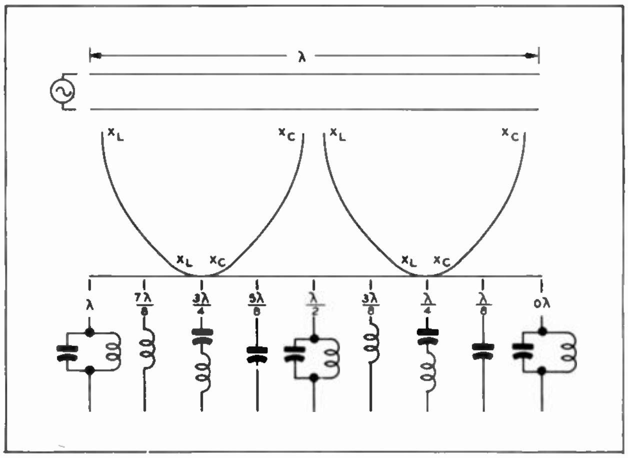


Figure 81. Equivalent Impedance Presented to a Generator Connected at Intermediate Points along a One Wave Length Transmission Line Terminated in an Open Circuit.

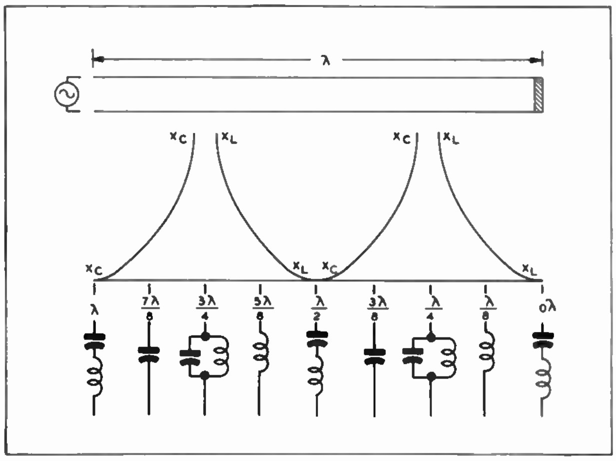


Figure 82. Equivalent Impedance Presented to a Generator Connected at Intermediate Points along a One Wave Length Transmission Line Terminated in a Short Circuit.

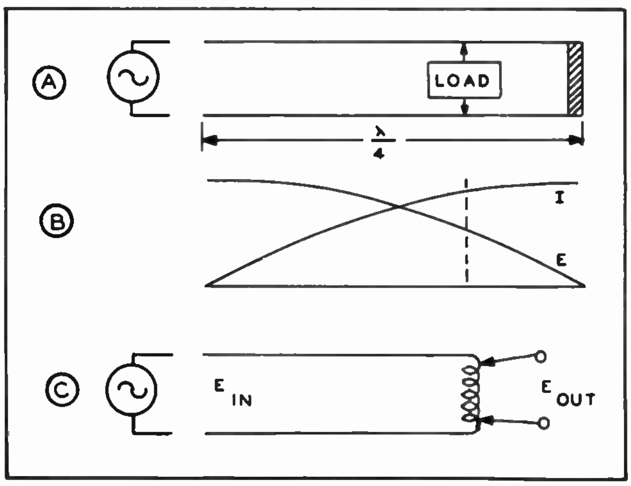


Figure 83. A Shorted Quarter-Wave Section of Transmission Line Acts as a Step-Down Transformer, When a Load Is Connected along Its Length.

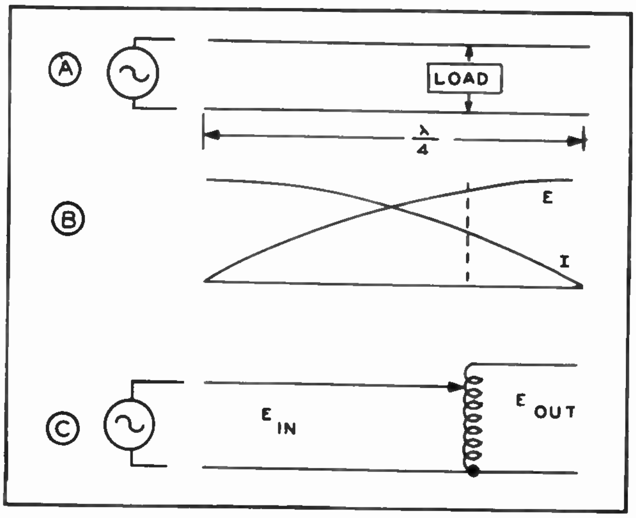


Figure 84. An Open Quarter-Wave Section of Transmission Line Acts as a Step-Up Transformer When a Load Is Connected along Its Length.

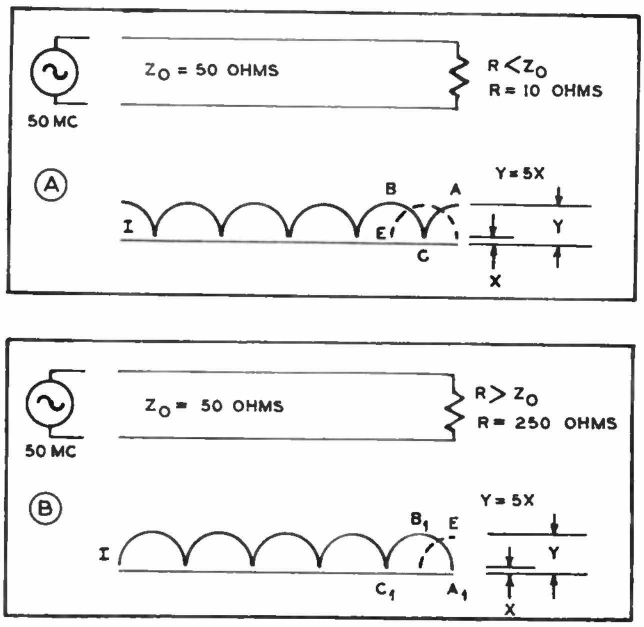


Figure 85. Standing-Wave Ratio Versus Degree of Mismatch.

and that of the other is 250 ohms. If the standing-wave current (shown as solid lines) is measured on one line at points B and C and on the other at points B′ and C′, it will be found that the current at B and B′ is 5 times that at C and C′. In each case, therefore, the standing-wave ratio is 5 to 1. However, figure 85A shows that there is a voltage null (dashed line) at the load end because the load resistance is less than the characteristic impedance and the line acts like a shorted line. Thus, if a standing-wave measuring device is available, it is a simple matter to determine whether the load resistance is smaller or larger than the line Zo; if the load resistance is greater than the Zo of the line, a neon bulb placed near the load will

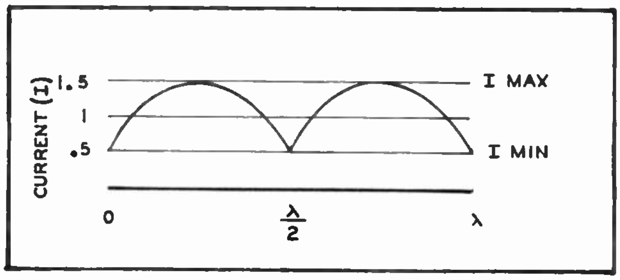


Figure 86. Determining Standing-Wave Ratio.

indicate a voltage loop (maximum brilliance), and conversely, if the load resistance is smaller than the Zo of the line, the neon bulb will indicate a voltage null (minimum brilliance).

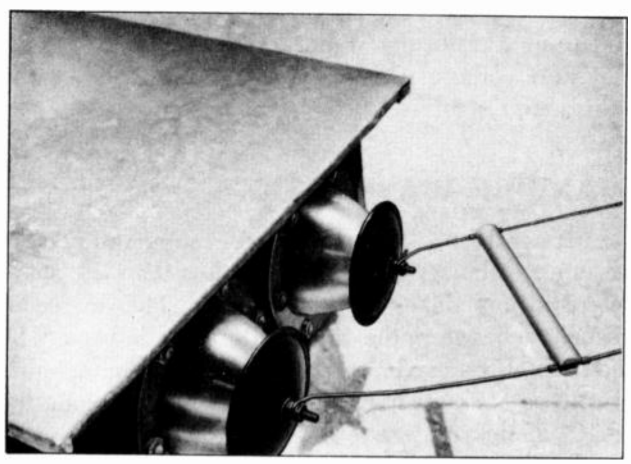
Figure 86 shows a standing wave of current where the current of the loop (I max.) is 1.5 amperes and at the null (I min.) is 0.5 ampere. By substituting these values in the following formula, the standing-wave ratio may be calculated.

$$\text{Standing-wave ratio} = \frac{\text{I max.}}{\text{I min.}} = \frac{1.5}{0.5} = \frac{3}{1} \text{ or 3 to 1}$$

Standing waves may be used to measure the exact frequency of the applied wave, by finding the distance between successive voltage or current loops, or voltage and current nulls and taking into account the velocity factor (K) of the line. In either case they are a half wave length apart, and the exact frequency can be calculated by substitution in the following formula:

$$\text{f mc.} = \frac{5905}{\lambda/2 \text{ (inches)}} \times K$$

$$\text{f mc.} = \frac{15000}{\lambda/2 \text{ (cm)}} \times K$$



Open-Wire Transmission Line Connected to Bowl-Type, Pyrex Feed-through Insulators.

MEASUREMENT OF STANDING WAVES

For the measurement of standing waves of current on an open-wire transmission line several methods are suggested. The simplest method involves the use of an r-f thermomilliammeter with adjustable brass or copper straps connected directly on the line. See figure 87. Heavy, stiff copper wire can also be used in lieu of the copper strap. The section of line, A to B, between the straps acts as a shunt for the r-f thermomilliammeter (milliammeter range 0–150 or 0–250 ma.). The current range of the meter can be adjusted by varying the distance between the strap connections on the line. This arrangement is very useful in determining if the current is correctly balanced (equal) in the lines; current loops should occur at corresponding points on the lines. Thus, if the currents are approximately the same when measurements are taken between points A to B and between A′ to B′, the transmission-line load and feed source are properly balanced with respect to each other and to ground. The magnetic fields produced by these currents in both lines have equal magnitudes and opposite polarities, so that they tend to conceal and reduce radiation from the line.

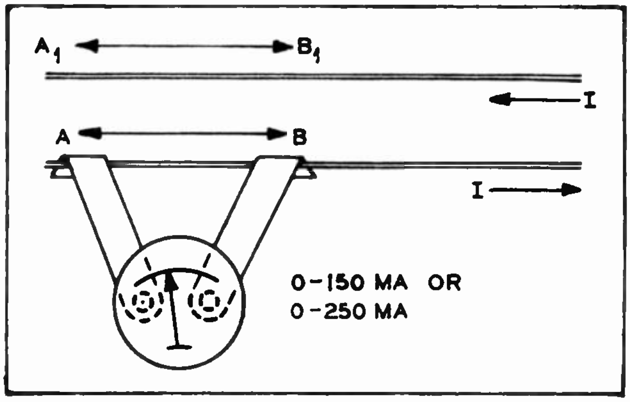


Figure 87. Shunt-Milliammeter Method for Measuring Standing Waves of Current on a Transmission Line.

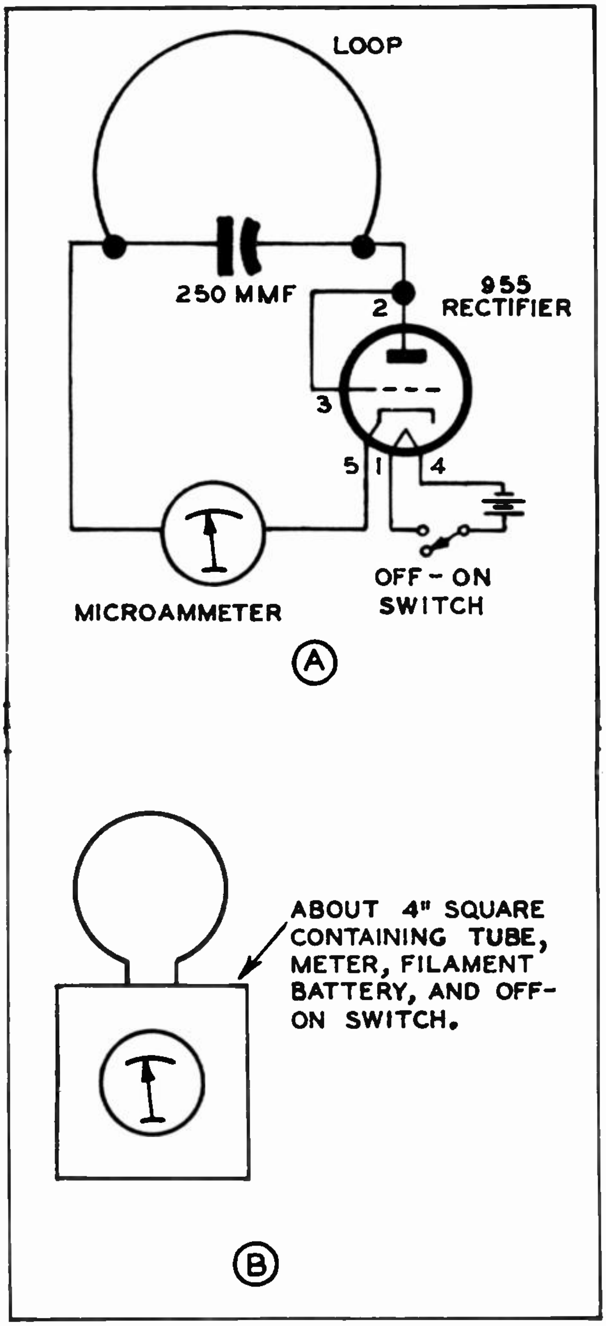


Figure 88. Instrument with Inductive Loop Coupling for Measuring Standing Waves of Current on a Transmission Line.

Another current-operated device consists of a small loop connected to a miniature diode vacuum tube and d-c meter, as shown in figure 88. For average current reading, the loop is coupled between the lines. For current loops on either line, the loop is moved along the outside of the line, keeping at a maximum distance for a suitable reading. A small crystal rectifier (1N23) can be used in place of the 955 acorn tube.

For measuring voltage loops, a neon tube (½ watt or larger depending upon the power), in series with a resistor, is connected across the line as shown in figure 89.

Standing waves of voltage can also be measured with a meter and selenium rectifier as in figure 90 (at higher frequencies a diode or crystal rectifier should be used). For a rough measurement of voltage along the line, a low-wattage fluorescent lamp can be used. It should be moved along the line without touching it.

For the measurement of standing waves on a concentric or coaxial-type line, a mechanical device in conjunction with an r-f voltmeter is inserted in series with the transmission line. It consists of a section of rigid coaxial line with a slot along the outer tube to permit loose coupling of an r-f voltmeter probe to the inner conductor. See figure 91. The dimensions of the slotted measuring line are dependent upon the frequency to be measured and the characteristic impedance of the line

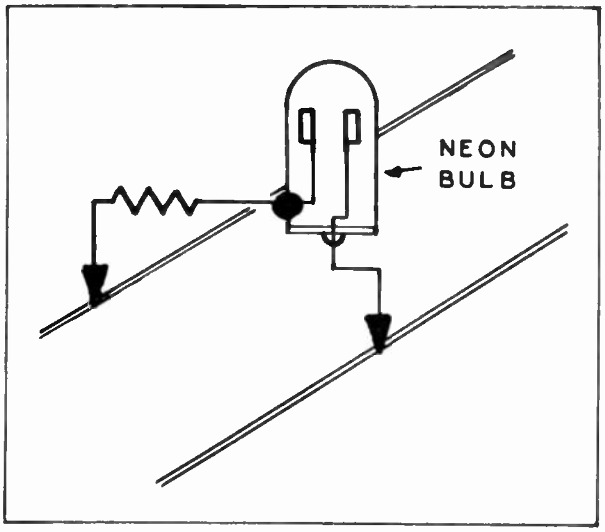


Figure 89. Instrument with Neon Indicator for Measuring Standing Waves of Voltage along an Open-Wire Transmission Line.

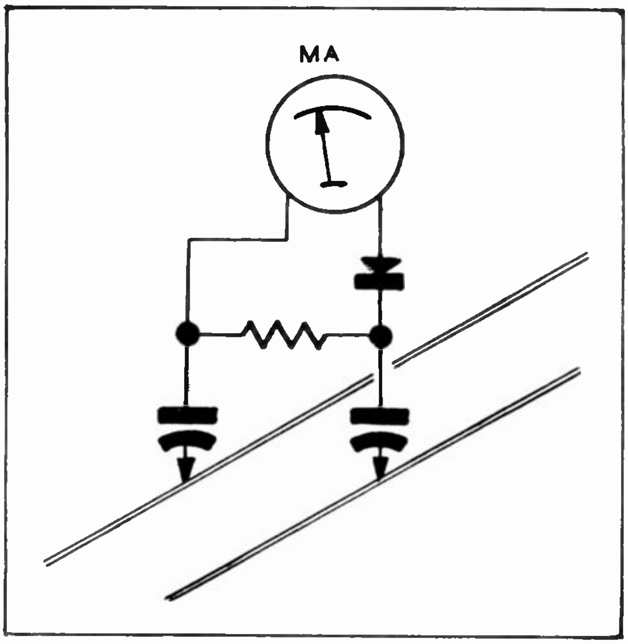


Figure 90. "Trolley System" of Measuring Standing Waves of Voltage at Higher Frequencies along an Open-Wire Transmission Line.

in which it is inserted. The slotted line is used to determine the following:

1. The standing-wave ratio along the line.
2. The nature of the load at a specific frequency in so far as reactance and resistance are concerned.

The r-f voltmeter device used in conjunction with the slotted line is usually a diode or crystal detector with a current meter and tuned input, capacitively coupled to the inner conductor.

The slotted-line measuring devices are generally employed in u-h-f work because of the physical restrictions at the lower frequencies. At frequencies above the v-h-f range, wave guides are used in place of the more common types of transmission lines, and they usually incorporate matching devices and slotted measuring lines or else they are accurately designed for the specific application desired.

STANDING WAVES ON TRANSMISSION LINES

At this point it is important to differentiate between standing-wave effects on resonant and nonresonant lines.

In the case of resonant lines, a maximum ratio of standing waves exist. No adverse effects are produced by this condition if certain precautions are observed. (These precautions are given later in the discussion.) This type of line is simple in construction and is advantageous to use in temporary or field installations.

A line is considered nonresonant when the standing-wave ratio is reduced to a negligible value. The losses on this type of line resolve into line attenuation and

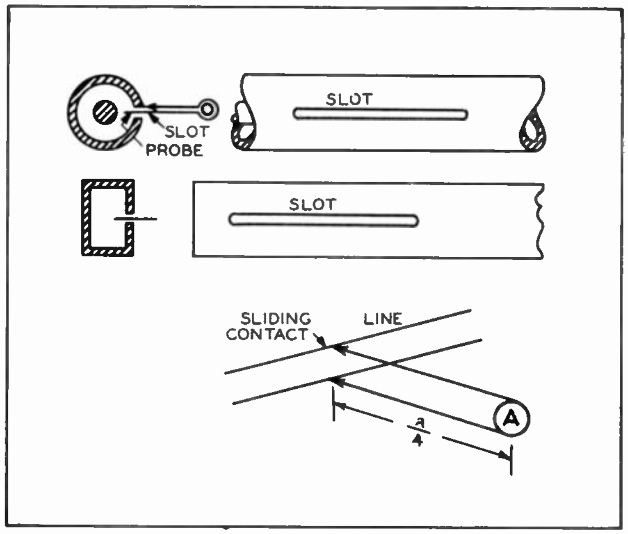


Figure 91. Coaxial Transmission Line and Rectangular Wave Guide, Showing Slotted Sections for the Measurement of Standing-Wave Ratio.

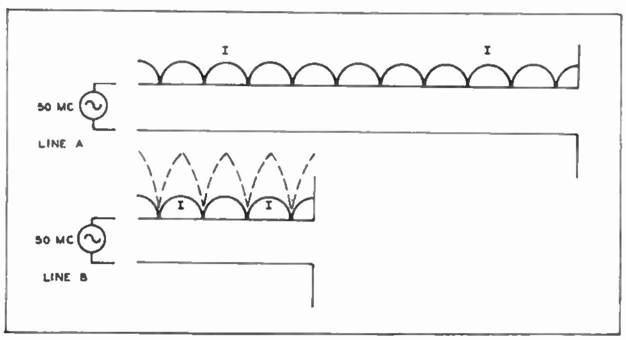


Figure 92. Effect of Length and Amplitude of Standing Waves of Current on Transmission-Line Losses.

ohmic losses, which are directly proportional to length. This type of line is widely used in permanent or semi-permanent installations where high efficiency warrants the detailed work required.

STANDING WAVES ON NONRESONANT LINES

The power losses in the form of heat and radiation, caused by standing waves on the line, increase as the standing-wave ratio and the length of the line increase. (The line approaches a matched, or "flat" condition, when the standing-wave ratio approaches 1 to 1.) Refer to figure 92. Both the lines in this figure have the same power input, frequency input, and output impedance. Also the same standing-wave ratio exists on both lines. Line A, however, has ten maximum current points existing along its length, while line B has only four. Consequently line A is dissipating more energy in the form of radiant heat. If the mismatch on line B were changed to produce a larger standing-wave ratio, as shown by the dotted line, the losses in line B (due to current heating and radiation loss) would approach those of line A. Excessive standing-wave currents make a coaxial cable quite warm. One way of detecting an excessive mismatch between the transmitter and antenna at moderate power is to feel the coaxial line after several minutes of operation. Warm spots on the line are a positive indication of standing waves and, consequently, of a mismatched condition between the line and the antenna.

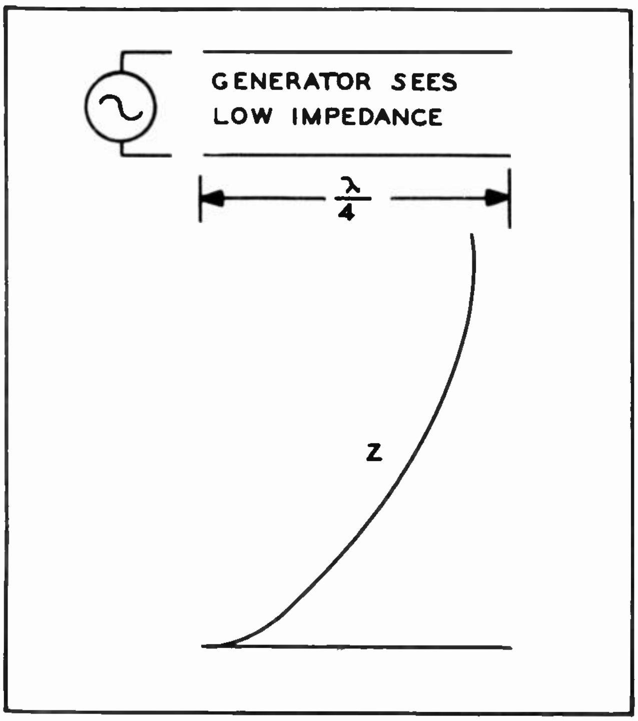
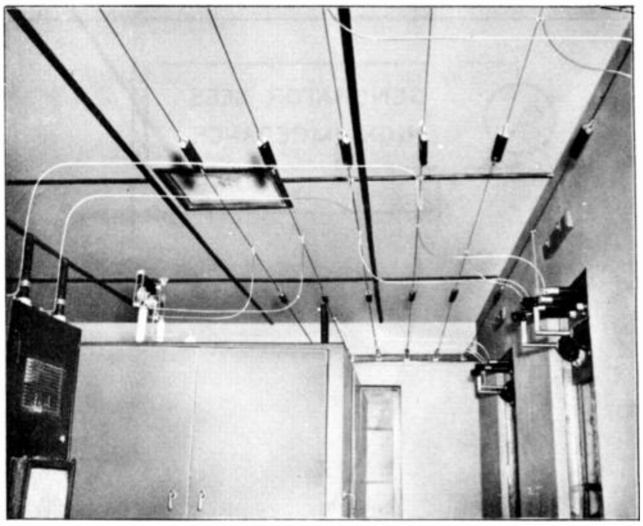


Figure 93. An Open Quarter-Wave Section of Transmission Line Used as an Impedance-Transforming Device to Transform a Low Impedance to a High Impedance.



Inside View of a Transmitter Building, Showing a Typical High-Power Transmission-Line Feeder System.

Methods of Reducing Standing Waves On Nonresonant Lines

Several methods of minimizing standing waves on a transmission line are in common use. A properly constructed transmission line which matches the impedance of an antenna has minimium standing waves. If the line does not match the antenna, impedance-matching transformers or other matching devices can be used.

Theory of Operation

The action of a quarter-wave section in impedance matching can be analyzed as follows. (see figure 93): A generator connected to a $\lambda/4$ section of line with an open termination "sees" a low impedance. A generator connected to $\lambda/4$ section of line with a shorted termination sees a high impedance. See figure 94. Thus, a $\lambda/4$ section has the property of "inverting," that is, a high or low impedance at one end appears as a low oı high impedance, respectively, at the other end. For example, if a low-impedance load is connected to a $\lambda/4$ section, the generator sees a high impedance and if the generator is a high impedance the load sees a low impedance. Carrying the analysis a bit further, it can be shown that an even multiple of a quarter wave length line repeats (see figure 95), while an odd multiple of a quarter wave length line inverts. This makes apparent the fact that a half wave length section of transmission line is similar to a 1:1 transformer.

MATCHING SECTIONS

A quarter-wave matching section can be used if both the line impedance and antenna input impedance are known and the antenna is resonant at the frequency of the radio wave exciting it. A special quarter-wave section of transmission line, commonly called a

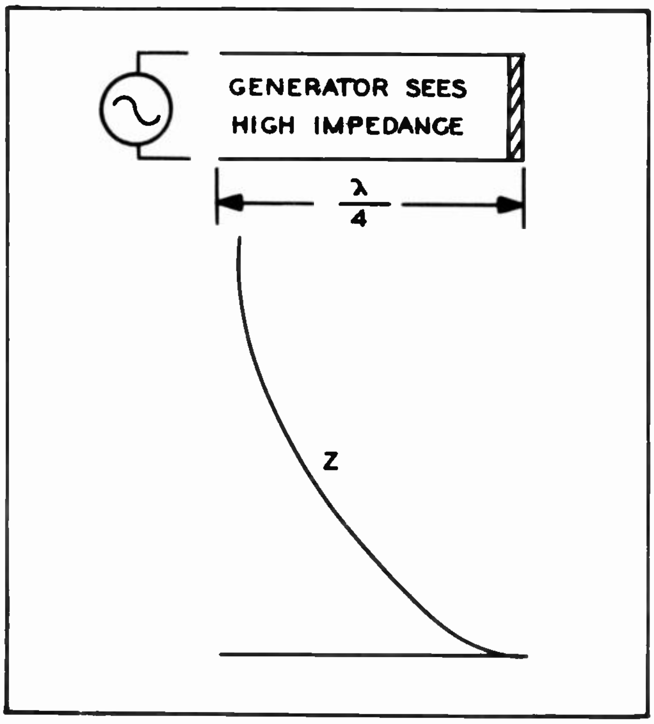


Figure 94. A Shorted Quarter-Wave Section of Transmission Line Used as an Impedance-Transforming Device to Transform a High Impedance to a Low Impedance.

Q bar, is inserted between the original transmission line and the antenna, as shown in figure 96.

The required characteristic impedance (Zo) of this quarter-wave section can be calculated by the following formula:

$$Z_o = \sqrt{Z_{in} \times Z_{out}}$$

where: Z_{in} = characteristic impedance of the transmission line

Z_{out} = impedance at point of coupling on antenna

Substuting the values in figure 96 in the formula:

$$Z_o = \sqrt{600 \times 72}$$
$$Z_o = \sqrt{43200}$$
$$Z_o = 207.8 \text{ or } 208 \text{ ohms.}$$

The dimensions for a quarter-wave section having a Zo of 208 ohms can be estimated by using the formula for parallel conductors, found on page 44.

The proper length of the quarter-wave section can be calculated from the formula:

$$\text{Length in feet} = \frac{234}{\text{frequency in mc.}}$$

This matching section is most effective at the frequency for which it is designed, however, it may be operated on adjacent frequencies as long as the standing-wave ratio on the line does not become excessive.

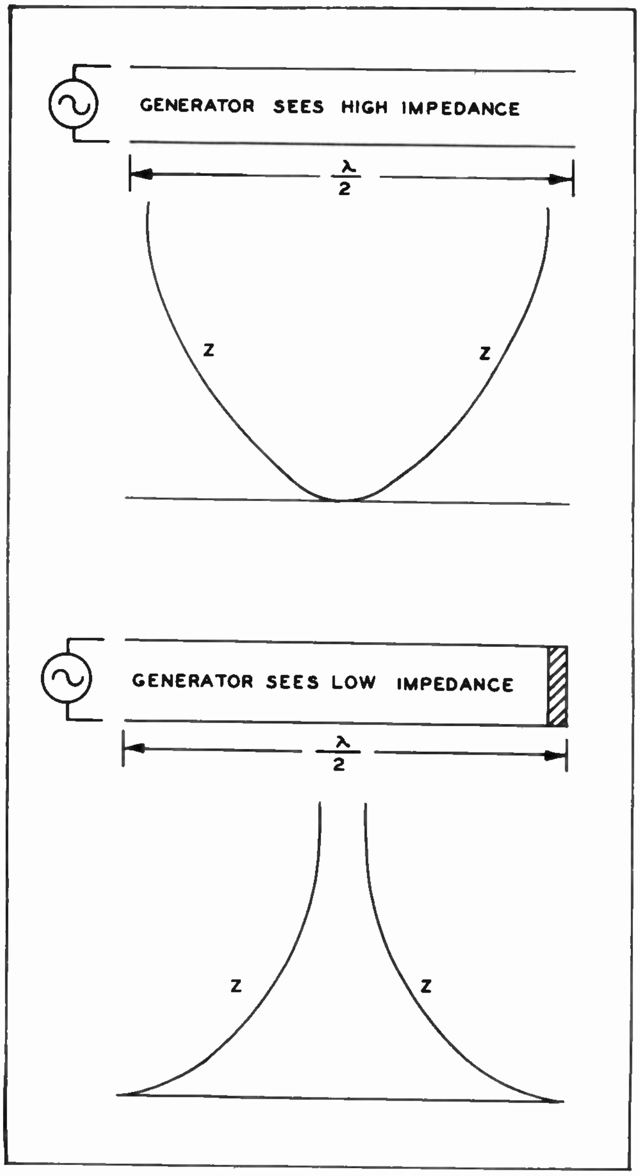


Figure 95. Impedance-Transformation Effects on Open and Shorted Half-Wave Sections of Transmission Line.

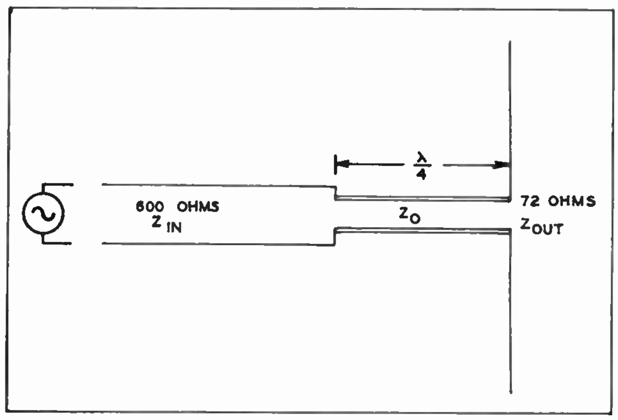


Figure 96. Q-Bar Matching Section.

Another common type of matching device incorporates an accurately constructed $\lambda/4$ section of transmission line, shorted at one end, with one leg of the other end attached to an end of the antenna. See figure 97. The transmission-line feeders are attached along the length of the $\lambda/4$ line at the points which produce the proper impedance match, i.e., best efficiency. When used in this manner the quarter-wave section is called a matching stub. A matching stub may also be used in coupling a center-fed, half wave length dipole to a high-impedance line. See figure 98.

An antenna and a transmission line can be matched, also, by spreading the feeder lines near the points of connection to the antenna. See figure 99. This method of matching is called "delta-matching"; it provides a gradual impedance transformation so that the proper match is obtained. Its disadvantage lies in the fact that it is very critical to adjust and cannot be used on harmonic frequencies. It has good efficiency on a very narrow band of frequencies.

With a half-wave antenna cut to the proper length at the center of the desired band of frequencies and a transmission line having a high characteristic impedance as compared with the 73-ohm center of the antenna, the angle of spread of the wires and the distance between the tap-on points at the antenna (see figure 99) can be approximated by the following data:

X = approx. 0.48λ
Y = approx. 0.12λ
Z = approx. 0.15λ
H is usually less than $\lambda/4$

The above data is most accurate when a 600-ohm transmission line is used. The exact length of the horizontal half-wave section must be determined by trial and error, because the length depends upon the effects of the ground, the height above ground, the frequency, and the surrounding structures. In practice, the dimensions Y, Z, and H are constructed as specified and only the length of the horizontal half-wave is adjusted by trial-and-error methods to give a practical match.

Another impedance-matching device, which is useful for coupling from an unbalanced (coaxial) line to a balanced antenna, such as a dipole, rhombic, etc., is constructed as follows: An electrical half wave length of the coaxial cable is prepared for connection at both ends. This section of line is doubled upon itself and taped or tied to the original transmission line, as shown in figure 100. The outer braids of the three ends of cable are soldered together and the inner conductors are connected as shown. The output impedance from this $\lambda/2$ transformer is equal to approximately 4 times the impedance of the coupled line itself. As an example of the application of this device, it could be used to couple a 70-ohm coaxial line to a folded dipole, which has an impedance of 300 ohms at the center. With the aid of this device, any coaxial line may be used to feed a balanced system of relatively high impedance. However, it finds the widest usage with receiving antennas.

Another impedance-matching device, which is practical only in low-frequency work, consists of an air-core transformer, designed to resonate at the mean frequency of operation. See figure 101.

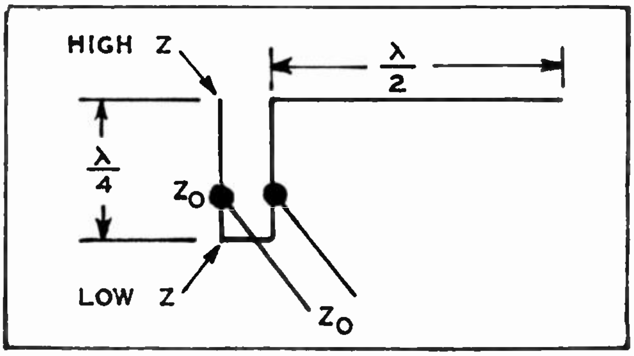


Figure 97. Use of a Shorted Quarter-Wave Section of Transmission Line for Impedance-Matching an End-Fed Half-Wave Antenna to a Transmission Line.

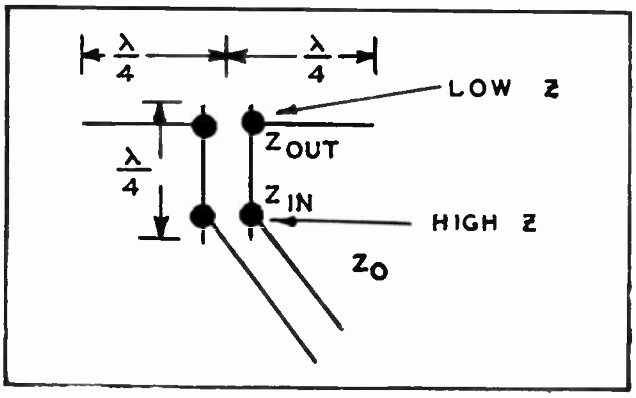


Figure 98. Use of an Open Quarter-Wave Section of Transmission Line for Impedance-Matching a Center-Fed Half-Wave Antenna to a Transmission Line.

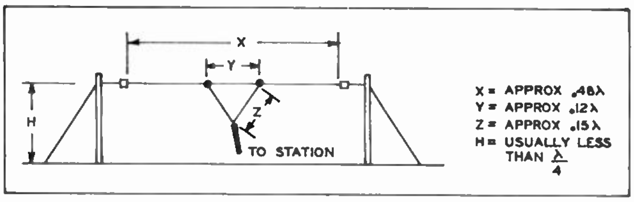


Figure 99. Delta-Matching System Used as an Impedance-Transformation Device.

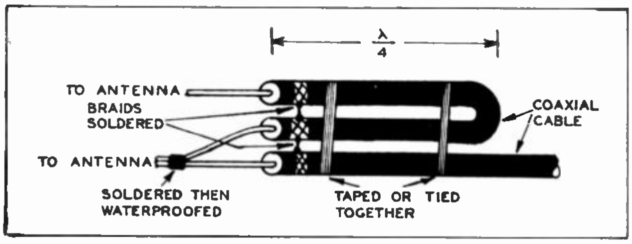


Figure 100. Half Wave Length Section of Coaxial Transmission Line Used as an Impedance-Transformation Device.

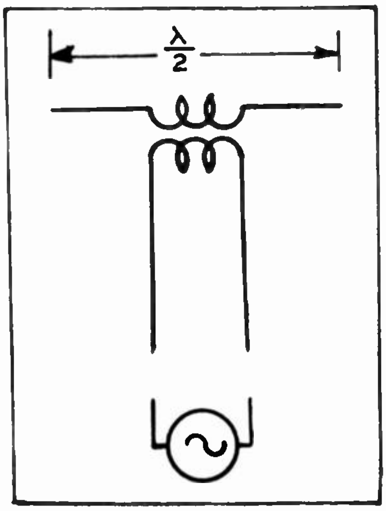


Figure 101. Air-Core Transformer Used as an Impedance-Transformation Device.

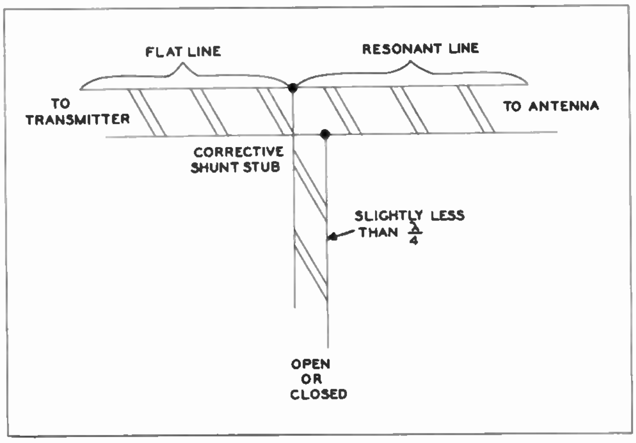


Figure 102. Method of Connecting a "Corrective" Stub to a Transmission Line.

Corrective Stubs

In a case where a long length of transmission line is required for a specific application and an impedance mismatch exists at the antenna, a device known as a corrective, or shunt, stub can be used to reduce the standing-wave losses incurred. See figure 102. This stub is a section of open-wire transmission line which has the same Zo as the feeder line; the end not connected to the transmission line can be either open or shorted, depending upon the length of the stub and the point of connection to the line.

At any point along a transmission line, upon which standing waves exist there is a specific impedance. This impedance may be extremely high or extremely low, or it may be intermediate in value with an inductive or capacitive component. A stub section of open-wire line of a length less than a quarter wave length presents an impedance, at its point of connection to the transmission line, which is either capacitive or inductive, depending upon whether it is open or shorted, and of an amount depending upon its length.

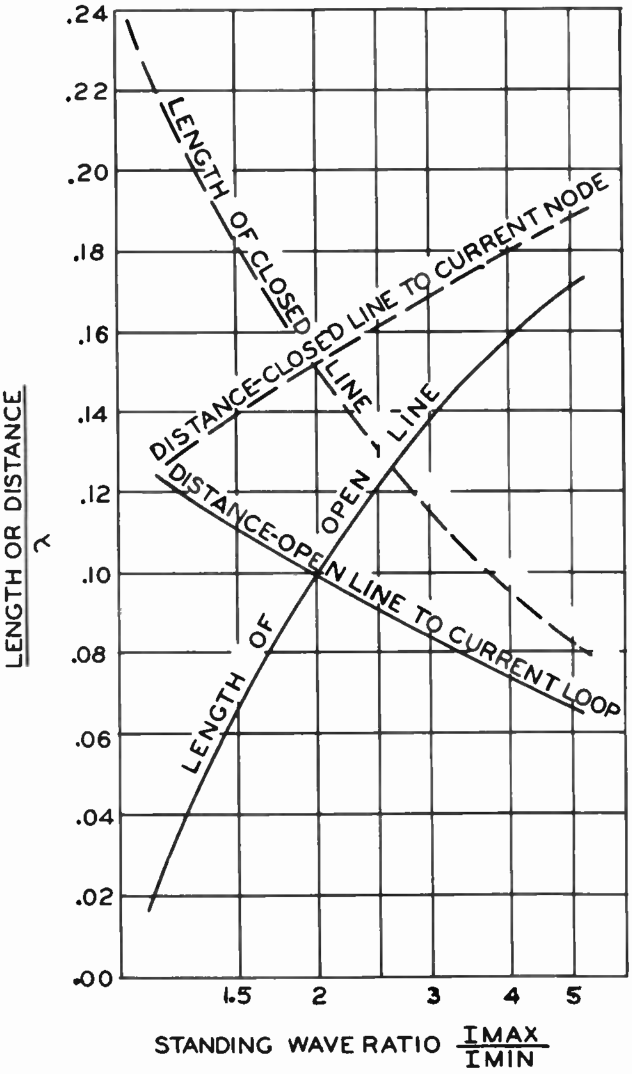
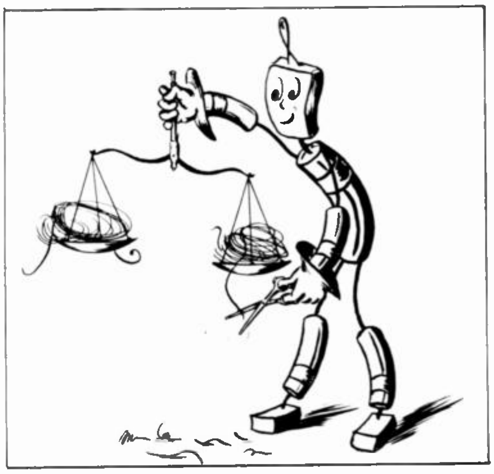


Figure 103. Graph for Determining the Length of a Corrective Stub and its Corresponding Point of Connection to the Transmission Line for a Given Relative Standing-Wave Ratio. All Distances are Measured from the Current Loop or Node Toward the Transmitter.



Therefore, in order to "flatten" a transmission line, a corrective stub may be connected to the line at a point where the reactance of the line is equal to the characteristic impedance of the line; when the stub is adjusted so that it has an impedance of equal value but of opposite sign to that at the point of connection, the reactive component existing on the transmission line at that point is cancelled, and the line appears to be terminated in its characteristic impedance.

Figure 102 shows a "corrective stub" connected to a transmission line. If the antenna is elevated so that the connection point of the stub at the transmission line is not accessible, the stub length may be extended by one or more half wave lengths.

The graph shown in figure 103 may be used to determine the point of connection of the stub to the transmission line as well as the stub length if the position of the standing waves of current and the standing-wave ratio are known. An open stub is used at a current loop while a shorted stub is used at a current node. In order to reduce losses in the transmission line to the greatest degree, the point of connection of the stub should be located as close as possible to the antenna.

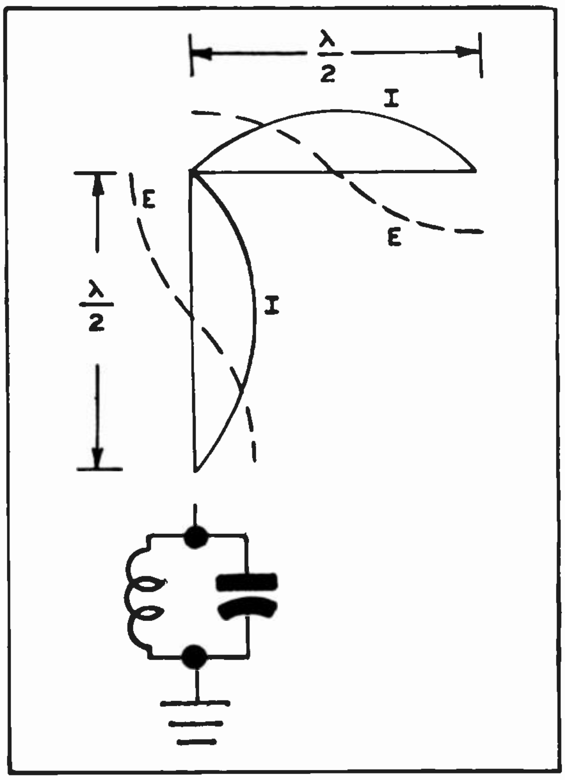


Figure 104. Standing Waves of Voltage and Current on a Half-Wave, Single-Wire, Resonant Transmission Line Used to End-Feed a Half-Wave Antenna.

Check of Impedance Match

Before connecting a transmission line to an antenna, make the following quick check to determine whether the antenna properly terminates the transmission line. It is assumed that the line-coupling circuit is properly matched to the final-amplifier plate circuit.

1. Determine the characteristic impedance of the transmission line and terminate the line with a noninductive resistance of a value equal to the characteristic impedance, and of sufficient wattage to dissipate the power to be applied.

2. Insert an r-f ammeter in series with one leg of the transmission line at the point of load termination.

3. Apply power to the line and note the r-f ammeter indication. Change the value of the terminating resistance until maximum meter indication is obtained. Calculate the power according to the formula, $P = I^2R$.

Note: In a two-wire line, the r-f ammeter should be inserted in series with each leg of the line at corresponding points on each conductor. The two readings obtained should be equal, indicating proper balance. In the formula, I equals the current reading on the r-f ammeter.

4. Turn off the power and remove the noninductive resistor from the transmission line.

5. Terminate the transmission line with the antenna to be used. Note: The matching section or the impedance-transformer device should be connected and adjusted so that the transmission line is properly terminated.

6. Apply power to the transmission line and note the r-f ammeter indication. Calcuate the power by means of the formula, $P = I^2R$.

7. Compare the two values of power calculated in steps 3 and 6. They should be approximately the same, indicating the proper impedance match. Readjustment of the matching device may be necessary to produce maximum line current.

8. If, in step 6, the currents in the two legs of the transmission line are unbalanced, the antenna system has a reactive component. Slight compensation for this reactance can be made by changing the length of one leg of the line or by inserting a variable series capacitor at the transmitter end of the line.

The radiation from the transmission line should be determined at the same time that the check in step 3 above is made. Signal-strength readings should be taken with a good receiver located about a mile away. Lengthen one side of the line and then cut off an inch or two of the added section at a time until the lowest radiated signal strength is indicated. At this point, the electrical symmetry of the line is achieved. The "flattest" standing-wave condition is attained when the r-f current indicator shows a uniform decrease in current as it is moved along the line from the transmitter to the antenna.

Standing Waves on Resonant Lines

The position and amplitude of the standing waves on a resonant transmission line is of primary impor-

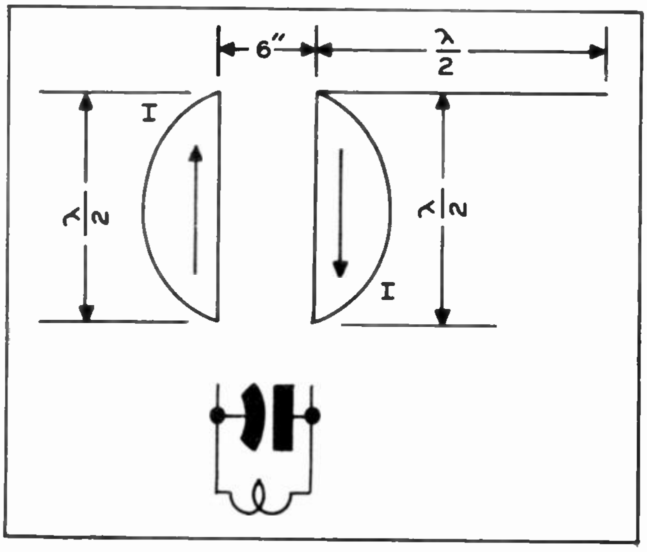


Figure 105. Zepp Feed System.

tance for an efficient antenna system. A transmission line of this type is actually an integral part of the antenna which it feeds, and the standing waves on the antenna are extended along the length of the transmission line. Since maximum amplitude of the standing waves is required for maximum radiation from the antenna, the length of the transmission line is of utmost importance.

The standing waves on the transmission line cannot be decreased without decreasing the radiation from the antenna. Radiation losses from the transmission line can be limited by keeping the line as short as possible. Stated another way, a resonant line which is an appreciable number of wave lengths long is not suitable for high power work.

A resonant line may be used to transfer power from the transmitter to a half-wave antenna, as shown in figure 104. The current and voltage distribution on the antenna and transmission line are also shown. Because this type of feed requires high voltage at the point of connection to the antenna, it is commonly called a "voltage feed." For this method of feed the transmission line should be approximately a half wave length long. Small errors in length can be corrected by adjustment of the tuning capacitor. Large errors can be compensated for by adding series capacitance and inductance. For best results, the feed line should be at a 90° angle with respect to the antenna.

Another type of voltage feed, known as the Zeppelin (Zepp) feed system, eliminates a great deal of the radiation loss incurred in a single-wire, voltage-fed antenna system. This is accomplished by placing a wire parallel to the normal feed line and feeding it with power of opposite phase to produce cancellation, and thus reduce radiation. The distance between the parallel feeders should be 6 to 12 inches (standard spacer

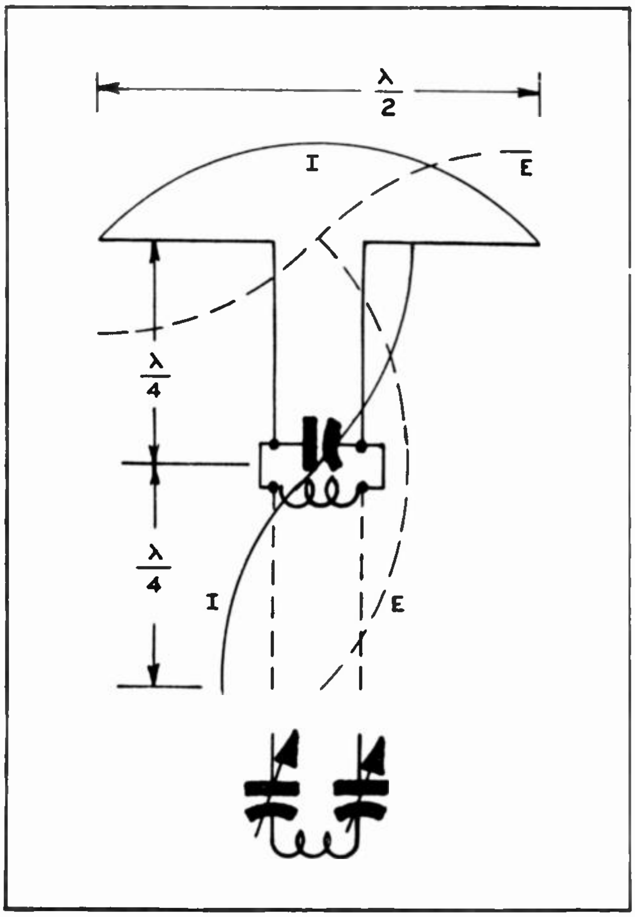


Figure 106. Standing Waves of Voltage and Current on a Quarter-Wave and a Half-Wave, Open-Wire Transmission Line When Used to Center-Feed a Half-Wave Antenna.

insulator dimensions), but may be varied for best efficiency. See figure 105.

Note that when using a resonant line an even number of quarter wave lengths long, a parallel-resonant output circuit is required at the transmitter to voltage feed the antenna shown in the example. Conversely, when it is required to couple a parallel-resonant output circuit of a transmitter to a high-impedance point on an antenna, a resonant line of an even number of quarter wave lengths must be used. If it is required to couple a series-resonant output circuit of a transmitter to a high-impedance point on an antenna, a resonant line of an odd number of quarter wave lengths must be used.

A resonant line may be used to transfer power from the transmitter to a half-wave antenna, as shown in figure 106. The current and voltage distribution on the antenna and transmission line are also shown. Because this type of feed requires high current at the point of connection to the antenna, it is commonly called "current feed." For best efficiency when using this method of feed, the transmission line should be approximately a half wave length long. Small errors in length can be corrected by adjustment of the coupling capacitor or capacitors. Large errors can be compensated for by adding series capacitance or inductance.

Note: The length of the resonant line depends upon the type of output circuit at the transmitter. If the transmitter output circuit is of the parallel-resonant type, the resonant line must be an odd number of quarter wave lengths long when feeding a low-impedance point on the antenna. If the transmitter output circuit is of the series resonant type, the resonant line must be an even number of quarter wave lengths long when feeding a low-impedance point on the antenna.

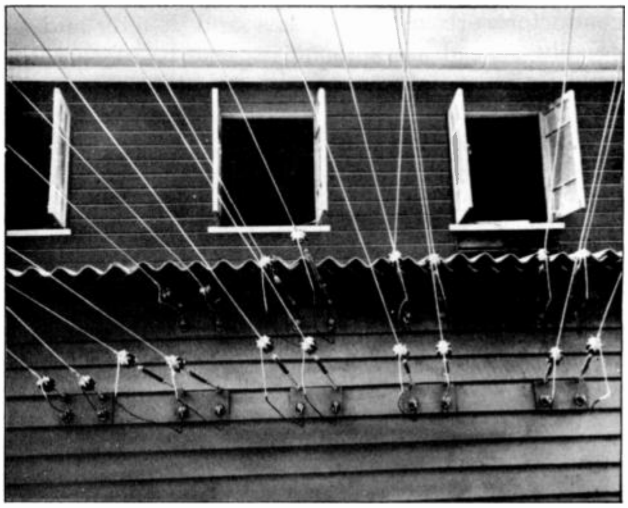
The method of feed to use depends upon many factors, the most important of which are the type of equipment available and the desired type of antenna system for that equipment. With high-power equipment, it is more practical to use current (low-impedance-point) feed so that the peak voltage on the transmission line will have the lowest possible value, thus reducing the danger to personnel. With low-power equipment, it is more practical to use voltage (high-impedance-point) feed. Either single or two-wire feeders may be used, the two-wire feeders being the more efficient of the two. For more detailed information on this subject, refer to Methods of Feed at the Antenna on page 64.

Transmission-Line Attenuation

In a transmission line the energy lost must be as little as possible, whereas with an antenna the radiation loss must be as great as possible. The energy lost along a line can be expressed in decibels per unit length (mile, meter, free-space wave length, or electrical wave length). For the general observations which follow the values given are in db. per electrical wave length. The losses for various types of transmission lines are as follows:

1. Nonresonant parallel wires—0.12 to 0.15 db.
2. Rubber-insulated twisted pair or coaxial line—1.00 db.
3. Dry lamp cord—about 1.4 db.
4. Dry air-insulated coaxial—very small.

The losses are directly proportional to the length of the line; in this case, the number of wave lengths is the multiplying factor.



Two-Wire Feed Lines Terminated at Transmitter Building with Spring-Supported Strain Insulators.

Transmission-Line Velocity Factor

Radio-frequency energy travels more slowly on a conducting line than through free space. The ratio of the speed of r-f energy in a conductor to its speed in free space is known as the velocity factor (K), and is dependent upon the dielectric constants of the supporting and spacing insulators composing the lines. Thus if an electrical wave length is measured on a transmission line, it will be shorter than a physical wave length by an amount depending upon the velocity factor. In the design of impedance-matching sections, it is most important that the theoretical length be reduced by an amount depending upon the velocity factor. Hence a $\lambda/4$ matching section is cut to a $\lambda/4 \times K$. The following is a tabulation of velocity factors (K) for various types of lines:

1. Two-wire open line
   - Large conductors with close spacing and numerous insulators—0.95
   - Small conductors with wide spacing and few insulators—0.98
2. Molded-pair line (Twinex)
   - Dry 300-ohm line—0.82
   - Dry 150-ohm line—0.77
   - Dry 75-ohm line
     - Receiving type—0.68
     - Transmitting type—0.71
3. Twisted-pair line (dependent upon number of twists per foot)—0.55 to 0.65

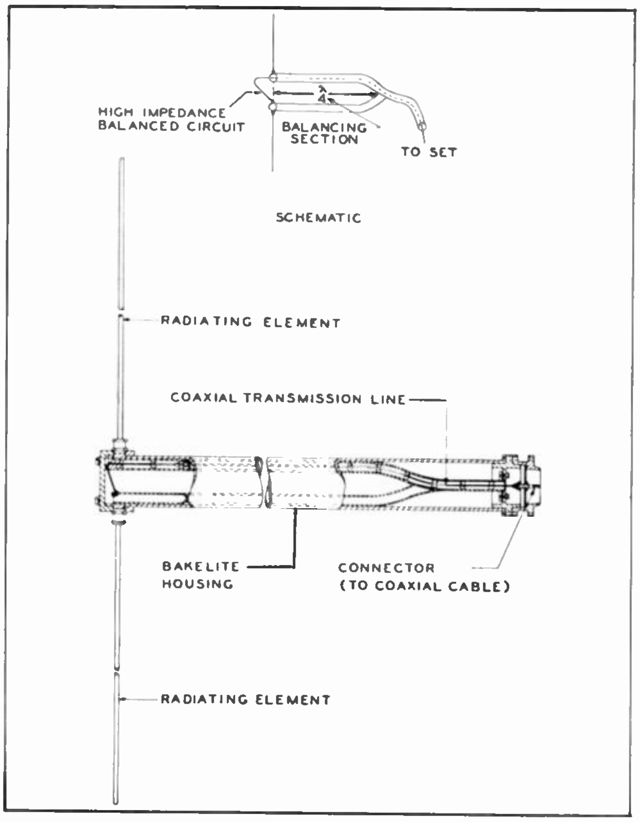
4. Gas-filled coaxial line (dependent upon ceramic material used)—0.83 to 0.94
5. Solid-dielectric coaxial line (polyethylene dielectric)—0.66

Balance and Unbalance in Transmission Lines

A balanced transmission line is a line in which the conductors are of equal size and length and are equally spaced throughout its length, so that they have equal capacity to ground and other surrounding objects. In such a line, the standing-wave currents flowing in the two wires are equal and opposite in phase, so that the fields surrounding the transmission line are cancelled and radiation is minimized.

It must be borne in mind that the primary object of the transmission line is to deliver the r-f energy from the transmitter to the antenna in an efficient manner. If the line is electrically unsymmetrical, the radiation losses are proportional to the amount of unbalance in the line currents. These losses are relatively unimportant if the lines are isolated or remote from nearby conductors, such as guy wires, telephone lines, power lines, rain pipes, etc. Sometimes a line which is physically symmetrical has unbalanced line currents due to the fact that one side of the line is so close to a conducting surface (grounded or otherwise) that considerable coupling exists between the two. The conducting surface has a loading effect upon the side of the line closest to it. Ordinarily, unbalance is not produced by the antenna system as it is usually electrically symmetrical. Acute turns in lines, lines passing closely at oblique angles, unequal lengths of jumpers, and poorly designed line-switching devices at the transmitter are common causes of an unbalanced condition.

Open-wire and insulated-twin-conductor transmission lines are easily balanced because the conductors are the same size and the spacing is constant. When an open-wire line is longer than a wave length, transposition, that is, alternately reversing the position of the wires at regular intervals, is used to preserve its balance to ground and to nearby objects. Special ceramic transposition blocks (feeder insulation) are required. See figure 107.



Vertical Half-Wave Dipole with Coaxial-Cable Balancing Section.

When using Zepp-feed, which is actually end-feed, with a half-wave antenna, an unbalanced-line condition is created, because the length of the antenna is unsymmetrically added to the transmission line. Even though the antenna is cut to an exact half wave, a condition of unbalance still exists. This condition is compensated for by the series capacitors in the transmission line.

When center feeding a half-wave resonant antenna, the problem of balance is simplified because of equal loading, but when a coaxial cable or concentric line is used, the physical arrangement of the inner and outer

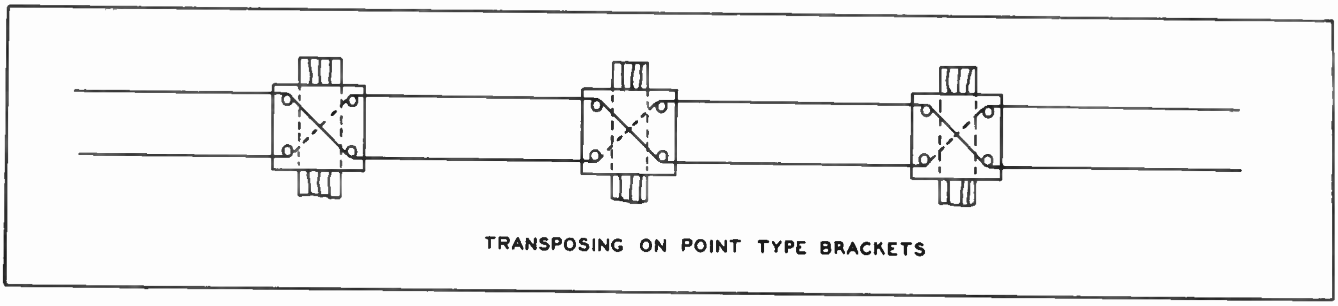


Figure 107. Line-Balancing Method for Open-Wire Lines Using Transposition Blocks.

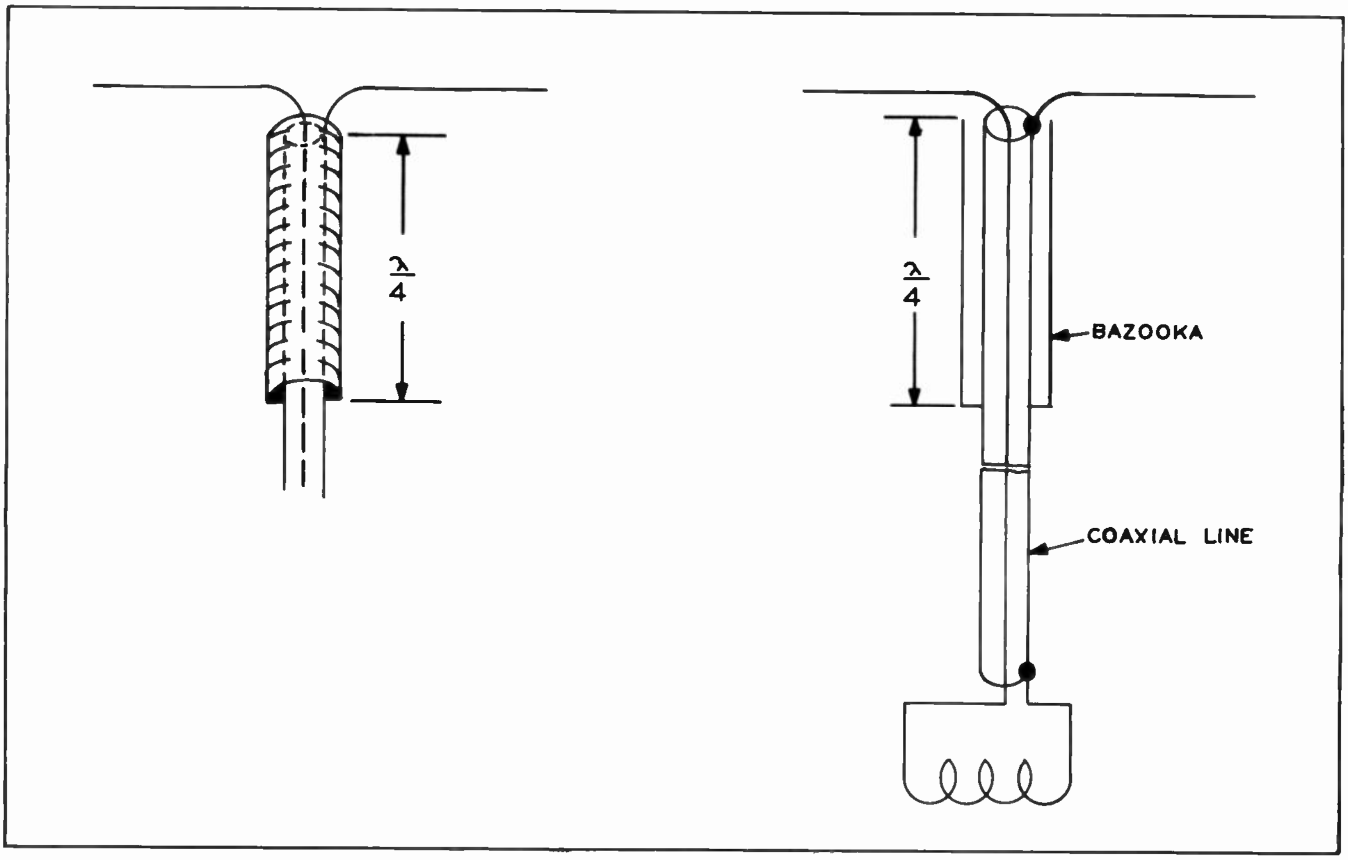


Figure 108. Line-Balancing Device for Coaxial Line, Commonly Known as a "Bazooka."

conductors causes an unbalanced condition. For v-h-f applications utilizing directional arrays, this factor is important because the feed line is generally perpendicular to the desired direction of radiation. This greatly impairs the effective directional qualities of the array and requires the use of a balancing arrangement as described below.

Unbalanced line conditions in an open-wire can be remedied by cut-and-try methods, such as moving the line away from absorbing surfaces and lengthening or shortening one of the sides. Some preventive measures are as follows: Make the line physically symmetrical and keep the spacing between the conductors below .01 wave length. If the spacing is less than 5 inches, more spacing insulators must be used, creating the disadvantage of increased weight.

One method of balancing the line currents requires the use of a detuning sleeve, or "bazooka," at the high-current termination point of a coaxial line. Figure 108 shows the bazooka, which is more commonly used at the higher frequencies. The bazooka is made a quarter wave length long at the operating frequency; the diameter of the bazooka should be much greater than the diameter of the coaxial line.

A variation of the above system of balancing an unbalanced line to feed a balanced antenna is shown in figure 109.

An unbalanced-line condition is more detrimental at higher frequencies, because the transmission-line losses increase with frequency. Therefore, the factor of balanced and unbalanced transmission lines is more important in v-h-f and u-h-f applications.

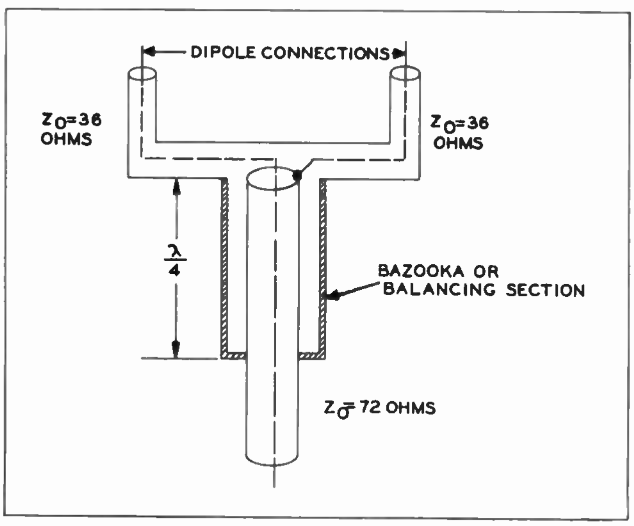


Figure 109. Use of a "Bazooka" and Additional Sections of Coaxial Cable to Balance a Solid-Dielectric Coaxial Transmission Line.

METHODS OF FEED AT THE ANTENNA

The most important factors in determining the method of feed at the antenna are the type of antenna and its impedance characteristics at resonance. The standing-wave distribution on a resonant antenna conforms to the various impedances presented along its length, as was discussed under the subject of Antenna Fundamentals. In order to effect the maximum transfer of power, the transmission line must be attached to the antenna in such a manner that its impedance sees an equivalent impedance at the point where it is connected.

METHODS OF FEED WITH RESONANT LINES

For all practical purposes, a resonant line is connected to an antenna at the highest or lowest impedance point, that is, at the voltage or current loop, respectively. It provides comparatively efficient transfer of power if its length is limited to one wave length. For distances greater than a wave length, a nonresonant line should be used. The resonant feeder line can have the same physical construction as the nonresonant line, but it is essentially an extension of the antenna to which it is connected. It is important, however, to maintain physical and electrical symmetry in the tuned-line construction, so that corresponding points on the line conductors have opposing fields of equal magnitude, and, therefore result in a minimum of radiation.

Two methods of feeding a half-wave antenna with resonant lines are shown in figure 110. Figure 110A shows a half-wave length of resonant line connected directly to the center of a half-wave antenna. At the transmitter end of the line is a series tuned circuit, which has a low impedance at resonance. The load, which is approximately 73 ohms at the center of the antenna, sees a low impedance looking into the half wave length of the line. The line-current balance can be determined by inserting r-f ammeters at points a and b. When the standing-wave currents on each line are measured by moving an r-f milliammeter along the outside of either line, the current curve obtained corresponds to that shown in the figure. Note that a high standing-wave ratio exists because at the current minimum points the current is almost zero while at the maximum points it is relatively high.

If it becomes necessary to construct a coupling circuit like the one illustrated in figure 110A, the following data may prove helpful: For the series-tuned, low-impedance line, low-voltage capacitors, each having the same value as the plate-tank capacitor, may be used. The wire may be the same size as that in the tank circuit. The number of turns on the coupling coils ranges from 15 to 3 for frequencies from 2 to 30 mc., respectively. In tuning a line of this sort, the initial coupling to the plate tank should be loose. Tune the

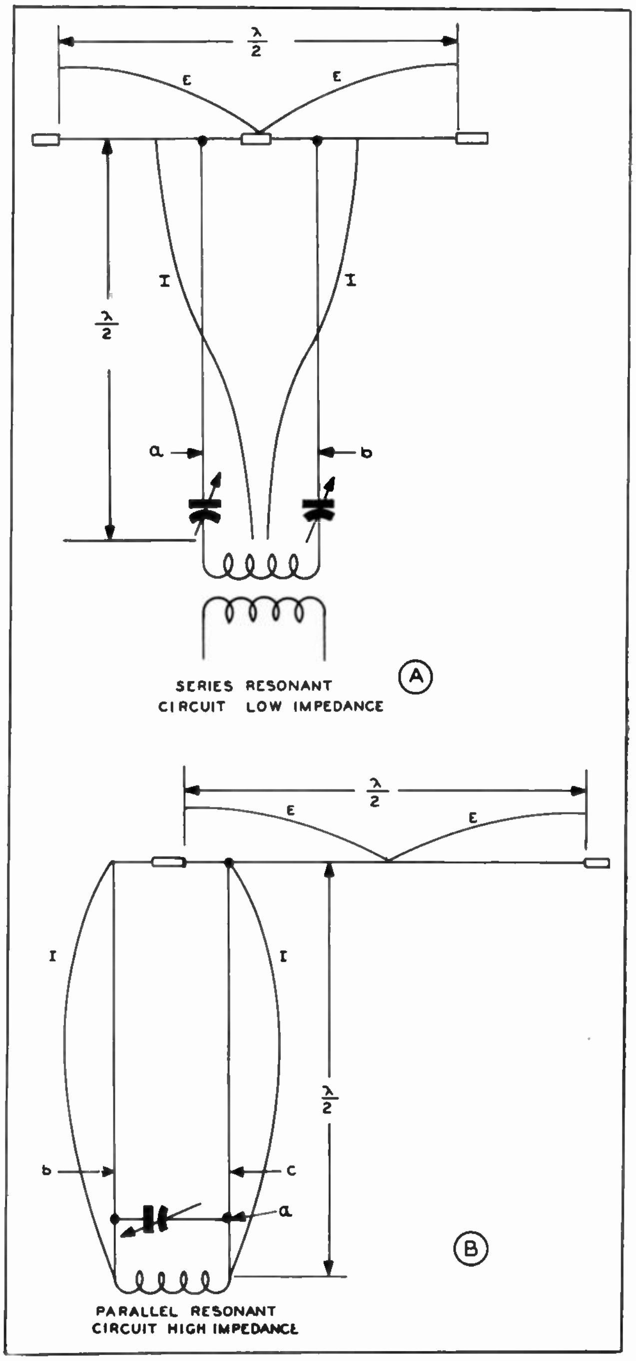


Figure 110. Methods of Feeding Half-Wave Antennas with Resonant Feeder Lines.

series capacitors for maximum balanced current in each feeder line. Tighten the coupling and re-resonate the plate tank circuit. Re-adjust the feeder-line current and increase the coupling between the line and the transmitter until maximum rated plate current is obtained. At this point, only a slight re-adjustment of the tank circuit for resonance should be necessary.

When current meters are not available, small flash-light bulbs can be used at the high-current points. To avoid burn-out of the bulbs due to high power, wire shunts can be used. After the feeder-line tuning ad-

Starboard View of Aircraft-Carrier Island, Showing the Maze of Antennas Used on the Fighting Ships of Today.

justments have been performed, the bulbs may be removed and the system operated. However, the line should be checked periodically for a balanced-line-current condition, because an unbalanced condition will cause unwanted radiation from the feeder lines.

Figure 110B shows a half wave length of a resonant line connected directly to the end of a half-wave antenna. At the transmitter end of the line is a parallel-tuned circuit, which has a high impedance at resonance. An impedance of approximately 2500 ohms exists at the end of the $\lambda/2$ antenna. Since a half-wave section of line acts as a 1-to-1 transformer, the antenna, looking into the feeder line connected to it, sees a high impedance. The reactive components existing at the end of the antenna will be cancelled out when the parallel-tuned circuit is resonated, in the same manner as when the series-resonant circuit was tuned in the center-fed antenna. (Sometimes it is necessary to use a variable condenser in series with one side of the line.)

If it becomes necessary to construct a coupling circuit like the one illustrated in figure 110B, the following data may prove helpful: The physical components of the parallel-resonant circuit should approximate those in the plate tank circuit. Since high r-f voltage exists across the parallel-resonant circuit, the capacitor-plate spacing should be about the same as that used in the tank circuit.

In tuning this circuit, an r-f voltage-indicating device (neon bulb) may be coupled to the transmitter end of the line at point a. Care should be taken when measuring at this point because of the high r-f voltages present. Initially, the tuned section is loosely coupled to the tank circuit, and the parallel tank capacitor is adjusted for maximum r-f voltage indication at the transmitter end of the line. Increase the coupling and again tune the plate tank circuit for a dip. Retune the parallel tank capacitor for maximum r-f voltage indication. Repeat with increased coupling until maximum rated plate current is obtained. If a suitable r-f current reading can be obtained at corresponding points b and c along the feeder lines and an unbalanced line-current condition is indicated, compensation should be made. Refer to Balance and Unbalance in Transmission Lines on page 62. It should be necessary to re-resonate the plate tank circuit only once after the line is first tuned.

Figure 111 shows a center-fed and an end-fed half-wave antenna, using quarter-wave tuned lines. The center-fed half-wave antenna, see figure 111A, has a parallel-tuned circuit, at the transmitter end of the feed line, which develops a high impedance. Thus the load or the center of the antenna, which is a quarter wave length away, sees a low impedance and, therefore, an approximate match is obtained.

The end-fed antenna in figure 111B has a series-tuned or low-impedance circuit at the transmitter end of its feed line. Since a quarter-wave line inverts the impedance, the end of the antenna looking into the line sees a high impedance and, therefore, an approximate match is obtained.

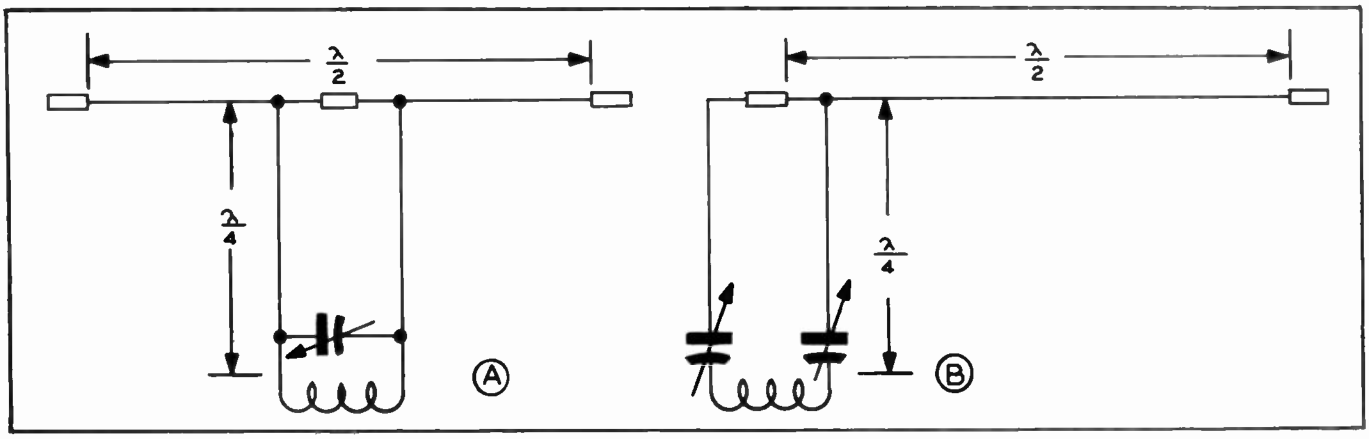
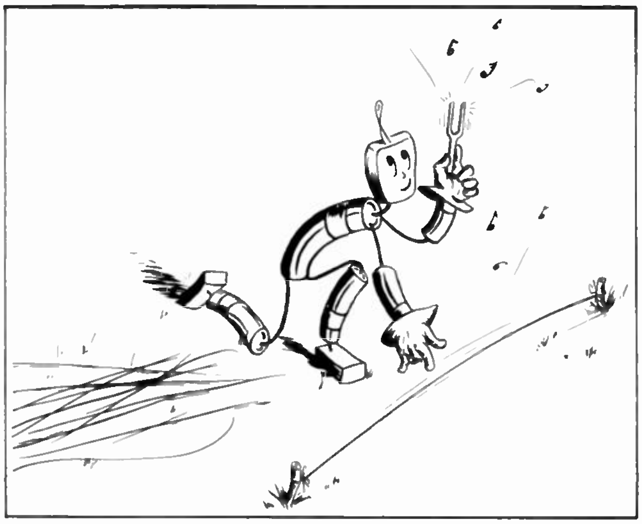


Figure 111. Methods of Feeding Half-Wave Antennas with Quarter-Wave Tuned Lines.



For tuning a half-wave antenna using quarter-wave tuned feed lines, the same procedure as for tuning the half-wave tuned feed lines may be used. Before starting the tuning of the series-resonant circuit in the end-fed line, the capacitors should be set for minimum value, then increased in equal amounts throughout the procedure.

One advantage of the tuned-line system, when a half or quarter wave length line is used, is that the length of the line may vary as much as 20% from the calculated length for the antenna resonant frequency and still operate efficiently. However, the antenna length must be correct for a narrow band of frequencies.

When the center-feed system is used, the half-wave antenna is said to be "current-fed," and when the end-feed system is used, the antenna is said to be "voltage-fed"; that is, if the antenna sees a *low* impedance at the feed point, it is *current-fed* and if it sees a high impedance at the feed point, it is *voltage-fed*.

RESONANT LINES AND HARMONICS

When an antenna system is to be used for multiband operation, a resonant type of feeder system is required, because the line will match the antenna only at the fundamental frequency. The most convenient type of feeder for multiband operation is a single-wire feeder. The single-wire feeder may be attached at one end of the antenna or at a point one-third of the total length of the antenna from the end. In either case, at harmonic frequencies, the feeder is a part of the radiating system and, therefore, the radiation efficiency is reduced. See figure 112 for additional information.

The most practical type of feeder for multiband operation is a two-wire feeder. The two-wire feeder may be attached at the end or at the center of the antenna, which is a half wave length long at the fundamental frequency. Since both lines of a feeder line, center-feeding an antenna, see equal amounts of impedance at any frequency, the feeder line has less unbalance and, thus, less radiation than an end-fed, two-wire feeder. Therefore, a center-fed, two-wire system is preferable for this application.

Whether a single-wire or a two-wire feeder system is employed for feeding a multiband antenna system, the type of tuning in the coupling circuit must be altered as the frequency is changed. The type of tuning, either series or parallel, depends upon the resonant length of the feeder line at the frequency of operation.

METHODS OF FEED WITH NONRESONANT LINES

It must be apparent by this time that a resonant or nonresonant condition of a transmission line is a direct function of the degree of mismatch between the antenna and the transmission line. The standing-wave ratio is the measure of this degree of mismatch. When

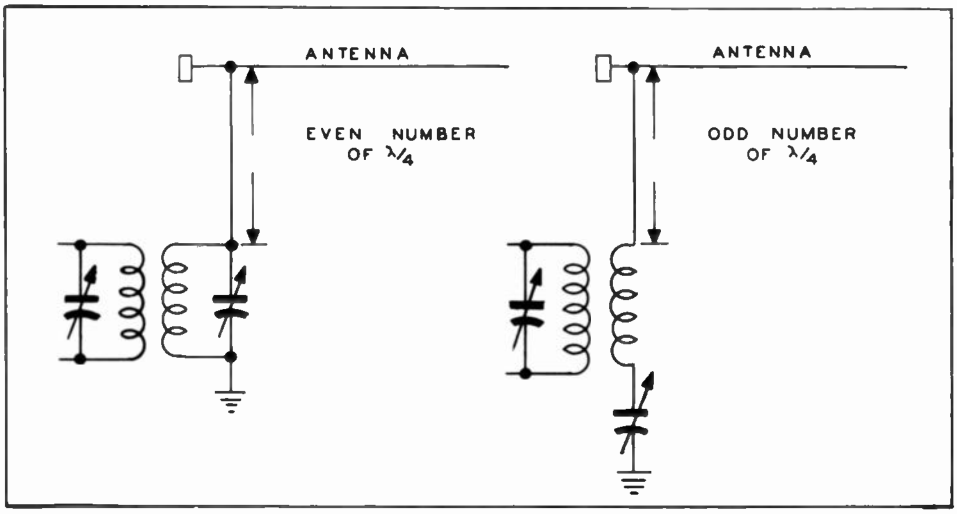


Figure 112. Methods of End-Feeding an Antenna with a Single-Wire Resonant Line.

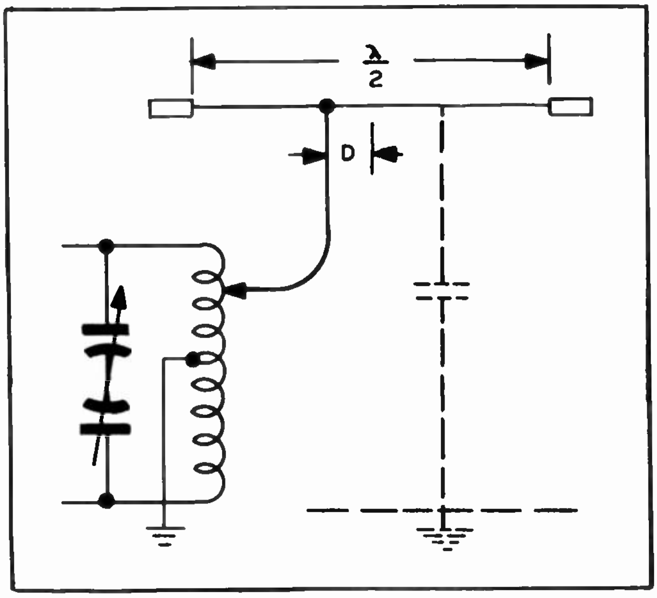


Figure 113. Method of Off-Center-Feeding a Horizontal Half-Wave Antenna with a Single-Wire Nonresonant Line.

a standing-wave ratio of 1.5 to 1 is obtained, for all practical purposes the feed line approaches a nonresonant condition. In selecting the method of feed, bear in mind that a reasonable degree of accuracy in construction is required to reduce the standing-wave ratio; therefore, the most applicable and practical method of feed for the problem at hand should be used.

SINGLE-WIRE FEED SYSTEM

This feed system, illustrated in conjunction with a horizontal half-wave antenna in figure 113, has the advantage of simplicity of adjustment and ease of construction. If the line is properly terminated at the antenna, it can be extended to any reasonable length. This type of feed system should be employed only when the site has a moist or highly conductive ground, because the capacity of the antenna to ground acts as the return path for the radio-frequency currents flowing in the antenna.

The distance D, from the center of the antenna to the point at which the single-wire feeder is connected, is approximately 14% of a half wave length. This point represents an impedance of approximately 500 or 600 ohms along a resonant antenna. The feeder should be brought straight down from the antenna for a distance of at least one third the length of the antenna.

Assuming that a single-ended tank coupling system is used, the tuning procedure is as follows: First, tap the feeder on the tank coil at a point of low r-f potential. Resonate the plate tank circuit and then move the tap in small steps toward a higher r-f potential point, until the antenna is loaded at the safe operating current point of the final tube. The plate-tank capacitor is re-resonated, of course, each time the tap is moved.

Maximum efficiency is obtained at the resonant frequency of the antenna. However, it can be operated within a small range of frequencies to either side of the resonant frequency with satisfactory results.

TWISTED-PAIR FEED SYSTEM

This feed system, shown in conjunction with a horizontal half-wave antenna in figure 114, is easy to install and has a low r-f potential due to its low impedance, but it is the least desirable type of nonresonant feed system from an efficiency standpoint.

Ordinary lamp cord or field telephone wire can be used. One type of twisted-pair line, the EO-1 cable, is fairly satisfactory at the lower high frequencies. Since the Zo of a twisted-pair feeder approximates 70 ohms, it may be used to feed the center of a half-wave antenna. In some cases, it may be necessary to "fan" the connection to obtain a proper match. If the twisted-pair line is not weather-proofed, it is practically useless for damp-weather conditions and should be used only for emergencies.

COAXIAL-CABLE FEED SYSTEM

Figure 115 shows a coaxial cable connected to the center of a half-wave antenna; this type of feed system finds universal use. The advantage of this system lies in the fact that the low impedance of the cable matches the low impedance at the center of the antenna. The coaxial cable can be used also for feeding an antenna array, provided that a matching system is used between the antenna and the line. The lower impedance limit of practical commercial coaxial cables is about 27 ohms, while the input impedance of an antenna array, such as a parasitic array, reaches a value as low as 4 ohms.

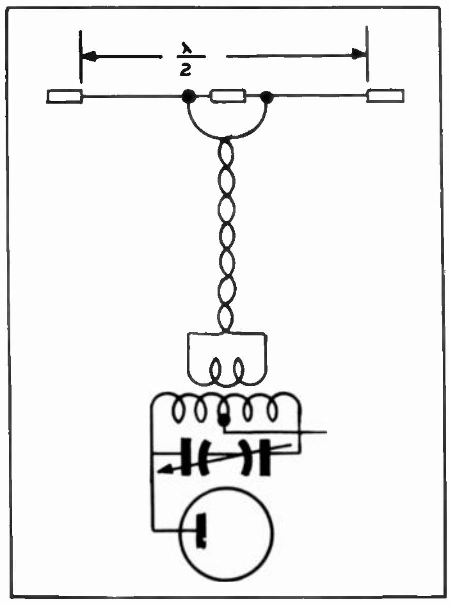


Figure 114. Method of Center-Feeding a Half-Wave Antenna with a Twisted-Pair Feed Line.

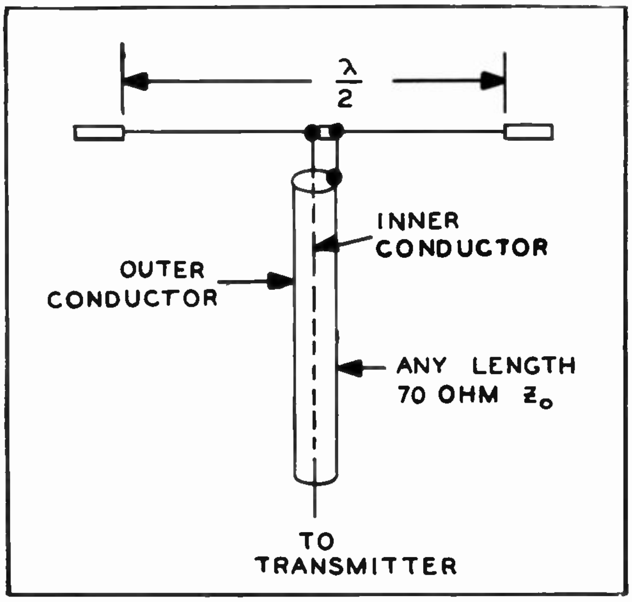


Figure 115. Method of Center-Feeding a Half-Wave Antenna with a Coaxial-Type Feed Line.

Various types of dielectrics are used in coaxial cables, each material having a specific dielectric constant. In all cases, the dielectric loss or the attenuation per unit of length depends upon the type of dielectric used. Since the conductors are closely spaced, the radiation from the line is a minimum, particularly if the line currents are balanced.

A feeder system employing a coaxial cable is especially suitable for coupling a transmitter to a Marconi antenna. Since one end of the Marconi is grounded, a good line balance to ground of the line currents is obtained by grounding the outside conductor of the line.

Concentric lines, which use copper or brass tubing and ceramic spacers and have an air dielectric (see figure 116), are generally used for special applications, such as in high-frequency receiver installations where it is desired to keep noise pickup to a minimum; in this case the line is buried about three feet below the ground. When used for transmitting purposes, the concentric line is filled with a gas and sealed to prevent voltage breakdown.

DELTA-MATCHED FEED SYSTEM

In cases where the characteristic impedance of the transmission line is too high to match by direct attachment of the line to the center of the antenna, an impedance-transformation method must be used. Figure 117 shows a common method of obtaining an impedance match under such conditions. The two conductors of the feeder line are spread apart prior to the points of connection on the antenna, so that the impedance of the transmission line is gradually transformed into a higher value equal to the impedance encountered at the antenna.

For an accurate feeder-line termination, the distances C and E may be calculated by the accompanying formulas, and adjusted for minimum standing waves on the feeder lines.

NOTE: The dimensions obtained by the use of these formulas are accurate only at the fundamental resonant frequency of the antenna and when the feeder-line characteristic impedance is 600 ohms. For a feeder line with a different characteristic impedance, compensation must be made by trial and error.

$$C\ (\text{feet}) = \frac{123}{f\ (\text{mc.})}$$

$$E\ (\text{feet}) = \frac{148}{f\ (\text{mc.})}$$

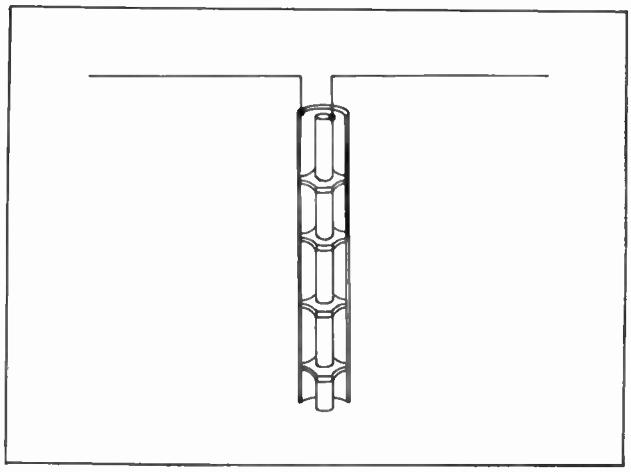


Figure 116. Method of Center-Feeding a Half-Wave Antenna with a Concentric Feed Line.

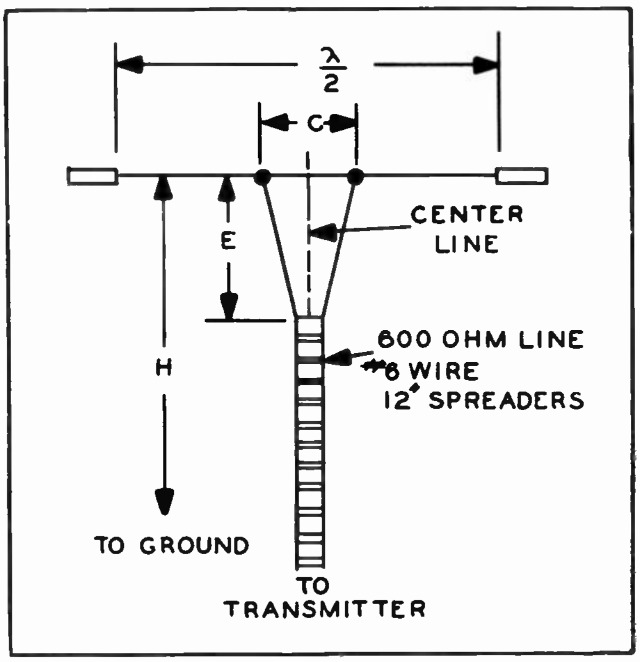


Figure 117. Method of Delta-Matching an Open-Wire Feed Line to an Antenna.

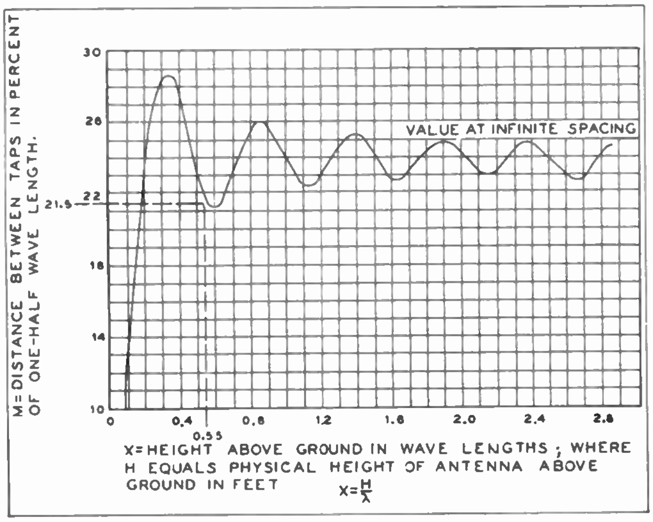


Figure 118. Graph for Determining the Points of Connection for a Transmission Line in a Delta-Matched System.

A useful graph for the approximate determination of the dimension C when using a delta-matched feeder is shown in figure 118.

The following example illustrates how the graph is used in the solution of a practical problem. Suppose that a horizontal half-wave antenna is to be used for general coverage purposes at 6 megacycles and is to be mounted at a height of 90 feet. Delta matching is to be used, and it is desired to determine the distance C between the taps on the antenna and the distance E between the antenna and the point where the spreading of the feeders should start. To solve this problem, proceed as follows: First, determine the physical length (in feet) of a wave length by using the following formula:

$$\text{Wave length (feet)} = \frac{300 \times 3.28}{f\text{ (megacycles)}} = 164.0 \text{ feet}$$

Then, convert the height of the antenna above ground from feet to wave lengths, using the equation:

$X = \frac{H}{\lambda}$ where H is the physical height (in feet) of the antenna above ground.

$$X = \frac{90}{164} = 0.548 \text{ or } 0.55\lambda$$

Locate the value of X on the horizontal axis of the graph in figure 118 and find the corresponding value of M which is 21.5%.

Compute the distance C between taps by multiplying the factor M with the physical length in feet of a half wave length.

$$C = M \times \lambda/2$$
$$C = 21.5\% \times 82$$
$$C = 17.6 \text{ feet}$$

The taps should be connected to the antenna at a distance from the center line equal to one half the value of C or 8.8 feet.

Determine the distance E and locate the end of the transmission line at that distance from the antenna; then string the wires between the antenna and transmission line, fastening them in a temporary fashion because slight changes may be required when making the final adjustments.

The major disadvantage of this type of feed system is the critical nature of the dimensions involved. No matter how accurately the calculations are made or how carefully the constructional details are followed, a slight readjustment of the dimensions will be necessary to improve efficiency.

The principal advantage of delta-matched feed system, which employs a balanced transmission line, is that the radiation from the line is kept at a minimum at the frequency for which it was designed. With this type of antenna feed, therefore, two transmitters can be operated simultaneously on adjacent frequencies without detrimental interference. For minimum reaction between the transmitting systems, the antenna ar-

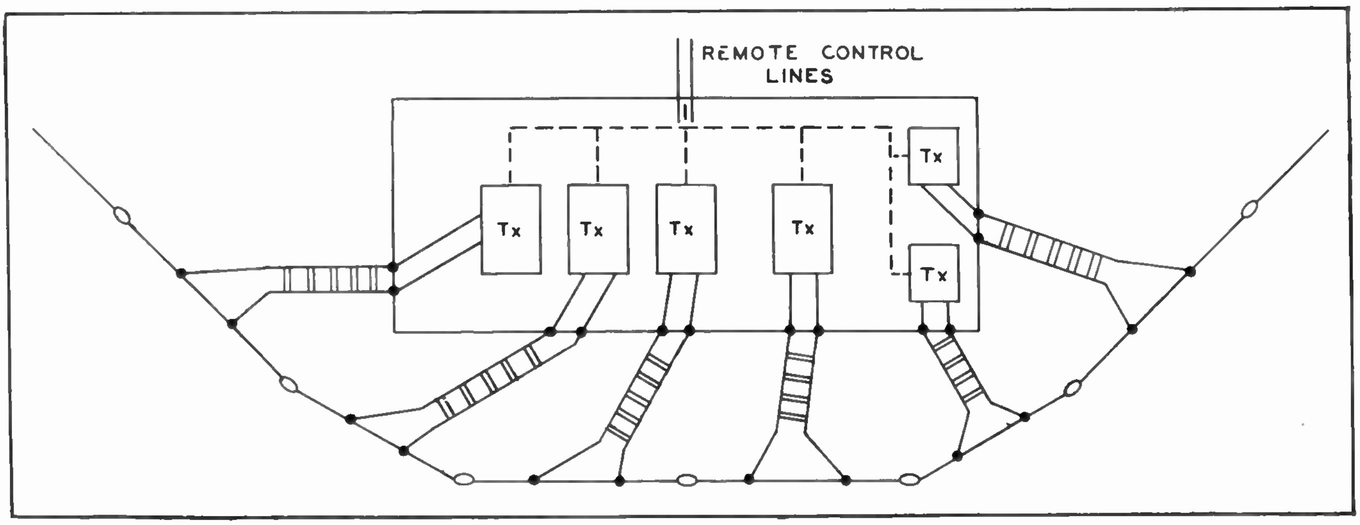


Figure 119. Use of a Delta-Matching System for Feeding Adjacent Antennas in a Large Antenna Park.

rays should be well separated, but in a practical situation this is not feasible due to physical limitations. Figure 119 shows a typical layout plan of an antenna park, with adjacent antennas utilizing the same supporting structures.

QUARTER-WAVE-STUB FEED SYSTEM

A nonresonant transmission line can be matched to an antenna by using a system called stub matching. The stub consists of a quarter-wave section of line connected to the antenna at the feed point. A quarter-wave open stub is used for feeding at a low-impedance point on an antenna and a quarter-wave shorted stub, for feeding at a high-impedance point on an antenna. The transmission line is connected to the proper points on the quarter-wave section, as shown in figure 120. The stub-matching device provides impedance transformation by autotransformer action.

In setting up an antenna installation of this sort, the following step by step procedure should be used.

1. Calculate the length (D) of the quarter-wave section by using the formula:

$$D\ (\text{feet}) = \frac{468}{2\,f\ (\text{mc.})} = \frac{234}{f\ (\text{mc.})}$$

2. Construct the quarter-wave section the same as the feeder line from the transmitter. For instance, if the transmission line is composed of #12 B. & S. wire with 6-inch spacers (600-ohm line), use the same size wire and spacing for the matching stub.

3. Connect the stub to the antenna as shown in figure 120A for a center-fed system or as shown in figure 120B for an end-fed system. Do not connect the transmission line.

4. Excite the antenna from a temporary antenna located one or two wave lengths away. The temporary antenna should be excited with 50 to 100 watts of r-f power.

5. If the antenna is end-fed, place an r-f milliammeter across the shorting bar and vary the position of the bar until a point is found where maximum current indication is obtained. The distance from this point to the antenna represents the correct physical length for a quarter-wave section. NOTE: If low power is used, the meter itself can be used as a shorting bar.

6. Solder two rigid leads to a noninductive resistor (several paralleled carbon resistors), the value of which equals the Zo of the transmission line to be used.

7. Place this resistor across the stub line at the shorting bar and move it along the stub away from the shorting bar until a point is found where the current indication on the meter is maximum.

8. Remove the resistor and attach the transmission line at the point on the stub where the resistor was connected for maximum indication.

9. Move the ends of the transmission line up and down slightly until maximum indication is obtained on the meter. The correct point is about $\lambda/8$ away from the shorting bar.

10. Leaving the transmission line connected, carefully move the shorting bar upward until the current increases to maximum, then back it off slightly until the current just *begins* to *decrease*. This makes the

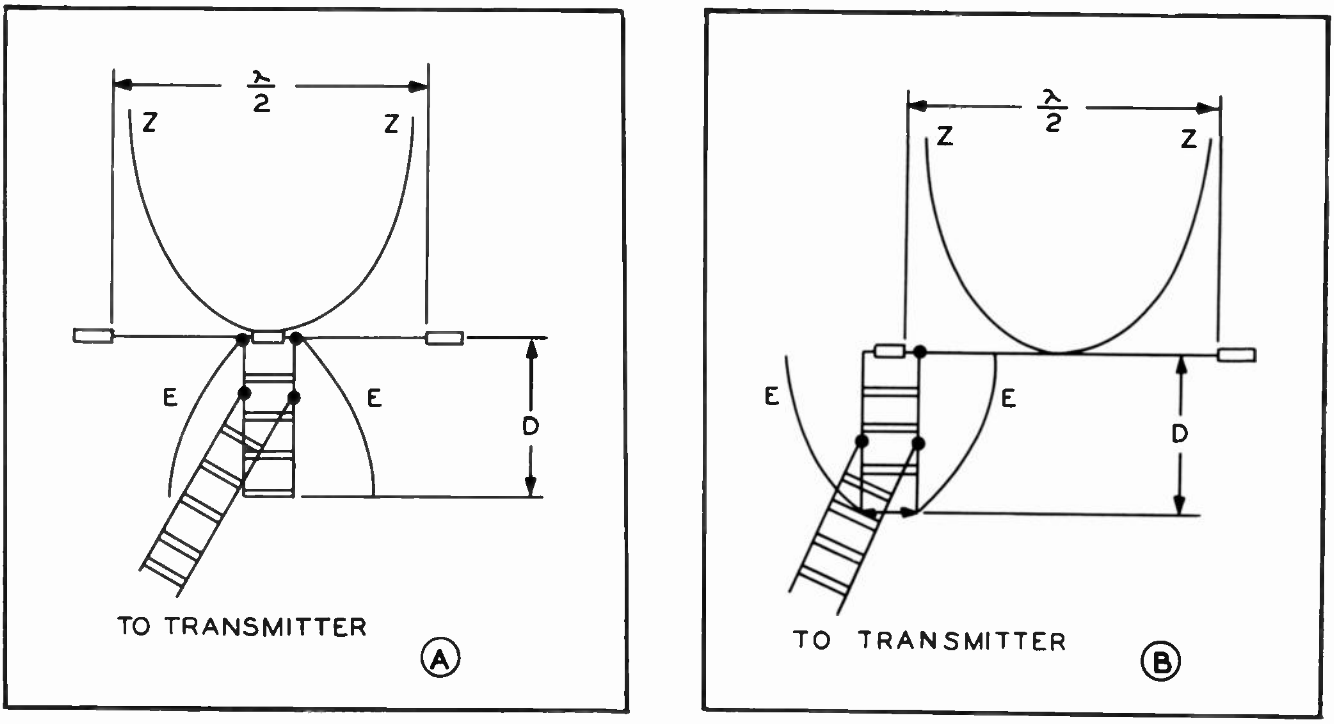


Figure 120. Methods of Matching a Half-Wave Antenna and an Open-Wire Feed Line with Open and Shorted Quarter-Wave Matching Stubs.

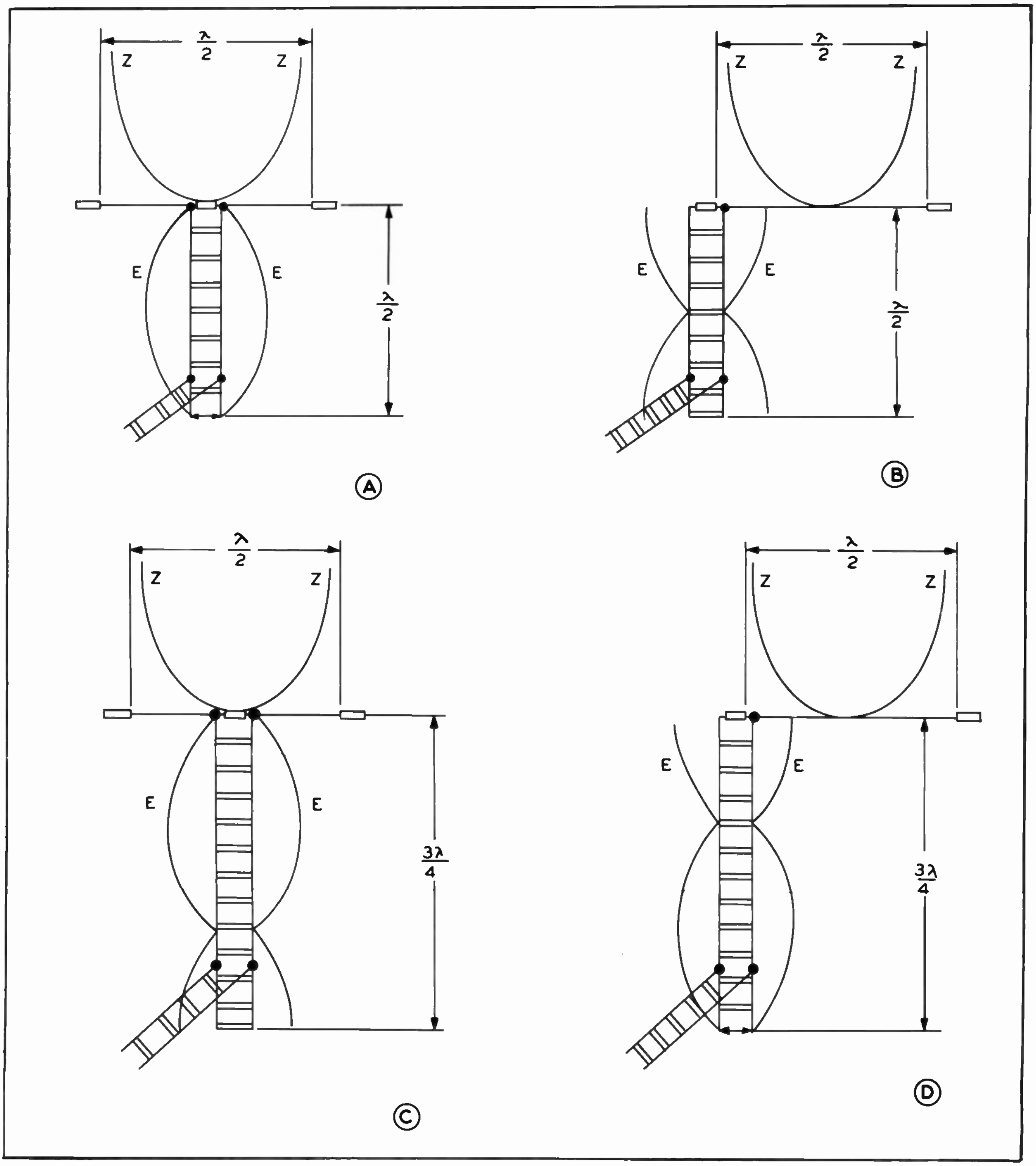


Figure 121. Methods of Matching a Half-Wave Antenna and an Open-Wire Feed Line with Half-Wave-Length and Three-Quarter-Wave-Length Matching Stubs.

matching section slightly longer than a quarter wave length.

11. Make a permanent connection of the shorting bar.

12. As a final adjustment, move the transmission-line taps slightly until maximum current indication is obtained, then make a permanent connection of the transmission line to the matching section.

13. Remove excitation from the temporary antenna and operate the system in normal fashion.

Use of the method above results in the line having a minimum standing-wave ratio. The adjustments in step 10 of the procedure tend to make the feed point appear as a pure resistive load.

The same general procedure can be used for an open matching stub. In determining the length of the quarter-wave matching section, however, the point of maximum *voltage* should be found. This may be accomplished by clipping off equal sections at the open end of the matching stub. The length of the matching section should be shortened slightly; that is, the open ends of the lines should be clipped off so that the stub is slightly shorter than the initially determined quarter wave length.

MATCHING STUBS OTHER THAN QUARTER WAVE

A half-wave or a three-quarter-wave matching stub can be used when the antenna height makes it inconvenient to attach the transmission line to a short matching section. Figure 121, A and B, shows the method of coupling to a half-wave matching stub, for feeding a center-fed or an end-fed half-wave antenna. The method of setting up the system is the same as that for the quarter-wave section. The half-wave section repeats the load; that is, it acts as a one-to-one transformer.

Figure 121, C and D, shows the method of coupling to a three-quarter-wave matching stub, for feeding a center-fed or end-fed half-wave antenna. The method of setting up the system is the same as that for the quarter-wave matching stub. The net result is also the same.

The disadvantage of any stub-type matching system is that it limits the operation to a narrow band of frequencies near the resonant frequency of the antenna. Also, when a half-wave or a three-quarter-wave matching stub is used, if the antenna length is incorrect for the operating frequency, considerable loss results from standing waves on both the matching section and the transmission line. The stub-type matching system can be used on a long-wire antenna with satisfactory results. Methods of feeding a long-wire antenna are discussed later.

ARTIFICIAL-LINE MATCHING SYSTEM

One of the simplest methods of coupling a transmission line to an antenna at low, medium, or high frequencies is by the use of an artificial line. By proper design of this type of coupling network, a wide range of transmission line impedances can be coupled to any range of antenna input impedances in a narrow band of frequencies.

The advantage of an artificial line over the various types of matching stubs previously mentioned is that the components can be lumped and built into a small weather-proofed enclosure and mounted at the antenna input; thus it has negligible effect on the field radiation pattern.

Figure 122, A, B, and C, shows three types of coupling networks for coupling a high-impedance transmission line to a low-impedance antenna.

Figure 122A shows a coupling network suitable for connecting a high-impedance line to an ungrounded vertical antenna. Figure 122, B and C, shows two methods of coupling a high-impedance line to a balanced antenna, such as a $\lambda/2$ dipole or a $\lambda/2$ dipole driven element in a parasitic array.

The coupling network acts to cancel out the reactive components that would exist if the transmission line were coupled directly to the antenna. Thus, the network must contain inductive and capacitive reactances of the proper values to make the antenna appear to the line as a pure resistance equal in value to the characteristic impedance of the line.

The values of inductance and capacity required can be found by calculation, if the antenna input impedance and transmission-line characteristic impedance are known. The inductive reactance can be found by the formula:

$$X_L = R_1 \sqrt{\frac{R_2}{R_1} - 1}$$

where R_1 = antenna input impedance
R_2 = transmission-line characteristic impedance

The capacitive reactance can be found by the formula:

$$X_C = \frac{R_2}{\sqrt{\frac{R_2}{R_1} - 1}}$$

To illustrate the use of the above formulas, consider a practical case where a 600-ohm, open-wire line (#12 B & S wire with 6-inch spacers) is to be coupled to a three-element parasitic array. The input impedance of the array is 10 ohms and the operating frequency is 20 mc. with a power input of 500 watts. Substitution in the inductive reactance formula gives:

$$X_L = 10\sqrt{\frac{600}{10} - 1}$$

$$= 10\sqrt{59}$$

$$= \text{approx. } 77 \text{ ohms}$$

The inductance necessary to produce an inductive reactance of 77 ohms at 20 mc. is found by the formula:

$$L = \frac{X_L}{2\pi f} \quad \text{where } f = \text{frequency in cycles}$$

$$\text{therefore } L = \frac{77}{2 \times 3.14 \times 20 \times 10^6}$$

$$= \frac{77}{125.6 \times 10^6}$$

$$= 0.61 \times 10^{-6}$$

$$= 0.61 \text{ microhenry}$$

Therefore 0.61 microhenry is the inductance of the coil required.

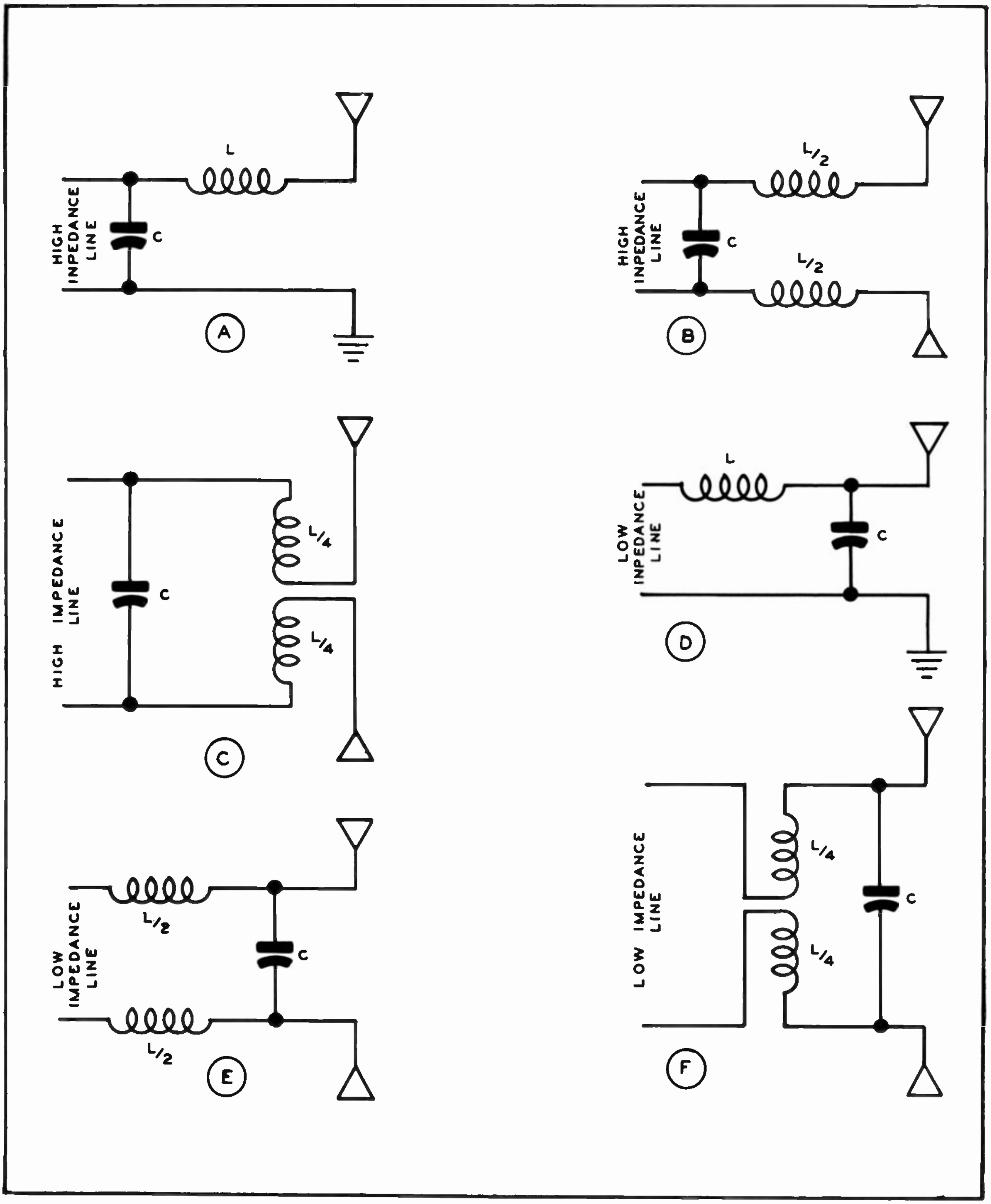


Figure 122. Artificial-Line Coupling Sections Used as Impedance-Matching Devices.

To design a coil having this value of inductance, the following formula can be used:

$$N = \sqrt{\frac{(3A + 9B)\,L}{0.2A^2}}$$

where N = number of turns
A = mean diameter of coil in inches
B = length of coil in inches
L = inductance required in microhenries

The wire for this coil should be the same size as that used in the transmission line. Tubing of an appropriate size may be used at high frequencies.

The choice of the coil dimensions depends upon the space and power considerations. If the 0.61-microhenry coil above is to be 2 inches in diameter and 2 inches long, the formula is solved as follows:

$$N = \sqrt{\frac{[(3 \times 2) + (9 \times 2)] \times 0.61}{0.2 \times 2^2}}$$
$$= \sqrt{\frac{24 \times 0.61}{0.8}}$$
$$= \sqrt{18.3}$$
$$= 4.2 \text{ or } 4 \text{ turns}$$

Since two coils are used for feeding the balanced antenna in the coupling network in figure 122B each coil should consist of two turns, and should be 1 inch long and 2 inches in diameter. If the coupling network in figure 122C is used, two coils of one turn each and 2 inches in diameter should be used for the close coupling shown. The spacing between turns of wire or tubing depends, of course, upon the coil dimensions desired.

To calcuate the capacity required, it is first necessary to compute the capacitive reactance, using the formula:

$$X_C = \frac{R_2}{\sqrt{\frac{R_2}{R_1} - 1}}$$
$$= \frac{600}{\sqrt{\frac{600}{10} - 1}}$$
$$= 77 \text{ ohms}$$

Thus the capacitive reactance is 77 ohms. Although, in this particular case, the capacitive and inductive reactances are equal, this condition will not occur in all cases.

The capacity required is calculated from the formula:

$$C = \frac{1}{2\pi f X_c} \quad \text{where } f = \text{frequency in cycles}$$

$$\text{therefore } C = \frac{1}{2 \times 3.14 \times 20 \times 10^6 \times 77}$$
$$= .000102 \times 10^{-6}$$
$$= 103 \times 10^{-6} \times 10^{-6}$$
$$= 103 \times 10^{-12}$$
$$= 103 \text{ micromicrofarads}$$

Thus, the value of capacitor C should be 103 micromicrofarads. The voltage rating of the capacitor, assuming that 500 watts is fed to the antenna, can be found by using the following formula:

$E = \sqrt{PR}$ where E = effective value of carrier voltage
P = antenna power
R = line Zo

$$E = \sqrt{500 \times 600}$$
$$= \sqrt{300{,}000}$$
$$= 100\sqrt{30}$$
$$= 547 \text{ volts}$$

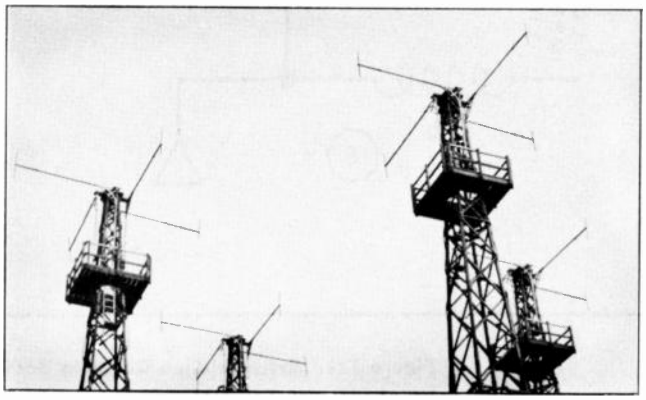
To obtain peak value of E, multiply E by 1.414: 547 x 1.414 = 773.5 volts (peak).

The peak voltage at 100% modulation is twice this value, or 773.5 x 2 = 1547 volts. Thus a 2000-volt capacitor is adequate.

After the unit is assembled and connected to the antenna, feed about 25 watts of power into the antenna, and adjust the variable capacitor for maximum antenna current, as indicated on an r-f ammeter or a small light bulb connected across the antenna input.

The next step is to check for standing waves of current on the line. The standing-wave ratio should be 1-to-1 along the entire length of the line, with perhaps an increased indication of current at either end. If standing waves of current do exist on the line and the position of the current loop is a $\lambda/4$ from the coupling transformer, the inductance should be decreased by slightly spreading the turns of the coil. To resonate the circuit, the capacity should be increased slightly. If a current node appears a $\lambda/4$ from the coupling transformer, the inductance is too low; it can be increased by slightly squeezing together the turns. The capacity should be reduced slightly. After the adjustments are made with low power, full power can be applied to the antenna.

The antenna-coupling unit for matching a low-impedance line to a high-impedance antenna input requires a different arrangement of the reactive components. Figure 122, D, E and F, illustrates these arrangements in schematic form. The same formulas are used in the calculations, with the exception that the designations for the input and output impedances are reversed. Thus the input impedance becomes R_2 instead of R_1.



Omnidirectional V-H-F Antenna Arrays for Air-to-Ground Communications in Conjunction with a Fighter-Control System.

COUPLING CIRCUITS

Thus far the different methods of matching the impedance of the transmission line to the antenna have been discussed. It is equally important to have an impedance match at the input of the transmission line; that is, between the transmitter-plate-tank circuit and the line. The coupling methods vary, depending primarily on the type of line used. Some systems are designed for maximum coupling efficiency at one particular frequency, such as broadcast, ship to shore, etc., while others are made to operate over a wide frequency range. The latter type, of course, requires considerable care in both design and construction, because the impedance match must be maintained over the entire frequency range.

Whatever method is used, it is important that the maximum amount of energy is transferred from the transmitter to the line, and that a minimum amount is wasted in the coupling unit.

V-H-F Communication Antennas Atop a Navy-Airfield Control Tower.

SINGLE-WIRE FEED SYSTEM

Figure 123A shows the method of coupling to a nonresonant, single-wire feed line, such as that used for exciting an off-center-fed Hertz. The proper feed point on the coil is found by moving the tap up from the low r-f potential end of the coil. The tap is adjusted for the rated plate current. The series capacitor serves to isolate the high-potential d-c plate voltage from the feed line. This method of coupling permits harmonic radiation and, therefore, is seldom used.

Figure 123B shows another method of coupling to nonresonant, single-wire feed line, which is used for the same purpose as the above circuit. The antenna tank circuit and the plate tank circuit are coupled together by an inductance link. The link consists of two loops, each having the minimum number of turns for satisfactory coupling, and interconnected by a piece of low-impedance coaxial cable. (A low-impedance, twisted-pair line may be used also.) One advantage of using link coupling is that the antenna tuning unit can be located remotely from the transmitter; that is, it may be located at the point where the antenna feeder lines enter the transmitter building. This reduces the loss of power normally incurred when antenna feeder lines are channeled through a building, and also makes it safer for personnel. The high voltages in the transmitter make it inconvenient and extremely hazardous to perform antenna adjustments if the antenna tuning unit is an integral part of the transmitter. This system tends to minimize harmonic radiation by reducing the capacitive (direct) coupling between the transmitter tank coil and the antenna tank coil, because a one or two-turn link has very low distributed capacity.

Figure 123C shows a method of coupling to resonant or nonresonant, single-wire feed lines, having a wide range of input impedances. Loading of the transmitter is adjusted by moving the tap on the plate tank coil. This method is used with a balanced or unbalanced plate tank circuit.

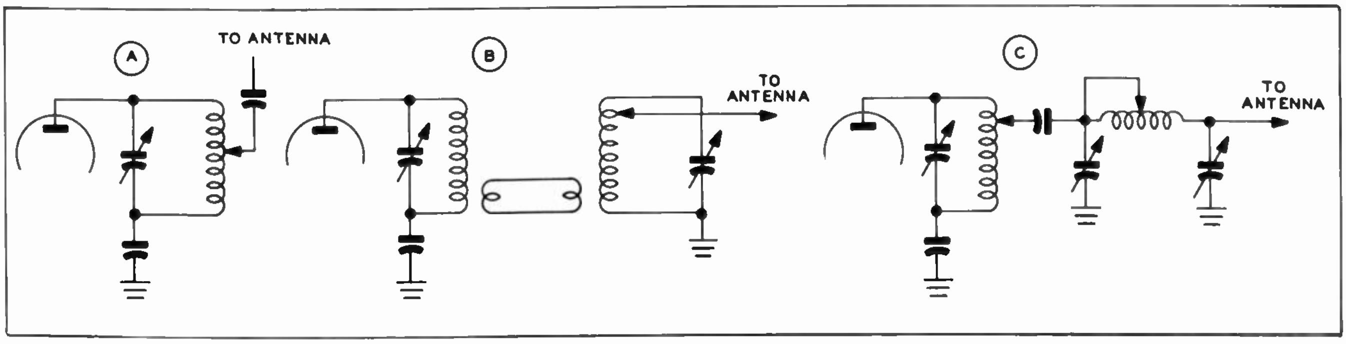


Figure 123. Common Methods of Coupling to a Single-Wire Feed System.

TWO-WIRE FEED SYSTEM

Figure 124 shows two methods of coupling to a matched, two-wire transmission line from an unbalanced tank circuit.

Figure 124A shows a small coupling coil which is tightly coupled to the plate tank circuit at a point of low r-f potential. This method is convenient for coupling to a low-impedance, coaxial or concentric-line cable.

Figure 124B shows a method of coupling to a nonresonant, two-wire line, having either a high or low impedance. The center of the antenna tank coil becomes the point of low r-f potential when the link is coupled at that point. The taps on the antenna tank coil are variable. Loading of the transmitter is adjusted by moving the taps away from, or toward the center of the antenna tank coil.

Figure 125 shows two methods of coupling to a nonresonant, two-wire line from a balanced tank circuit. Figure 125A shows a method of connecting a nonresonant, two-wire line directly to a balanced tank circuit. This method is particularly suitable for use with open-wire lines. Loading of the transmitter is adjusted by moving the taps equidistantly away from, or toward the center of the tank coil, which is the point of low r-f potential.

Figure 125B is a variation of the method illustrated in figure 124B. By coupling the link to a point of low r-f potential on the plate tank circuit, harmonic radiation is minimized. Loading is adjusted by moving the taps equidistantly away from, or toward the center of the antenna coil. If moving the taps produces an excessive detuning effect on the plate tank circuit, the circuit constants (link coupling, etc.) should be changed.

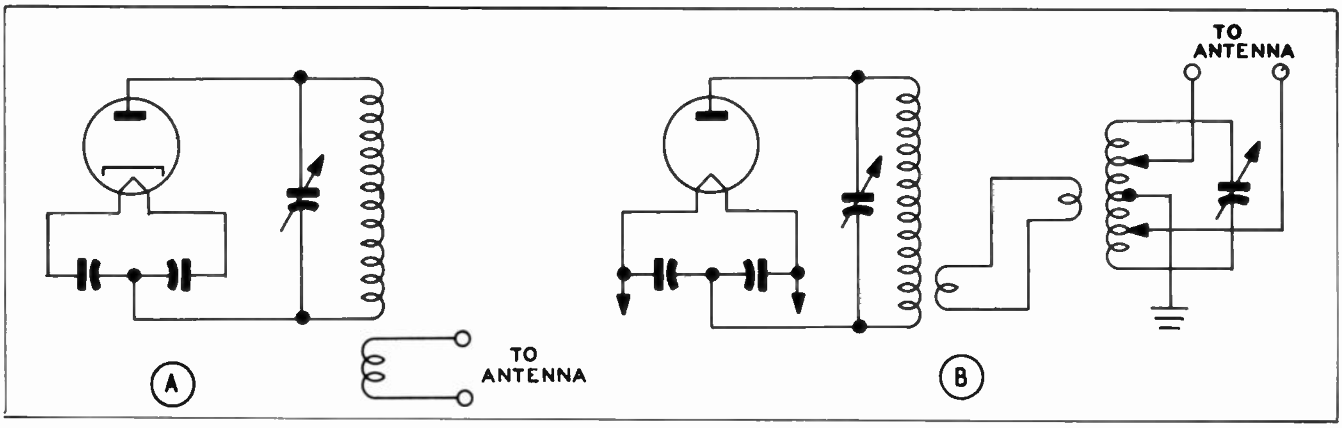


Figure 124. Common Methods of Coupling to a Two-Wire Feed System from an Unbalanced Tank Circuit.

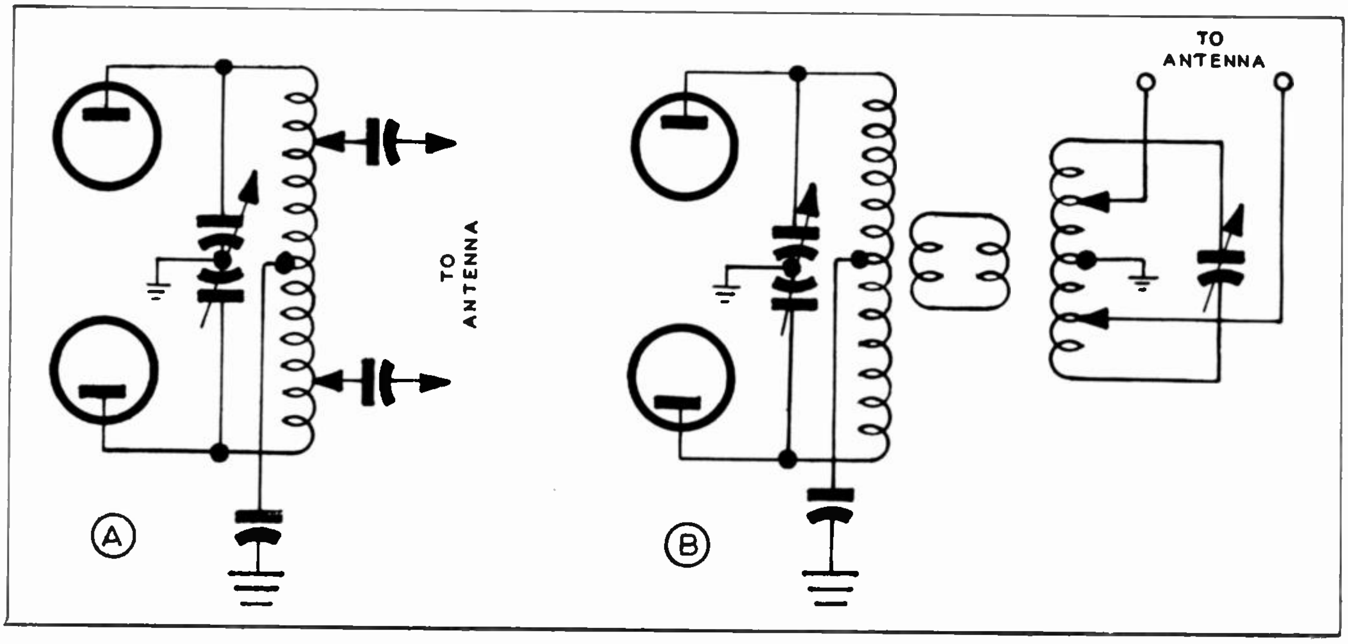


Figure 125. Methods of Coupling from a Balanced Tank Circuit to a Nonresonant, Two-Wire Transmission Line.

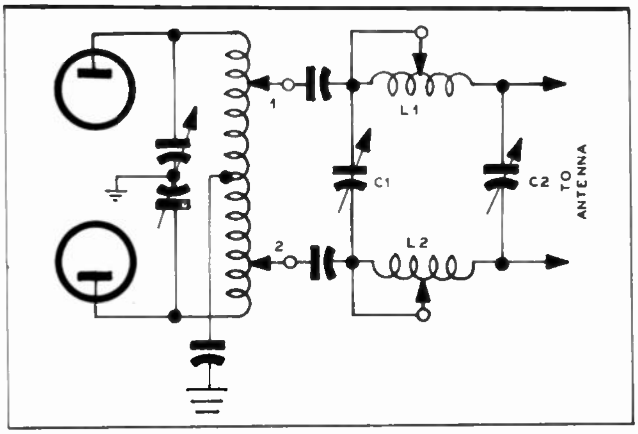


Figure 126. Double-Pi-Section Filter Network for Coupling to a Resonant or Nonresonant Transmission Line.

Figure 126 shows a double pi-section filter, which is used to couple to a resonant or nonresonant line. The principal advantage of this type of coupling is that a transmitter which is operated over a wide frequency range can be coupled to either a resonant or nonresonant line. A balanced plate tank circuit is usually used with this type of coupling. The procedure for tuning a system of this type follows:

1. Connect the antenna tuning unit to the transmission line.
2. With the transmitter on low power and the antenna tuning unit disconnected from the plate tank coil, tune the plate tank capacitor for minimum final-amplifier plate current. Lock the control at this setting.
3. Make trial, symmetrical settings of the taps on coils L_1 and L_2. (For high frequencies, short out about two-thirds of each coil; for low frequencies, short out about one-third of each coil.)
4. Set capacitor C_1 at minimum, and capacitor C_2 at about one-half capacity.
5. Remove the plate power from the transmitter and couple the antenna to the transmitter by connecting taps 1 and 2 at points about one-fourth of the distance from each end of the plate tank coil.
6. Apply the plate power to the transmitter and quickly tune C_1 through its range until a resonant condition is indicated by the plate current meter of the final amplifier.
7. If the desired full-load plate current is not obtained, try a different setting of C_2 and repeat step 6.
8. Rotate C_2 through its range; if for all settings of C_2 the plate current is too high or too low, try different settings of the taps on coils L_1 and L_2 and, also, of the taps on the transmitter tank coil. (Taps 1 and 2 are moved toward the ends of the plate tank coil until maximum rated plate current is flowing.)
9. To minimize the harmonic output, carefully set C_1 for the exact minimum plate current.

CAUTION: When making adjustments in the transmitter during tuning operations of this sort, the plate power should be removed from the final tank circuit. Most transmitters, even of moderate power, are equipped with interlock safety switches, which remove the primary source of high voltage. However, these switches should never be relied upon particularly when more than one individual is involved in the operation. Bear in mind that DEATH IS PERMANENT, and that high voltage has sent many men, including experts, to the land of eternal rest and peace.

LOADING RESONANT TRANSMISSION LINES

Two common types of coupling systems for loading resonant transmission lines, such as those used to feed Zepp antennas and center-fed doublets, are shown in figure 127. In either system, L_1 could be coupled directly to the plate tank without the use of the link, as shown; however, the direct coupling is to be discouraged for two reasons: First, it is inconvenient to make coupling adjustments on the plate tank circuit with relatively large coils. Second, since the antenna-coil size increases as the frequency is lowered, excessive capacitive coupling between the plate tank and the antenna coupling circuit is produced by the increase in distributed capacity. Such capacitive coupling must be minimized to prevent harmonic radi-

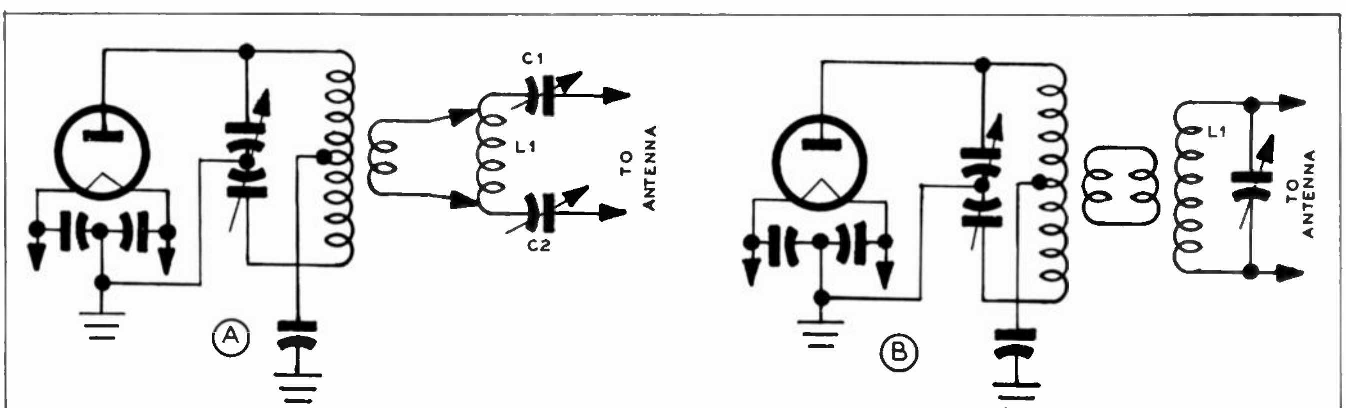


Figure 127. Methods of Coupling to a Resonant, Two-Wire Transmission Line.

ation, which produces interference with receiving services, such as radio teletype, facsimile, etc. When a 1-to-5-turn link, which has only a small amount of distributed capacity, is coupled at a low r-f potential point on the plate tank, harmonic radiation is reduced. An electrostatic shield (Faraday Screen) may also be used to reduce harmonic radiation. For constructional details, see page 182.

Link coupling can be used for either a series-tuned or a parallel-tuned line, as shown in figure 127. To tune the series-resonant-coupling circuit (figure 127A), reduce the coupling between the link and the plate tank to a minimum, and tune the plate capacitor for resonance. Place the taps on L_1 at points a few turns either side of the geometrical center, and set C_1 and C_2 for minimum capacity. Slightly increase the coupling between the link and plate tank and tune C_1 and C_2, simultaneously, to find the resonance point of the coupling system. If r-f current meters are in the line, they should indicate a maximum at the resonance point. Reresonate the plate tank capacitor; the plate-current meter should show an increase over the initial reading. Again increase the coupling between the link and the antenna tank and reresonate the plate capacitor; the plate-current meter should again show an increase over the initial reading. Repeat the process until maximum coupling of the link is attained. If, at this point of loading, maximum rated plate current is not obtained, completely uncouple the link from the plate tank, move both taps another turn away from the geometrical center of the coupling unit, and repeat the entire tuning process. The procedure given above is rather elaborate but its use pays off, because sudden overloading of the final tube, with consequent damage, is prevented.

For tuning the parallel resonant circuit (figure 127B), the procedure is similar, except that a single tuning capacitor is used. R-f current meters in the line near the coupling circuit will indicate a very low value when the coupling system is tuned to resonance.

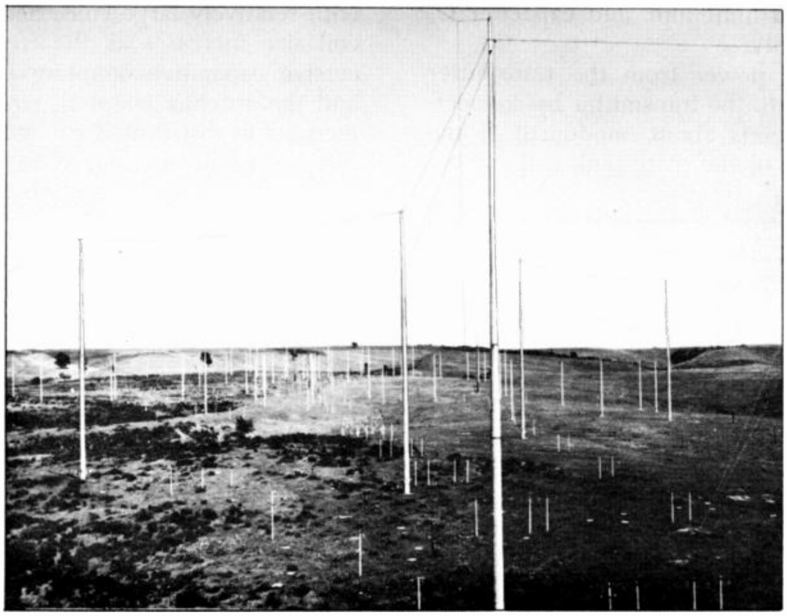
The type of transmission line to use with a specific coupling circuit depends upon whether the coupling circuit is balanced or unbalanced and of generally high or low impedance over the operating range. The frequency and power of the coupled signals, the type of antenna, and the method of feed are also very important factors to be considered.

FEEDER SYSTEM VS. COUPLING CIRCUIT

For connecting an unbalanced coupling system to a high-impedance, unbalanced antenna, such as an end-fed Hertz, a single-wire feeder of adequate physical and electrical size is necessary, because the feeder is part of the radiating system.

For connecting a balanced coupling system to a low-impedance, balanced antenna, a solid-dielectric coaxial cable of the proper impedance should be used on very high frequencies at moderate power; a concentric line of the proper impedance should be used when high power is involved at any frequency.

For connecting a balanced coupling system to a high-impedance, balanced antenna, a twin-lead line should be used on medium and high frequencies at low power and an open-wire line with a suitable matching device should be used when high power is involved at any frequency. When the distance from the transmitter to the antenna is not too great (less than one wave length), the type of transmission line to use is usually governed by the coupling circuit incorporated in the transmitter. Figure 128 illustrates some commonly used methods of coupling from a transmitter to a transmission line.



Large Antenna Farm, Showing Antenna-Supporting and Transmission-Line-Supporting Poles.

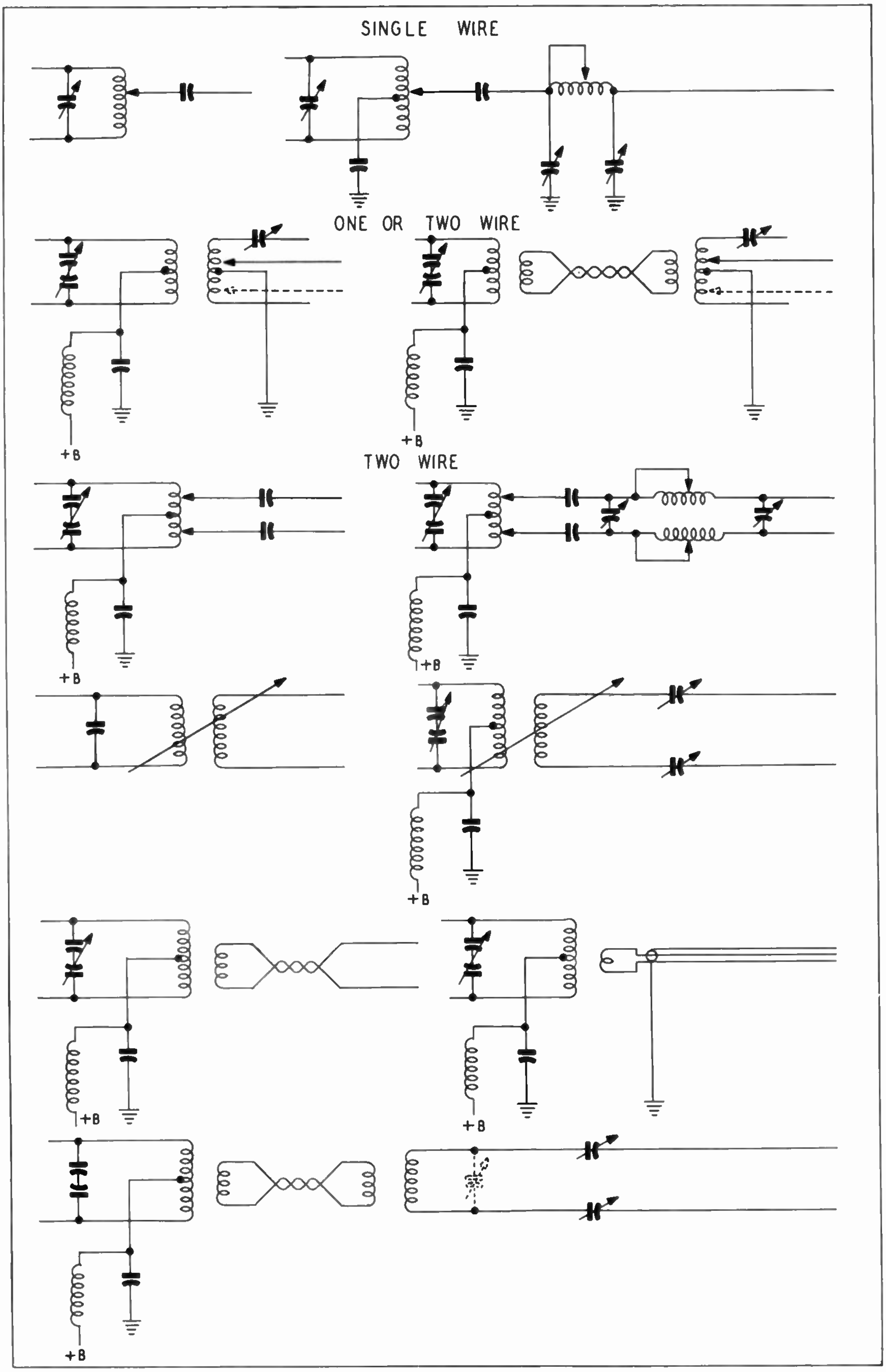


Figure 128. Methods of Coupling.

EXAMINATION No. 2

True or False

1. Tuned transmission lines may be converted into untuned transmission lines by proper termination into the load, which is the antenna. ....

2. The characteristic impedance of a transmission line is an inherent property, and is determined by the size and spacing of the conductors as well as the dielectric between the conductors. ....

3. A general rule to cover open parallel-wire type lines is that when the size of the wire is large with respect to the spacing between the wires, the pair of wires will have a high characteristic impedance. ....

4. A transmission line is considered untuned, or flat, when it is terminated in an impedance equal to its characteristic impedance. ....

5. The standing waves which may be present on untuned transmission lines can be reduced by using impedance-matching transformers or other matching devices. ....

6. The amplitude of standing waves appearing on an untuned transmission line increases as the difference between the frequency of the applied signal and the antenna's resonant frequency increases. ....

7. A transmission line one wave length long and terminated in a short presents a low impedance at its input. ....

8. The relative positions of voltage and current nodes appearing on a transmission line are a good indication of the nature of the termination on the transmission line. ....

9. A balanced condition is always obtained in a transmission line when the two conductors are of equal length. ....

10. An unbalanced condition in a transmission line is more detrimental at higher frequencies because the transmission-line losses increase with frequency. ....

Multiple Choice

(Underline the correct answer.)

1. When it is desired to feed a number of antennas situated relatively close to one another, with minimum interference between them, the most desirable system is

a. stub-matched feed system.
b. delta-matched feed system.
c. single-wire-line feed system.
d. twisted-pair feed system.

2. For connecting an unbalanced coupling system to a low-impedance point on a balanced antenna operating in the v-h-f band, at moderate power,

a. an air-dielectric concentric line should be used.
b. a balanced open-wire line should be used.
c. a twisted-pair line should be used.
d. a solid-dielectric coaxial cable should be used.

3. A resonant transmission line is, for all practical purposes, connected to any antenna

a. near the end.
b. at the highest or lowest impedance point.
c. near the center.
d. near the lowest impedance point.

4. Any two-wire-fed antenna system can be used on harmonic frequencies by

a. changing the type of tuning in the coupling circuit.
b. proper spacing of the feeder lines.
c. means of capacitive coupling to antenna.
d. shortening the length of feeder lines.

5. If a generator is connected to an open transmission line which is ¾ wave lengths long at the frequency of the generator, it will effectively see

a. a parallel-resonant circuit.
b. a capacitive load.
c. a series-resonant circuit.
d. an inductive load.

6. The ratio of the maximum value to the minimum value of voltage or current measureable along the length of a matched transmission line is proportional to the

a. length of the transmission line.
b. type of transmission line.
c. frequency and amount of power applied to the transmission line.
d. degree of mismatch between the transmission line and the load (antenna).

7. A nonresonant transmission line is realized when the transmission line is

a. physically unsymmetrical.
b. an even number of half wave lengths long.
c. matched to an equivalent resistive load.
d. untunable.

8. A transmission line an odd multiple of quarter wave lengths long can be made to match a

a. high impedance to a low impedance, or vice versa.
b. balanced transmission line.
c. resonant line to a nonresonant antenna.
d. low impedance to a low impedance.

9. When employing a resonant transmission line an even number of quarter wave lengths long to end-feed a horizontal half-wave antenna, the transmitter output-coupling circuit must be

a. series-resonant.
b. parallel-resonant.
c. tuned to slightly above the carrier frequency.
d. of the balanced-output type.

10. In coupling any transmission line to a transmitter, link coupling gives the advantage of

a. low power losses at higher frequencies.
b. increasing signal-to-noise ratio.
c. reducing harmonic radiation.
d. increasing capacitive coupling at lower frequencies.

Subjective

1. Describe the relative physical dimensions of parallel open-wire-type and concentric-type transmission lines with high and low characteristic impedances.

2. Describe the resultant effect on the standing-wave distribution on a resonant transmission line when the load is changed from a pure resistance slightly greater than the characteristic impedance of the line to

a. an inductance.
b. a capacity.
c. a pure resistance much less than the Zo of the line.

3. Describe two methods of balancing an unbalanced transmission line.

4. What is meant by a current-fed and a voltage-fed antenna? Give an example of each type.

5. Name three factors determining the type of transmission line which should be used with a specific coupling circuit.

TYPES OF ANTENNAS

As mentioned before, all antennas may be classified into two basic types—Hertz or Marconi. Sometimes an antenna is identified by the method of feed, but the characteristics remain essentially the same regardless of the type of feed. For example, a half-wave antenna may be called a doublet, a center-fed doublet, an off-center-fed Hertz, a Zepp-fed Hertz, etc., but it is still a half-wave antenna.

The common antennas used by military and civilian organizations are classified as follows:

1. Half-wave antennas
2. Parasitic arrays
3. Driven arrays
4. Long, single-wire antennas
5. V antennas
6. Rhombic antennas
7. Low, medium, and high-frequency antennas
8. Very-high-frequency and ultra-high-frequency antennas
9. Special-application antennas

HALF-WAVE ANTENNAS

General

The simple half-wave antenna is by far the most widely used type of antenna for almost all radio-frequency applications. Half-wave antennas are generally referred to as Hertz antennas. Other names, such as doublet, delta-matched, and Zepp, are used but all of these are identical antennas with various methods of impedance matching for different types of feeder systems.

As was pointed out previously, the directivity of a half-wave (or, for that matter, any antenna) is affected somewhat by polarization. Figure 129A shows roughly a cross section of the field pattern when looking down directly at a horizontal antenna, while figure 129B shows a cross section of the same field pattern when viewed broadside from a position on the earth.

Although maximum radiation intensity is broadside to the antenna, as shown in figure 129A, it is just as great in a vertical direction, as shown in figure 129B. Thus, any waves leaving the antenna at a steep vertical angle will have appreciable field intensity. Notice that there is considerable useful radiation off the ends of the antenna at angles above the horizontal. This effect is useful at high frequencies when it is desired to communicate over a relatively short distance by high-angle sky-wave transmission.

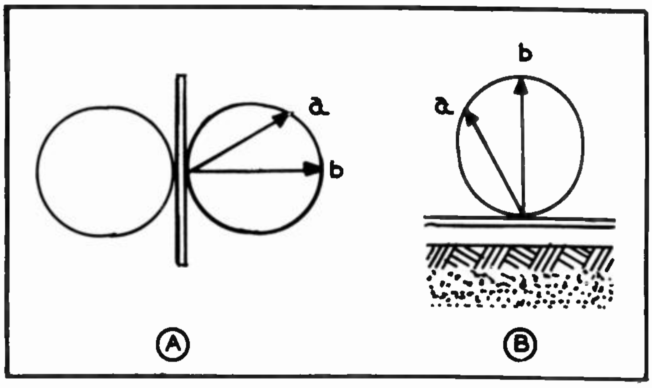


Figure 129. Free-Space Radiation Patterns of a Half-Wave Antenna, Showing Top and Side Views.

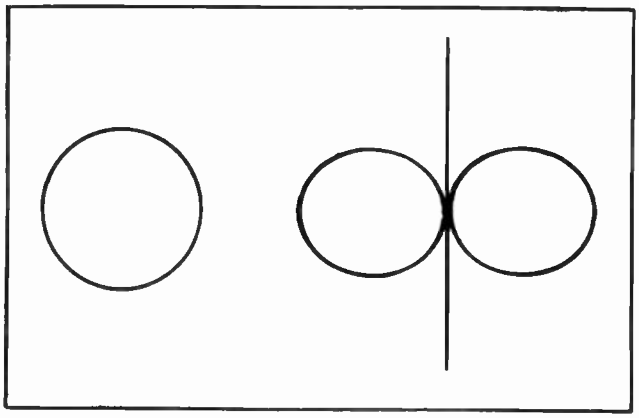


Figure 130. Free-Space Radiation Patterns of a Vertical Half-Wave Antenna, Showing Top and Side Views.

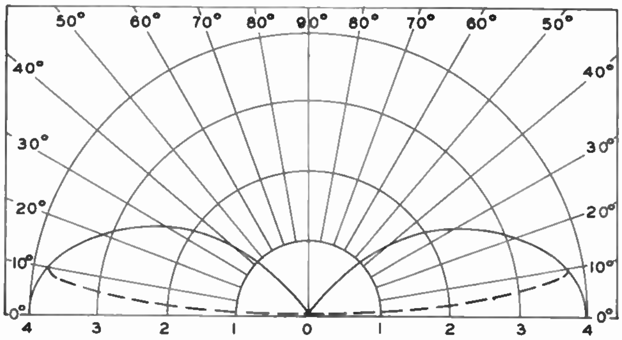


Figure 131. Vertical-Plane Radiation Pattern of a Vertical Half-Wave Antenna One Quarter Wave Length above a Perfectly Conducting Ground.

The free-space directive pattern, looking down from the top of a vertical half-wave antenna, resembles a circle. Referring to figure 130, note that at the same vertical angle the field intensity is the same at any point in a circle around the vertical antenna. However, the ground-absorption losses for waves propagated at a low angle will be appreciable if the terrain has poor conductivity and the frequency is above 5 mc. Thus for frequencies above 12 mc., the half-wave vertical antenna should be as high as possible above the ground. However, the height should be some fraction of a wave length which gives the maximum reenforcement of signal energy, due to the ground-reflection factor. As the height of the antenna is increased, the sharper the directive characteristics become.

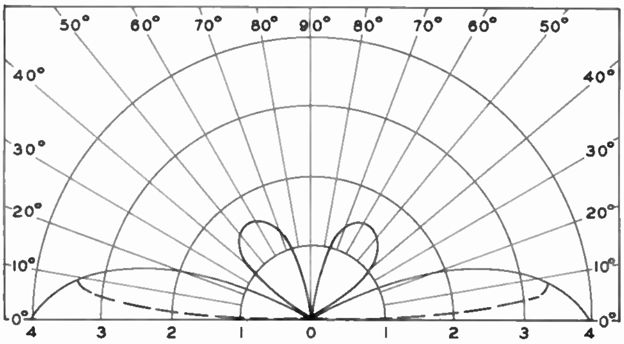


Figure 132. Vertical-Plane Radiation Pattern of a Vertical Half-Wave Antenna One Half Wave Length above a Perfectly Conducting Ground.

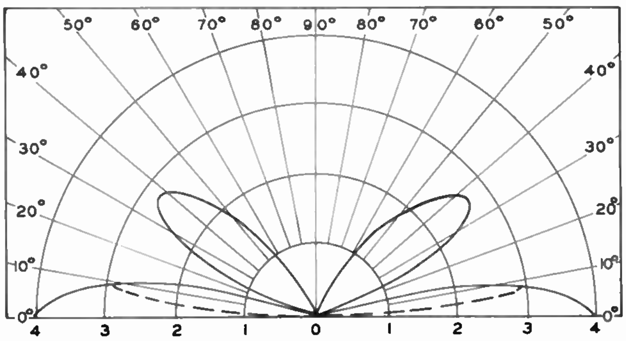


Figure 133. Vertical-Plane Radiation Pattern of a Horizontal Half-Wave Antenna Three Quarter Wave Lengths above a Perfectly Conducting Ground.

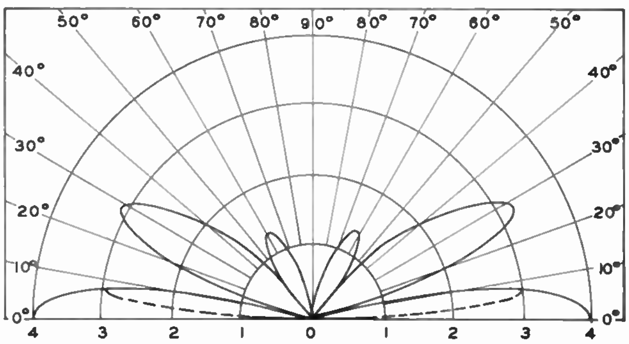


Figure 134. Vertical-Plane Radiation Pattern of a Vertical Half-Wave Antenna One Wave Length above a Perfectly Conducting Ground.

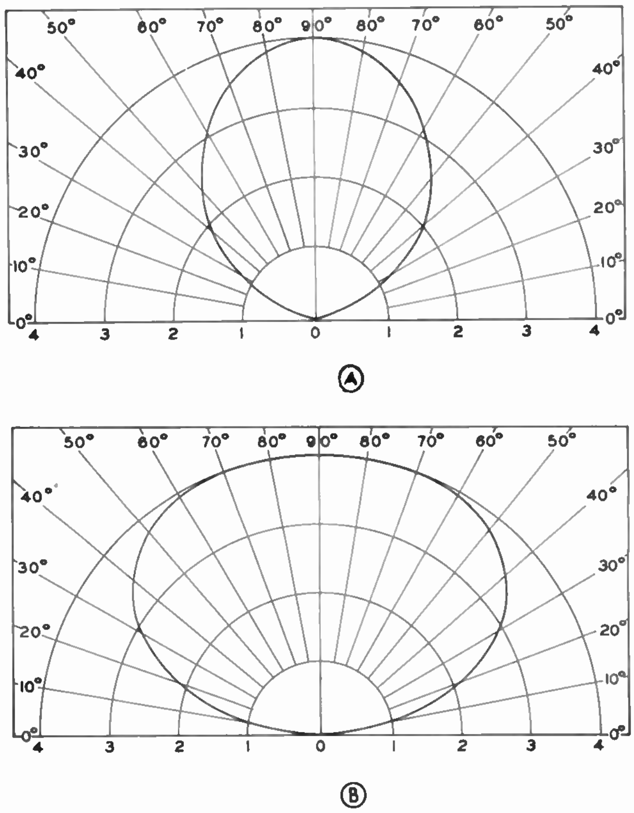


Figure 135. Vertical-Plane Radiation Pattern of a Horizontal Half-Wave Antenna One Quarter Wave Length above a Perfectly Conducting Ground. A shows the pattern as viewed in the direction of the wire and B shows the pattern as viewed at right angles to the wire.

Figures 131 to 134, inclusive, show the vertical-plane radiation patterns of a vertical half-wave antenna at different heights above a perfectly conducting ground.

Figures 135 to 140, inclusive, show the vertical-plane radiation patterns of a horizontal half-wave antenna in the direction of and at a right angle to the wire at different heights above a perfectly conducting ground.

Theoretical radiation patterns are computed by multiplying the free-space-pattern field intensity at particular angles by the ground-reflection factors for those angles.

In general, a horizontal half-wave antenna should be strung in an *east and west* direction for maximum broadside field intensity in a north and south direction. A vertical half-wave antenna should be placed as high as possible for maximum field intensity at radiation angles of 15 degrees and below.

Installation of a Half-Wave Horizontal Antenna

Suppose that it is desired to establish reliable radiotelephone communications in a mountainous region from Modesto, California, to Nevada City, California, which is about 200 miles to the north, and to Bakersfield, California, which is about 175 miles to the south. The following factors must be considered: Ground waves cannot be used, because the ground transmission path is poor, over mountainous country; therefore, short-skip sky waves must be utilized. High-angle radiation is necessary for the short skip, and it may be obtained by placing the antenna at a mean height of about a quarter of a wave length or less above the ground. (Mean height takes the factor of wire sag into account.)

For working the two points mentioned above, a general-coverage, horizontal, half-wave antenna with

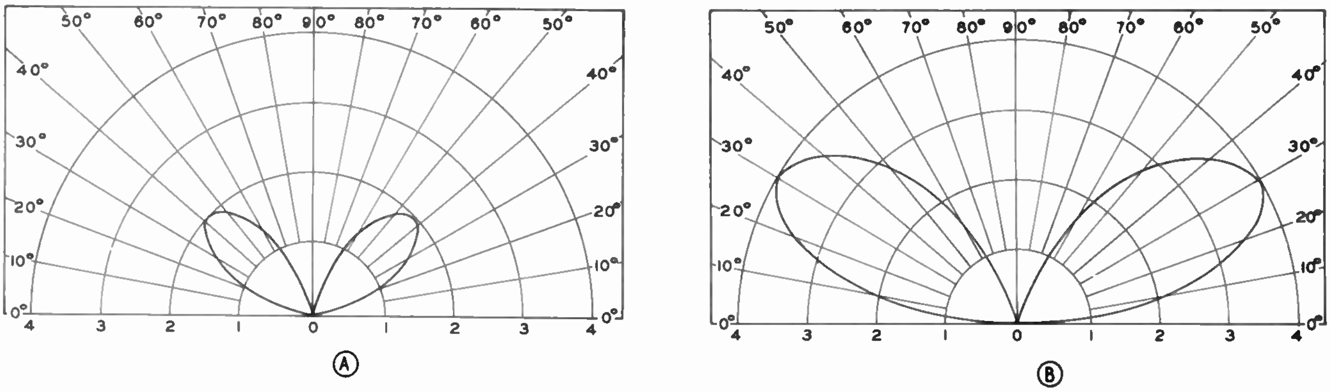


Figure 136. Vertical-Plane Radiation Pattern of a Horizontal Half-Wave Antenna One Half Wave Length above a Perfectly Conducting Ground. A shows the pattern as viewed in the direction of the wire and B shows the pattern as viewed at right angles to the wire.

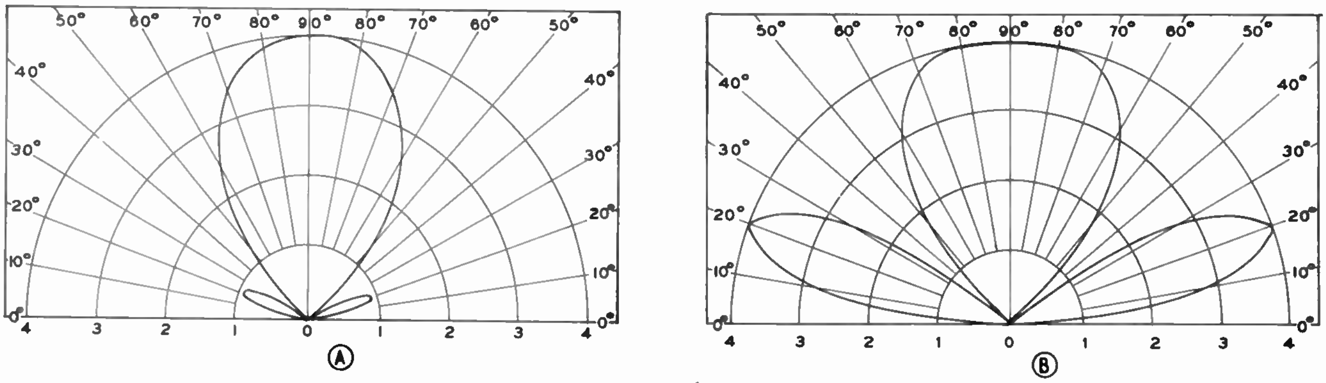


Figure 137. Vertical-Plane Radiation Pattern of a Horizontal Half-Wave Antenna Three Quarter Wave Lengths above a Perfectly Conducting Ground. A shows the pattern as viewed in the direction of the wire, and B shows the pattern as viewed at right angles to the wire.

its ends pointing east and west will give the desired directivity.

For daytime communication under these conditions, a frequency of approximately 6 mc. is favorable. For army administrative work, which requires long hours of service, a BC-610 transmitter (part of Radio Sets SCR-399 and SCR-499) having about 300 watts phone output is applicable.

In setting up an antenna for the conditions given above, the following step-by-step procedure can be used. Refer to figure 141 and to page 157 for additional constructional details.

1. Calculate the physical length of a half-wave antenna for 6 mc.

$$\text{Length in feet} = \frac{468}{\text{freq. (mc.)}} = 78 \text{ feet}$$

2. Inspect the surrounding terrain and locate a site for the antenna. The site chosen should have the following features:

a. Clear area, fairly level in the east-west direction for at least 100 feet and sloping down slightly in other directions. Avoid rocky terrain, if possible.

b. No tall buildings, hills, trees, or other large obstructions within 100 feet.

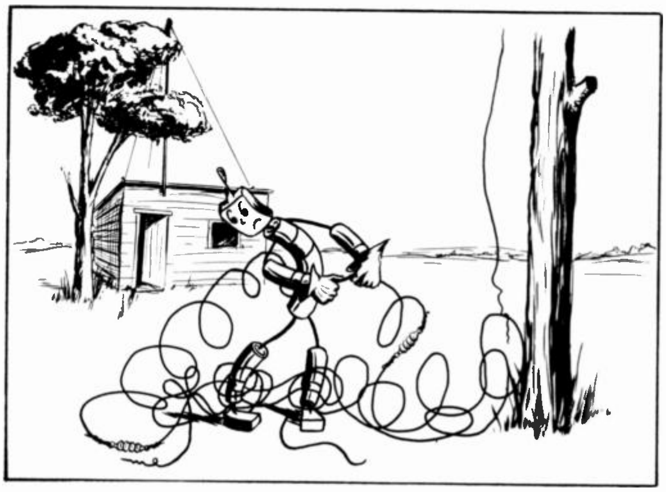
c. Site should be near transmitter location.

3. Procure the following material:

a. Approximately 100 feet of either #10 or #12 B. & S. guage enameled-copper, copperweld, or bronze wire (preferably stranded).

b. Three strain insulators; 1 two or four-inch and 2 six-inch.

c. Two 100-foot lengths of ½-inch Manila rope and 2 pulleys.



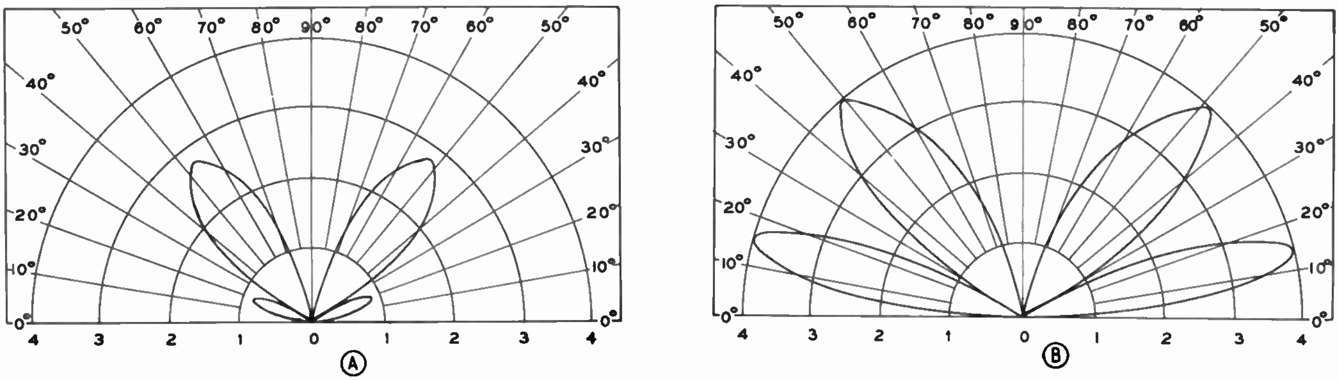


Figure 138. Vertical-Plane Radiation Pattern of a Horizontal Half-Wave Antenna One Wave Length above a Perfectly Conducting Ground. A shows the pattern as viewed in the direction of the wire and B shows the pattern as viewed at right angles to the wire.

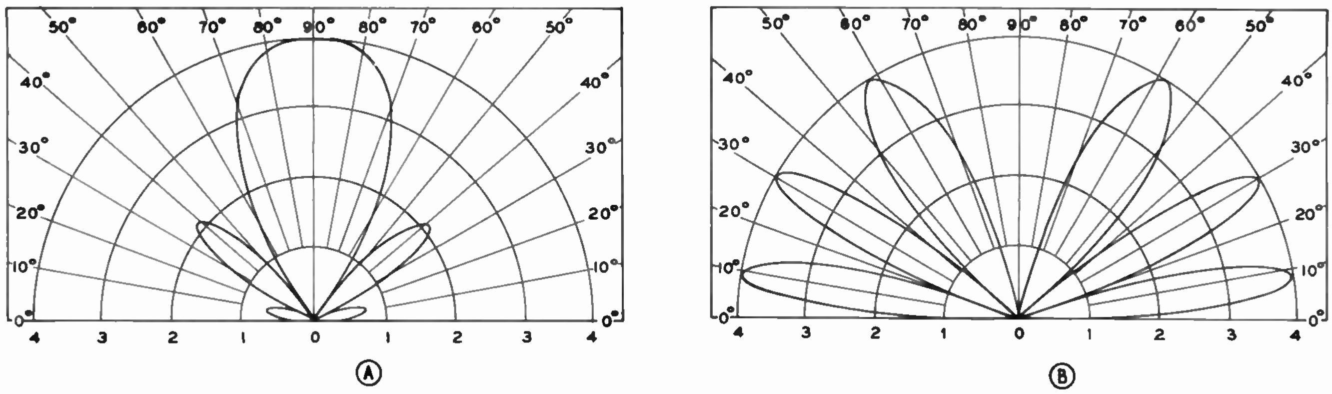


Figure 139. Vertical-Plane Radiation Pattern of a Horizontal Half-Wave Antenna One and a Quarter Wave Lengths above a Perfectly Conducting Ground. A shows the pattern as viewed in the direction of the wire and B shows the pattern as viewed at right angles to the wire.

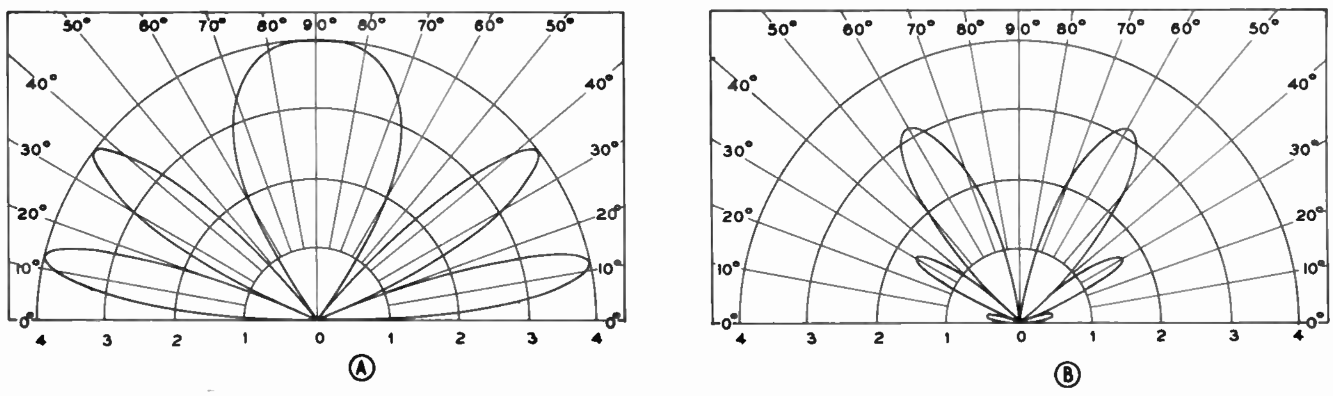


Figure 140. Vertical-Plane Radiation Pattern of a Horizontal Half-Wave Antenna One and a Half Wave Lengths above a Perfectly Conducting Ground. A shows the pattern as viewed in the direction of the wire and B shows the pattern as viewed at right angles to the wire.

d. Counterweight.

e. Two poles or supporting masts, 40 to 60 feet high, and suitable materials for guys and anchors, if necessary. Sufficient poles or supporting masts and materials to suspend the transmission line from the transmitter site to the antenna site are also required.

f. Length of 70-ohm coaxial transmission line (RG-12/U or RG-13/U as needed).

g. Lay-cit cable grip or equivalent as required.

h. Clearance lights for towers as prescribed by local authorities.

4. Determine the depth to which the poles or supporting masts will be inserted into the ground and mark the pole for this depth. Fasten a pulley to each pole about ¼ wave length (45 feet) from this ground line, and thread the 100-foot ropes through the pulleys.

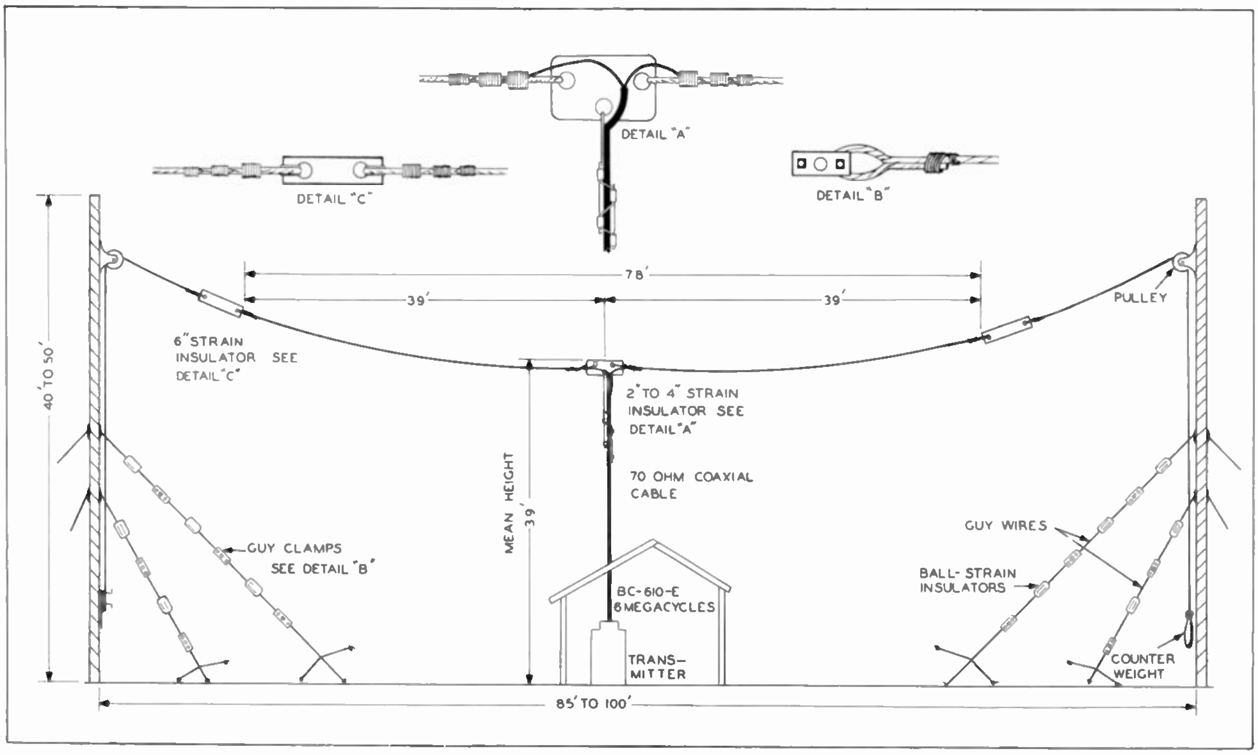


Figure 141. Installation of a Horizontal Half-Wave Antenna.

5. Erect the two poles or masts, using the manual gin-pole method (described on page 158), 85 to 100 feet apart, on an east-west line. Install guys as required. Install poles or supporting masts, messenger cables, etc., for the transmission line, if required.

6. Cut two lengths of antenna wire and attach them to the three strain insulators, so that when the wires are stretched, the length of each wire from the end-insulator eye to the center-insulator eye is 39 feet. Allow a 5% additional length of wire folded back at each end insulator for tuning adjustments to be made later. Make no permanent connections at the end insulators.

7. Attach a Lay-cit cable grip, or equivalent, to the transmission line and the center strain insulator. Solder one end of the coaxial cable (for preparation, see page 174) to the center of the antenna in the usual manner; that is, connect the braided or shield to one side, and the center conductor to the other side. For methods of weather-proofing this connection, see page 175. The specified coaxial cable has a characteristic impedance which approximates the 73-ohm radiation resistance at the center of this half-wave antenna.

8. Attach each end strain insulator to one of the ½-inch Manila ropes on each pole or mast and raise the antenna to the desired height by means of the ropes and pulleys. Attach the counterweight to one rope and center the antenna between the two poles. Fasten the other rope to the other pole and adjust the weight of the counterweight until a satisfactory amount of sag is obtained. See figure 141 for details.

9. Connect the coaxial transmission line to the transmitter. Set the transmitter for low-power operation and tune the oscillator and driver stages to 6 megacycles. Adjust the antenna coupling to produce a small but recognizable indication of loading when the power-amplifier plate tank is tuned to resonance. (The proper amount of coupling can be determined by first tuning the power-amplifier plate tank to resonance with the antenna disconnected and then, with the antenna connected, retuning the plate tank. Adjust the coupling, if necessary, to obtain a small but recognizable increase in plate current at the resonance dip.) Resonate the power-amplifier plate tank and note the power-amplifier plate-current and grid-current meter indications.

10. Retune the oscillator and driver stages to a frequency slightly less than 6 megacycles. Again resonate the power-amplifier plate tank and note the plate-current and grid-current meter indications.

a. If the frequency of the transmitter is now closer to the resonant frequency of the antenna, the power-amplifier plate-current meter will indicate more plate current while the power-amplifier grid-current meter will indicate less grid current. In this case, the frequency of the transmitter should be reduced again and the indications checked. This procedure should be continued until no further improvement is obtained. At this point, the frequency of the transmitter should be measured by means of an *accurate* frequency meter, such as an SCR-211-( ) Frequency Meter. The percentage of error in the length of the antenna may be determined from the difference between the desired 6-megacycle operating frequency

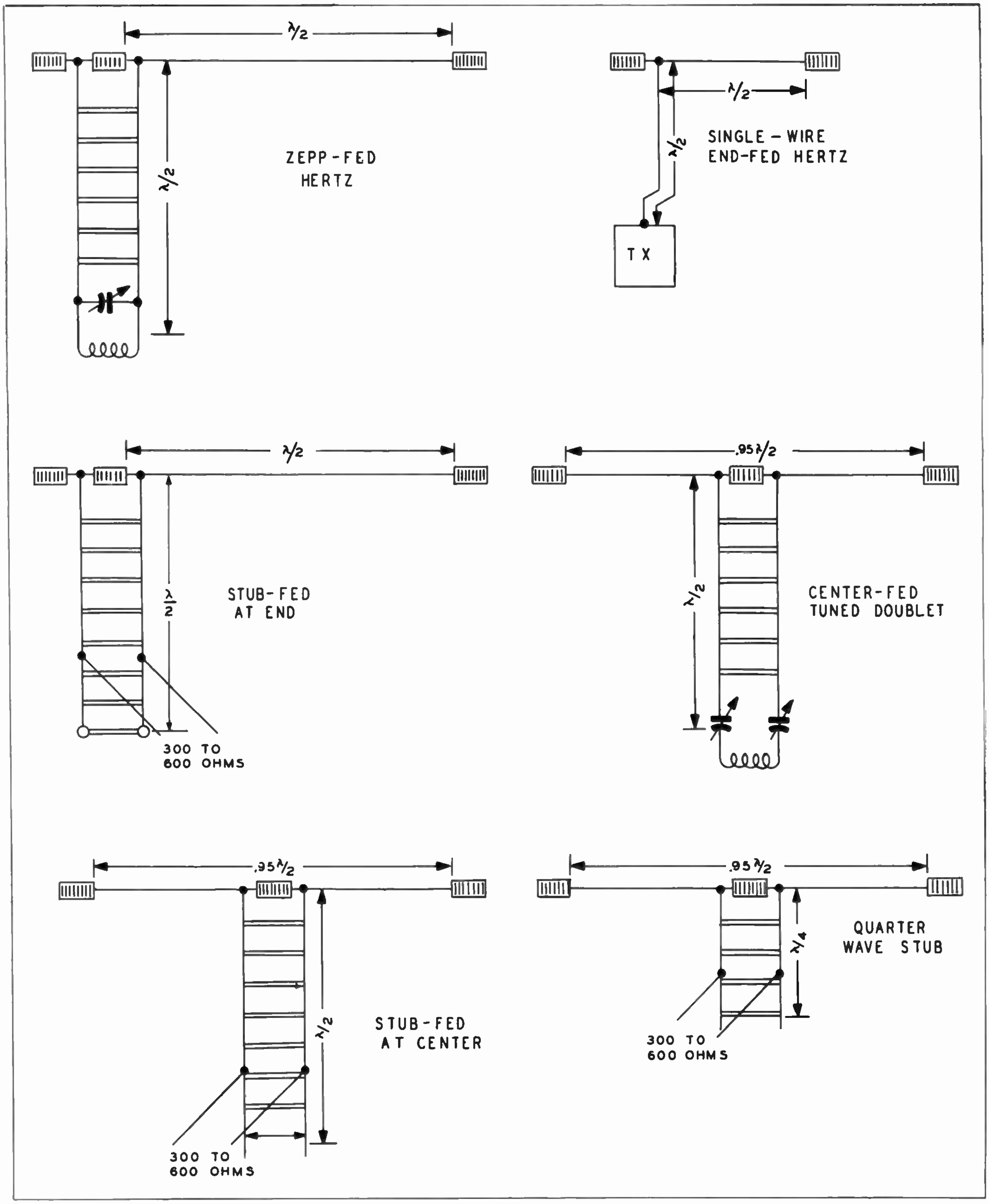
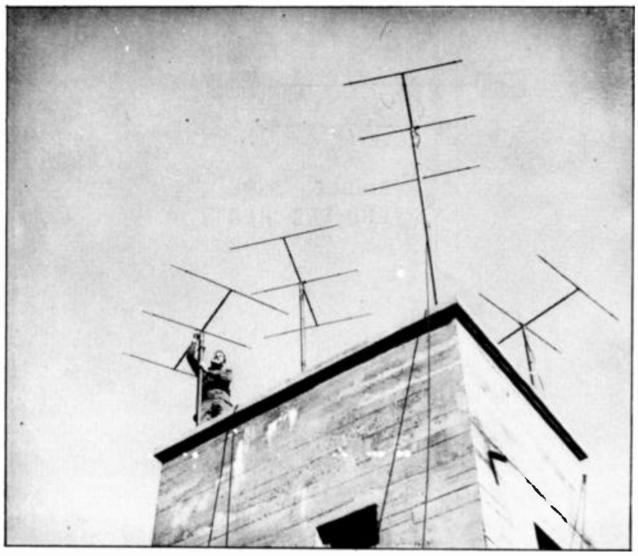


Figure 142. Examples of Basic Half-Wave Antennas.



Three-Element Parasitic Arrays for a V-H-F Radio-Link Installation.

and the actual measured resonant frequency of the antenna. The antenna should be lowered and shortened (on each end) by an amount equal to one-half the length of the antenna times the percentage of error. For example: If, in performing the resonance check on the antenna in question, it was determined that its resonant frequency is 5.8 megacycles, the percentage of error in length is determined as follows:

$$\% \text{ error in length} = \frac{\text{desired freq. minus resonant freq.}}{\text{desired freq.}} \times 100$$

$$\text{or } \frac{6.0 - 5.8}{6.0} \times 100 = 3.3\%$$

Therefore, the necessary correction in the length of each half of this antenna is 39 feet x 3.3% or approximately 1 foot 4 inches.

After the antenna length is altered, the antenna should be raised to the proper operating position and again checked for its resonant characteristic at the desired operating frequency.

b. If lowering the frequency of the transmitter did not result in an improvement of the system, the antenna is too short. In this case, it will be necessary to determine the resonant frequency of the antenna by increasing the transmitter frequency until resonance is reached and measuring the frequency with a frequency meter. Calculate the percentage of error in length and the amount that each half of the antenna must be increased as described above.

11. After the correct length of the antenna is determined by the above method, the antenna ends looped through the end-insulator eyes should be tightly wrapped, trimmed, and soldered.

12. Operate the communications system and obtain signal-strength reports from the receiving sites at Nevada City and Bakersfield for various antenna

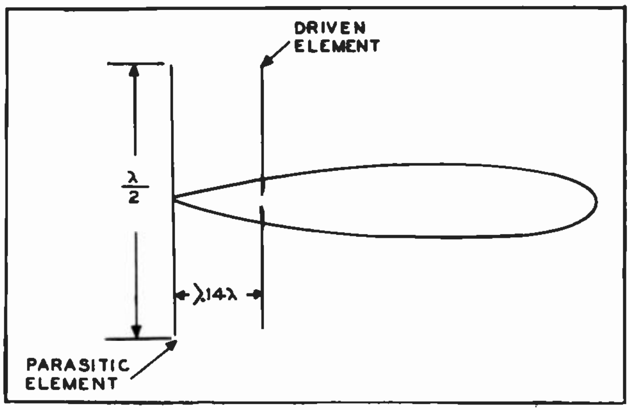


Figure 143. Use of a Parasitic Element or Reflector to Cause a Reinforcement of R-F Energy in the Direction of the Driven Element.

heights. By this method, the best permanent height for the transmitting antenna may be found.

13. If reliable communication results over a period of a few weeks of operation, the system can be considered satisfactory. However, if short-skip operation at nighttime is unsatisfactory, a lower frequency must be used. This makes it necessary to have an additional antenna or a standby transmitter and antenna for nighttime operation.

PARASITIC ARRAYS

The limited directive property of a half-wave antenna makes it necessary to use other types of antennas when it is desired to produce a concentration of radio-frequency energy in a specific direction. One of the most common directive antennas is called a "parasitic" array.

A parasitic array is perhaps the simplest of all directional arrays to understand, and is one of the more commonly used types for v-h-f point-to-point communication work by the armed forces. To understand the development of the directive effect, first consider the fact that if two conductors of equal length are placed parallel to each other and one of them is excited with r-f energy at its resonant frequency, a current will be induced in the other conductor which will, in turn, produce a radiated wave. Thus both conductors radiate energy and, if they are sufficiently separated (greater than 0.14 wave length), the secondary radiated wave from the "parasitic" element will be in phase with the incident wave from the so called "driven" element. These two waves will combine and reinforce each other in the direction of the driven element. See figure 143.

The effect is more easily understood by considering the parasitic element as a reflecting mirror for the waves traveling in its direction from the half wave length driven element.

Conversely, if the elements are separated by less than 0.14 wave length, the radiated wave will be reinforced in the direction toward the parasitic element. See figure 144.

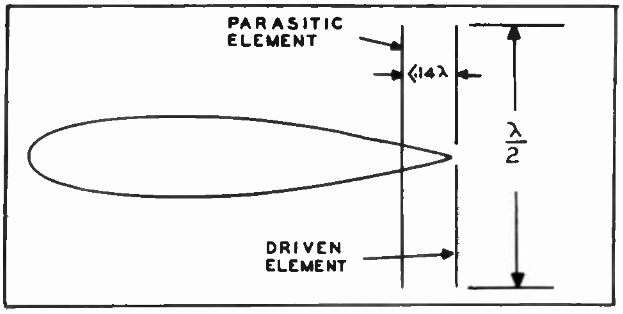


Figure 144. Use of a Parasitic Element or Director to Cause a Reinforcement of R-F Energy in the Direction of the Parasitic Element.

Self-Resonant Parasitic Element

When the parasitic element is the same length as the radiator (driven element), it is called self-resonant and the spacing determines whether it is a director or reflector. A parasitic element of this length spaced less than 0.14 wave length acts as a director, producing a relatively high antenna gain. A parasitic element of this length spaced greater than 0.14 wave length acts as a reflector, producing a relatively high antenna gain. At a spacing of 0.14 wave length, the parasitic element causes radiation equally in both directions, producing a relatively small antenna gain.

Tuned Parasitic Element

When the parasitic element is shorter (tuned to a higher frequency) than the driven element, it is called a director and reinforces radiation in the direction of a line pointing toward itself from the driven element. See figure 145.

When the parasitic element is longer (tuned to a lower frequency) than the driven element, it is called a reflector and reinforces radiation in the direction of

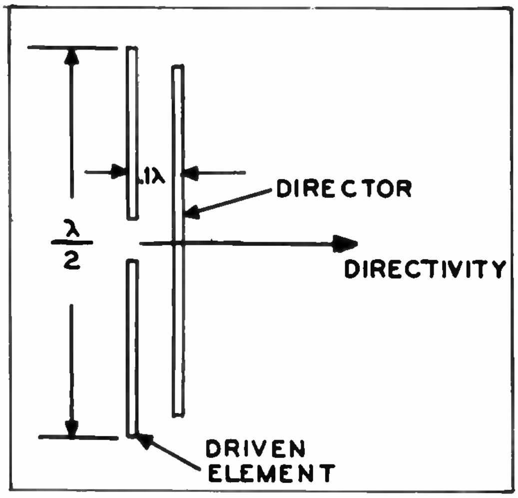


Figure 145. A Parasitic Element Shorter than the Driven Element Acts Like a Director.

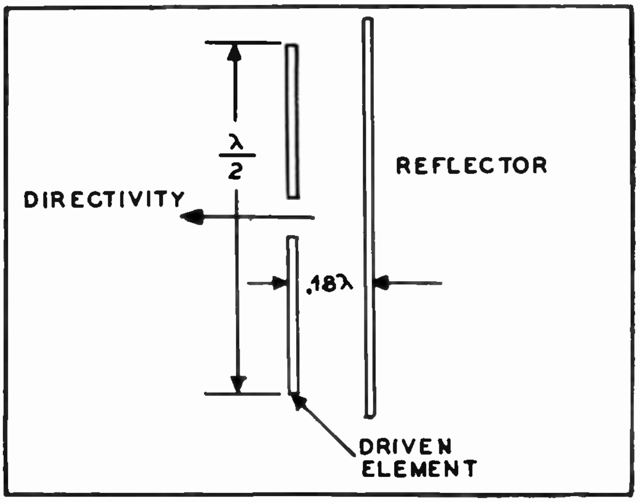


Figure 146. A Parasitic Element Longer than the Driven Element Acts Like a Reflector.

a line pointing away from itself toward the driven element. See figure 146.

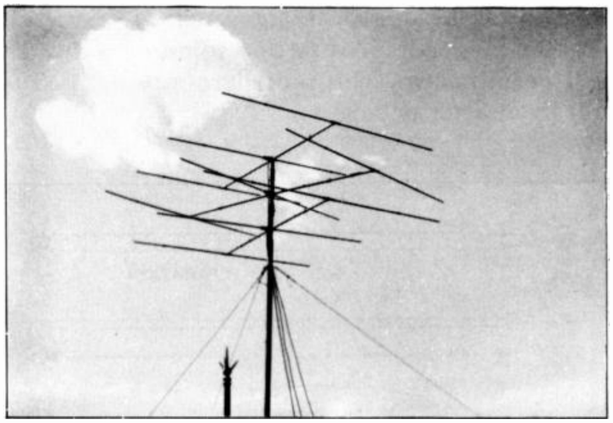
The spacing is the chief factor in determining the gain of an antenna-reflector or an antenna-director combination, while the lengths of the parasitic elements determine the sharpness of resonance of the multi-element array.

A multi-element parasitic array can be made to work over a wide frequency range by adjusting the director length to resonate at the highest frequency to be covered and the reflector length to resonate at the lowest frequency to be covered. This sacrifices some gain at all frequencies, but maintains a more uniform gain over the frequency band being worked.

Tuned Parasitic Array

A reflector is usually placed 0.15 to 0.25 wave length away from the driven element, while a director is usually placed about .1 wave length away.

The antenna elements are usually constructed of



Stacked Three-Element Parasitic Arrays for V-H-F Communications Work.

copper, brass, or aluminum tubing, ½-inch or more in diameter. The use of large diameter conductors broadens the frequency response of this type of array. The elements are made adjustable in length at both ends.

In tuning a reflector or a director of a transmitting parasitic array, its length is first adjusted for maximum forward gain, then for minimum backward gain, or gain in a direction opposite to the desired directivity. The tuning process balances the capacitive and inductive reactances of the array, so that the proper phase relationship exists between the waves radiated from the elements to produce maximum radiation efficiency in the desired direction. However, in practice, tuning for a maximum front-to-back ratio, rather than for maximum forward gain, results in high attenuation of signals and noise arriving from the rear; this method is more applicable for receiving parasitic arrays.

The spacing between the elements and the element lengths should be adjustable for maximum tuning efficiency. However, the adjustable elements can be spaced a quarter wave length at the higher frequencies.

The addition of parasitic elements to an array increases the directivity, but in practice there is a limit to the number that can be used. The limit is established by the following factors:

1. As the number of elements is increased, the radiation resistance decreases, causing higher heat losses, subsequent power loss, and over-all lowering of the radiation efficiency.

2. The extremely high selectivity of the multi-element array restricts its use to a relatively small band of frequencies on either side of that for which the system is designed.

3. Due to the lowering of the radiation resistance of the antenna, the feeder system employed becomes a distinct problem.

The above factors restrict the use of multi-element arrays to low and medium power work. By constructing arrays of tubing of larger diameter and better conducting surfaces, such as silver-plated copper, the radiation efficiency may be increased.

A step-by-step procedure for adjusting a two-element beam follows. This procedure may be used for either a director or reflector.

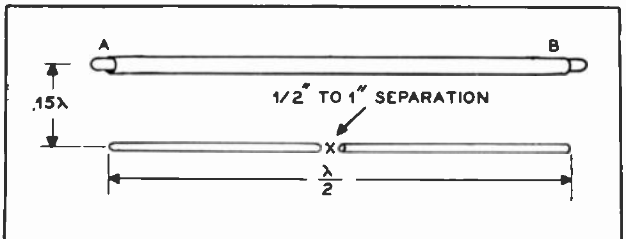


Figure 147. Physical Arrangement of a Two-Element Parasitic Array.

1. Calculate the physical length of the radiator by the formula:

$$\text{Length of } \frac{\lambda}{2} \text{ in feet} = \frac{468}{\text{freq. (mc.)}}$$

2. Assemble the array as shown in figure 147.

3. Couple a low-power transmitter (50 to 100 watts), tuned to the resonant frequency of the antenna, at point x. Use low-impedance coaxial cable. (RG-9/U, which has an impedance of 51 ohms, will produce a mismatch when coupled at point x, where the impedance is about 30 ohms, but it will probably be the lowest value available.)

4. Erect a temporary half-wave antenna, with a low range r-f milliammeter connected at the center, about 1 to 10 wave lengths away. (A communications receiver having a built-in "S" meter can be used in place of the r-f meter, or a vacuum-tube voltmeter can be placed across the diode load resistor of a receiver covering the frequency range.)

5. Turn the array so that the reflector is facing the temporary antenna.

6. Apply power and adjust extensions A and B on the reflector, in very small amounts, for *minimum* indication. (A walkie-talkie, a field line, or other suitable signalling system may be used to facilitate the operation.)

7. After minimum signal indication is obtained, the reflector length should be decreased slightly so that the minimum reading increases about 1%, and the extensions secured.

8. Turn the array so that the radiator faces the temporary antenna. A signal gain in the ratio of 10 to 1 should be indicated. For maximum receiving efficiency, this front-to-back ratio should be maintained. The maximum radiation efficiency forward, or in the direction of directivity, will not be affected much by shortening the reflector in step 7.

An array using a *director* is adjusted in the same manner. A maximum front-to-back ratio, rather than maximum gain forward, should be sought. However, in the final adjustment after minimum radiation off the back of the antenna has been determined, the director length should be increased slightly. (In both cases, this detuning is necessary to reduce the selectivity, and to offset excessive attenuation of the signal in the forward direction.)

The gain in the forward direction of the two-element arrays discussed above is approximately 4 or 5 times greater than that obtained from a single dipole.

Three-Element Parasitic Array

Figure 148 shows a three-element parasitic array. The input impedance at the feed point approximates the radiation resistance, which is 8 to 10 ohms. A 50-ohm or 70-ohm coaxial line or any high-impedance line can be coupled to the antenna if a suitable matching system is used. The matching system should be

INPUT IMPEDANCE AND APPROXIMATE GAIN OF VARIOUS PARASITIC ARRAYS

Type of Antenna	Input Impedance (ohms)	Gain Over Dipole (db)
Dipole	72	0
Folded dipole	300	0
Dipole and reflector	60	3 to 4
Folded dipole and reflector	250	3 to 4
Dipole, reflector, and director	20 to 30	4 to 6
Folded dipole, reflector, and director	80 to 120	4 to 6
Stacked dipoles	35 to 40	3 to 4
Stacked folded dipoles	150	3 to 4
Stacked dipoles and reflectors	25 to 30	6 to 7
Stacked folded dipoles and reflectors	100 to 120	6 to 7
Dipole turnstile	35 to 40	—1.5
Folded dipole turnstile	150	—1.5

properly readjusted after the antenna tuning is completed.

The following tuning-adjustment procedure can be used for a three-element array.

1. Assemble the array as shown in figure 148; cut the driven element to $\frac{.95}{2}\lambda$.
2. Couple a 50 or 100-watt transmitter at point X.
3. Erect a temporary antenna, as indicated in the tuning procedure for the two-element array. A portable, temporary antenna for frequencies above 25 mc. can be constructed in the form of a half-wave loop, as illustrated in figure 149. It should be oriented parallel with the parasitic array.
4. Swing the array so that the reflector is adjacent to the temporary antenna.
5. Adjust the *director* a short distance at a time until minimum signal is indicated by the meter on the temporary antenna.
6. Adjust the *reflector* length, as in step 5 above, for minimum indication on the temporary-antenna meter.
7. It may be necessary to "touch up" both the director and reflector for absolute minimum signal indication.
8. Swing the array so that the director is facing the temporary antenna.
9. Adjust the length of the *director* for *maximum* signal indication.
10. Secure all adjustment extensions and connections.
11. Measure the front-to-back ratio by taking the maximum and minimum signal indications when the array is pointed directly at, and directly away from the temporary antenna. This ratio should be approximately 9 to 1. The array should now be raised to its operating height and properly secured.

The maximum forward gain of the three-element array is considerably greater than that of the two-element array. A four-element array has greater directivity than the others described above. It represents the practical limit, relative to the number of elements used, for *ordinary* tactical use. However, as many as eight elements may be used in a properly designed array or beam antenna, for operation over a very narrow band of frequencies. Figure 150 shows the layout for a four-element array.

Tubing 1 inch, or greater, in diameter should be used to maintain the maximum ratio of radiation resistance to ohmic resistance. The tuning procedure is similar to that of the three-element array. Orient the array so that the back or reflector end is facing the temporary antenna. Adjust the parasitic elements for

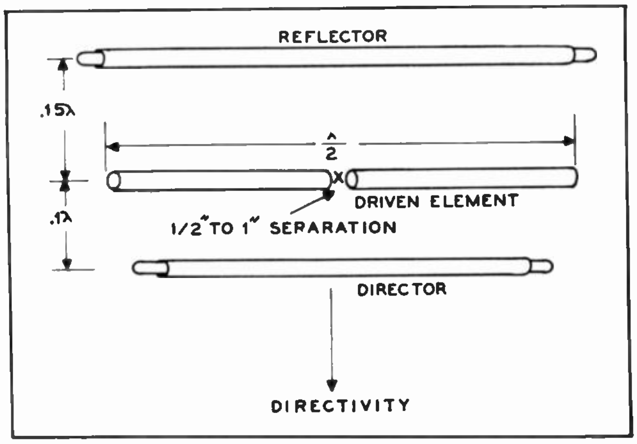


Figure 148. Physical Arrangement of a Three-Element Parasitic Array.

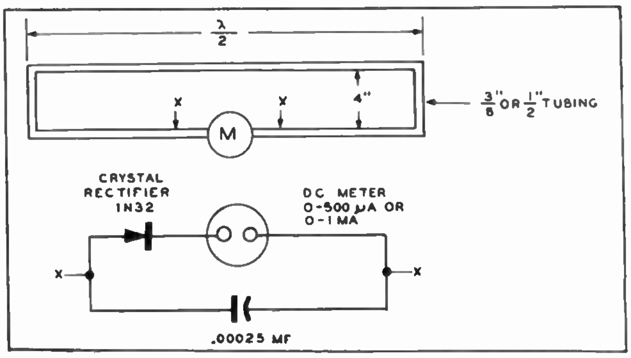


Figure 149. Directive Loop-Type Antenna with Metering Circuit for Checking a Parasitic Antenna Array.

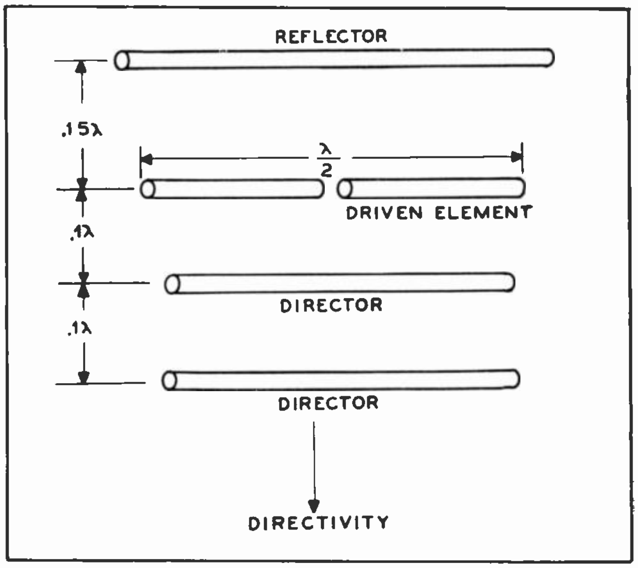


Figure 150. Physical Arrangement of a Four-Element Parasitic Array, Employing Two Directors and One Reflector.

minimum signal indication, beginning with the director nearest the driven element. Then tune the second director for minimum (not necessary to tune for absolute minimum) and, finally, tune the reflector for minimum. Swing the array 180° so that the directors are facing the temporary antenna. Then tune the directors for *maximum* forward gain. All joints should be permanently secured, after which the assembly is ready to be elevated on the mast.

In many instances, parasitic elements are constructed with insulated spacers at their centers, and a bond is used between the two sections. More accurate tuning of this type of array can be accomplished by disconnecting the bond between the two sections of one parasitic element before tuning the other parasitic element. This should be done during the preliminary adjustment procedure. After one parasitic element is adjusted, its bond is disconnected and the other parasitic element is tuned after the bond between its sections is connected.

It will be recalled that the radiation resistance is a function of the antenna height, and that the antenna efficiency is a function of the radiation resistance. The proper height of an antenna array for maximum radiation resistance can be determined experimentally. A half-wave antenna of the same length as the driven element of the parasitic array, with an r-f current indicator connected at its center and driven by a low-power transmitter, is raised to various heights until maximum current is indicated. The height at which maximum current is obtained is the proper height for maximum radiation efficiency. However, it may not necessarily be the correct height for obtaining the desired directivity (*high* or *low angle*). The approximate height for a given wave angle can be determined by the use of ground-reflection-factor charts or by the "cut-and-try" method. The latter method requires the use of a pulley arrangement for raising and lowering the array. To obtain the most effective results, the array should be checked by one or more stations with which communication will normally be conducted, according to a carefully prearranged plan.

Construction of a Parasitic Array

Parasitic arrays find their greatest use on frequencies above 14 mc. Compact construction of an array for a lower frequency becomes impractical. The weight factor of an array at the lower frequency limits requires the use of heavy supporting structures, such as telephone poles or towers. At the ultra high frequencies where the total weight due to the reduced size of the elements is relatively smaller, the use of pipes or rods (suitably guyed) for supporting masts is practical. In most cases, the element adjustments must be made near the ground, which means that when the array is hoisted to its permanent position on top of the supporting mast the field pattern will suffer some change, and will require slight compensation.

For the lower-frequency antenna arrays, the supporting members for the elements can be wood "two-by-fours" or composition tubing. With a little mechanical ingenuity, a rugged, substantial job, which will withstand the destructive effects of high winds, can be produced. All element extensions and joints should be carefully bonded, to prevent antenna-resistance changes due to oxidation over long periods of time.

Sometimes it is advantageous to rotate the array, in which case it is called a rotary beam. This can be done by supporting the array with a bearing at the top of the pole or tower. A d-c or a-c motor, which is controlled from the transmitter shack, is coupled to the rotating element through a high-ratio gear-reduction system. The motor may be a one-quarter or one-half horsepower motor, depending upon the size of the array. For convenience in operation, a selsyn system can be incorporated to indicate the compass direction of the beam.

At the higher frequencies, steel pipe or composition tubing is usually used as a mast. The shorter length elements are rigid enough to be self supporting. Figure 151 shows a conventional type used for military radio communication on frequencies between 70 and 100 megacycles. The horizontal element supports are of metal, and have no appreciable effect on the antenna performance. The solid metal junction points of the elements and supports are made at low-impedance points. Field effects due to induced currents in the supporting arms are negligible, because they are perpendicular to the radiating elements at this close range. Arrays of this type are usually employed for single-frequency operation. Adjustments of the element lengths at the ultra high frequencies are more critical and extreme care must be exercised. Thus, the reflector or director-element extensions are moved only about 1/8 inch or 1/4 inch at a time when tuning the array.

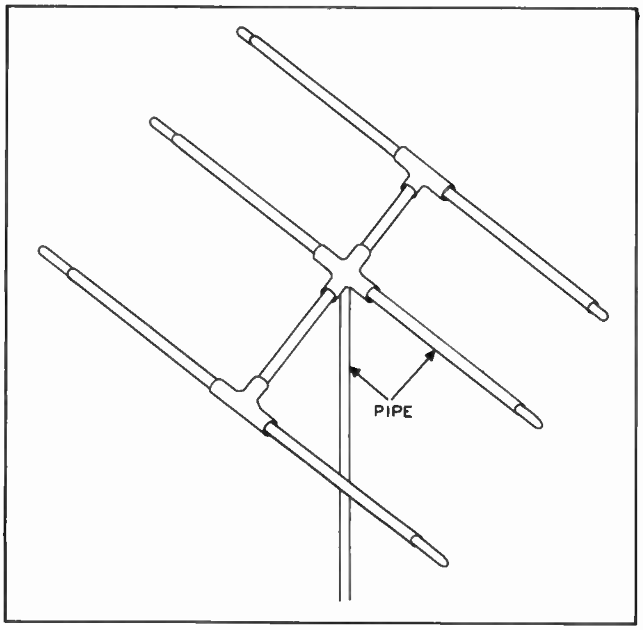


Figure 151. Three-Element Parasitic Array of Steel Pipe on a Steel-Pipe Mount.

DRIVEN ARRAYS

In the preceding discussion, it was concluded that a parasitic antenna array is best suited for low-power work, because of the increase in the over-all power loss of the antenna system as the number of parasitic elements is increased. A "driven array," which retains the narrow-beam characteristics of the multi-element parasitic array overcomes this difficulty and, therefore, is capable of handling high power.

The driven array consists of a number of elements (usually half-wave dipoles), which are fed in phase or out of phase from a common source. Driven arrays are usually subdivided into three basic types: the collinear, the broadside, and the end-fire.

Collinear elements lie in the same plane or axis, and are excited in phase. The radiation pattern is broadside to the plane of the elements. See figure 152.

Broadside elements lie parallel to one another, and are excited in phase. The radiation pattern is also broadside to the plane of the elements. See figure 153.

End-fire elements lie parallel to one another, but are excited out of phase. The radiation pattern is in the plane of, and at right angles to the elements. See figure 154.

The radiation pattern produced by any one of the three types of driven arrays depends mainly upon the following factors:

1. The number of elements
2. The physical placement of the elements in relation to each other
3. The spacing between the elements
4. The phase relationship of the energy feeding the different elements

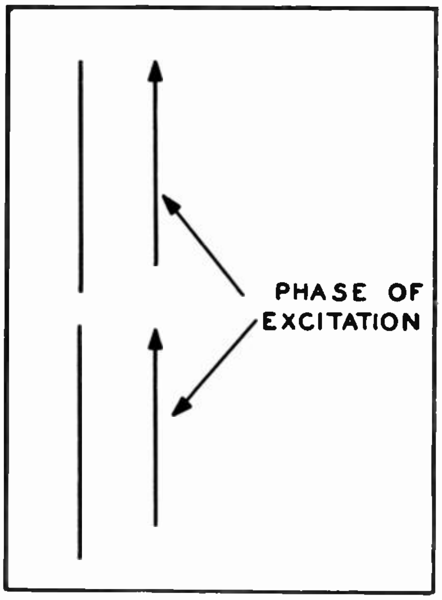


Figure 152. Collinear-Type Array, Showing Phase of Excitation.

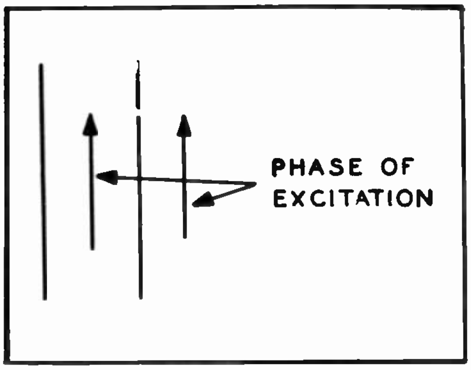


Figure 153. Broadside-Type Array, Showing Phase of Excitation.

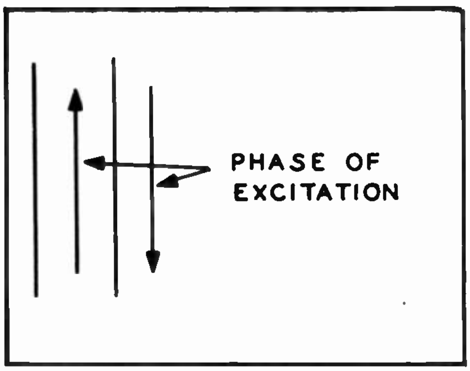


Figure 154. End-Fire-Type Array, Showing Phase of Excitation.

Collinear and broadside types of driven arrays always give bidirectional radiation patterns, but the end-fire type can be made to produce either a bidirectional or unidirectional radiation pattern.

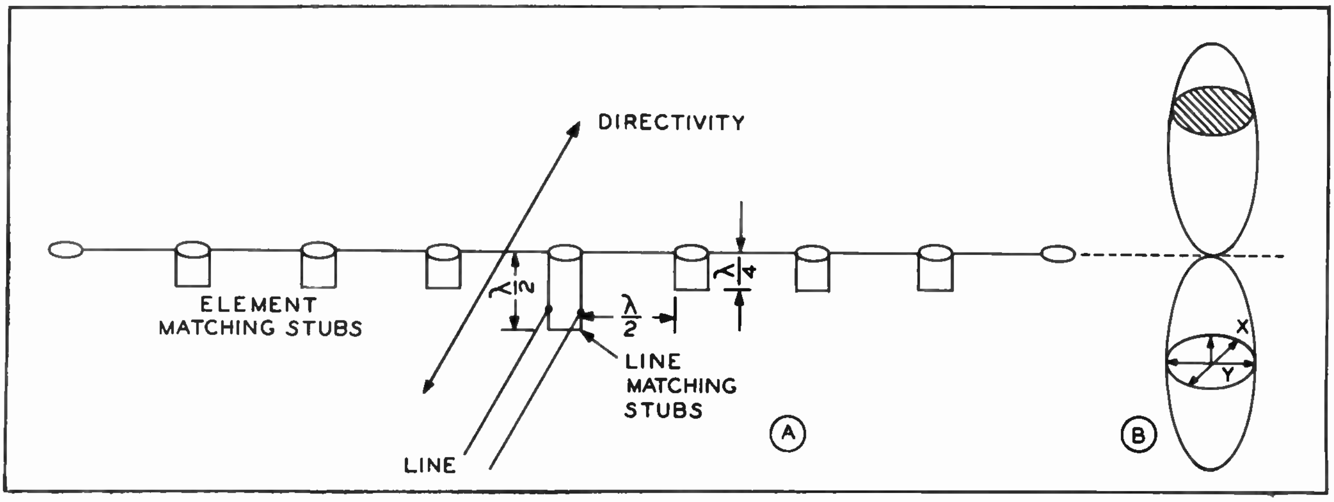


Figure 155. Physical Arrangement of a Simple Collinear-Type Array and the Resultant Field Pattern.

Collinear Array

Figure 155A shows the general layout of a simple collinear array. The array can consist of two or more half-wave elements. If the elements are a half wave long, the matching stubs are a quarter wave long. However, the elements can be made as long as 0.8 of a wave length, in which case the matching stubs are made correspondingly shorter. If the array is used as shown, the bidirectional field pattern will be broadside to the array. See figure 155B. The spacing of the lines in the matching stub should be such that the distance from center to center of the adjacent collinear elements does not exceed 0.75 wave length, when these elements are 0.5 wave length long.

In constructing an array of this type, the first element (or elements) to be fed by the line is connected and tuned. Elements, together with their matching stubs, are added one at a time. As each element is added, its matching stub is tuned for maximum current in the shorting bar; the input-line matching stub is then tuned for maximum current. This process must be repeated when more elements are added. Although adjusting the current to maximum at the shorting bar does not guarantee that the element length is one half wave length, it does cut down the radiation from the matching-stub section.

Broadside Array

Figure 156A shows the general layout for 8 vertical half-wave elements excited in phase, and spaced a half wave length apart.

The bidirectional radiation pattern is broadside to the array, as indicated in figure 156B, which shows the field pattern as viewed from above. The over-all gain of the system depends upon the number of elements and the spacing between the elements. Whenever possible, a matching-stub system is used to feed the array because of its inherently low radiation resistance.

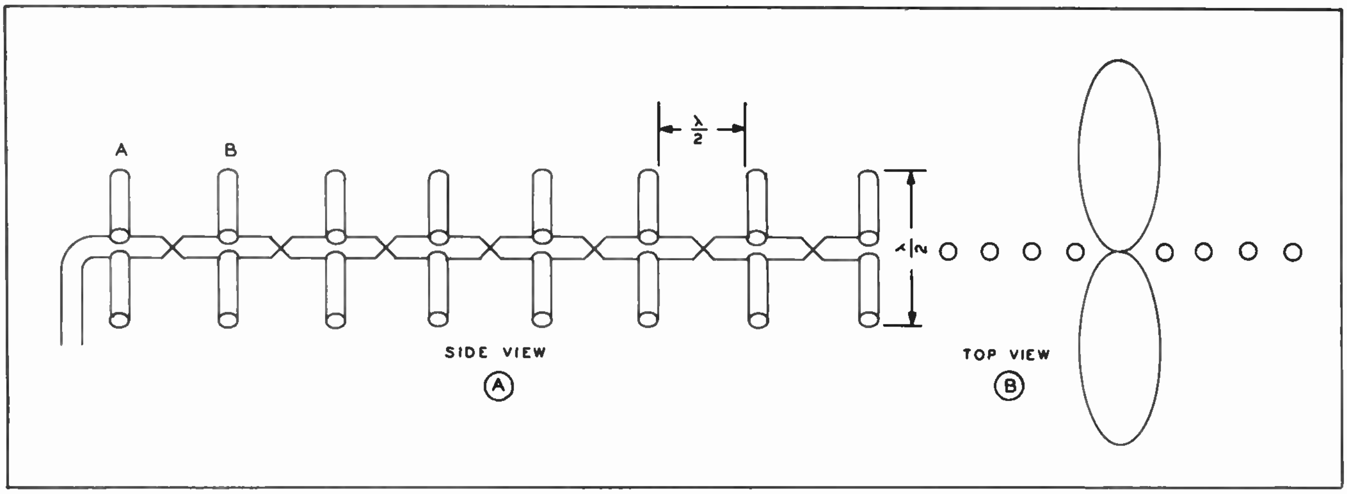


Figure 156. Physical Arrangement of a Simple Broadside-Type Array and the Resultant Field Pattern.

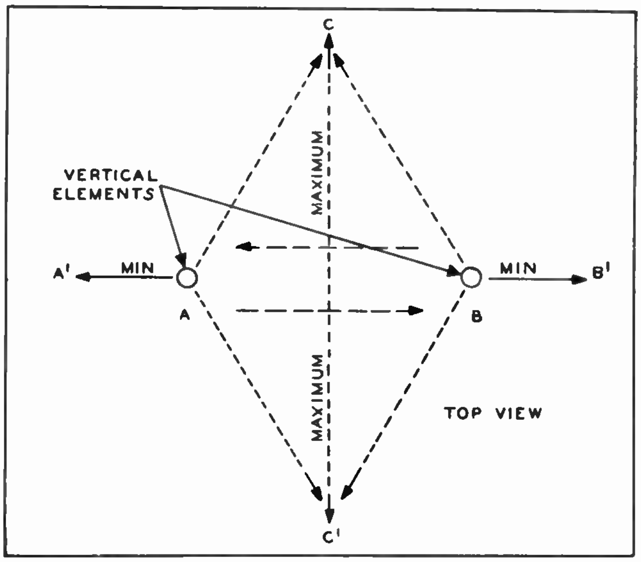
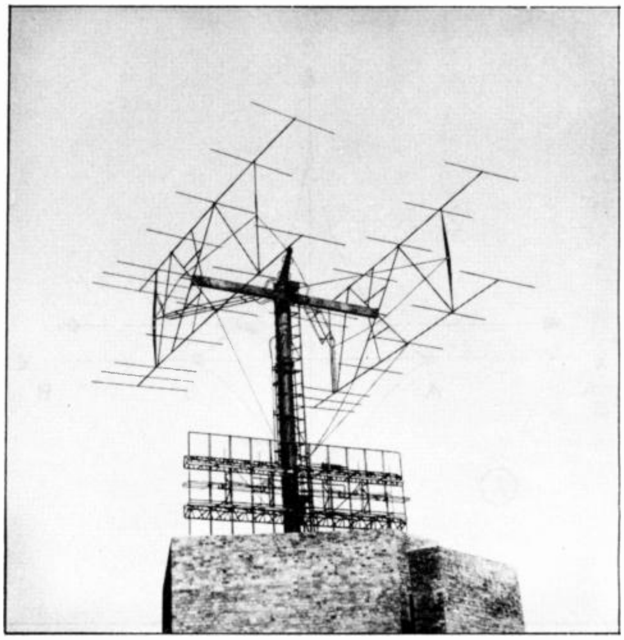


Figure 157. Analysis of the Resultant Directivity of a Broadside-Type Array.



Examples of Yagi and Broadside-Type Arrays.

The bottom end of the elements of a vertical broadside array may be at ground level. The ground acts to reinforce the signal in the same fashion as if a single half-wave antenna were involved.

To understand how the energy is directed broadside, consider the action in two elements A and B of the array, which are vertically polarized. In figure 157, the elements are shown as viewed from above. Along the line A′B′ in space, the radiated fields from A and B are out of phase and tend to cancel. However, along the line C C′ in space, the radiated waves from A and B are in phase and, therefore, reinforce each other to produce a considerable gain in the broadside direction.

End-Fire Array

Figure 158A shows the arrangement of a horizontally suspended end-fire array. The elements are a half-wave long, and are spaced a half wave length apart. The currents in the elements are out of phase.

The radiation pattern is bidirectional off the ends of the array, as shown in figure 158B. The gain of this system depends primarily upon the number of elements and their spacing. The array shown is fed at the center of the center element, which is a low-impedance point. This symmetrical type of feed results in a better current balance in the entire system. The vertical angle of radiation depends mainly upon the height above ground.

To understand how the end-fire directive effect is obtained, refer to figure 159A which shows two elements of an end-fire array. The dashed lines from A to C and from A to C′ and the continuous lines from B to C and from B to C′ represent two fields opposing each other by 180°, thus resulting in energy-travel cancellation in the direction C and C′. Figure 159B illustrates the phasing of the fields from A and B in the broadside direction CC′.

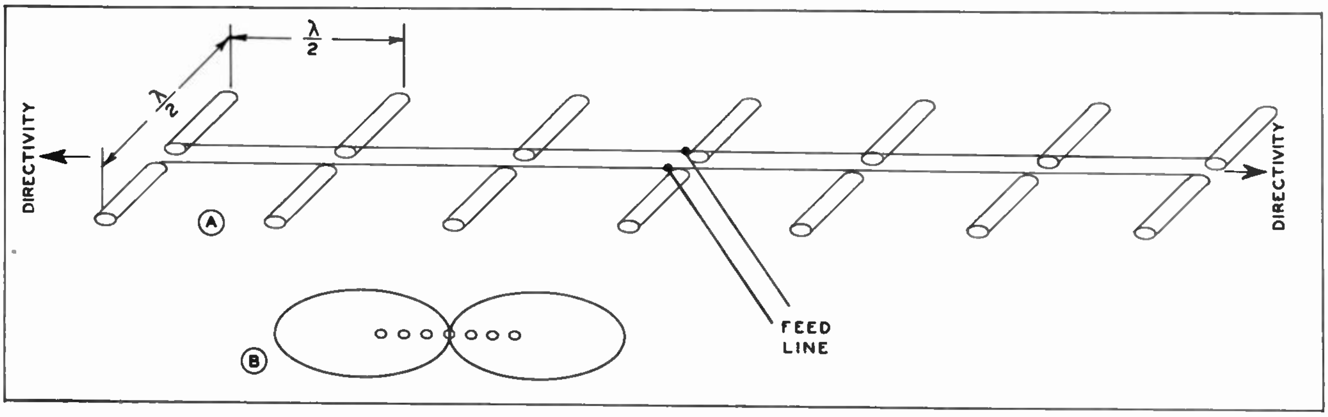


Figure 158. Physical Arrangement of a Simple End-Fire Array, Showing the Resultant Field Pattern.

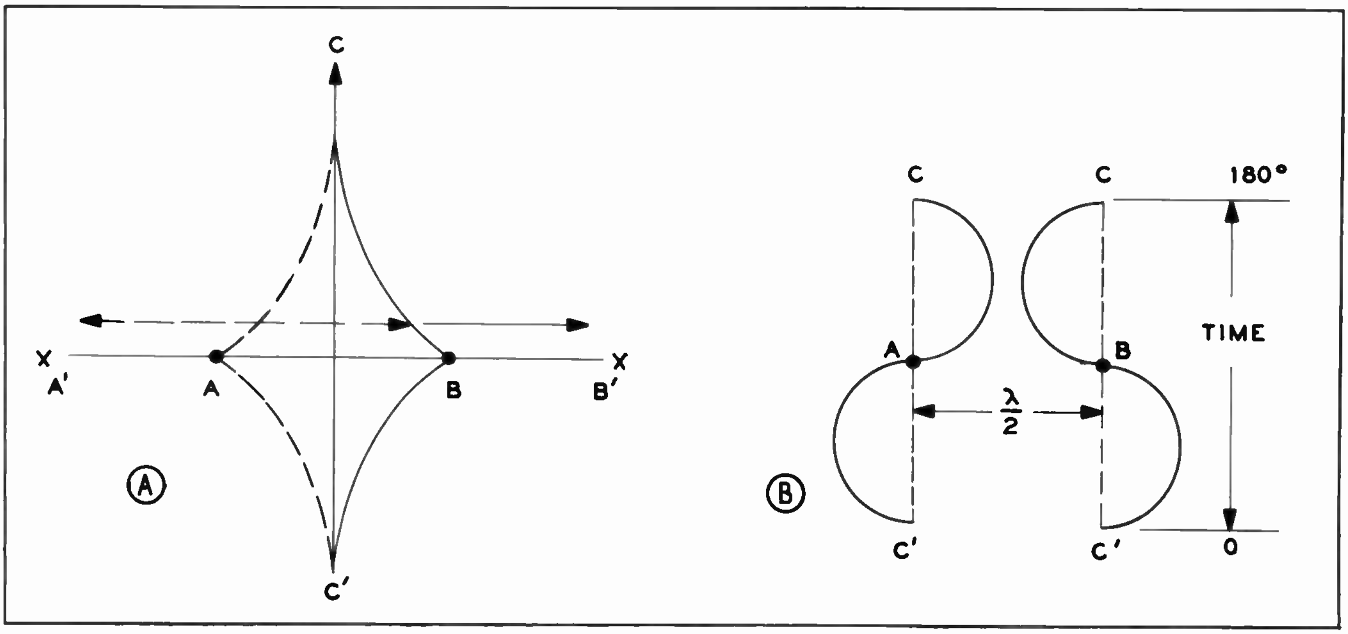


Figure 159. Analysis of the Field Pattern of an End-Fire-Type Array.

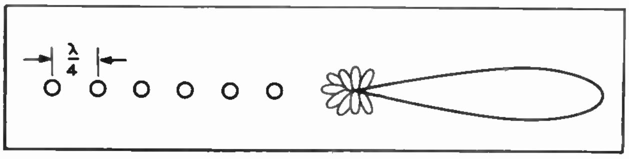


Figure 160. Directivity of the Radiation Pattern from a Six-Element, End-Fire-Type Array.

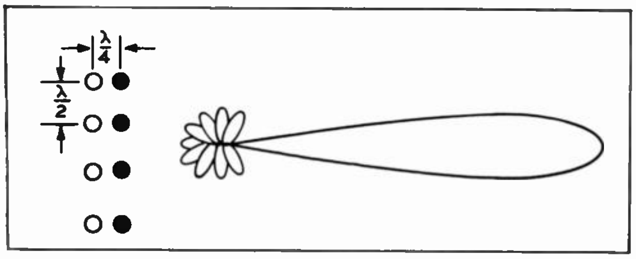


Figure 161. Directivity of the Radiation Pattern from Two Rows of Vertical Dipoles, with the Front Dipoles Fed in Phase and the Rear Dipoles Fed Out of Phase.

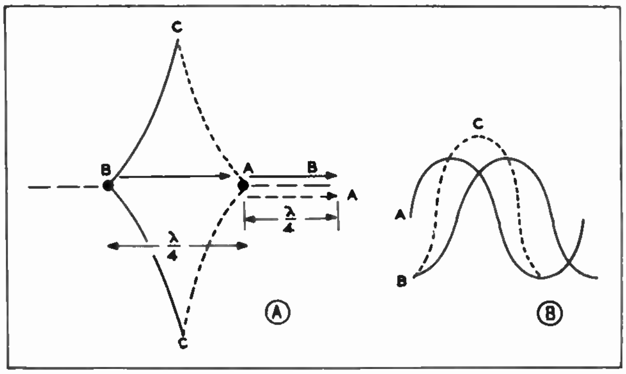


Figure 162. Development of Directivity of Pattern from Two Dipoles Spaced a Quarter Wave Length Apart and Fed 90° Out of Phase.

From element B in the direction B′, the wave has traveled 180° before the wave from A starts in the same direction. At the same time, electrons have traveled from one end of element A to the other end. Three important things happen simultaneously to produce the end-fire effect.

1. The current in element A reverses its direction.
2. The induction field 180° away from B in the direction of B′ reverses toward element B.
3. At precisely the instant that the actions described in steps 1 and 2 above start, the wave from element A begins to travel toward element B. Thus by the time the field from point B′ has arrived back at element B, and is ready to start back toward B′ (the r-f energy coming in from the transmitter feed line keeps it moving), the field from A has just arrived at B. The field from A arrives at B at precisely the right instant to allow it to depart in the direction of B′, in phase with the field generated by element B. The two fields thus combine to reinforce each other in direction B′.

The same process takes place in the direction A′, thus producing a bidirectional effect.

If a row of dipoles are spaced a quarter wave apart, and excited so that the currents in adjacent elements are 90° out of phase, a unidirectional end-fire effect will be obtained. Figure 160 shows the directive pattern obtained when a row of six dipoles were so spaced and phased.

Figure 161 shows a row of vertical dipoles (black circles) excited in phase and spaced a half wave apart, and another row of dipoles (white circles) placed a quarter wave behind and excited 90° out of phase; the front dipoles act as a reflector system. This array produces a sharp broadside directional beam. The reflector dipoles act as parasitic reflectors if no direct excitation from the feed line is applied. To understand the reflector action in the last two arrays mentioned, refer to figure 162A, which shows two half-wave dipoles spaced a quarter wave apart and excited so that the current in dipole A lags the current in dipole B by 90°.

Since the current in dipole A lags the current in dipole B by 90°, the field of A arrives at C or C′ 90° ahead of the field from B. However, the fields will add, as shown by the dotted lines in figure 162B. Since the waves from B and A, travelling toward C and C′, combine so that their resultant is along a 45° vector line, the algebraic sum is $\sqrt{2}$ or 1.414. Thus the signal intensity in the direction of C or C′ is 1.414 times that from either dipole A or B alone. (It should be mentioned, however, that for efficient end-fire directivity this condition is not desirable.)

Horizontal, End-Fire Array, Used in the High-Frequency Band and Commonly Known as a "Fishbone" Array.

Since the distance between A and B is equal to 90 electrical degrees and since the current in A lags that in B by 90°, the wave front from B arriving at A will be exactly in phase with the field starting from A toward A′. Thus the two fields combine arithmetically: $1 + 1 = 2$. This addition is possible because no phase shift is present. Thus a gain of 2 is realized in this direction. In the direction B′, the wave traveling from A to B arrives at B in phase opposition to the field produced at B. Thus energy travel in the direction B′ is cancelled.

Several types of stacked broadside arrays are in common use. Two simple types are shown in figure 163. Their physical construction is the same, but in one the two elements are excited 180° out of phase.

In figure 163A, the parallel dipole elements are a half wave long, and are spaced a half wave length apart. The two dipoles are fed so that their currents are in phase, thus producing broadside bidirectional field patterns. The polarities indicated show the in-phase condition. This array is commonly known as a "lazy H" array.

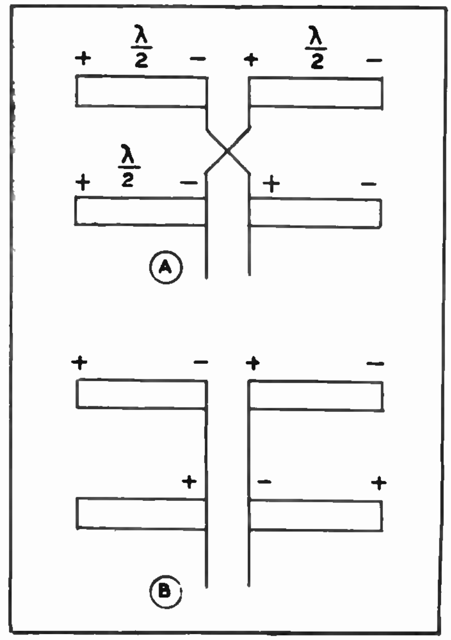


Figure 163. Layout of Stacked Broadside Array, Showing Two Methods of Phase Excitation.

In figure 163B, the currents in the dipoles are 180° out of phase with each other. The polarities indicate that a high-angle vertical-plane radiation pattern will result.

Since both of the above arrays are fed at high voltage points, either a tuned line or an untuned line with a matching stub may be used. The sharpness of the beam may be increased by decreasing the spacing be-

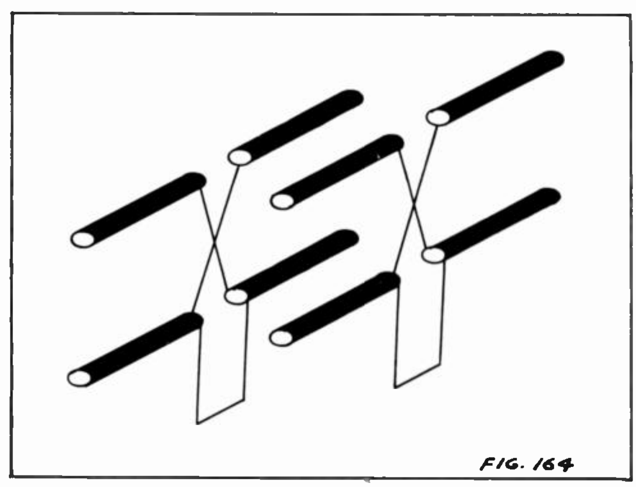


Figure 164. Physical Arrangement of a Stacked Broadside Array with Matching Stubs.

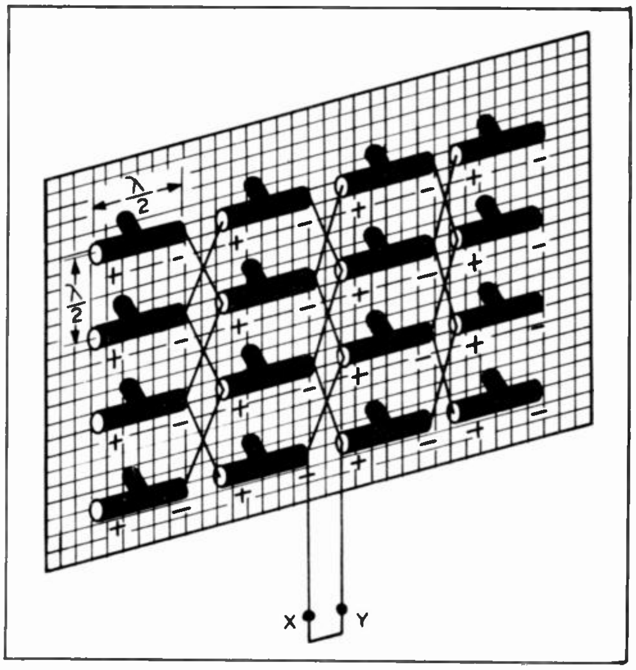


Figure 165. Physical Arrangement of a Special 16-Dipole Broadside Array, Mounted on a Parasitic Wire-Screen Reflector.

tween the dipoles; however, the feed line connecting these dipoles must be kept a half wave long. If less than half wave spacing is used, the feed line should be tuned to the top dipole first, then the lower dipole elements should be adjusted for minimum standing waves on the feed lines.

Figure 165 shows a special broadside antenna. Sixteen dipoles are connected in such a manner that they are all excited in phase. The spacing between the horizontal rows of dipoles is an electrical half wave length. A properly constructed screen is placed one tenth to one quarter wave length behind the array of dipoles. This screen, which acts as a parasitic reflector for the fields from the phased dipoles, directs the radio-frequency energy in a forward direction, and allows practically no radiation in a direction behind the screen.

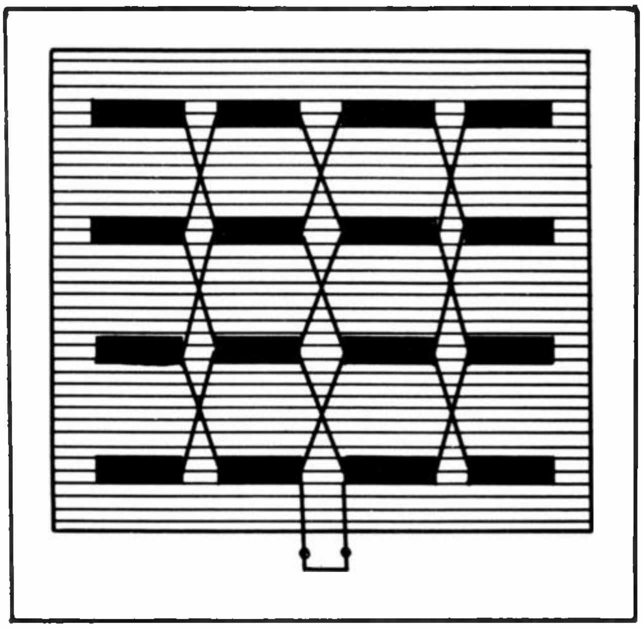


Figure 166. Layout of a 16-Dipole Broadside Array, Mounted on a Regular Screen-Type Parasitic Reflector.

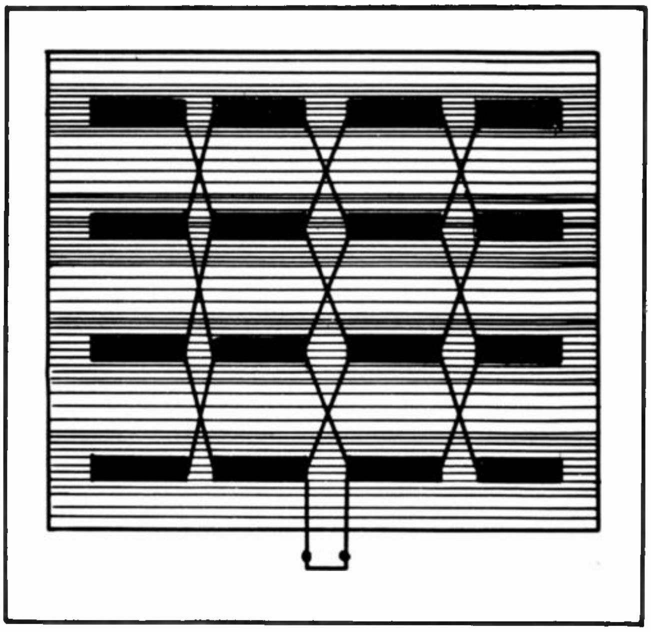


Figure 167. Layout of a 16-Dipole Broadside Array, Mounted on an Irregular Screen-Type Parasitic Reflector for Additional Reinfocement.

The parasitic reflector will provide the highest array efficiency if it is constructed of nonmagnetic sheeting. For frequencies below 100 mc., an array of this sort using sheet metal for the screen would have an exorbitant weight. It is general practice to use either a mesh screen or a system of wires arranged parallel to the line of dipoles, and placed a quarter wave length behind the dipoles. Figures 166 and 167 show two layouts of this type of array. The excited dipoles are identical. In figure 167, the weight of the array is reduced by having a greater concentration of small wires directly behind the dipoles. This type of system provides better mechanical stability in high winds.

The dipoles are supported by short metallic elements, between a λ/4 and an λ/8 long, connected to the parasitic reflector. Since the metallic supports are attached to the center of each dipole element, they form a parallel circuit with the feed point. This lowers the radiation resistance of the array.

Each of the dipoles in the special array has an impedance of 2500 ohms at the feed point, with a λ/4 spacing between the dipole and the reflector. For an λ/8 spacing between radiator and reflector, the impedance at the feed point decreases to about 2000 ohms. The arrangement of the eight dipoles as shown produces an effective parallel circuit. Thus the impedance at the ends of the elements falls to a value of about 1600 ohms. Since the array of eight dipoles are in phase, the input impedance is found simply by dividing 8 into 1600: $\frac{1600}{8} = 200$ ohms. The actual value may be between 180 and 200 ohms. For maximum efficiency, a matching section should be used for coupling the feeder line to the driven array.

Other types of phasing arrangements can be used. For instance, it is possible to produce a unidirectional effect by placing two identical arrays a $\lambda/4$ apart so that the dipoles of each are parallel. The elements in each "curtain" are excited so that the currents in the corresponding elements of the two arrays are 90° out of phase. The propagation will be broadside in the direction of the array having the lagging current. Driven arrays of this type which require critical adjustment for efficient operation, are not widely used.

Other arrangements include the use of two arrays placed end to end. They are excited so that the energy flow in one array is 180° out of phase with that in the other.

Figure 168 shows the method of feed for a 16-dipole stacked broadside array, and the associated radiation pattern.

Sterba-Curtain Array

For the transmission of high-power, directional communications signals, a type of stacked collinear array called the Sterba-curtain array is used. Basically, a simple Sterba array consists of a combination of stacked elements as shown in figure 169. The dotted line shows the distribution of the standing-wave currents on the array. The feed line is introduced at a low-impedance point (x-y). It can be fed at either a high or low-impedance point, depending upon the transmission line used. Figure 170 shows a complete phased array, including a curtain reflector. The arrays are suspended between two steel towers by means of messenger cables. Metallic spacers a $\lambda/4$ long separate the two driven arrays. The spacers are usually made of steel tubing. Both the curtains may be excited with the current from the line, or the "back" curtain may remain unconnected from the line, and act as a parasitic reflector. This array consists of four Sterba sections for the front unit, and four for the back unit or curtain reflector. For powers ranging from 5 to 30 kw., #12 to #6 B. & S. wire size should be used. The wire used should have high tensile strength (steel-core copper wire), as the total weight imposes severe mechanical strains (several tons at tower tops) throughout

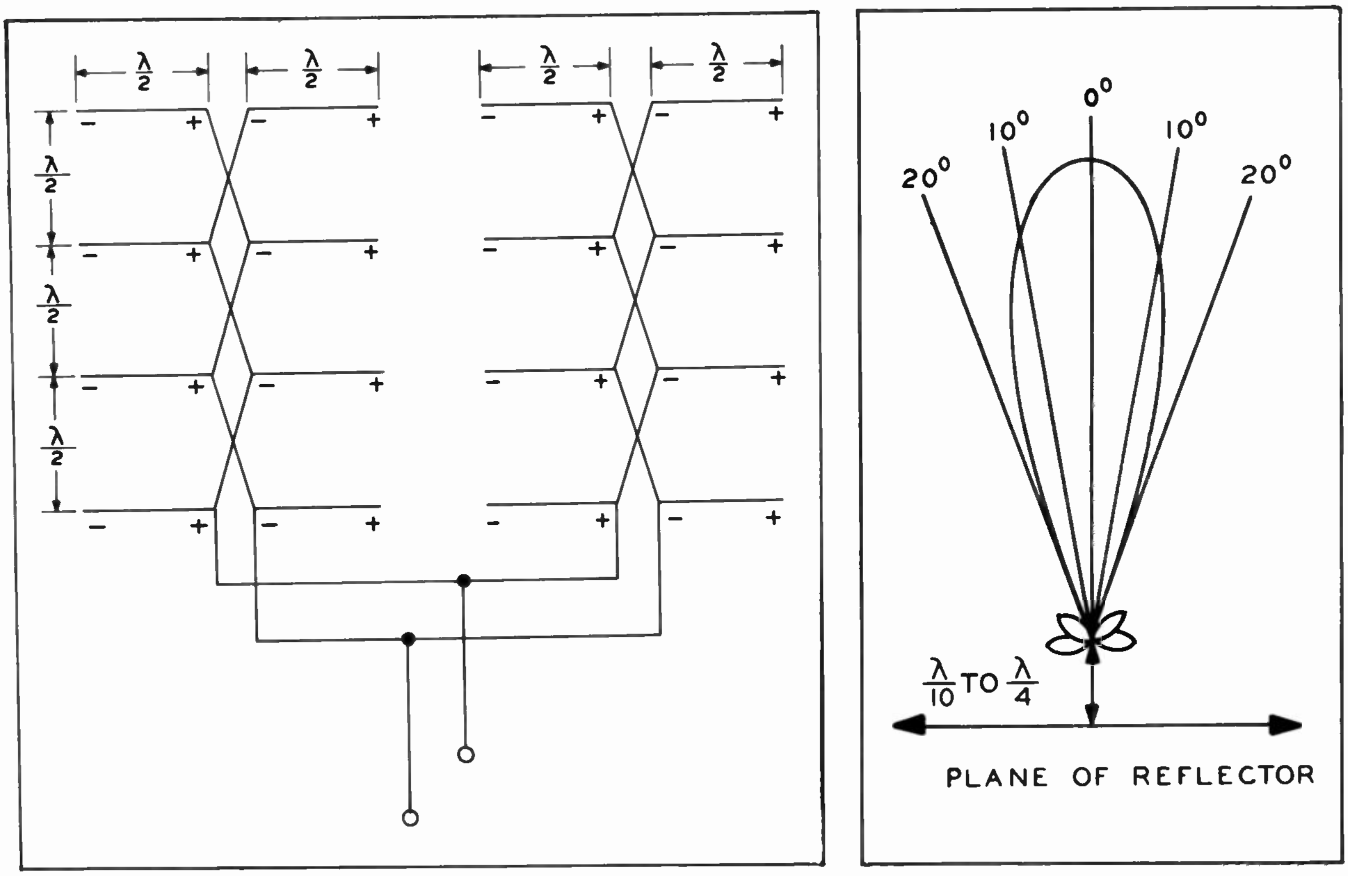


Figure 168. Method of Feeding a Stacked, 16-Element Broadside Array and the Associated Radiation Pattern.

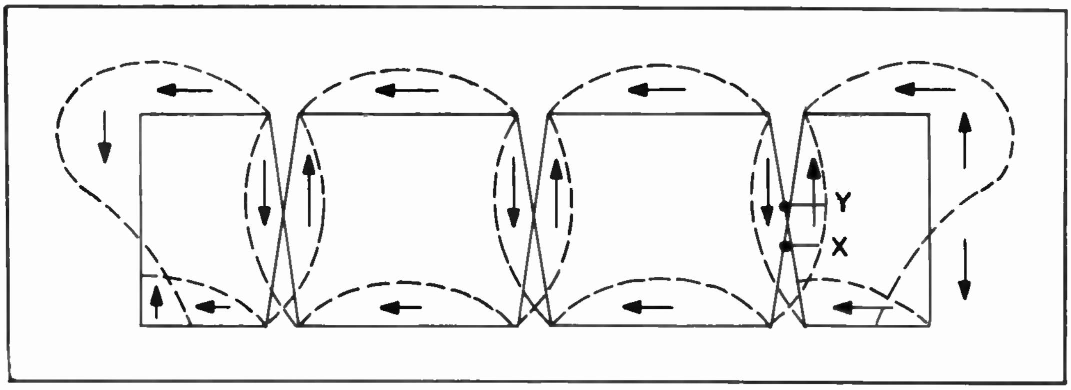


Figure 169. Method of Feeding a Stacked Collineur Array. This array is commonly known as a Sterba Curtain.

the array. The array is supported by stranded-steel messenger cables. Curtain sizes differ, as the range of a Sterba "farm" may cover wave lengths from 65 to 15 meters.

For the shorter wave lengths (higher frequencies), a greater number of Sterba sections can be suspended in a given tower separation. For example, if the 8-section Sterba array shown in figure 170 were used for 60 meters, the same tower separation could be used for a 16-section, 15 or 20-meter Sterba array. The broadside beam width from the latter array would be considerably sharper, reaching a probable low value of 10° to 15°. The 90-meter curtain using 8 elements has an approximate beam width of 35° to 40°, in a broadside unidirectional pattern. The lowest part of the curtain should be at least a $\lambda/4$ above the earth. Each section of the Sterba should be excited in phase with its adjoining section. Either a high or low-impedance line can be used for feeding the curtain, but in either case a matching system must be used.

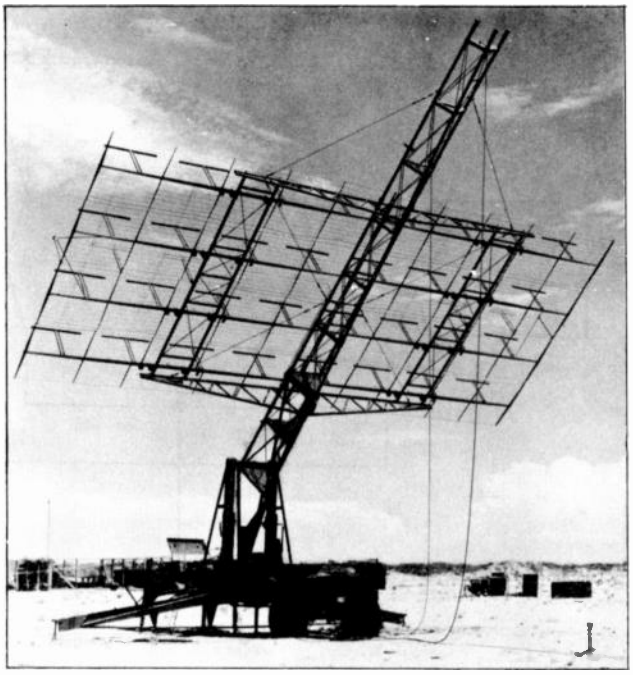
LONG SINGLE-WIRE ANTENNAS

In the discussion of half-wave antennas, it was learned that the maximum radiation is broadside to such an antenna. By utilizing a long single-wire antenna of a wave length or more, the maximum radiation lobes will be at an angle less than 90° with respect to the antenna axis. A long-wire antenna radiates more power in the direction off the ends than a half-wave antenna radiates in the broadside direction. This relative increase in efficiency is taken advantage of in many low-frequency and medium-frequency radio installations, where an antenna of simple construction is required.

The directional characteristic pattern of a long-wire antenna consists of a number of lobes, with the main lobe making the smallest angle with respect to the wire axis. Increasing the length of the antenna reduces the angle that the major lobe makes with the axis, and also increases the number of minor lobes. However, more of the power is concentrated in the major lobes, and less in the minor lobes. From figure 66 it can be seen that at about 8 wave lengths any further increase in the antenna length has no appreciable effect on the angle that the main power lobe of radiation makes with respect to the wire axis.

Normally an unterminated, single-wire antenna of sufficient length has bidirectional radiation characteristics off the ends. If this antenna were terminated in a pure resistance equal to the characteristic impedance of the antenna, the radiation pattern would be unidirectional (toward the terminated end).

In order to utilize to better advantage the low-angle directivity effects of the long-wire antenna, the system can be tilted downward from the horizontal at the terminated end. For instance, referring back to figure 66 the lowest vertical wave angle of propagation for a one and one half wave length antenna is 40°. If the



Stacked Collinear Array of Folded Dipoles, Supported by Quarter-Wave Stubs on a Wire-Screen Reflector. This array is used for detecting and plotting the path of high speed aerial objects.

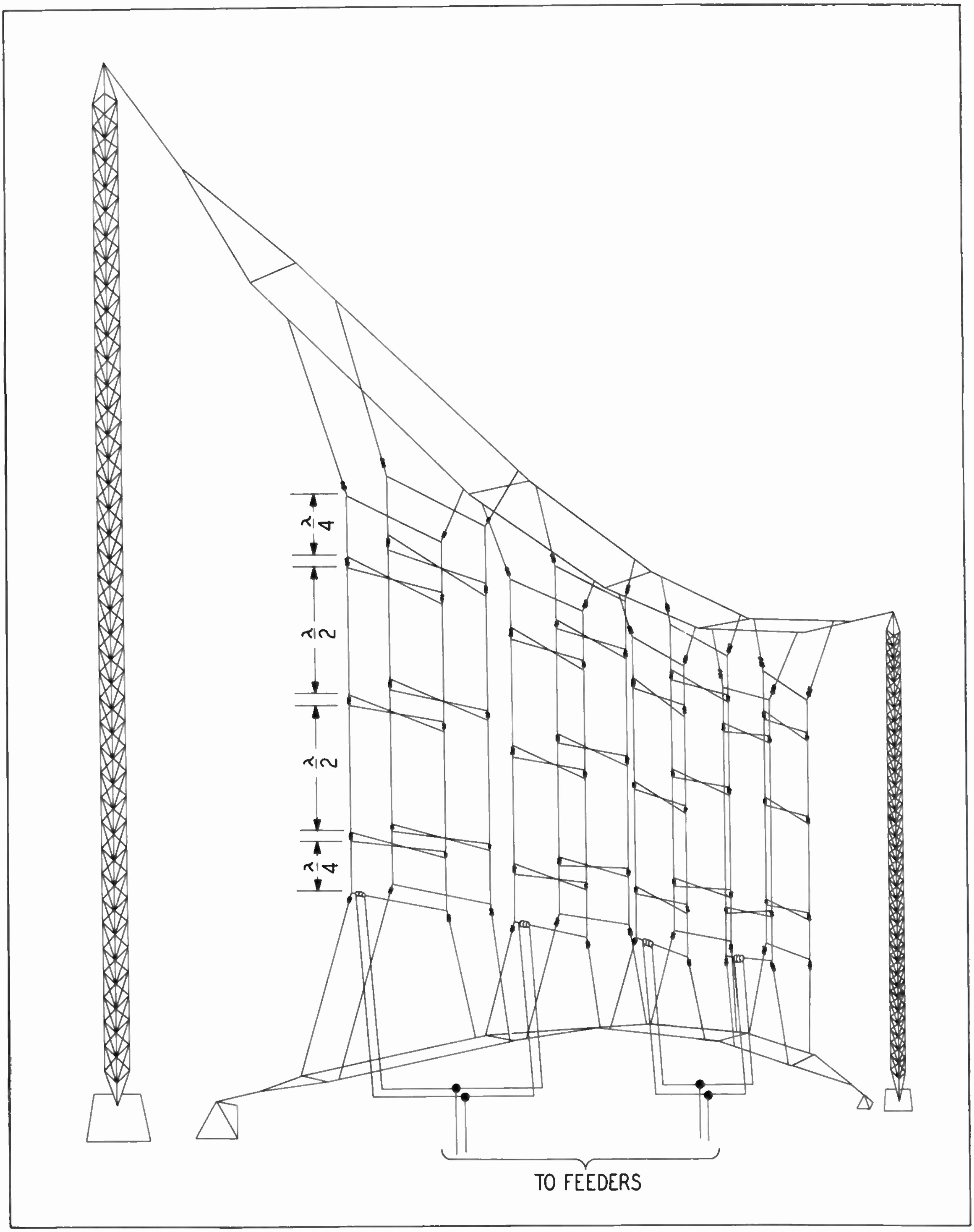


Figure 170. Physical Layout of a Complete Sterba-Curtain Array, Showing Method of Feed and Supporting Structures.

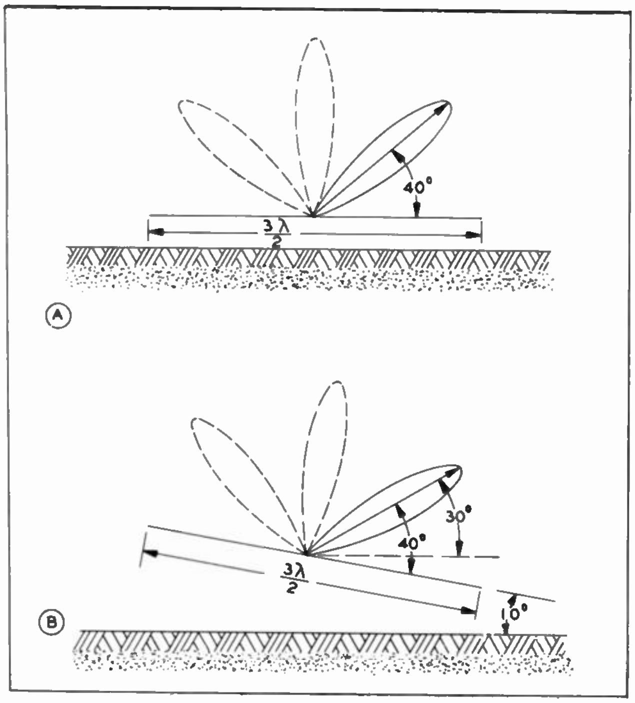


Figure 171. Tilting a Long Single-Wire Antenna, Showing the Effect on the Vertical Angle of Propagation (Free-Space Condition).

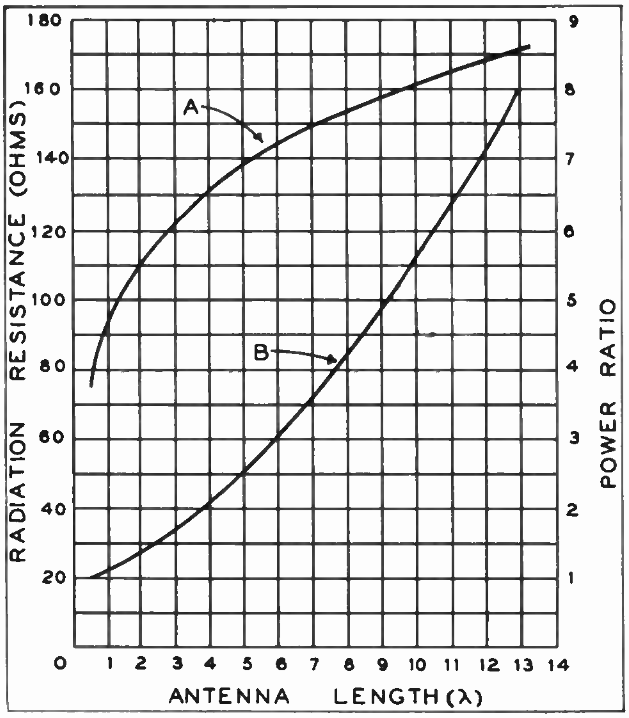


Figure 172. Chart Showing the Variations in Radiation Resistance (A) for Different Lengths of Antenna Wire and Power Ratio (B) of the Lobe of Maximum Radiation for a Long-Wire Antenna as Compared to that of a Half-Wave Antenna.

antenna is tilted downward from its horizontal position about 10°, the vertical wave angle with respect to the wire will not be changed but it will be lowered to about 30° with respect to ground. See figure 171.

As was discussed in connection with a half-wave antenna, the height above ground of the antenna has an effect on the gain of the antenna. If possible, the antenna should be hung at a height that gives maximum radiation at the desired vertical angle. The low end of a tilted long-wire antenna should have a height of at least a λ/2 at the lowest operating frequency.

The long-wire antenna is normally operated at its fundamental frequency or at some harmonic, so that maximum power can be introduced into it. As the antenna length is increased the radiation resistance increases. See figure 172. The radiation resistance given is that of an antenna in free space. This factor is affected somewhat by the height of the antenna above ground.

The proper electrical length of a long-wire antenna can be found from the formula:

$$L\ (\text{feet}) = \frac{492\ (N - 0.05)}{\text{freq. (megacycles)}}$$

where N = number of λ/2 desired for antenna length

The free-space diagrams in figure 173 clearly illustrate how the length of the antenna determines the concentration of radiated power and the subsequent direction of the radiated pattern. As can be seen, the directional characteristics differ from that of a half-

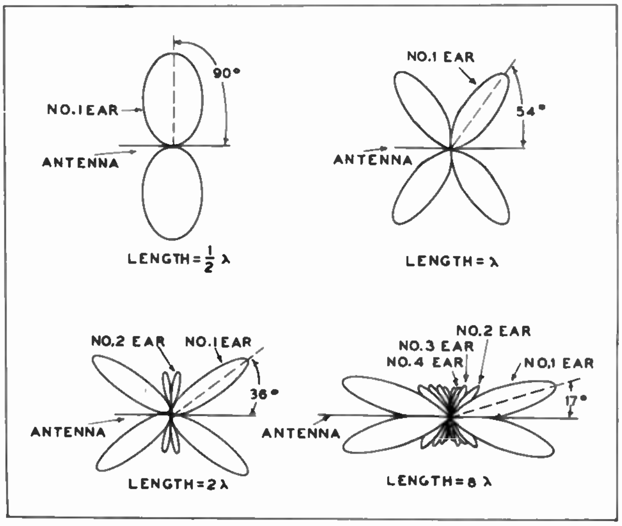


Figure 173. Effect of Increasing the Length of an Antenna upon Its Free-Space Radiation Pattern.

wave antenna. This is true because the distance from a remote object to various parts of the wire may differ by an appreciable fraction of a wave length, and also because, when the wire is more than a half wave length long, the currents in different parts of the wire may differ somewhat in phase. This results in a radiated field from each elementary λ/2 section of the long-wire antenna; these different fields add vectorially to give a sum that determines the direction of the pattern.

When feeding a long-wire antenna, it is of great importance to maintain the proper phase relationship of the currents in adjacent half-wave sections along the antenna. For the proper directivity and gain, each of the adjacent half-wave sections must be out of phase. The recommended point of feed is usually at the end or at a current loop. When a two-wire line is used, it would be preferable to feed the antenna at a current node (voltage loop) but in this case there would exist at the point of feed two adjacent half-wave sections the currents of which would be in phase. This would destroy the low-angle radiation characteristics of the long-wire antenna. This effect can be minimized by selecting a point of feed at a voltage loop near the end of the antenna. When the feed point is a current loop (voltage node), there is no change in the phase relationship of the current in the antenna; therefore, the feed point can be at any current loop along the wire.

Quarter-wave and Q-bar matching sections can also be used in feeding long-wire antennas, but this practice limits the operation to a narrow band of frequencies. Normally when resonant feeder lines are used for feeding a long-wire antenna, it may be operated over a wider range of frequencies. Compared to a half-wave antenna, the long-wire antenna, because of its increased radiation resistance, tunes more broadly just as a tuned circuit tunes more broadly when shunt resistance is introduced to lower the "Q" of the circuit.

The tuning procedure for a long, single-wire antenna does not differ materially from that of a half-wave antenna. By accurately determining the proper physical length of the antenna, greater ease of coupling and better transfer efficiency will be attained.

The antenna should be cut slightly longer than the calculated value so that it can be pruned during adjustment. The antenna tuner should be resonated with the antenna disconnected from the feed line; then if less inductance (more capacitance) is required to resonate the circuit with the antenna attached, the antenna is too long and should be pruned. When the antenna is of the correct length, it will have no detuning effect when it is connected to the antenna tuner.

"V" ANTENNAS

In the discussion of long, single-wire antennas, it was learned that the directivity of the main power lobe increases as the antenna length is increased. By utilizing two long-wire antennas arranged in the form of a "V" and fed 180° out of phase (see figure 174), the major lobes of radiation from each leg or section of the "V" add up along a line bisecting the apex angle Θ and tend to cancel in other directions.

The "V" antenna is widely used in amateur and military applications because of its simple construction and comparatively high gain. When the "V" is fed with a tuned feeder system, it can be operated satisfactorily on several harmonically-related bands. Figure 175

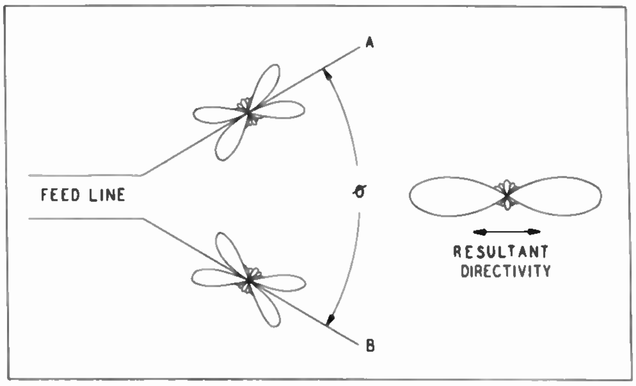


Figure 174. Analysis of the Formation of a Directional Radiation Pattern from a Resonant "V"-Type Antenna.

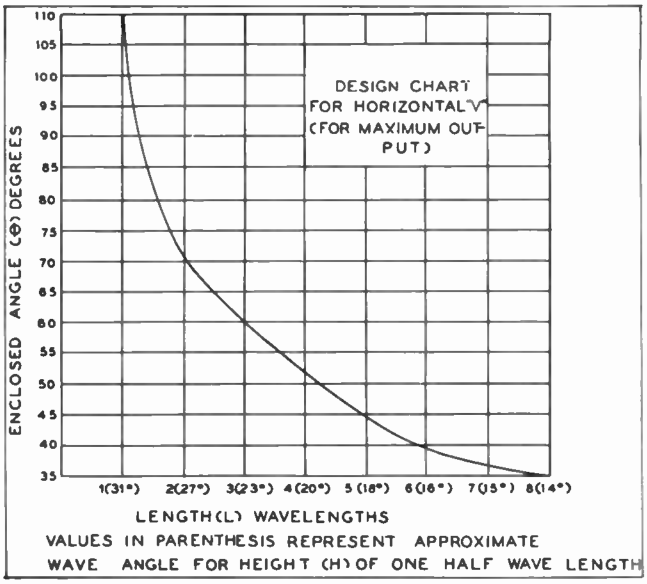


Figure 175. Relationship of the Enclosed Apex Angle of a "V" Antenna to the Length of Its Legs.

shows the relationship of the enclosed apex angle Θ to the length of the legs of the "V" antenna in wave lengths.

The individual sections of the "V" antenna are placed so that the apex angle or angle between them is twice the angle that the major lobe makes with the wire axis of a single section if used alone. It can be seen from the graph in figure 175 that the apex angle decreases with an increase in leg length and increases with a decrease in leg length. When the legs are shorter than 3 wave lengths, the apex angle is always made smaller than that determined by the lobes of radiation. Note that the legs of the "V" should always be at least a half wave length above the ground and, if possible, a full wave length.

As was mentioned in the discussion on long-wire antennas, the angle that the long-wire antenna makes with the horizontal determines to some extent the angle of radiation. The same principle also applies to

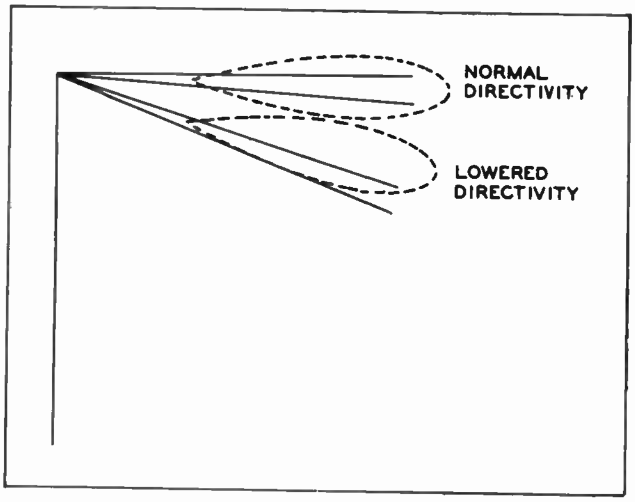


Figure 176. "V" Antennas, Showing the Effect of the Tilt Angle upon the Angle of Radiation.

"V" antennas, and is illustrated in figure 176.

A lower vertical wave angle can be realized by erecting the so called "V-beam" antenna on sloping ground. For example, suppose it is desired to establish a 10-mc. communications system between two points located 1200 miles apart. The space available is large enough to accommodate a "V" antenna, with each leg three wave lengths long. The terrain has a smooth slope of 10° from the horizontal. The length of each leg is calculated by the formula:

$$L = 492\frac{(N - 0.05)}{10} = 492\frac{(6 - 0.05)}{10} = 293 \text{ feet}$$

The supporting structure at the apex end should be approximately one half wave length high. The apex angle, as computed from the graph in figure 175, should be 60° and, on level terrain, the vertical wave angle would be approximately 23 degrees.

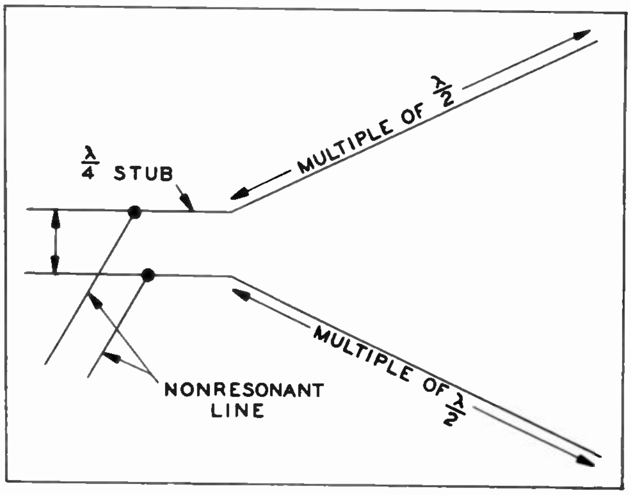
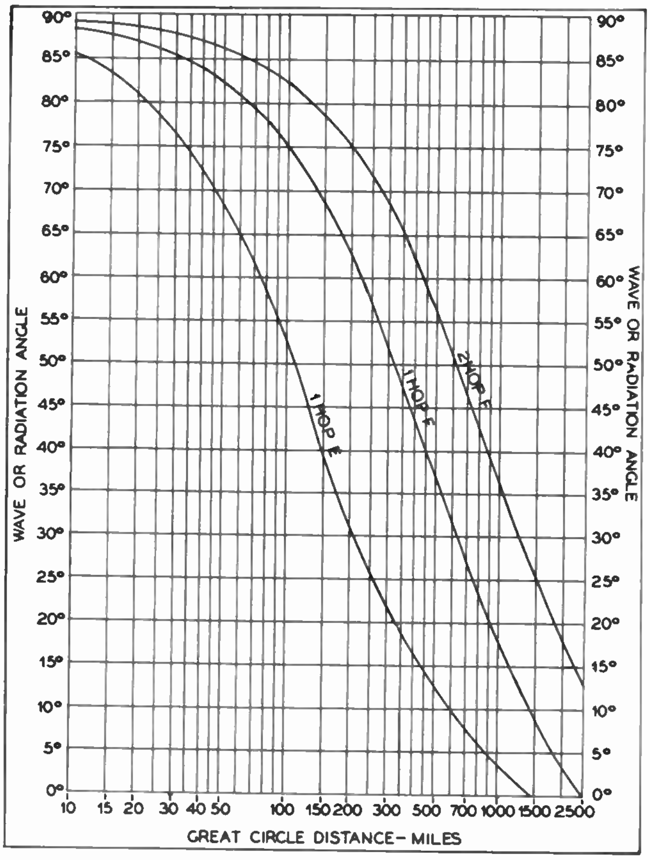


Figure 177. Simple Method of Feed for a "V" Antenna, Employing a Quarter-Wave Matching Section.

The approximate distance coverage under average conditions with an "F" layer height of 200 miles can be estimated from chart 10. For a wave angle of 23 degrees the distance is approximately 800 miles. Thus on level terrain it would be necessary to produce a lower wave angle of propagation to cover the distance required. Since the antenna is on a slope of 10°, the effective angle of radiation is actually 23° — 10° or 13°. Hence, the distance coverage as determined from chart 10 is approximately 1200 miles.

CHART 10
SKY-WAVE RADIATION ANGLE VERSUS GREAT CIRCLE DISTANCE

Note: This chart is based on an "F"-layer height of 200 miles and an "E"-layer height of 65 miles.



As was mentioned before, the two legs of the "V" must be fed 180° out of phase for correct operation. A resonant 600-ohm, open-wire line attached to the apex of the "V" antenna, with one feeder tied to each leg, is perhaps the simplest method of feed for broadband operation. If a quarter-wave matching section is employed, as indicated in figure 177, a nonresonant line may be used. Note that if the legs of the "V" are made multiples of a half wave length, the quarter-wave matching section should be closed at the free end.

A terminated "V", often called a nonresonant "V", is composed of two legs which are terminated in a resistance of 400-to-800 ohms connected from the end of

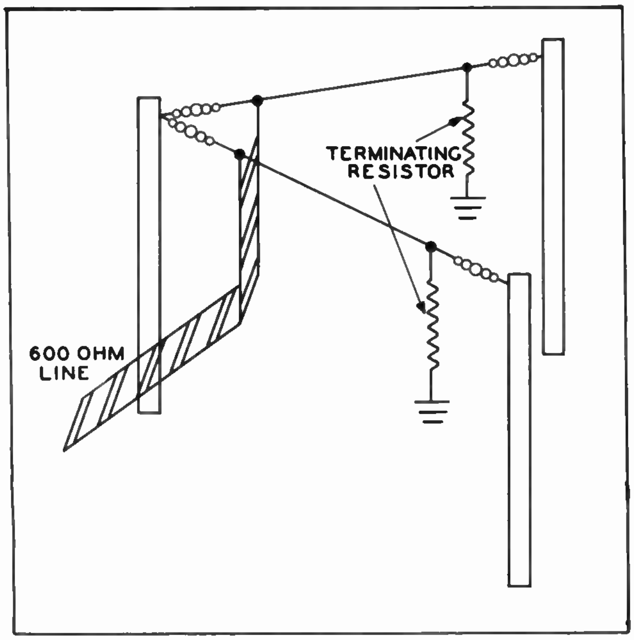


Figure 178. Physical Layout of a "V" Antenna, Showing the Method of Termination and Feed.

each leg to ground or to the ground screen. See figure 178. This terminated "V" antenna provides a practically unidirectional radiation pattern in the direction of the terminated ends. The terminating device should have as small an amount of inherent inductance as possible, and should be capable of dissipating one third of the power output of the transmitter. The values of the terminating resistors are adjusted for minimum standing waves on the feeders; this procedure is repeated for several operating frequencies until the optimum value of resistance is obtained.

The "V"-beam-antenna gain can be increased considerably by a system known as "stacking." In this system, two "V"s are stacked one above the other, a half wave length apart, and are fed so that corresponding legs are in phase with each other, and opposite legs are out of phase. See figure 179. This type of system has the same disadvantage as other phased arrays; that is, the operation is limited to a narrow band of frequencies. However, the gain of this stacked "V"-beam array is at least twice that of a single "V".

In another system of making the "V" antenna unidirectional, a second "V" is placed an odd quarter wave length back of the first, and the two "V"s are fed 90° out of phase. The reflecting "V", as the rear "V" is called, acts as a parasitic element and, therefore, tends to restrict the antenna system to a narrow band of frequencies. The addition of this parasitic element lowers the over-all radiation resistance and, therefore, the impedance of the feeder line must be lowered accordingly to eliminate a mismatch. See figure 180 for an example of this type of "V" antenna.

More elaborate reflector-type "V" antennas are illustrated in figure 181. For the array shown in figure 181A, antennas W and X must be excited so that legs A and B are in phase; similarly, in antennas Y and Z, legs C and D must be fed in phase. However, in order to obtain reflector action, the current flow in antennas W and X must be lagging the current flow in antennas Y and Z by 90°. The proper phasing can be accomplished with the feed system shown. The array shown in figure 181B provides increased directivity in a horizontal plane, which is sometimes a desirable feature.

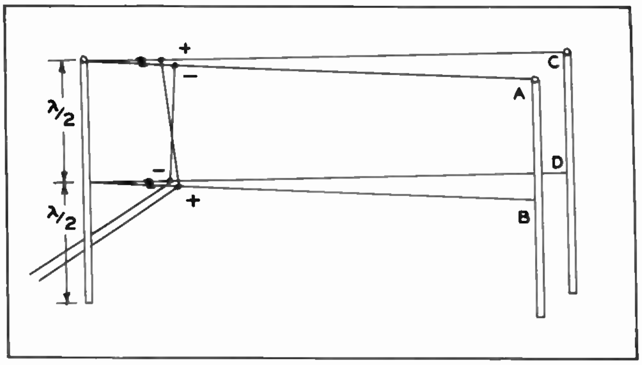


Figure 179. Stacked "V"-Beam Antenna, Showing Phase of Excitation.

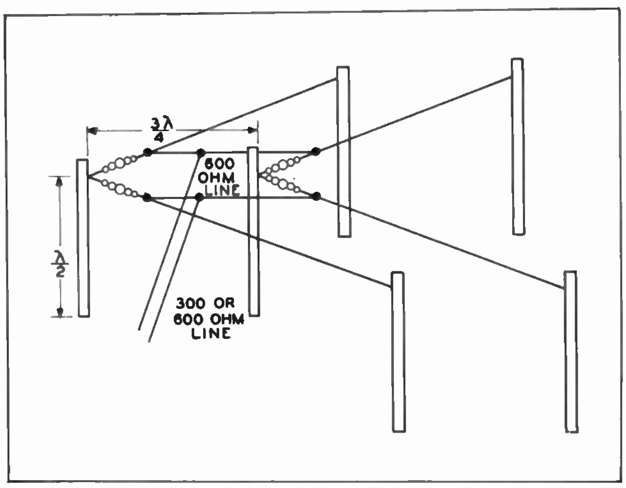


Figure 180. Unidirectional "V" Antenna, Consisting of Two Single-Wire, "V"-Beam Antennas Properly Spaced and Fed 90° Out of Phase.

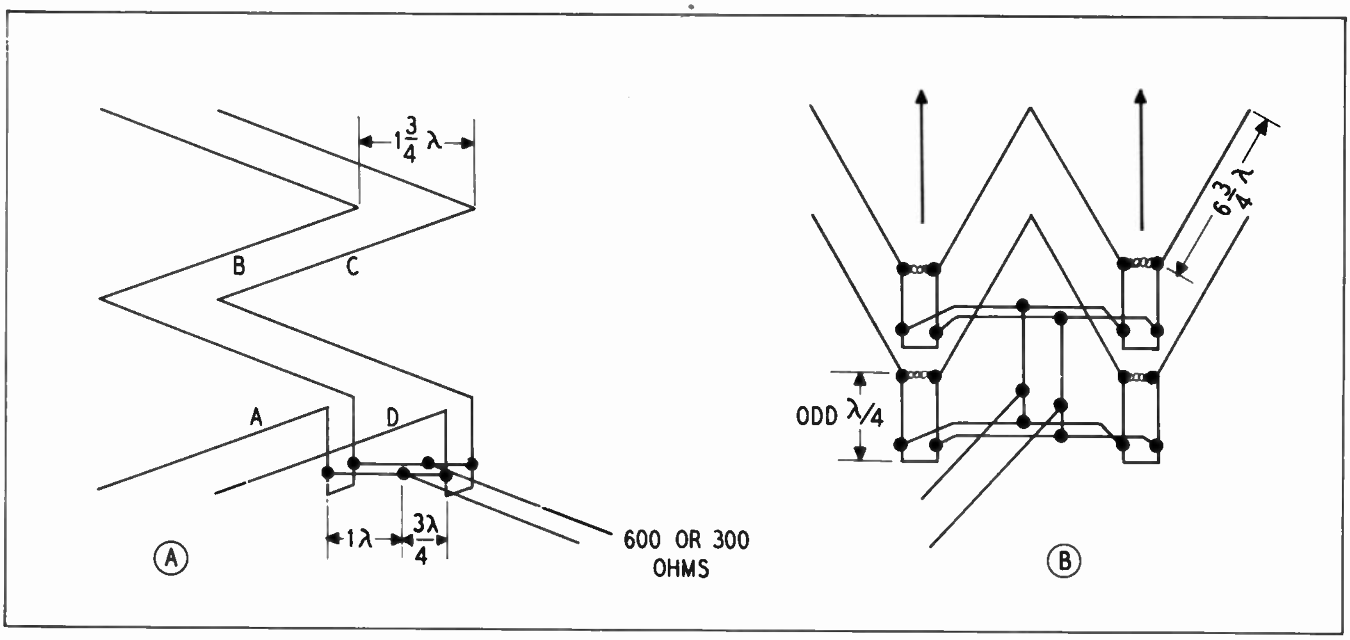


Figure 181. Reflector-Type "V" Antennas with Feed Systems.

EXAMINATION No. 3

True or False

1. A ground screen has a greater effect on low-angle radiation than on high-angle radiation. ....

2. The higher a vertical half-wave antenna is placed above the ground, the sharper its directive characteristics. ....

3. At equidistant points, at the same vertical angle from a half-wave vertical antenna, the measurable field intensity will be the same. ....

4. The difference between a self-resonant parasitic element and a tuned parasitic element is that a self-resonant parasitic element is spaced less than 0.14 wave length from the driven element, while a tuned parasitic element is spaced more than 0.14 wave length from the driven element. ....

5. In the final adjustment of the length of a director element of the parasitic array, the length of the director will be increased slightly to reduce the selectivity of the array. ....

6. The radiation resistance of a parasitic array increases as the number of parasitic elements increase. ....

7. The final adjustment to be made on a parasitic array is for maximum gain in the forward direction. ....

8. The over-all gain of a broadside driven array depends upon the number of elements and the spacing between the elements. ....

9. Increasing the length of a single-wire antenna reduces the angle that the major power lobe makes with the wire axis. ....

10. In a long-wire antenna, the currents in adjacent sections must be out of phase; therefore, this type of antenna can only be fed at a current node. ....

Multiple Choice
(Underline the correct answer.)

1. The least-significant factor in determining the gain of an antenna-reflector combination or an antenna-director combination is
   a. number of elements.
   b. spacing between elements.
   c. length of the director or reflector accordingly.
   d. height above ground.

2. The input impedance at the feed point of a three-element parasitic array approximates the radiation resistance, which is
   a. approximately 8 ohms.
   b. the same as a half-wave dipole.
   c. approximately 55 ohms.
   d. approximately 600 ohms.

EXAMINATION No. 3 (Cont.)

3. An array consisting of two $\lambda/2$ elements, parallel to each other, spaced $\lambda/2$ apart, and fed so that their currents are in phase has a
   a. unidirectional end-fire pattern.
   b. bidirectional end-fire pattern.
   c. omnidirectional pattern.
   d. bidirectional broadside pattern.

4. Since, when feeding a long single-wire antenna with a two-wire feeder, the currents in the adjacent half-wave sections must be out of phase to radiate efficiently, care must be taken to feed the antenna at a
   a. point of low current, remote from the end.
   b. point of high voltage, remote from the end.
   c. point of high current.
   d. point $\lambda/2$ from one end.

5. The individual sections (legs) of the "V" antenna are placed so that the apex angle between them is the angle that the major lobe makes with the wire axis from a single section (leg), multiplied by
   a. 2.
   b. ½.
   c. 4.
   d. the complement of the angle.

6. An important factor to consider when high-angle radiation is desired from a horizontal half-wave antenna is the
   a. size of the antenna wire.
   b. time of the year.
   c. height of the antenna.
   d. conductivity of the soil.

7. Parasitic-type antenna arrays are often employed for point-to-point communication because of their
   a. low radiation resistance.
   b. simplicity of adjustment and construction.
   c. small size.
   d. high directivity.

8. Two conductors of equal length, placed parallel to each other, and one conductor excited by r-f energy at its resonant frequency will produce a reinforcement of r-f energy in the direction of the excited element when
   a. they are fed at a current loop.
   b. they are separated by more than 0.14λ.
   c. they are at least $\lambda/2$ above the ground.
   d. they have a high radiation resistance.

9. When a highly directive radiation pattern is desired with an increase in antenna selectivity, use a
   a. long single-wire antenna.
   b. low angle of radiation.
   c. $\lambda/4$ wave Marconi antenna.
   d. parasitic array.

10. In tuning a three-element parasitic antenna array for maximum receiving efficiency, it is necessary to maintain
   a. a low signal-to-noise ratio.
   b. a front-to-back ratio of approximately 10 to 1.
   c. maximum forward gain.
   d. low selectivity and high sensitivity.

Subjective

1. Explain the difference between a self-resonant parasitic element and a tuned parasitic element.

2. Name two adjustments that can be made on a three-element parasitic antenna array to increase its efficiency over a wider frequency range.

3. Describe the fundamental difference between the collinear, broadside, and end-fire types of driven arrays. State the phase of their excitation, physical layout, and resultant radiation pattern.

4. The characteristic low-radiation-angle property of the long single-wire antenna recommends this type of antenna for specific applications. With a prescribed length for such an antenna, how can the radiation angle be lowered still further?

5. Name four primary factors which must be considered prior to the construction and installation of a "V" beam antenna.

RHOMBIC ANTENNAS

Each type of beam antenna, such as a parasitic array, a driven array, and a "V" array, has its individual advantages and limitations, but in recent years the trend of directional-antenna design has been to the rhombic types, particularly for use in the 2-to-30-megacycle band. The rhombic-type antenna belongs to the family of long-wire antennas. Its chief advantages are:

1. Broad-band frequency coverage
2. Excellent directivity in both the vertical and horizontal planes
3. With proper orientation, a good signal-to-noise ratio for reception
4. Relatively simple in design and construction
5. High power-handling capability

Figure 182 shows the basic rhombic-antenna layout.

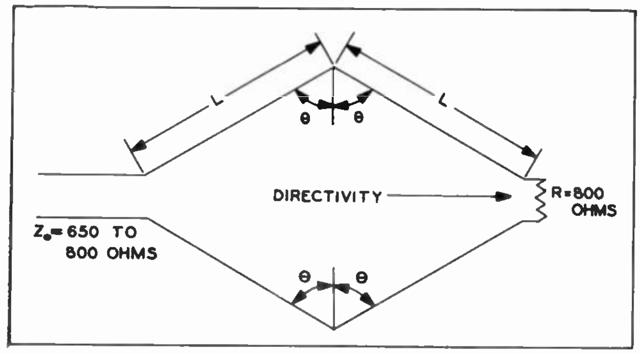


Figure 182. Layout of a Basic-Rhombic Antenna, Showing the Terminating Resistor and Feed Line.

Half-Rhombic Antenna

The simplest type of rhombic antenna to understand is the tilted-wire or half-rhombic antenna. Although this type of beam antenna finds its greatest use in the range of frequencies from 30 to 70 megacycles, it is still considered a long-wire array because the side lengths must be several wave lengths long at the lowest frequency of operation. Figure 183 shows the physical layout of such a system.

The effective current flow is indicated by the direction of the arrows. Theoretically, half of the power is consumed by the antenna resistance (I^2R losses and

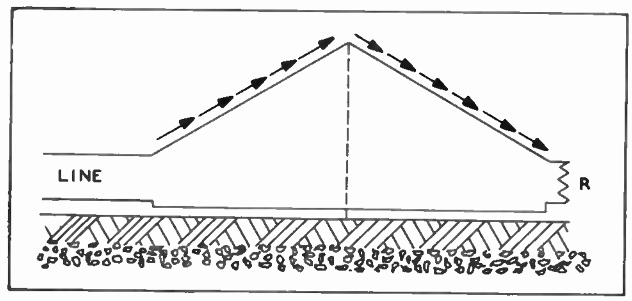


Figure 183. Layout of a Terminated Half-Rhombic Antenna, Showing the Direction of Effective Current.

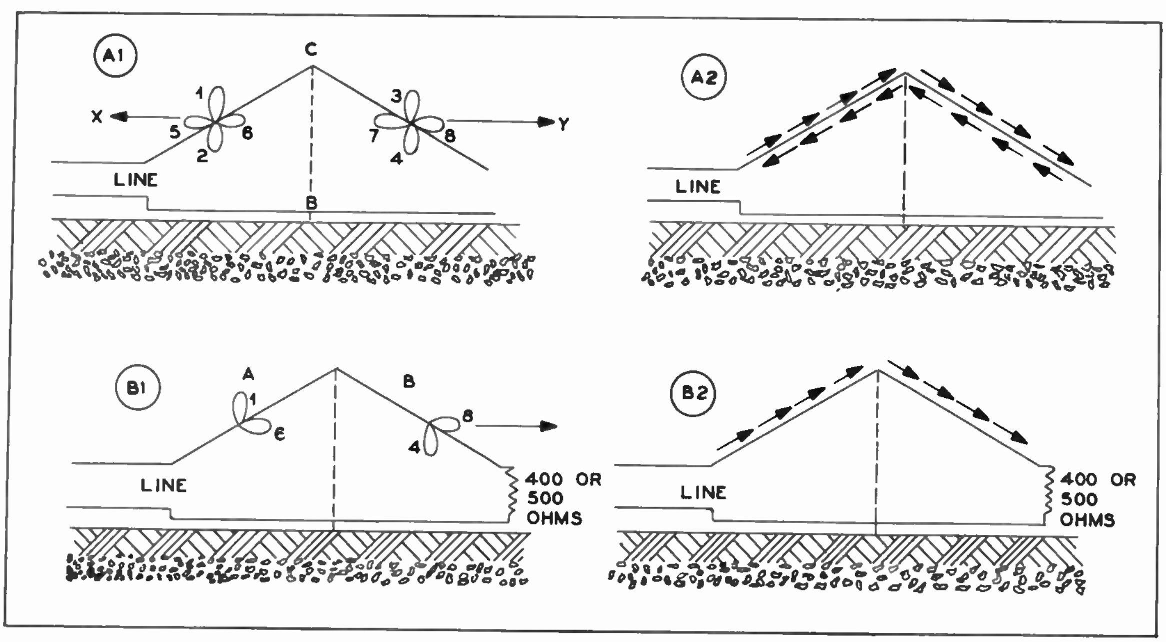


Figure 184. Directional Characteristics of Unterminated and Terminated Half-Rhombic Antenna.

radiation resistance loss) while the remaining portion is dissipated in the terminating resistance R. The counterpoise acts as a low resistance return path for r-f currents, and also establishes a good reflecting plane for the antenna.

The directional characteristics of the half-rhombic antenna can be analyzed by studying figure 184, A and B.

In figure 184(A1), the half-rhombic is unterminated. The fields in lobes 1 and 2 cancel; similarly, the fields in lobes 3 and 4 cancel. Thus very little energy is radiated in a steep vertical direction. However, in the horizontal plane, the fields in lobes 7 and 5 combine to produce strong radiation in the direction X, while the fields in lobes 6 and 8 combine to produce strong radiation in the direction Y.

In figure 184(B1), the half-rhombic is terminated with a 400-to-500-ohm, noninductive resistance. As in the unterminated half-rhombic, the radiation in a steep vertical plane tends to be cancelled. The fields of lobes 6 and 8 combine, to produce strong radiation in a horizontal plane in the direction of the terminated end. The unidirectional lobing effect of the terminated half-rhombic is easily understood by considering the current flow in the unterminated and terminated half-rhombic antennas. In the case of the unterminated half-rhombic, which is of a resonant length, the current flows from the line to the end of the antenna and is reflected back to the line. See figure 184(A2). This process results in standing waves of current. The vectorial addition of the fields produced by these standing waves of current account for the bidirectional pattern. See figure 184(A1). In the case of the terminated half-rhombic, the system is considered nonresonant and the wave travel is unidirectional because there are no reflections of current from the terminated end. See figure 184(B2). If the antenna had no resistance, the current would be uniform throughout its length. However, due to the resistance of the antenna, the current decays in an exponential fashion, as shown in figure 185. The

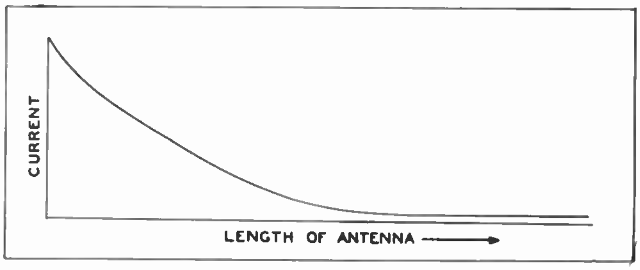


Figure 185. Exponential Decay of Current along the Length of a Terminated Half-Rhombic Antenna.

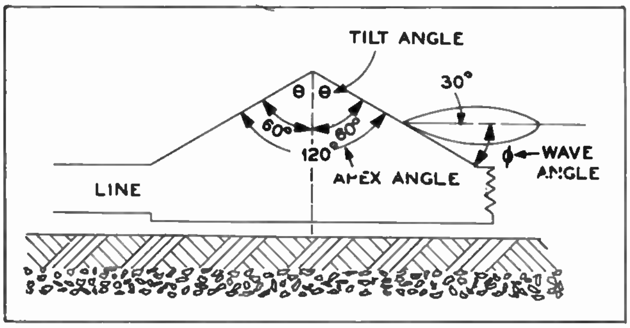


Figure 186. Physical Layout of a Terminated Half-Rhombic Antenna, Showing the Relationship of Tilt Angle to Wave Angle.

vectorial addition of the fields resulting from this current produce a vertically polarized lobing pattern favoring the direction of the terminated end.

To obtain the desired lobing effect for a given frequency range, the legs of the half-rhombic must be correctly aligned. First, determine the angle that the major lobes make with the antenna. The approximate lobing angle for a given half-rhombic-antenna leg length is the same as that for a single long-wire antenna. Refer to figure 66. Thus a half-rhombic with each leg three wave lengths long at the lowest frequency of operation produces a lobing angle of approximately 30° with respect to the wire.

For optimum results, the tilt angle should be made the complement of the wave angle with respect to the wire, or 90° minus 30° equals 60°. The apex angle is twice the tilt angle. Thus, the physical layout for this half-rhombic requires an apex angle of 120°, as shown in figure 186. This layout is approximately correct for transmitting at a very low angle, or line of sight. In other words, the net result is almost perfect vertical

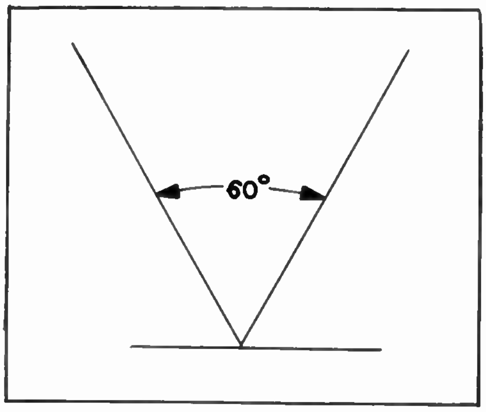


Figure 187. Directivity of the Radiation Beam in a Horizontal Plane from a Terminated Half-Rhombic Antenna.

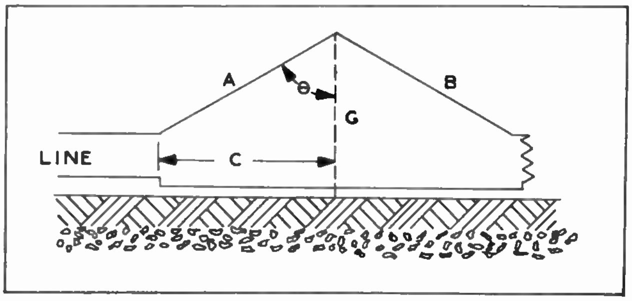


Figure 188. Layout of a Terminated Half-Rhombic Antenna, Showing the Relationship of the Ground Projection to the Length of a Leg.

polarization. In the horizontal plane a searchlight-beam radiation effect is produced, as shown in figure 187. Increasing the frequency of the transmitted wave effectively increases the leg lengths, thus narrowing the beam width.

The setup described above will operate efficiently for transmission. However, if the system is to be used for both transmission and reception, the construction features must be modified to produce good reception. The currents induced in the antenna by the received signal do not add in correct phase at the receiver to produce maximum gain; this is to be expected from this purely unidirectional antenna, because reception may occur in other than the normal direction. To produce good results for both transmission and reception, a compromise in the antenna design must be made. The following procedure can be employed for optimum results:

First, the tilt angle for best transmission results is calculated, as previously described for the half-rhombic antenna with given leg lengths. Then another tilt angle is calculated so that the ground-line projection of one side of the half-rhombic antenna, on a line joining the ends of the antenna, is exactly one half wave length shorter than the leg length. In other words, the second tilt angle is calculated so that projection "C" in figure 188 is one half wave length shorter than leg "A"; this tilt angle Θ will be smaller than that calculated for best transmission results. The difference between the two tilt angles is found. One half of this value is subtracted from the tilt angle which gives best transmission results (or added to the tilt angle which gives best reception results), and the resultant tilt angle is used in the construction of the antenna.

For example, suppose that a half-rhombic antenna, four wave lengths long at the lowest operating frequency of 31.2 mc., is to be constructed. To find the optimum tilt angle for the best transmission and reception, proceed as follows:

1. Figure 66 shows that for an antenna two wave lengths long the angle of the major lobe with respect to the wire is about 38°.

2. Therefore, the tilt angle for best transmission is 90° — 38°, or 52°.

3. The length of one leg (of two wave lengths) at 31.2 mc. is approximately 2 x 30 feet, or 60 feet.

4. Since a half wave length is 15 feet, the length of the ground-line projection of the leg is 60 feet — 15 feet, or 45 feet.

5. The ratio 45/60 or 0.75 equals the sine of the tilt angle Θ.

6. Therefore the tilt angle for best reception is the arcsin of 0.75 which is 48.5° (obtained from table of natural functions).

7. Subtract the latter calculated tilt angle from the former: 52° — 48.5° equals 3.5°.

8. Take one half of the difference of the two calculated tilt angles: 0.5 x 3.5° equals 1.75°.

9. Add the result obtained in step 8 to the value of the tilt angle determined in step 6: 48.5° plus 1.75° equals approximately 50.25°, which is the tilt angle required for optimum transmission and reception results.

The lowest operating frequency of the half-rhombic is determined by the height of the structure available. Whenever the half-rhombic is to be utilized for lower frequencies a guyed-balloon arrangement can be used to obtain the extreme height required. For frequencies between 1 and 8 megacycles, the height at the apex of the balloon-supported half-rhombic should be approximately 600 feet. For frequencies between 5 and 18 megacycles, the height should be approximately 300 feet. In areas where winds exceed 20 m.p.h., the support at the apex should be a large box kite.

Chart 11 makes it unnecessary to use trigonometric functions in determining the dimensions of a half-rhombic antenna. The dimensions given are expressed in wave lengths, but are easily converted to linear feet by means of the formula:

$$\text{Length of a full wave length in feet} = \frac{984}{\text{freq. (mc.)}}$$

CHART 11
DESIGN INFORMATION FOR HALF-RHOMBIC ANTENNAS

Length of a Triangle Leg, Measured in Wave Lengths at Operating Frequency	Tilt Angle Θ	Height of Upper Triangle Apex from Counterpoise (Pole Height), Measured in Wave Lengths at Operating Frequency	Entire Counterpoise Length, Measured in Wave Lengths at Operating Frequency
1	30°	0.87	1
2	50°	1.3	3
3	57°	1.6	5
4	62°	1.9	7
5	65°	2.1	9
6	67°	2.3	11
7	68°	2.6	13
8	70°	2.7	15
9	70.5°	3.0	17
10	71°	3.3	19
11	72°	3.4	21
12	73°	3.5	23

The best location for a half-rhombic antenna is over level ground; however, it may be constructed on gently sloping ground where there are no obstructions in the transmitting path. The terminated end should not be pointed at a mountain, building, or bridge or the signal directivity will be impaired. For reception the signal path should not cross man-made noise sources, such as electrical power lines, electrical railway systems, highways, and factory buildings. It must be remembered that the half-rhombic is essentially a vertically polarized antenna and, therefore, will pick up vertically polarized man-made noise in the signal path. The half-rhombic usually finds its greatest practical application in temporary field installations. For additional information on siting, refer to Choosing Antenna Site for Optimum Operation on page 163.

Full-Rhombic Antenna

The primary requisite of a beam-type antenna for good reception is a high signal-to-noise ratio. For good transmission characteristics at the frequencies at which rhombics are employed, a relatively low vertical angle of radiation (0° to 20°) and controlled lobing of the radiation pattern in the horizontal plane are required. The full rhombic antenna meets these requirements and, in addition, has a broad operating frequency range.

The full-rhombic antenna can be considered as a development of the half-rhombic or inverted "V". However, the rhombic types to be discussed are designed for operation in the horizontal plane. By placing two half-rhombics side by side, as shown in figure 189, and terminating their ends with a noninductive resistance, a unidirectional lobing pattern is obtained in the direction of the terminated end. The tilt angle Θ, shown in the figure, must be adjusted to equal 90° minus the angle Ø, between the main forward power lobe and the individual leg, which is determined by the antenna length. This insures that maximum directivity is in a line bisecting the rhombic as indicated.

In order to obtain the correct phasing of the lobes for maximum radiation in the desired direction, the straight-line distance, AB, between the centers of the legs, must be one half wave length less than the distance ACB. This follows from the fact that lobe 1 is 180° out of phase with lobe 3. By making the distance between these lobes one half wave length (180°) less, lobe 1 will arrive at point B in correct time phase to add to the field of lobe 3, and thus increase the intensity of radiation in the desired direction. A similar action takes place between lobes 2 and 4 on the other

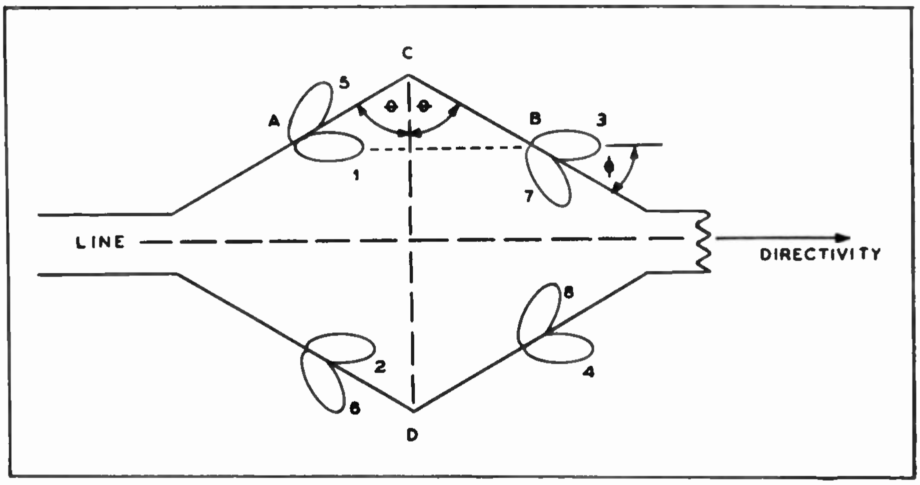


Figure 189. Terminated-Full-Rhombic Antenna, Showing the Effective Radiation Lobes from Individual Legs and the Resultant Directivity.

side of the rhombic. All other lobes combine to produce a cancellation of radiated energy in the line of the minor axis CD. Correct termination of the rhombic antenna with approximately an 800-ohm, nonreactive resistance produces an almost infinite front-to-back ratio. This means that very little radiation takes place toward the input end of the antenna. The gain of a rhombic with side lengths of four to five wave lengths is over 40 times that of a half-wave dipole. About one half of this gain is realized by using two wave lengths to each of the four sides.

The important items in the design of a rhombic antenna are as follows:

1. Vertical wave angle
2. Electrical length of the sides
3. Tilt angle
4. Height of antenna above ground

The starting point in the design of a rhombic antenna is the determination of the required vertical wave angle of propagation, which depends primarily on the distance to be covered and the frequencies to be used. The distance coverage ranges from 200 miles to over 3000 miles, while the practical frequency range is from 5 megacycles to 35 megacycles. Maximum distance coverage is obtained with wave angles from 0 to 10°. (The vertical wave angle is computed in the same manner as for other long single-wire antennas.)

Once the correct wave angle has been selected, the side length, L, the tilt angle, Θ, and the height above ground, H, must be determined. Since the wave angle becomes smaller as the side lengths of the rhombic are increased, it can be expected that, as the frequency of the transmitted signal is increased, the wave angle of propagation is decreased, with a consequent gain in distance coverage.

If a particular rhombic whose lowest operating frequency is 5 megacycles has a 2-to-1 frequency coverage, it will give good directive radiation up to 2 x 5 megacycles or 10 megacycles. In order to communicate with a station located 400 miles away, it was found that when using a 5-megacycle signal the approximate wave angle was 48° via the F_1 layer (200 mile height). When the frequency was raised to 10 megacycles, the distance range with the same antenna was increased to approximately 900 miles and the wave angle was reduced to approximately 22°.

Varying the height of an antenna modifies the radiation patterns in both the vertical and horizontal planes, and also affects the over-all gain, particularly if the rhombic has short-length sides (2 wave lengths per side, or less).

Thus it follows that, for a certain optimum rhombic-antenna gain, the three quantities, tilt angle Θ, length L, and height H, are interrelated factors. The tilt angle is determined by the formula:

$$\sin \Theta = \cos \emptyset = 90° - \emptyset \qquad \text{where } \Theta = \text{tilt angle},\ \emptyset = \text{wave angle}$$

The length of each leg in wave lengths is determined by the formula:

$$L = \frac{\lambda}{1 - \cos 2\emptyset}$$

The height is determined by the formula:

$$H = \frac{\lambda}{4 \sin \emptyset}$$

The following example is given to illustrate the use of the above formulas: By consulting m-u-f charts, it is found that communications can be established with a station 1000 miles away by using a frequency of 12 megacycles and a wave angle of 20°. Determine the dimensions of the rhombic and the mean height at the point of maximum sag.

1. Determine the tilt angle as follows:

$$\sin \Theta = \cos \emptyset = \cos 20° = 0.9397$$
$$\Theta = 70° = \text{tilt angle}$$

2. Determine the leg length as follows:

$$L = \frac{\lambda}{1 - \cos 2\emptyset} = \frac{1}{1 - \cos 2(20°)} = \frac{1}{1 - \cos 40°} = \frac{1}{1 - .766} = \frac{1}{.234}$$

= 4.27 or approximately 4.25 wave lengths

The total length of one side is 2 × 4.25 = 9.5 wave lengths. To find the physical length of each side of the rhombic, the formula for calculating the length of a long-wire antenna can be used:

$$L\ (\text{feet}) = \frac{492\ (n - .05)}{\text{freq. (mc.)}}$$

where n = number of half wave lengths
9.5 wave lengths = 19 half wave lengths

Substituting in the above formula:

$$L\ (\text{feet}) = \frac{492\ (19 - 0.05)}{12} = \frac{492\ (18.95)}{12} = 777 \text{ ft.}$$

$$\text{Each leg length} = \frac{777}{2} = 388.5 \text{ feet}$$

3. Determine the mean height of the antenna at the point of sag as follows:

$$H = \frac{\lambda}{4 \sin \emptyset} = \frac{1}{4 \sin 20°} = \frac{1}{4\ (.342)} = \frac{1}{1.368}$$

= 0.73 wave length

The height in feet per wave length at 12 mc. is:

$$\frac{984}{12} = 82 \text{ feet}$$

The mean antenna height in feet is:

$$82 \times 0.73 = 60 \text{ feet}$$

Thus, in the example given above, the tilt angle is 70°, the leg length is 388.5 feet, and the mean height above ground is 60 feet.

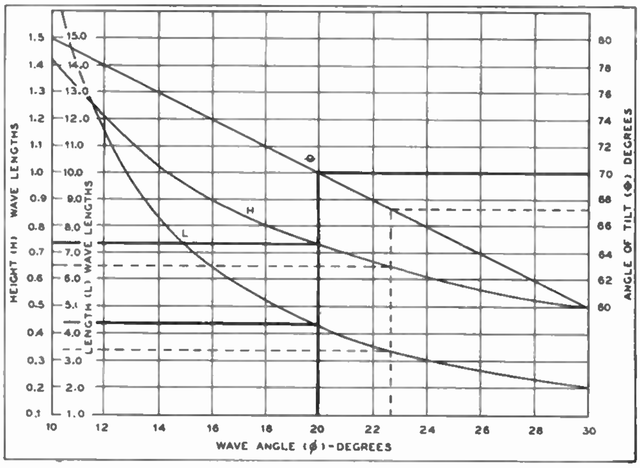


Figure 190. Design Chart for Constructing Rhombic Antennas for Maximum Output.

To eliminate the mathematics employed in the preceding example, the chart shown in figure 190 may be used. This chart provides the necessary information for designing a rhombic antenna to give maximum radiation in the desired direction. If any one of the four quantities, the height, length, angle of tilt, or wave angle, is known, the other three quantities can be found in the chart.

To use this chart in solving the previous example, where the wave angle desired is 20°, locate the value 20° on the wave-angle scale at the bottom of the chart and draw a straight line from that point through the curves of the chart. Draw straight lines from the points on the curves where this vertical line intersects them to the corresponding scale for the respective curve. These lines are shown in figure 190 as heavy black lines. The values obtained from the chart are as follows:

Height (H) = 0.73 wave length or (by conversion) 60 feet

Length (L) = 4.25 wave lengths or (by conversion) 388.5 feet

Angle of tilt (Θ) = 70°

Thus the same values are obtained as were determined by mathematical means and the process is much simpler.

To further illustrate the use of this chart, the following additional example is given. Suppose that, for a given installation, the height of the antenna is to be 0.65 wave length. Find the leg length (L), the tilt angle (Θ), and the wave angle (Ø). To solve this problem by means of the chart, proceed as follows: Draw a vertical line through the point on the H curve which intersects a horizontal line corresponding to 0.65 wave length from the height (H) scale. Draw horizontal lines from the points of intersection of the vertical line on the curves to their corresponding scales. All of these lines are shown as dashed lines on the chart in figure 190. Then read the values on the scales. They are as follows: Length, 3.4 wave lengths; tilt angle, 67.3°; and wave angle, 22.7°.

The rhombic antenna design methods discussed are based on an ideal system for maximum transmission and reception efficiency under average conditions. For various reasons, a departure from the ideal design must be made. For instance, where space considerations are a factor, the side lengths of the rhombic may have to be shortened. On the other hand, the installation may not have sufficient height, due to the unavailability of supporting structures of either wood or metal construction. The length of the sides of the rhombic may also be limited because of tactical reasons. Sometimes the antenna sides are deliberately made shorter to increase the vertical wave angle of propagation at the higher operating frequencies, and to broaden the radiation pattern. The latter is usually necessary to offset ionospheric effects, which may cause a shifting of the communications path in long-distance communication. Regardless of the reasons for a compromise in the design, for optimum performance in a given frequency range, two basic factors must be considered. First, if the desired height can not be attained, the length of the sides must be increased. Second, if the side lengths are shortened the height of the antenna must be increased. In either case, the over-all efficiency of the rhombic is lowered. The term efficiency as used here refers to the signal gain and directivity for transmission in the forward direction and signal-to-noise ratio for reception from the same direction.

One significant difference in the maximum-output design method and the compromise-design method may be observed by comparing figures 190 and 191. Figure 191 shows the design chart for determining the dimensions of a rhombic antenna by the compromise method. Note that the tilt angle and wave angle in the compromise design chart are not complements of each other and that the formula, $\sin \Theta = \cos \phi$, is no longer practical in the computations. Since the wave angle ϕ is affected more by the length than by the height, the

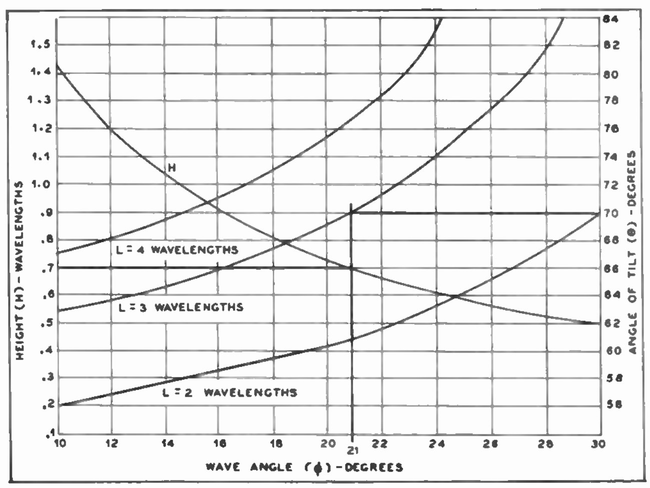


Figure 191. Design Chart for Constructing Rhombic Antennas by the Compromise Method. If the length (L) and either the tilt angle (Θ) or wave angle (φ) are known, the other dimensions can be found.

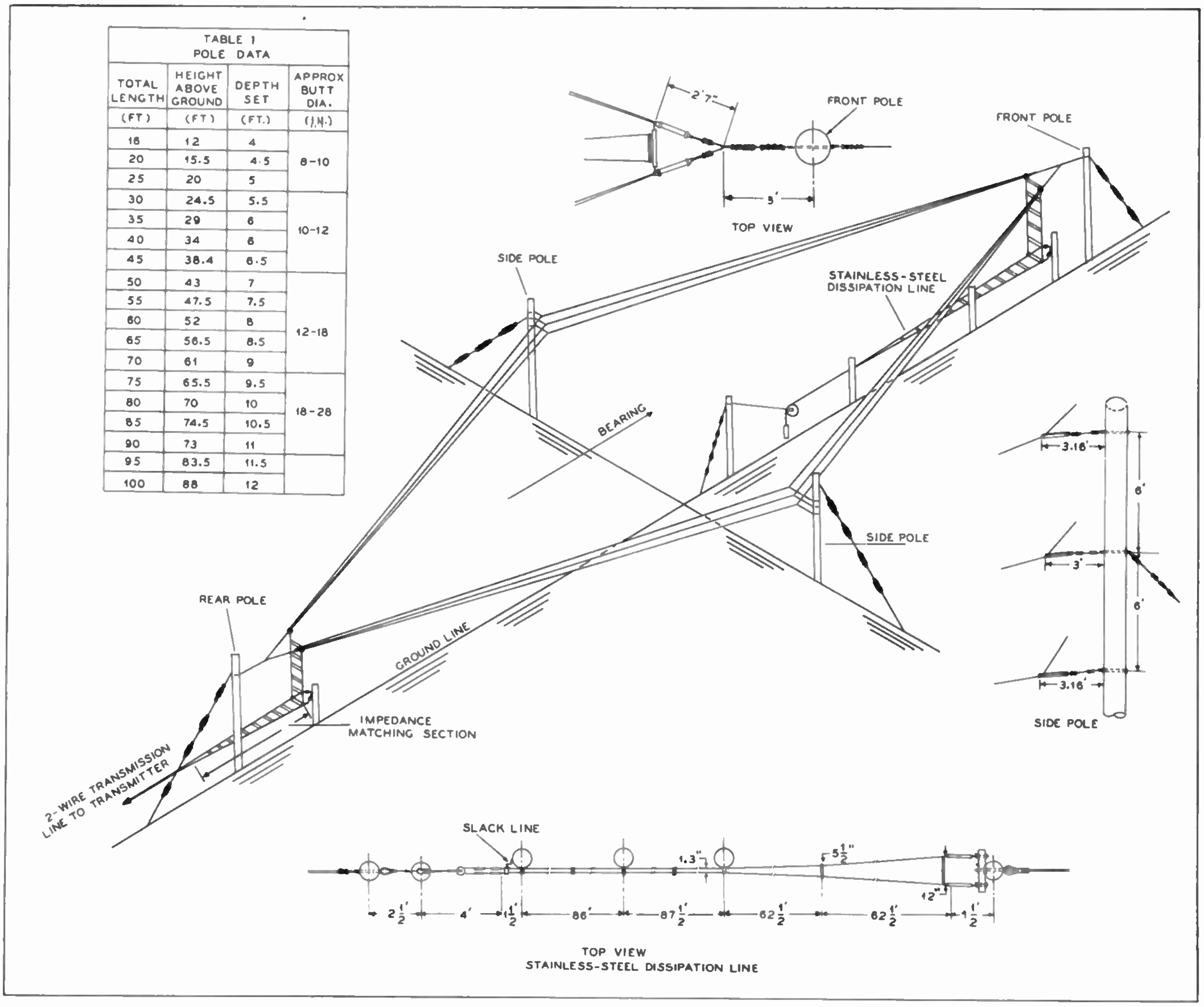


TABLE 1
POLE DATA

TOTAL LENGTH (FT)	HEIGHT ABOVE GROUND (FT)	DEPTH SET (FT.)	APPROX BUTT DIA. (IN.)
16	12	4	8–10
20	15.5	4.5	
25	20	5	
30	24.5	5.5	10–12
35	29	6	
40	34	6	
45	38.4	6.5	
50	43	7	12–18
55	47.5	7.5	
60	52	8	
65	56.5	8.5	
70	61	9	
75	65.5	9.5	18–28
80	70	10	
85	74.5	10.5	
90	73	11	
95	83.5	11.5	
100	88	12	

Figure 192A. Physical Arrangement of a Three-Wire or "Curtain" Terminated Rhombic Antenna, Showing Details of Dissipation Line and Connections to Front and Side Poles.

following formula is used for calculating the tilt angle for a given height, as calculated by the maximum-output method.

$$\sin \Theta = \frac{L - 0.371}{L \cos \emptyset}$$

where Θ = tilt angle
L = leg length
$\emptyset$ = wave angle

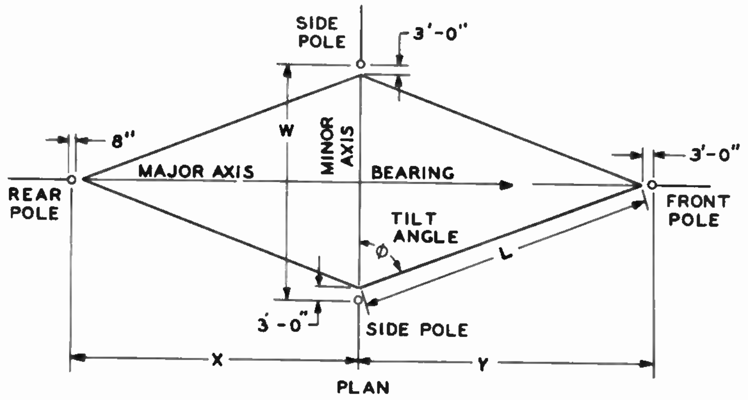
The compromise-design chart is used in the same manner as the maximum-output design chart in figure 190, except that the leg length (L) and one other value must be known. For example, suppose that for a given antenna it is known that the leg length (L) is 3 wave lengths and that the desired wave angle ($\emptyset$) is 21°. Find the correct height (H) and tilt angle (Θ). To solve this problem by means of the compromise-design chart proceed as follows:

Draw a vertical line from the point 21° on the wave-angle scale through the curve L = 3 wave lengths. Locate the point of intersection with curve H and extend a horizontal line to the height (H) scale. Locate the point of intersection of the vertical line with the curve L = 3 wave lengths and extend a horizontal line to the angle of tilt (Θ) scale. These horizontal lines indicate that the correct height is 0.7 wave length and that the correct tilt angle is 70°.

For information on the siting of a full-rhombic array, refer to the subject, Choosing Antenna Site for Optimum Operation on page 163.

Terminating Impedance

The primary purpose of the terminating impedance of a rhombic antenna is to produce a sharp, unidirectional radiation pattern. For low-power (up to 1 kw.) transmission, the terminating impedance is usually an 800-ohm, noninductive, carbon resistor. For reception, the terminating impedance is generally composed of low-wattage carbon resistors. The transmitting rhom-



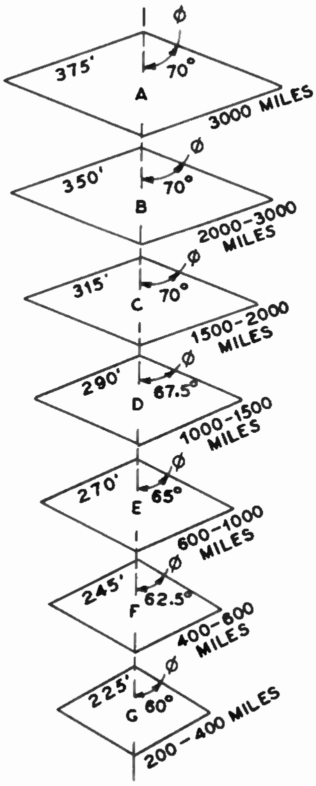


TABLE 2
RHOMBIC ANTENNA DATA

TYPE	RANGE	L	Ø	H	P	W	X	Y	WIRE SAG 30°	WIRE SAG 60°	WIRE SAG 90°	TYPE
	(MILES)	(FT.)	(°)	(FT.)	(FT.)	(FT.)	(FT.)		(IN.)	(IN.)	(IN.)	
A	3000 +	375	70°	65	67	262.4	352.7	355	34	40	48	A
B	2000-3000	350	70°	60	61.9	245.6	329.5	331.8	29	35	42	B
C	1500-2000	315	70°	57	58.5	221.6	296.7	299	23	28	34	C
D	1000-1500	290	67.5°	55	56.2	228	268.7	271	20	24	30	D
E	600-1000	270	65°	53	54	234	2454	247.7	17	21	26	E
F	400-600	245	62.5°	51	52	232	219	221.3	14	17	21	F
G	200-400	225	60°	50	51	231	195.7	198	12	15	18	G

LEGEND

L-LENGTH OF SIDE INCLUDING INSULATOR (APEX TO APEX)
Ø-TILT ANGLE
H-AVERAGE HEIGHT OF ANTENNA ABOVE AVERAGE GROUND LEVEL
P-HEIGHT OF HARNESS ATTACHMENT TO POLE ABOVE AVERAGE GROUND LEVEL
W-POLE SPACING-MINOR AXIS
X-POLE SPACING-REAR END POLE DIVISION OF MAJOR AXIS
Y-POLE SPACING-FRONT END POLE DIVISION OF MAJOR AXIS

SAG TABLE BASED ON A 60° F STRINGING TENSION OF 288 LBS. 12.8% OF THE RATED BREAKING STRENGTH OF THE CONDUCTOR

NOTE: THE DATA OF H AND P ARE BASED ON MIDDLE CURTAIN. THE UPPER AND LOWER CURTAIN VALUES OF P ARE THE SAME AS MIDDLE CURTAIN AT THE MAJOR AXIS ENDS ONLY. AT THE MINOR AXIS ENDS THE VALUES OF P ARE, UPPER CURTAIN: P+6 FT, LOWER CURTAIN: P-6 FT.

Figure 192B. Design Information for Three-Wire "Curtain" Rhombic Antenna.

bic is usually terminated with two to four specially-designed carbon resistors of about 200 watts rating. The resistors are sometimes mounted in a spring-clip fuse mounting, the whole assembly being housed in a weather-proofed plywood box about 2′ × 1½′ × 1′. The box is located at the terminated end of the antenna on the pole. In order to minimize capacity effects, the resistor combination is connected to form a series circuit. The connecting leads in the terminating network must be made as short as possible to prevent inductive effects. If insulators and supporting elements with metallic fittings are used throughout the antenna, it may be necessary to tune out the resulting lumped capacitances by critical adjustment of the connecting conductors in the terminating network. These lumped capacitances produce undesirable resonance effects at certain frequencies, which in turn modify the unidirectional pattern otherwise obtained with the proper termination.

If it is desired to make frequent adjustment of the termination, the impedance housing can be placed at a suitable height near the base of the terminating pole. The terminating-impedance network is then connected to the antenna termination with an 800-ohm line. The latter may consist of nichrome or stainless-steel wire. (Sometimes a bank of carbon filament lamps connected in series-parallel can be used for the termination.)

It has been found in practice that when the conventional rhombic is operated over a wide frequency range the input impedance varies considerably. (Theoretically the input and output impedance should be equal, although the latter usually has a slightly higher value.) For example, the input impedance of a typical single-wire rhombic varies from a maximum of about 820 ohms to a minimum of 700 ohms, when the applied frequency is varied from 5 megacycles to 13 megacycles. Increasing the frequency up to 22 megacycles reduces the input impedance to a minimum value of 600 ohms. Thus it can be seen that even with the proper 800-ohm termination, resonance effects with a departure from the ideal unidirectional lobing cannot be avoided, using the single-wire rhombic.

The problem of maintaining a constant input impedance with respect to the terminating impedance, over a wide frequency range, can be solved by the use of a multiple-wire rhombic, commonly called the "curtain" rhombic, as shown in figure 192. The spacing of the wires at the side poles, in the vertical plane, is 1 to 5 feet. When the frequency is varied from 5 to 21 megacycles, the input impedances remain fairly constant, with a maximum variation of plus or minus 50 ohms. A 600-ohm feed line can be coupled directly to the input of the multiple-wire rhombic.

Dissipation Line

When rhombic antennas are operated at high power (above 1 kw.), the problem of impedance termination becomes more complex. In the half-rhombic antenna, for example, about 50 per cent of the r-f power is dissipated in the terminating impedance. Compact, non-inductive resistors capable of dissipating over 1 kw. of power have, to date, been impossible to manufacture.

It has been found practical to use a dissipation line, consisting of a suitable length of stainless-steel wire, as a terminating impedance for powers between 1 kw. and 40 kw. Steel wire with a galvanized surface can also be used, but it will change value in time, due to rusting at points where the galvanized coating breaks open.

The dissipation line (see figure 193) is constructed of No. 14 A.W.G., annealed, stainless-steel wire, and includes the down lead, all in one length. The down-lead portion is made up as a 2-wire line (each wire consisting of 2 strands No. 14 A.W.G., stainless steel, long-lay twist), spaced 12 inches, and has a characteristic impedance of approximately 650 ohms. The down lead becomes part of the horizontal portion of the dissipation line by a right-angle bend, and at this point a modified exponential line begins. See figure 194. The 2-wire down lead is transformed into a 4-wire dissipation line without the necessity of joining or splicing. The 12-inch spacing diminishes, the 2 strands (long-lay twist) of each line wire become separate spaced lines, and thus, in a line length of exactly 62.5 feet, the 12-inch spacing tapers to 5.5 inches as the side members diverge to 1.3 inches at the dissipation-line spreader insulator. See figure 193. In the next 62.5-foot length of line, the 5.5-inch spacing tapers to 1.3 inches, while the side members remain spaced 1.3 inches

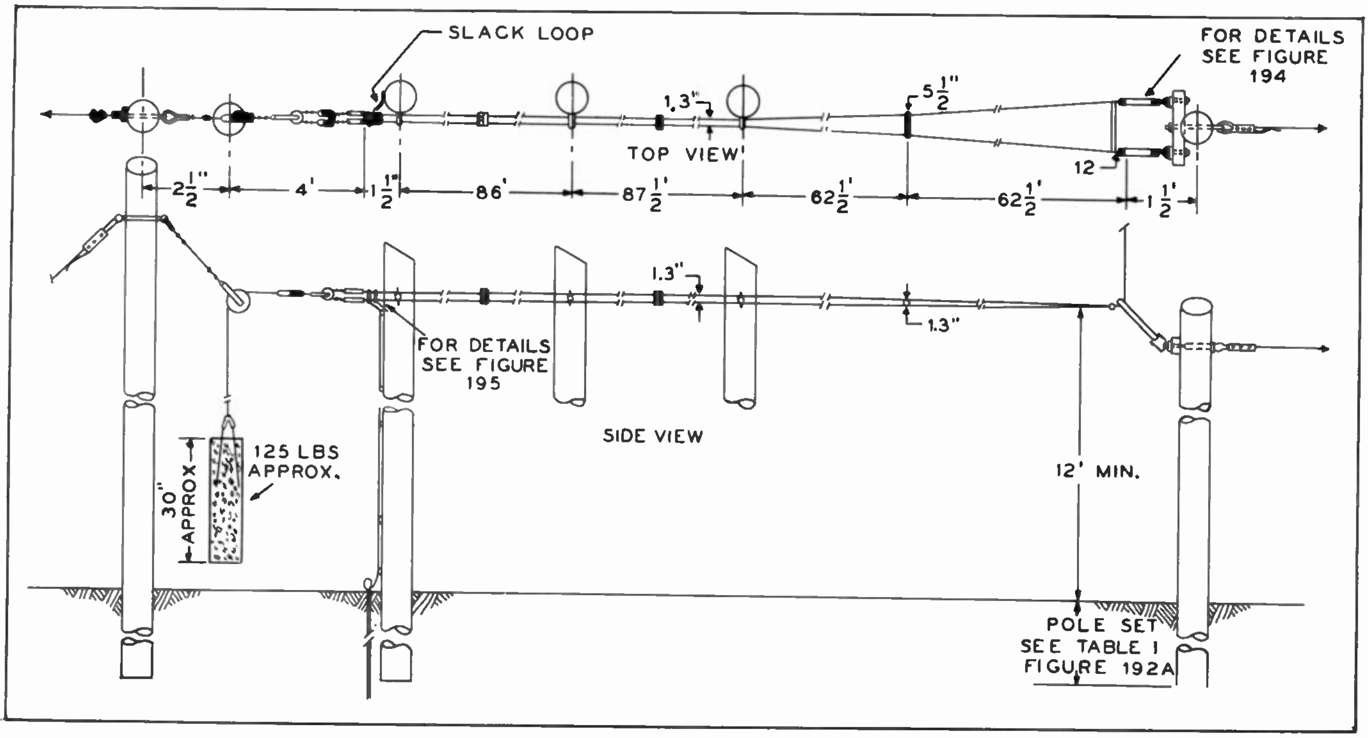


Figure 193. Dissipation Line for Use with a Full-Rhombic Antenna, Showing Details of Construction.

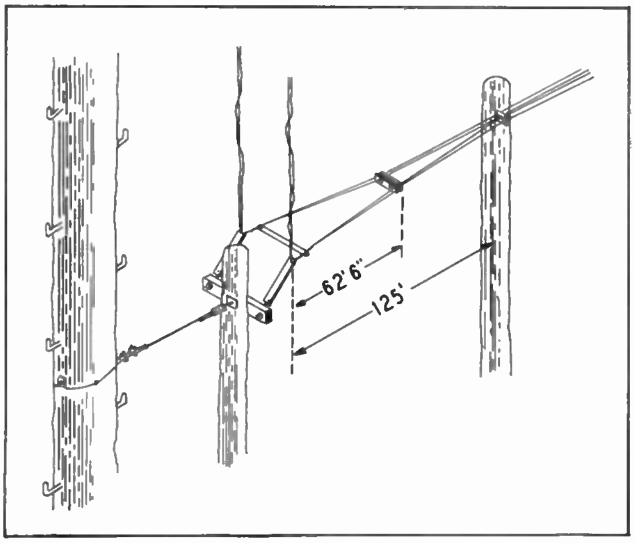


Figure 194. Details of Down Lead and Exponential Portion of Dissipation Line.

apart. From this point, the line continues as a 1.3-inch square, spaced, 4-wire line. The modified exponential portion of the dissipation line transforms the approximately 650-ohm impedance of the down leads to approximately 200 ohms. The equally spaced 4-wire portion of the dissipation line is fundamentally two 400-ohm lines in parallel, one of which is terminated in an open circuit (not connected to anything) and the other of which is terminated in a short circuit (ends connected diagonally) and grounded. See figure 195.

The nichrome-wire, or stainless-steel-wire dissipation line is usually grounded at the electrical center as a precaution against lightning hazards.

An alternate impedance-termination system, generally used for input powers above 50 kw., is the re-entrant line termination. In this system, the rhombic is terminated in a transmission line, which in turn is coupled back to the antenna input through the proper voltage-matching and phasing networks. Thus some of the energy in the dissipation line is fed back to the antenna, so that considerably less than 50% of the energy is wasted.

The energy in the re-entrant line is fed back to the antenna input line in the proper phase by means of matching-stub arrangements. If quarter-wave stubs are used, the center point of the stub shorting element can be grounded as a protection against lightning hazards. It is obvious that for any variation from the stub frequency the stub must be retuned.

Checking Termination

One of the important problems in rhombic-antenna work is that of maintaining electrical symmetry in the antenna, the transmission line, and the antenna-coupling circuit at the transmitter. The main requirement in achieving this end is a proper impedance termination of the rhombic, assuming that sufficient care was used in the construction of the antenna to obtain physical symmetry.

Electrical symmetry in the antenna-coupling circuit and in the transmission feed line can be accomplished by first making the necessary corrections on the transmission feed line and then ironing out the irregularities in the antenna-coupling circuit.

Checking the termination of a single-wire rhombic requires the use of a balanced oscillator and an SCR-211 Frequency Meter. If the frequency meter is not available, a well-calibrated, stable, communications receiver with a b.f.o. or an "S" meter will do.

A high L/C ratio should be used in the tank circuit of the balanced oscillator for a given frequency-range coverage. The unit should be portable to facilitate handling.

To check the termination of a single-wire rhombic, disconnect the transmission feed line and proceed as follows:

1. Tune the oscillator to a frequency within the range of frequencies to be applied to the antenna.

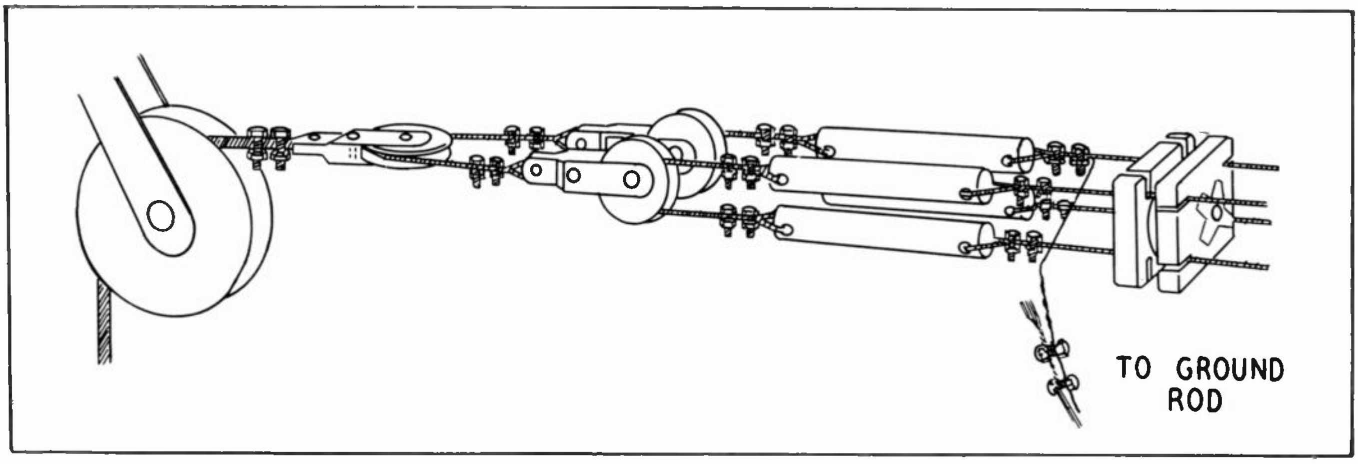


Figure 195. Details of Dissipation-Line Termination.

2. Connect a pair of coupling leads to an 800-ohm carbon resistor of suitable wattage rating (use a 600-ohm resistor for a 3-wire rhombic).

3. Determine the approximate safe loading point of the oscillator by connecting the free ends of the coupling leads symmetrically to each side of the midpoint of the coil.

4. Disconnect the 800-ohm resistor and measure the oscillator frequency with the SCR-211 Frequency Meter (or receiver).

5. Connect the oscillator to the antenna input terminals, and measure the frequency with the SCR-211 Frequency Meter (or receiver).

6. If the frequency shift is negligible, tune the oscillator to a higher or lower frequency and repeat step 5.

7. If a large frequency deviation results, the terminating impedance should be increased or decreased until the indicated frequency deviation is negligible.

8. The process should be repeated to cover the frequency range on which the antenna may be operated, until a value of terminating impedance is found which gives a fairly "flat" antenna characteristic over the entire frequency range.

Critical adjustment, to offset parasitic effects due to stray capacity and other causes, requires the use of additional special equipment in conjunction with the balanced oscillator. The use of this equipment in ordinary rhombic-antenna applications is of doubtful value. However, for efficient fixed-plant, high-power installations, all circuit irregularities should be determined and, if possible, corrected.

In the above procedure for checking the termination of a single-wire rhombic, it was assumed that the oscillator used was portable, and could be carried up the antenna pole to the antenna input terminals. If for any reason the frequency-shift checks must be made on the ground, the following procedure may be used.

1. Suspend an 800-ohm line (600-ohm line if a multiple-wire rhombic is used) from the antenna-input terminal point of the rhombic, but leave it disconnected from the antenna.

2. Terminate the lower end of the line so that it is one half wave length long at approximately the lowest frequency to be applied to the rhombic.

3. Assuming that the tap adjustments on the oscillator-plate-tank coil are correct for feeding an 800-ohm (or 600-ohm) load, connect the oscillator into the half-wave section and tune it until resonance with the line is indicated. The oscillator tuning is correct if there is no frequency change when the oscillator is disconnected from the half-wave section.

5. Measure the oscillator frequency.

6. Connect top end of the half-wave section to the antenna input terminals.

7. Measure the oscillator frequency change and, if it is appreciable, increase or decrease the value of the terminating impedance until the oscillator frequency change is negligible.

8. Calculate the lengths of four or five half-wave-length sections of 600-ohm line, covering the frequency range over which the rhombic is to be operated. (For example, if the frequency range is 5 to 10 megacycles, cut a half-wave section for each of the following frequencies: 6, 7, 8, 9, and 10 mc.)

9. Shorten the 600-ohm line to the next higher frequency range and repeat steps 1 through 7.

10. Proceed as above, until the impedance termination over the entire frequency range of the antenna is correct. (Note: At the high-frequency end of the operation, the half-wave-length sections may be too short to reach the ground; in this case, the 600-ohm line may be made one wave length long.)

Although the proper impedance termination is required to prevent resonance effects on the rhombic, and to maintain a "flat" input-impedance characteristic, it is impossible to achieve a uniformly high front-to-back ratio throughout the entire operating-frequency range. At frequencies where the leg length is an odd multiple of a wave length long, an infinite front-to-back ratio is approached. The front-to-back ratio becomes progressively smaller as the leg length changes from an odd multiple to an even multiple of a quarter wave length. The ratio also becomes smaller in antennas having short leg lengths. If a fairly uniform front-to-back ratio is desired, the terminating impedance can be reduced in value from the characteristic impedance of the rhombic. However, this will introduce resonance effects at some frequencies.

Transmission Lines for Feeding Rhombics

From the preceding discussion it can be seen that a rhombic antenna is basically a modified form of balanced transmission line, terminated in its characteristic impedance. For maximum radiation efficiency, it is desirable to adjust the system so that a balanced circuit over a wide frequency range is seen by the input transmission line. The transmission feed line should also be properly balanced, particularly when the antenna is used for transmitting.

If a multiple-wire rhombic is used for transmitting, the feed problem is relatively simple. A 600-ohm, open-wire transmission line is connected directly to the antenna input terminals. Since the multiple-wire rhombic presents an almost uniform input impedance the reflection losses along the transmission line are negligible, provided that the proper coupling is used between the transmitter and the line. This requires the use of a balanced antenna-coupling circuit, such as a pi-section filter, between a balanced plate-tank circuit and the lines. The complete feed system can be checked by, first, disconnecting the transmission line from the antenna and terminating it with a resistance of sufficient wattage rating and having a value equal to the characteristic impedance of the line. The standing-wave ratio should be checked over the entire frequency range, while keeping the power input from the transmitter constant. If an unbalanced-line condition is indicated, one side of the line can be pruned about an inch at a time, until the best balance is ob-

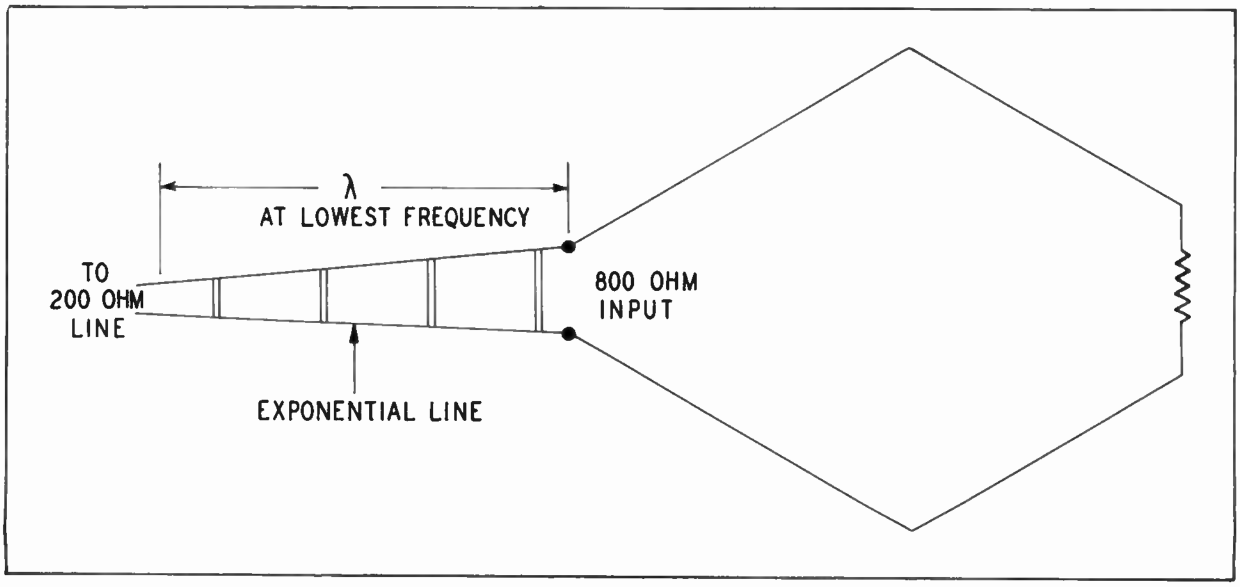


Figure 196. Exponential Line-Matching Section for a Terminated Full-Rhombic Antenna.

tained. It may also be necessary to rearrange the physical placement of the feed-line wires to correct the irregularity. In the checks given above, it is assumed that circuit balance between the final plate tank and the line is correct.

After the above procedure is completed, the feed line should be connected to the antenna, after first removing the terminating resistance used in the line tests. The transmission-line tests should be repeated over the entire frequency range to double check the system. This will insure negligible radiation from the transmission line even if it is over 20 wave lengths long. The line-radiation effects during the tests can be observed by reading the signal voltage on a good receiver, placed about a mile away.

If transmission-line current-meter readings were taken, they should be recorded. *A resistance measurement* of the system should also be made and recorded at the initial installation. This should include measurements of the total circuit from the transmitter end, and across each side to ground if the terminating circuit is grounded. Periodic checks will indicate any changes in the ohmic value of the system.

The problem of feeding a single-wire rhombic antenna, which has a characteristic impedance of approximately 800 ohms, differs a little from that for the multiple-wire rhombic. An open-wire line of this characteristic impedance requires an increased wire spacing, which results in greater radiation losses. If efficiency is not a major factor, a standard 600-ohm line (#6 B. & S. copperweld wire, spaced with 12-inch insulators) can be used for feeding the single-wire rhombic. A 600-ohm line connected to an 800-ohm rhombic will naturally produce a mismatch, with resulting standing waves. By introducing a simple matching transformer, as shown in figure 196, this mismatch can be reduced somewhat. For operating powers below 1 kw., when the single-wire rhombic is located a short distance from the transmitter, a 200-ohm or 300-ohm open-wire line may be used for feed purposes. However, an exponential line must be connected between the line and the antenna, as shown in figure 196. To prevent any resonant effects, if the line and the antenna have an impedance ratio greater than 2 to 1, the exponential line should be approximately one wave length long at the lowest frequency to be applied to the antenna. The smaller the impedance ratio between the line and the antenna, the shorter the exponential-line matching section must be. Obtaining the correct taper on the exponential line may be a little difficult, but by experimenting the correct results can be obtained.

If the antenna is to be used for both transmission and reception, a balanced four-wire line with opposite wires connected together will work well for both applications. The balanced four-wire line is less receptive to distant noise pick-up than the two-wire line and, therefore, is more efficient for receiving purposes.

The previously described methods for checking and eliminating circuit irregularities can also be applied to the single-wire rhombic.

Rhombics used exclusively for reception will differ somewhat from the transmitting rhombic. Transmitting rhombics, operating with power inputs up to 200 kw., use #6 B. & S. copperweld wires; the same size wire must be used for large receiving rhombics. Smaller size wires do not have sufficient tensile strength for the long suspensions required in rhombic work. No particular advantage is gained by using multiple-wire rhombics for reception, except for a reduction in precipitation static.

The termination resistance is usually a low-wattage carbon resistor, because little power is involved. How-

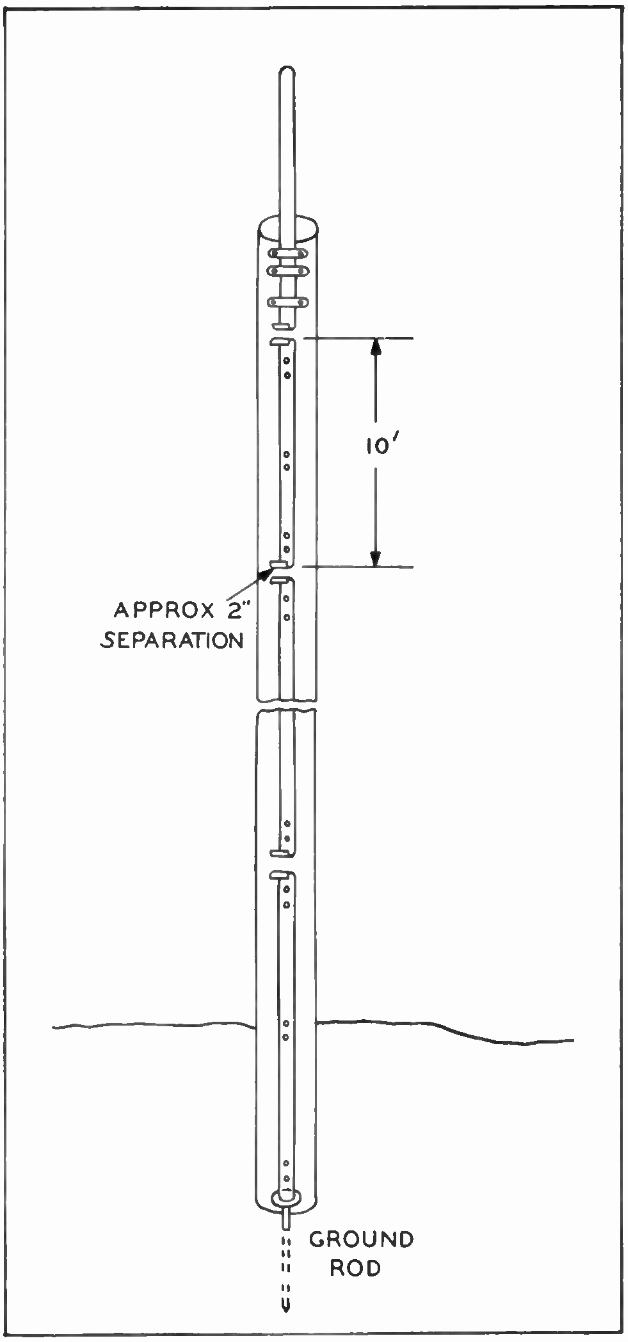


Figure 197. Lightning Protectors for the Termination Pole of a Full-Rhombic Antenna.

ever, the resistor might be destroyed by lightning. Hence, lightning protection must be installed, preferably on the terminating pole. Figure 197 shows a suitable arrangement. When steel supporting towers are used, the problem of lightning protection is considerably lessened.

The receiving-rhombic transmission line must be so constructed that high attenuation of both local and distant noise is obtained. Long open-wire lines, including the two-wire types if transposed, are not too susceptible to distant noise pickup. However, local noise sources are very troublesome even if the lines are properly balanced.

The use of low-impedance coaxial cable (polystyrene dielectric) results in little noise pickup. The best insurance against the pickup of noise of all types is obtained by using concentric-line cable, which is properly matched at the antenna. The whole length of the cable from the receiving point to the antenna is buried at a depth of 2 or 3 feet. If the ground contains corrosive elements, the outside surface of the concentric-line cable (brass or copper tubing at least 1 inch in diameter) must be coated with tar, or other protective substances.

When either type of coaxial line is used, a proper balance to ground should be maintained. By use of the proper coupling arrangement, as many as six receivers may be operated from the same rhombic antenna. A receiver multicoupler may be used for this purpose, but the over-all gain is lowered about 25%. (Refer to page 181 for detailed information on multicoupler units.) Another method is to parallel the receivers across one antenna after first inserting a series-connected inductance and variable capacitor of approximately 100 mmf. This method is not recommended for permanent station installations, because the tuning adjustments of the series capacitors are not entirely independent of each other, and thus require frequency checks and adjustments to insure proper operation. See figure 198 for a schematic diagram of this method of coupling.

Other Rhombic Types

If the rhombic antenna is left unterminated, a bidirectional radiation pattern in the line of the major axis is obtained. The gain in either direction is approximately the same as that for the terminated rhombic.

The disadvantages of the unterminated rhombic are: First, a uniform lobing pattern is not maintained as the frequency is changed; therefore, the magnitude of the secondary lobes may be objectionable. Second, a tuned line is generally used because the unterminated rhombic is resonant. The practical use of tuned lines, however, is limited to installations where the transmitter and antenna are close together. When the rhombic is located some distance from the transmitter, an untuned line must be used. This makes it necessary to use a stub-matching system, which limits the operation to a very narrow band of frequencies.

For reception, the unterminated or resonant type of rhombic has poor noise-discrimination characteristics. For example, noise signals arriving from the direction of transmitter feed line will cause interference with signals of equal amplitude arriving from the direction of the unterminated end. On the other hand, if noise considerations are disregarded, the unterminated rhombic gives better gain results than a half-wave dipole or a single "V" antenna.

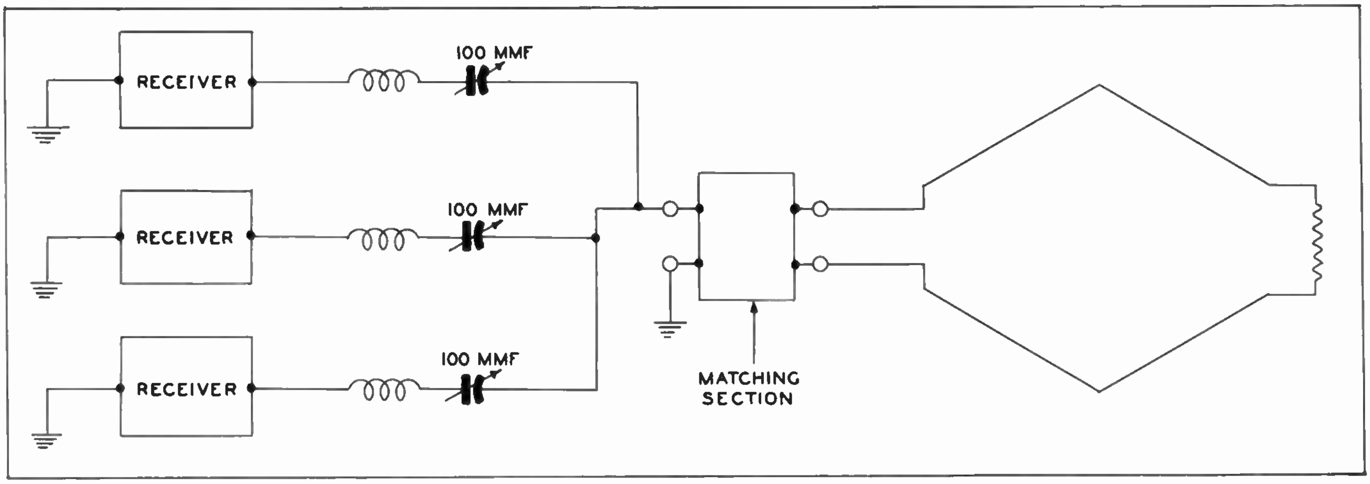


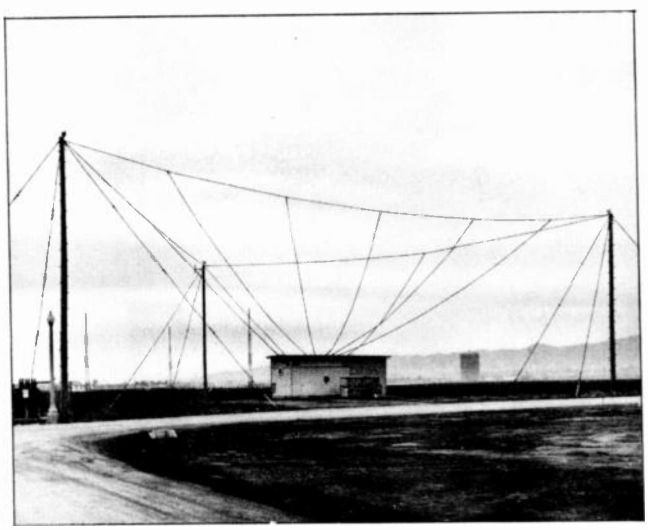
Figure 198. Method of Coupling Three Receivers to One Rhombic Antenna.

Less widely used rhombic systems are broadside rhombics and vertical rombics. Vertical rhombics give excellent results at very high frequencies and, at these frequencies, they are relatively easy to construct.

LOW, MEDIUM, AND HIGH-FREQUENCY ANTENNAS

In the basic antenna theory section, it was pointed out that sky-wave transmission is unreliable in the Arctic latitudes, due to frequent magnetic disturbances of the ionosphere. However, it is possible to maintain consistent communication by utilizing low-frequency ground waves. The low-frequency spectrum extends from .03 mc. to 0.3 mc. General-coverage ground-wave communication is also feasible in all latitudes by the use of the medium frequencies, 0.3 mc. to 3 mc.

In view of the fact that ground waves are vertically polarized, the antenna systems discussed here are those which propagate vertically polarized waves.



High-Frequency, Single-Wire Horizontal and Vertical Transmitting Antennas.

Vertical-Antenna Types

The main types of vertically polarized antennas are the vertical Marconi, the top-loaded vertical, and the flat top.

The vertical Marconi usually takes the form of a steel structure, such as a tower. Sometimes, however, a

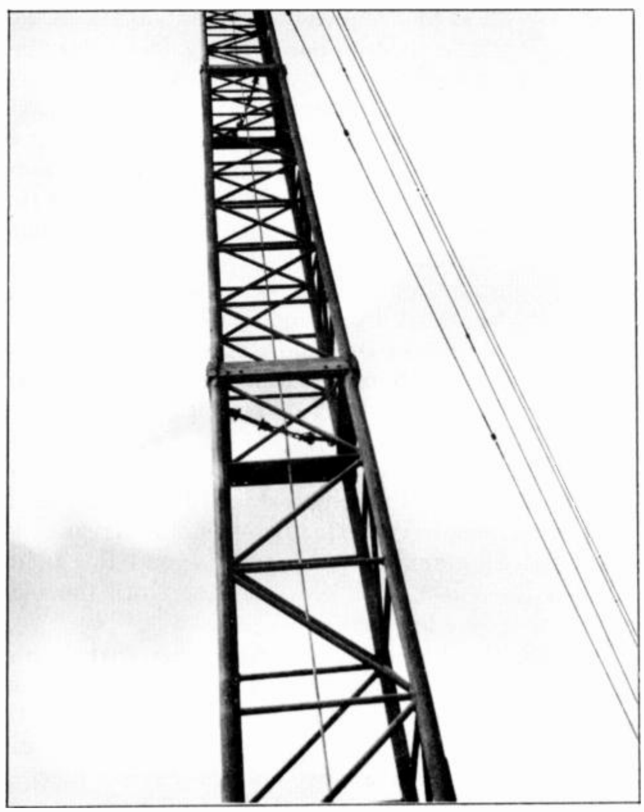


Figure 199. Supporting Tower for a 60 Kw.-Powered Vertical Antenna, Showing Antenna Wire Suspended in Center of Tower by Insulating Brackets to Prevent Shorting.

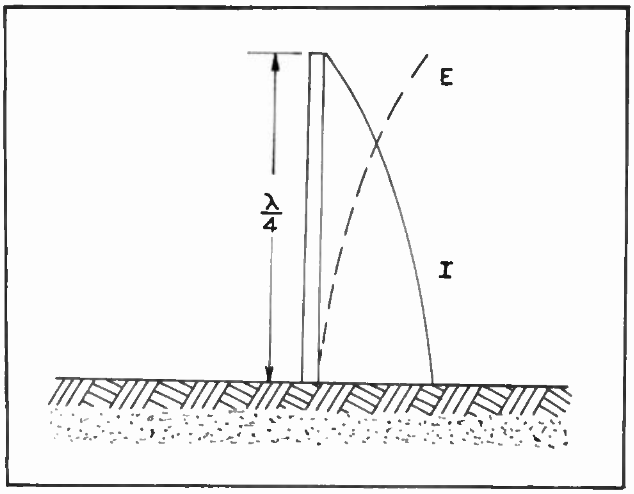


Figure 200. Normal Current-and-Voltage Distribution on a Grounded Quarter-Wave Marconi Antenna.

copper-wire antenna is suspended within the tower, and insulated from it. Figure 199 illustrates this type of construction.

The length of a vertical antenna, which is actually its height, varies inversely with frequency. For example, the height of a quarter-wave Marconi at 410 kilocycles is 600 feet, whereas, at 1500 kilocycles, the height is 164 feet. Thus it can be seen that practical antenna heights depend upon constructional considerations as well as the frequency of operation.

Referring once again to basic theory, let us examine the current and voltage distribution on a grounded $\lambda/4$ Marconi antenna. See figure 200. The current is maximum at the base of the antenna, while at the top, it is practically zero. Conversely, the voltage is minimum at the base, and maximum at the top. Shortening the antenna for any reason will change the sinusoidal character of the current and voltage distribution. The current flow throughout the antenna becomes less as the height is decreased from one-quarter wave length. This, in turn, reduces the field strength, which is proportional to the antenna current. Thus, the effective height of a vertical antenna determines, to a large extent, its efficiency.

The effective height of a quarter-wave vertical antenna is about 0.6 of its physical length. At one eighth of a wave-length the effective height decreases to about 0.5. Shortening the antenna beyond this point reduces the effective height, and therefore the efficiency, to a very low value.

It might also be mentioned at this time that the radiation resistance of the quarter-wave vertical antenna, which is 36 ohms, also decreases as the physical length (height) is decreased. The radiated power depends upon the radiation resistance and the current flowing in the antenna circuit. Since the ground forms a part of the antenna circuit, its resistance affects the total current flowing in the antenna. Thus the total dissipated antenna power $P_t = I^2 (Ra + Rg)$; where Ra = radiation resistance, Rg = ground resistance, and I is the antenna current as measured at the base of the antenna (high-current point). Therefore the radiated power = total dissipated power minus power in ground circuit or radiated power $= P_t - I^2Rg$.

Obviously, if the ground resistance can be made to approach zero, the radiated power will increase in proportion. The lowest value of ground resistance can be obtained by connecting the base of the antenna to a suitable counterpoise, whose radials are at least one-quarter wave length long. For a typical example of counterpoise arrangement, and additional information on counterpoises, refer to the subject of Grounds and Counterpoises on page 171.

In evaluating the above facts it becomes apparent that the major problem in vertical antenna operation at low frequencies, is maintaining a high efficiency with antennas of reduced length.

Resonating Short Vertical Antenna

Basically, the problem of resonating a short vertical antenna (shorter than three-eighths wave length) so that it is electrically equivalent to a quarter wave length, resolves simply into overcoming the high capacitive reactance present. This is the capacitive reactance as seen by space and the earth. Figure 201 A and B gives a relative idea of this capacitance. Obviously, more inductance must be added. This addition is usually a lumped inductance in the form of a tapped coil, or variometer, inserted at the lower end of the antenna. If the antenna is to be operated over a wide frequency range, a large variable capacitor should be placed in series with the coil and antenna. Figure 202A shows the schematic layout of this arrangement, while figure 202B shows the current distribution along the antenna circuit. The value of the current in the coil is the same,

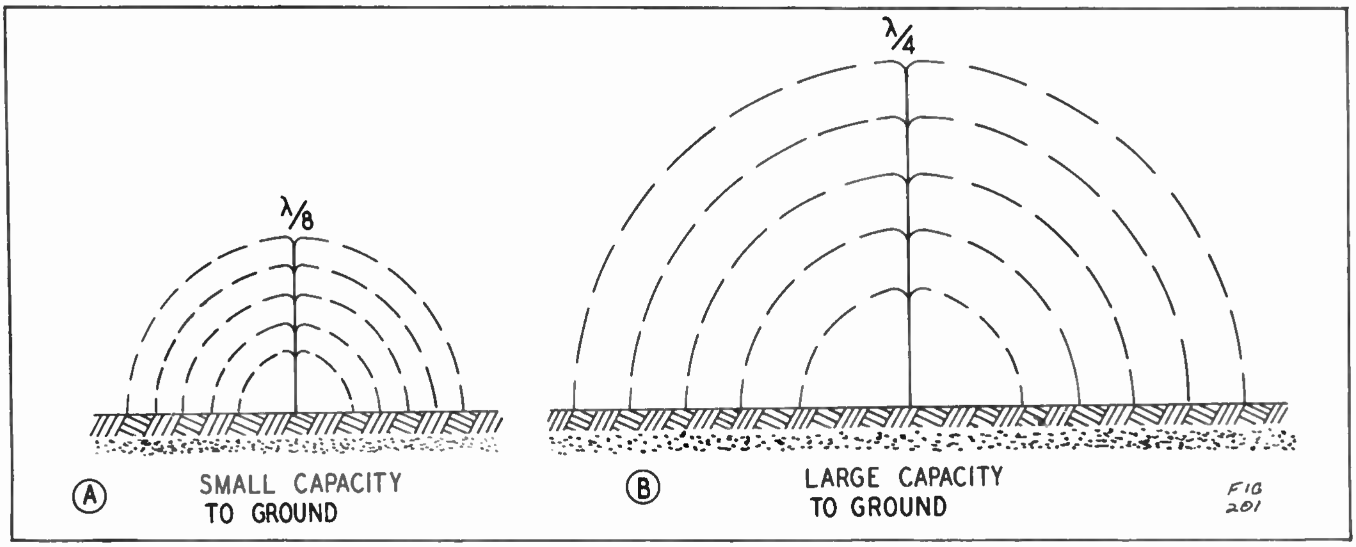


Figure 201. Vertical Antennas, Showing How the Capacity to Ground Varies with the Length.

but the current distribution now approximates the sine-wave distribution on a quarter-wave antenna. An effective increase in radiation resistance also results, thus increasing the radiated power.

This method finds universal application in shipboard, aircraft, and vehicular installations where efficiency must be compromised. The efficiency of the vertical whip antenna, used on vehicular installations, is particularly poor, and may reach a value as low as 5 per cent. Another disadvantage is the high voltage developed at the antenna end of the loading coil, due to the high circulating current in the coil. Operators of high-powered equipment of this type, should be aware of this danger.

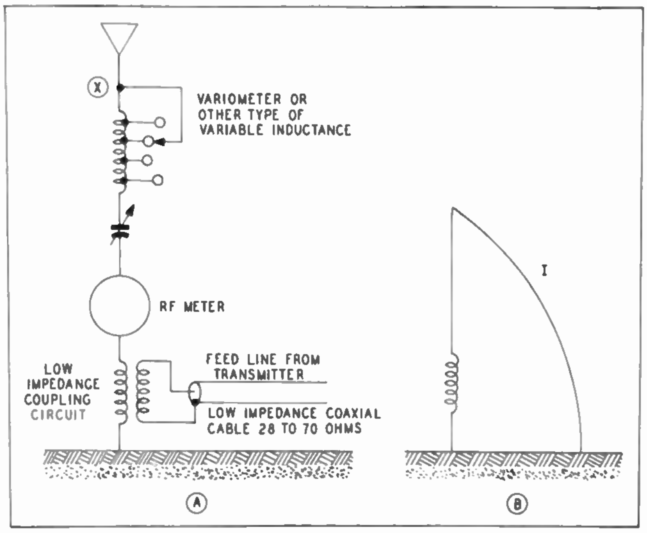
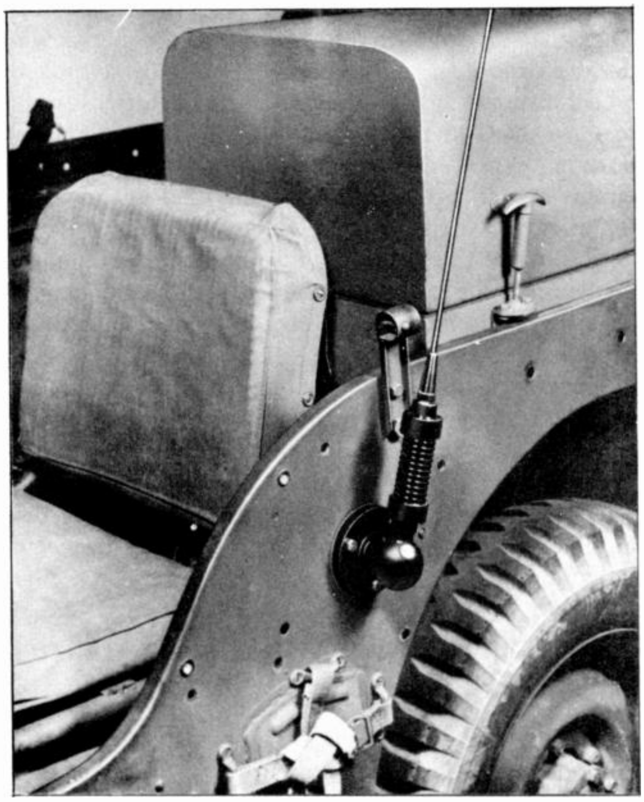


Figure 202. Schematic Layout of a Vertical Antenna, Showing the Current Distribution.

Top Loading

Inserting the loading coil near the base of the short, grounded vertical antenna produces a small increase in radiation resistance, on the order of 4 or 5 ohms. This increase can be carried to about 20 ohms by inserting the lumped inductance about 0.2 wave lengths from the top of the antenna. The value of the inductance in this case should be fixed at a larger value than



Vehicular Installation of a Whip Antenna.

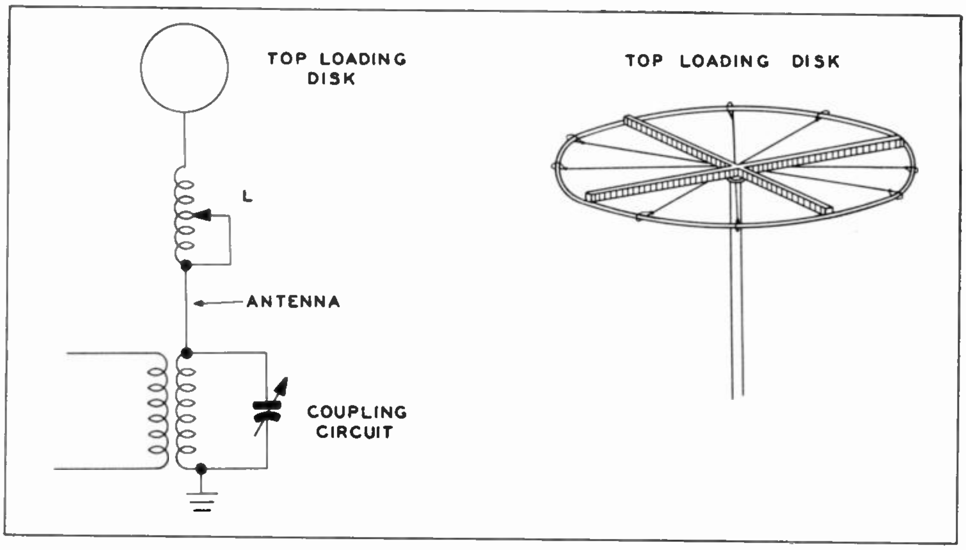


Figure 203. Common Method of Top-Loading a Vertical Antenna.

that required for antenna resonance at one-quarter wave length. Tuning can then be accomplished by inserting a large variable capacitor in the lower portion of the antenna circuit. A suitable inductance of approximately 350 microhenries can be constructed by winding an 11- or 12-inch coil on a low-loss form, 5 inches in diameter, with no. 12 or no. 14 B. & S. copper wire. The wire insulation may be enamel or double-cotton.

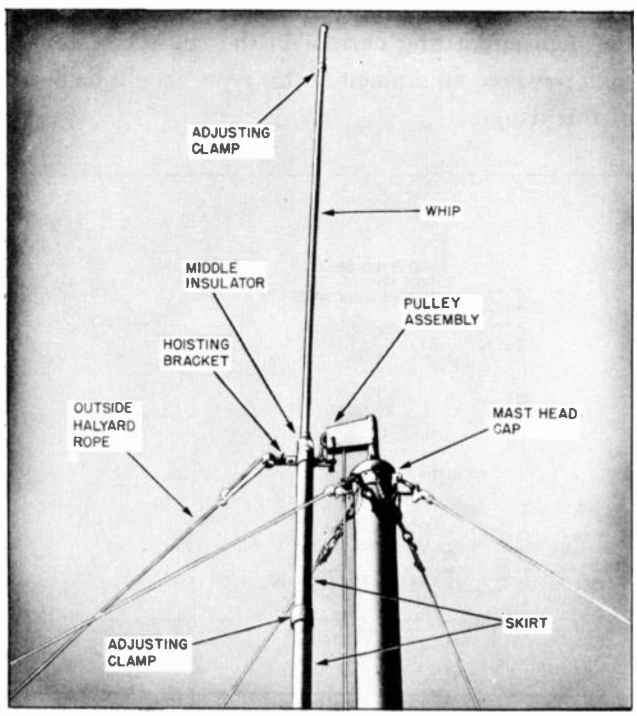
The efficiency of this system may be further increased by adding a large lumped capacitance in series with the inductance at the top of the antenna. The capacitor can be in the form of a large sphere, cylinder, or disk. The disk capacitor is usually a spoked-wheel arrangement of aluminum conductors. In order to have more of the current flowing in the radiating portion of the antenna, a parallel-resonant coupling circuit is used between the antenna and the transmitter. Figure 203 shows a typical arrangement.

The size of the top-loading capacitance required depends upon the ground resistance and the frequencies used. Poor ground systems require larger top-loading capacitors.

The disadvantages of the top-loading system are: first, the antenna has poor frequency-discrimination characteristics; second, due to physical size and arrangement, it is not suitable for vehicular or aircraft use. It therefore finds its greatest use in fixed ground installations, and, to a lesser degree, in shipboard installations.

Quarter-Wave Vertical Antenna Feed Methods

The quarter-wave vertical antennas, such as the grounded or ungrounded steel towers, use a series-or shunt-feed system. The shunt-feed system is illustrated in figure 204. The coupling "loop" consists of the triangular loop formed by capacitor C, feeder line 1, the lower portion of antenna 2, and the section of ground between the antenna base and earth. The proper feed tap point, X, can be determined empirically, by the following method: First, terminate the low-impedance line (70-ohm coaxial line, or, for high power, concentric cable) in its proper nonreactive load of suitable wattage rating. An r-f ammeter must also be inserted at the end of the line. Using the frequency at which the antenna is to operate, apply full power to the line. Record the line-current reading. Remove the terminat-



Adjustable-Height Whip Antenna with Mast Support.

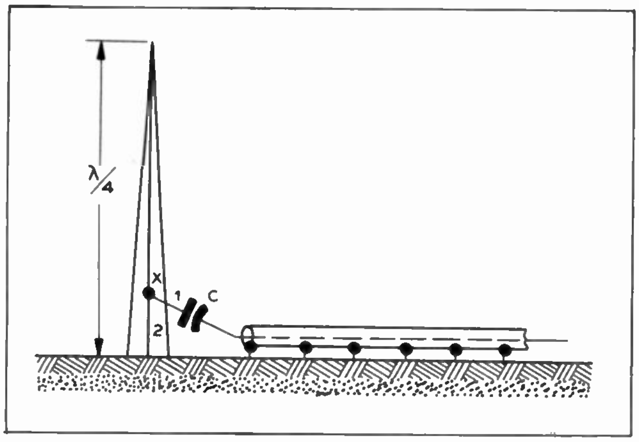


Figure 204. Method of Shunt-Feeding a Vertical Antenna.

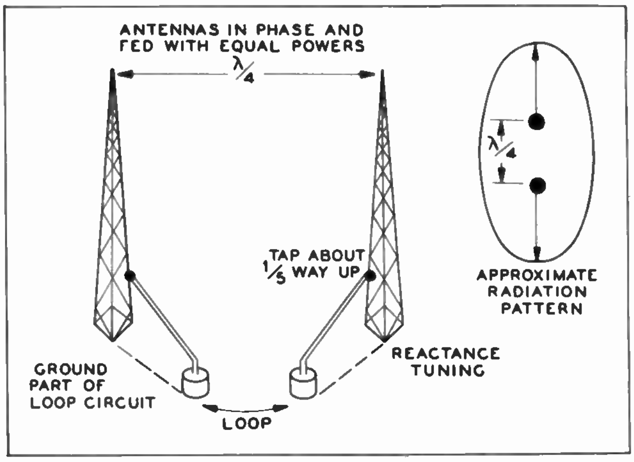


Figure 205. Method of Obtaining a Broad Bidirectional Beam with Two Shunt-Fed Vertical Antennas.

ing resistor, and tap the line onto the antenna, with the r-f ammeter still connected in the line. The proper tap point is the point where the line current reading approximates the reading obtained in the line-current test. For best results, field-strength readings should be taken at one or more points, about a mile or a mile and one-half distant from the antenna. The series capacitor should be adjusted to cancel out the reactance of the loop circuit.

Two or more tower-type antennas are often used to obtain a directional radiation pattern in the horizontal plane. The antennas are usually shunt-fed in the same manner as the single-tower antenna. In order to produce a broad bidirectional pattern, the towers are spaced between one-quarter and one-sixth wave length apart, and are excited in phase. Figure 205 shows the physical arrangement of this system.

Quarter-Wave Vertical Hertz Antennas

Ungrounded quarter-wave vertical antennas are extensively used for fixed-frequency operation. The antenna tower rests on ceramic insulators, 2 to 6 feet high. In order to series-feed this antenna, the impedance existing between the antenna base and ground must be properly matched to the transmission line. With proper tower design the base impedance is approximately 36 to 38 ohms if the antenna height is exactly one-quarter wave length. The fact that reactive components invariably exist at the tower base introduces difficulties in matching the antenna to the line. With unity power factor (antenna exactly at resonance), a properly matched, low-impedance line, and a 1 kw. input at 100 per cent modulation, the peak voltage between the antenna base and ground is over 500 volts. Any decrease in frequency which effectively changes the height from a quarter wave produces a large increase in the peak voltage developed at the base. If the antenna is made one-half wave length high, with unity power factor, the peak voltage developed at the base for 1 kw. power at 100 percent modulation is approximately three times that for the quarter-wave ungrounded vertical antenna. This follows from the fact that a voltage loop exists at the base of the half wave vertical antenna, and the impedance at the base is approximately 300 ohms.

For medium- and low-power work, a modified shunt arrangement is suitable. Basically, this may consist of an inductance between the insulated tower base and ground. The transmission line is tapped onto the inductance at the proper point near the grounded end.

In order to minimize reactance effects, a properly designed coupling network, usually a pi network, can be connected between the low-impedance transmission line and the tower base. This is the preferred method when using high-power antenna inputs.

Vertical Antenna Radiation Effects

By carefully analyzing the vertical antenna discussions previously presented, it is seen that the primary aim is to produce a maximum current flow in the radiating portion of the antenna. The simplest way to accomplish this is to construct antennas having a greater effective length than a quarter wave. In this way, the current loop can be moved up along the vertical radiating portion of the antenna; at the same time, a voltage loop (high-impedance point) approaches the base of the antenna. The latter effect helps to reduce the amount of current flowing in the ground portion of the circuit. Any currents flowing in the ground circuit, of course, result in wasted power.

The effective height of the vertical radiator can be increased by any one of three methods:

1. Increasing the length beyond a quarter wave.
2. Placing a lumped inductance or capacitance in series with the quarter-wave antenna at its base.
3. Terminating the straight, vertical portion of the antenna in a "flat top" arrangement of conductors.

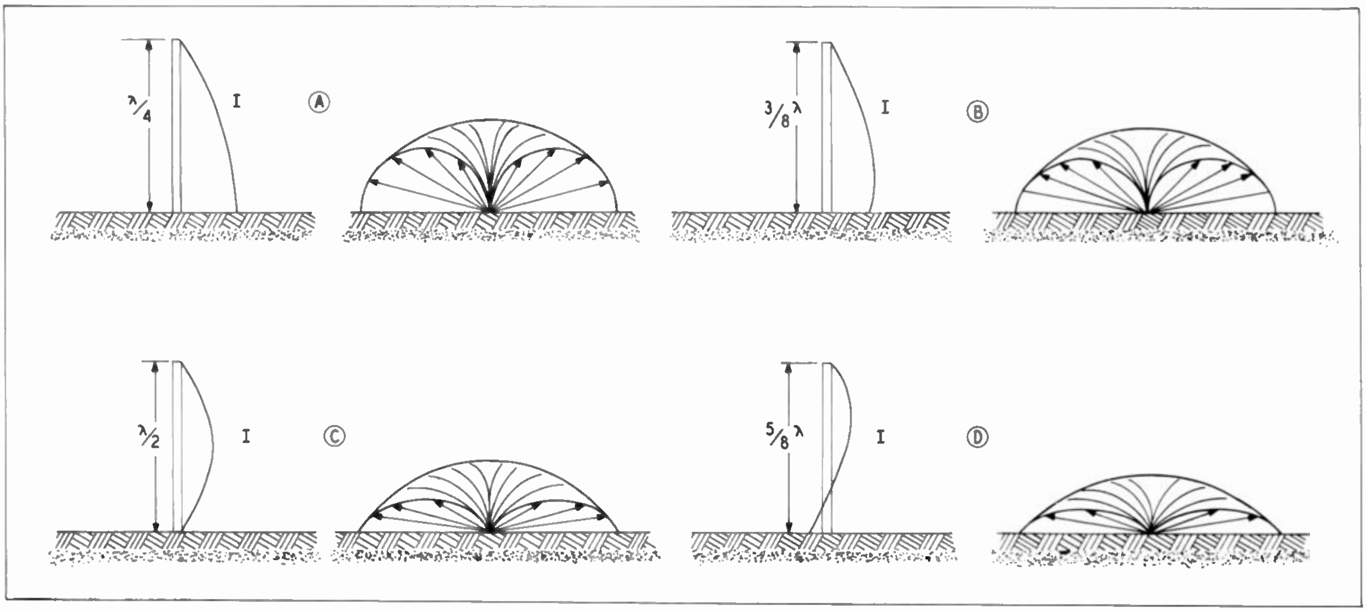


Figure 206. Effect of Increased Height on the Horizontal Radiation Patterns of a Vertical Antenna Greater than a Quarter Wave Length.

Any of the above systems shifts the current loop upward into the more useful radiating portion of the antenna, and are discussed below in consecutive order.

Physical Lengths Greater Than a Quarter Wave Length

The effect of increasing the physical length (height) becomes readily apparent by observing figure 206 A to D which shows the field patterns in the horizontal plane and the corresponding current distribution along the antenna.

It will be noticed that the high angle of radiation is progressively lowered as the antenna length changes from a quarter wave length to five-eighths of a wave length. Since the current loops occur well up on the antenna, more and more of the energy is concentrated along the horizontal plane.

In the case of the quarter-wave or shorter vertical antennas, a considerable amount of energy reaches the D and E layer at the higher angles of propagation. During day-time operation, most of this energy is absorbed in the D and E layer, or is greatly attenuated, so that a negligible amount of signal energy returns to the earth by this path. However, at night, when the E layer is nonexistent, the energy that left the antenna at high angles reaches the F_2 layer. Since less absorption of the signal occurs in this layer, most of the energy is returned to earth. The signal energy returning in the zone approaching the ground-wave limit causes fading. The portion returning beyond the ground-wave limit causes interference to receiving services on the same frequency channel.

Since vertical antennas longer than five-eighths wave length display strong high-angle-lobing characteristics, they are generally not suitable for ground-wave propagation. See figure 207 A and B.

Flat-Top Vertical Antennas

Perhaps the most widely used method for increasing the effective height of the current loop in a vertical antenna is a "flat top" or "folded top" arrangement of conductors. This scheme is particularly favorable for

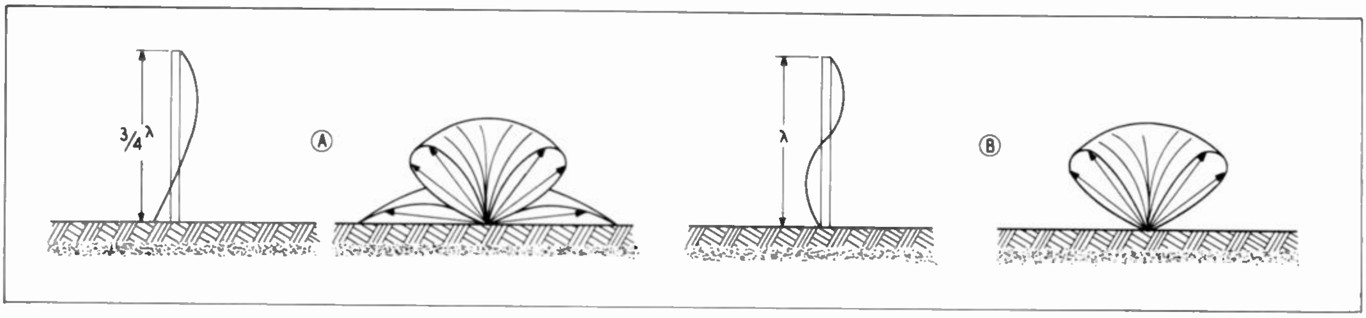


Figure 207. Vertical Antennas Greater than Five Eighths Wave Length, Showing High-Angle Lobing Characteristics.

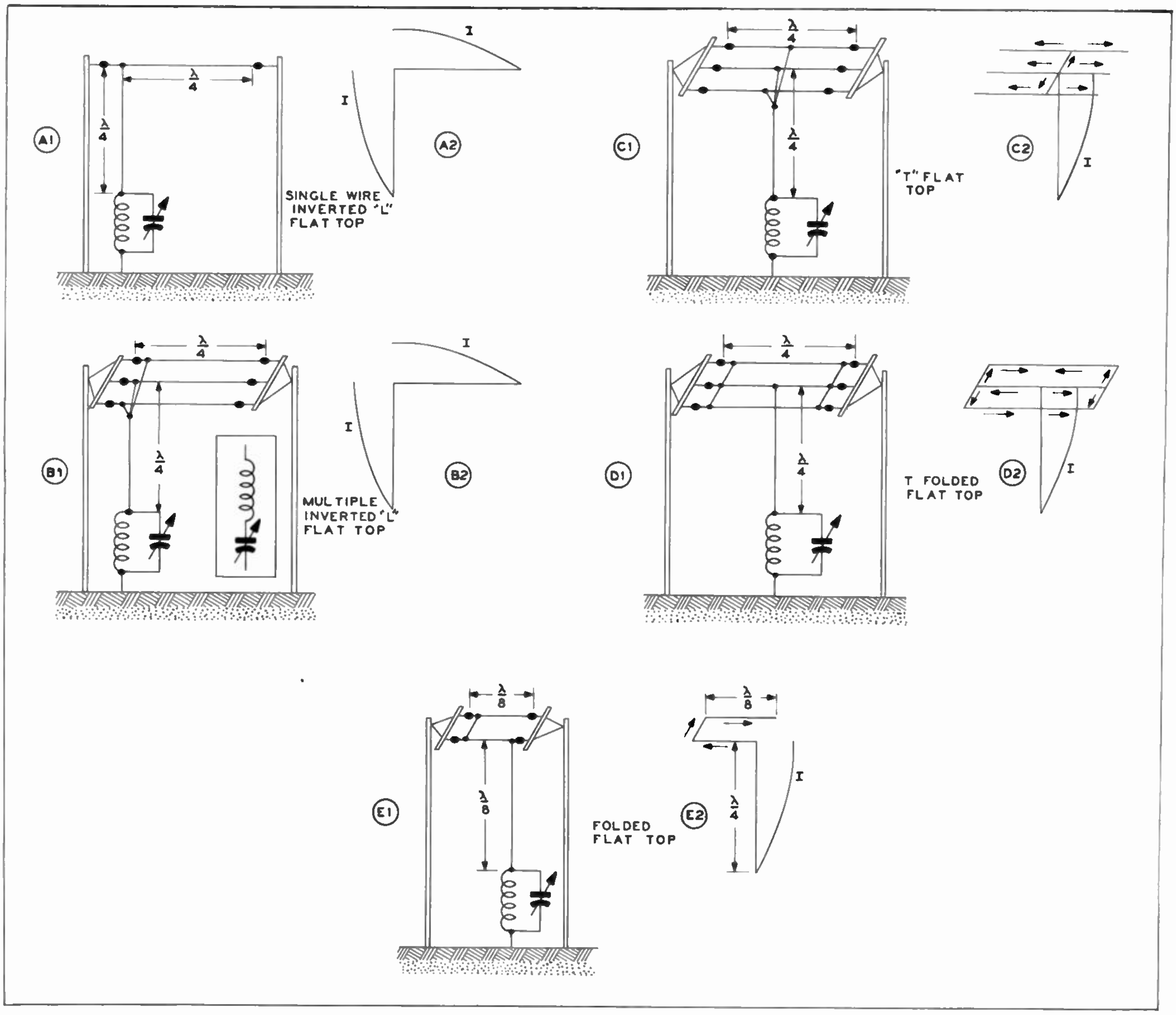


Figure 208. Prevalent Types of Flat-Top Vertical Antennas, Showing the Coupling Circuits and the Current Distribution.

operation in the low-frequency range. Figure 208 A to E illustrate the prevalent types of flat-top vertical antennas.

Figure 208 (A1) shows an inverted "L", single-wire vertical antenna. The length of the straight vertical portion is one-quarter wave length; the length of the horizontal portion is also one-quarter wave length. Thus, as can be seen in figure 208 (A2) the current loop is at the topmost part of the straight vertical portion, with resultant increased radiation efficiency. However, considerable energy leaves the antenna at relatively high-radiation angles, in a direction opposite the free end, due to current flow in the horizontal section.

Figure 208(B1) shows an inverted "L" antenna with a multiple-wire flat-top arrangement. The efficiency of this inverted "L" is somewhat better than that of the single-wire type. Although it has good ground-wave propagation characteristics, it also radiates considerable energy at a high radiation angle. Since a high-voltage loop exists at the input end, a parallel-tuned coupling arrangement is suitable.

Figure 208(C1) shows the method for obtaining some cancellation of the fields in the vertical plane due to the out-of-phase currents in the flat-top conductors.

Figure 208(D1), (D2) and (E1), (E2) shows the arrangement of horizontal conductors to effect a maximum cancellation of the fields due to current flow in the "flat top". The folded-top arrangement offers the best possibilities for minimizing high-angle radiation, especially in the low-frequency operating range.

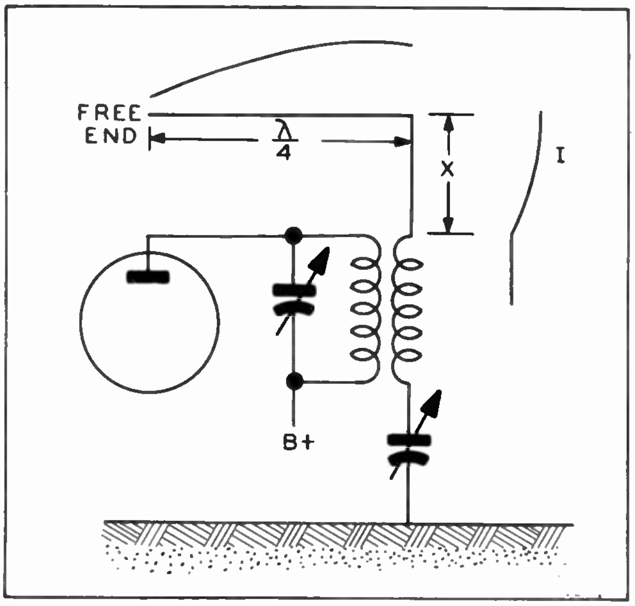


Figure 209. Use of a Series Loading Coil to Increase the Effective Length of a Short Vertical Antenna.

The ideal quarter-wave-length height of the straight vertical portion of vertical antennas, operating on low frequencies, is impossible to attain for some applications. It will, therefore, be found in practice that series loading coils are necessary, as shown in figure 209. As the distance "X" of the straight vertical radiating portion becomes less than one-eighth wave length, due to lowered operating frequency, a considerable r-f potential develops at the free end of the antenna and at the antenna terminal of the loading coil. The coil has a high inductive reactance at the lowered frequency, while the antenna end has a high capacitive reactance. The latter condition usually causes corona discharges across the insulator at the free end of the antenna. Obviously, the remedy is to increase the "flat-topping". If only one or two wires are normally used, the number

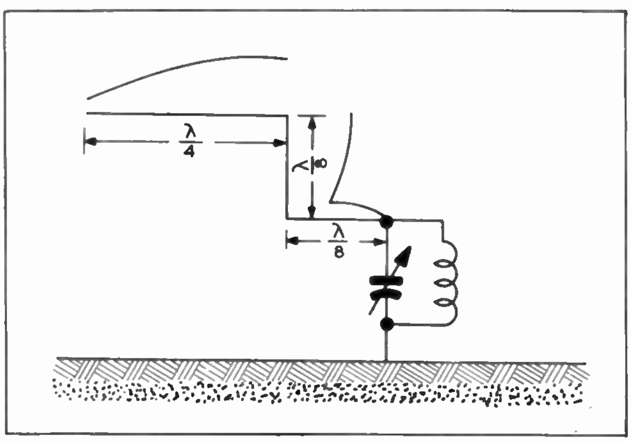


Figure 210. Method of Effectively Increasing the Height of the Current Loop in a Short Vertical Antenna.

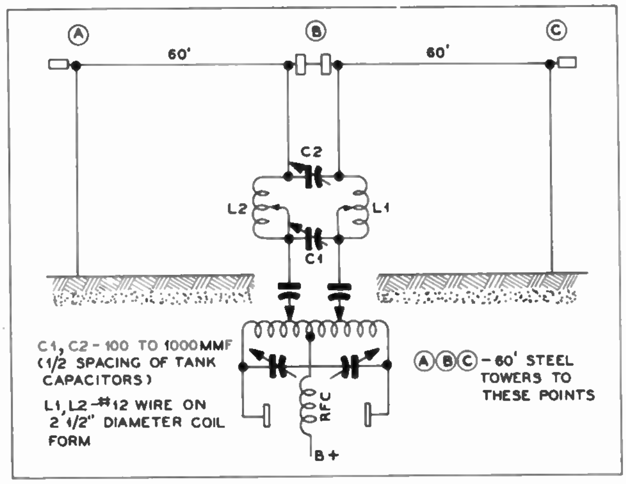


Figure 211. General-Coverage "Bent"-Type Antenna.

should be increased to between four and eight. If the distance "X" is more than one-eighth wave length, a parallel tuning arrangement is preferable.

Another method of increasing the height of the current loop is shown in figure 210. Although the straight vertical part of the radiator is only one-eighth wave length long, the current loop occurs at its topmost part. The additional one-eighth wave length section between the lower end of the vertical section and the coupling loop serves as a transmission line. It is supported by wooden poles at a height of 6 or 7 feet above ground.

Miscellaneous Types of Vertical Antennas

Vertical antennas may of necessity have odd constructional features. For example, if the horizontal length is a limiting factor, the far end of the horizontal section may be bent over or, if the height is limited, the horizontal length can be increased. Any method may be employed as long as the system can be resonated, but it is important that the current loop occur well up along the straight vertical portion of the radiator. If sky-wave operation is desired, the current loop should occur on the horizontal part of the radiator.

Figures 211 and 212 illustrate two different types of radiators. Figure 211 shows a "bent" type, with the two towers forming the folded portion of the radiating system. Figure 212 shows the common "crow-foot" antenna, which incidentally has a characteristically low resonant frequency.

The efficiency of these two types is somewhat lower than that of the vertical antenna previously described; however, they are well suited for many tactical operations.

An important point to remember regarding any of the vertical type antennas used for ground-wave prop-

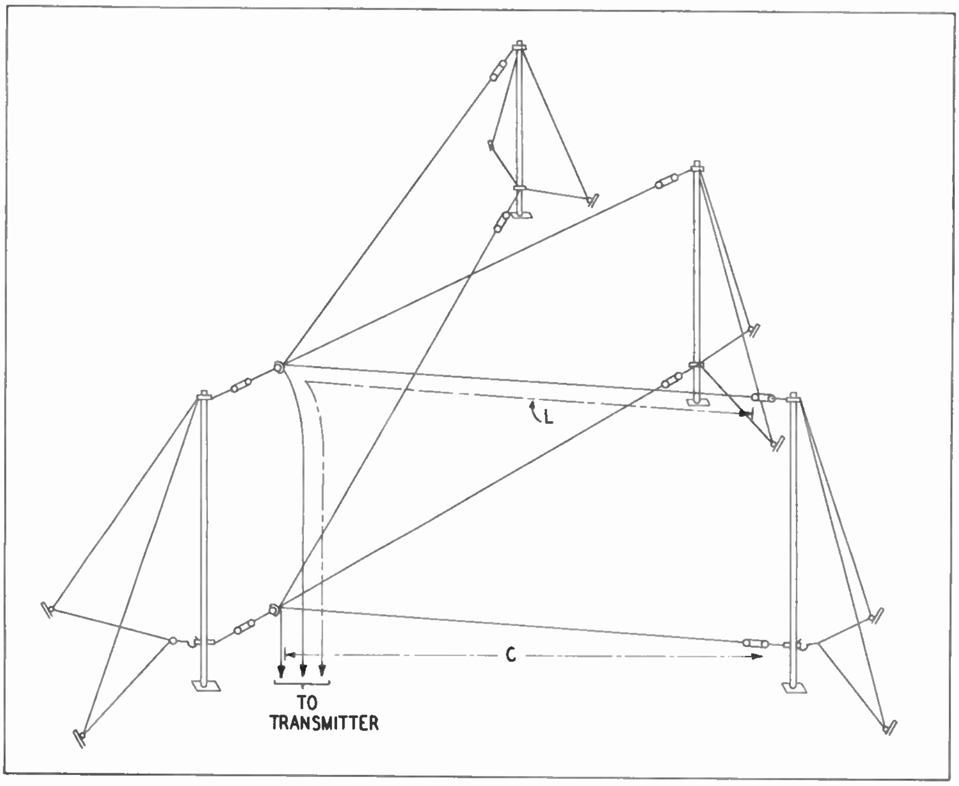


Figure 212. "Crowfoot" Antenna for Low-Frequency Operation.

agation is that the vertical radiating portion should be suspended in a straight vertical plane. Another point to remember is that the efficiency of the radiating system depends to a great degree on the care used in the construction of the ground system or counterpoise.

Double-Doublet Antenna

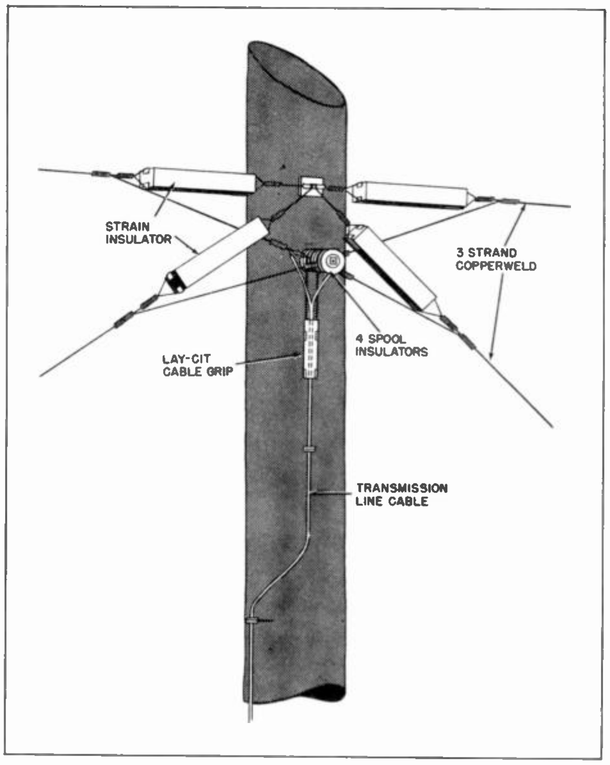
This type of antenna is widely used in fixed-plant installations for receiving purposes. It consists of two half-wave antennas criss-crossed at their center, and attached to the end of a 150-ohm or 200-ohm feed line. See figure 213.

In usual practice, one of the doublets is cut to a half wave length at the lower of the two operating frequencies and the other, for the higher. This arrangement gives a broad frequency coverage with good results. However, the signal-to-noise ratio is decreased. Its other characteristics are comparable to that of two separate half-wave antennas in that the maximum response is broadside to the antenna.

The tuning procedure for this type of antenna is similar to that for an ordinary half-wave antenna.

Beverage or Wave Antennas

During the early part of World War II, the problem of maintaining consistent communications in the northern latitudes became a vital factor in AACS (formerly Army Communication Service) operations. The AACS



Special Cross-Connect Construction Detail on Transmission-Line Pole for a Double-Doublet Receiving Antenna.

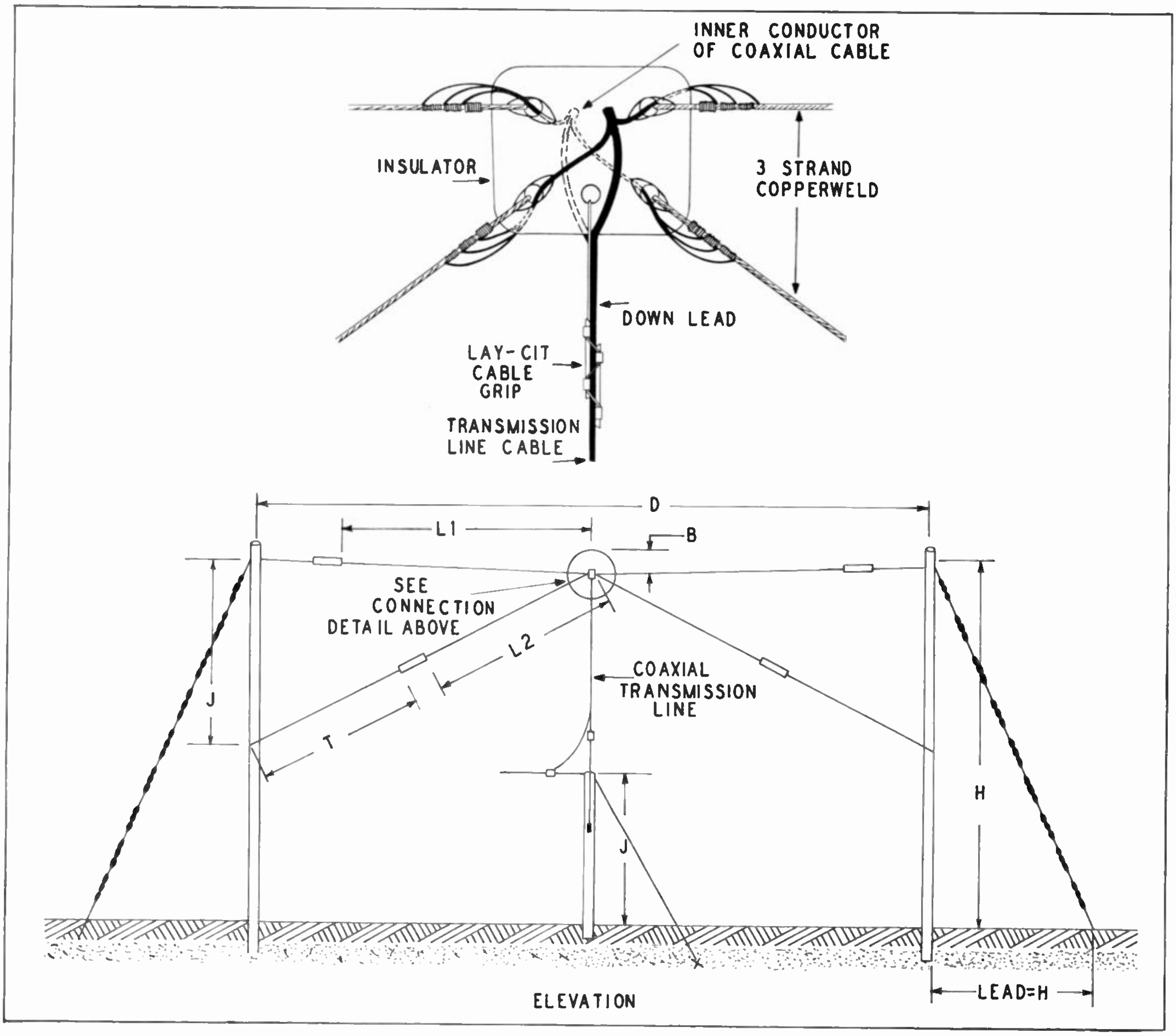


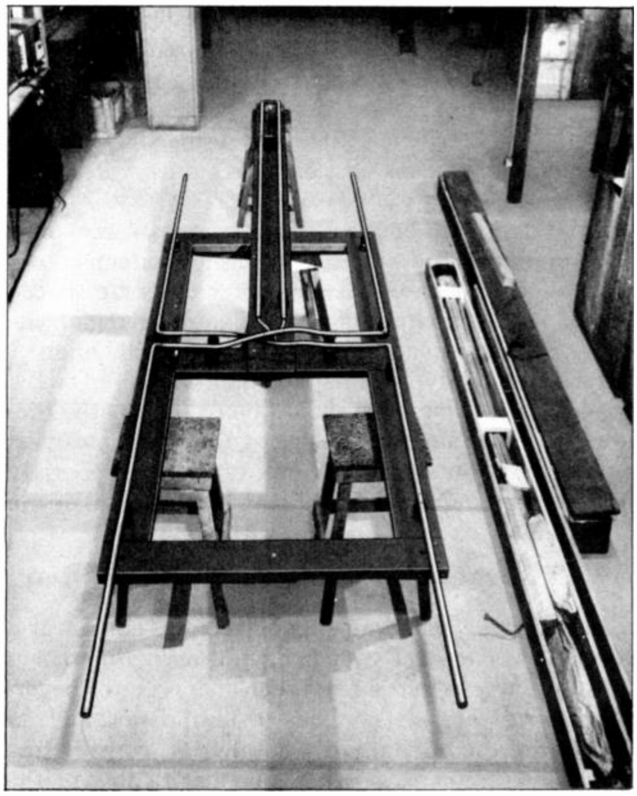
Figure 213. Double-Doublet Antenna.

communication chain extended from northeastern U. S. to England by way of Labrador, Greenland, and Iceland. High-frequency communication was found unreliable due to the severe magnetic storms originating in the polar regions.

Since low-frequency ground waves are least affected by magnetic disturbances, their employment offered the logical remedy for this acute situation. However, low-frequency ground-wave propagation has two inherent disadvantages. First, noise conditions in the low frequency spectrum are relatively great and, second, ground waves suffer a high degree of attenuation in travelling along the earth's surface and, thus, limit the distance coverage. To offset these disadvantages, the radiated power had to be increased and, in addition, the antenna directivity had to be improved.

The horizontal long-wire beverage (or wave) antenna met the general requirements of a good directive system. Although it transmits and receives vertically polarized waves, which are subject to ground absorption, its radiation efficiency is good. Furthermore its structural simplicity and ruggedness favors its use in northern latitudes, where high winds and icing conditions are a prevalent destructive force. In addition it operates more efficiently over poor terrain, such as rocky or sandy soil.

The long-wave beverage antenna consists of one to five wires, between one and two-and-one-half wave



Vertical Double-Doublet Antenna Mounted on a Wooden Support, Ready for Erection.

lengths long, terminated in a noninductive resistor. Since their general use is in the 100-to-200-kc. range, the antennas are 8000 to 15000 feet long.

The major factors to be considered in establishing the physical location of a beverage antenna are as follows:

1. Local noise conditions in antenna area
2. Proximity of antenna to receiving site
3. Terrain conditions
4. Antenna orientation

The terminated beverage has a high signal-to-noise rejection ratio. Therefore, signals arriving from the direction of the unterminated end, and from the sides, are greatly attenuated. It is highly receptive, however, to both signal and noise fields arriving from the direction of the terminated end. Therefore, along the line of the antenna beyond the terminated end, the signal path should be free of man-made and other incidental noise sources. In order to minimize transmission-line noise pickup, the receiving site should be located near the antenna terminals.

Although the beverage operates more efficiently over poor terrain, the ideal antenna site requires a flat, level path extending beyond the terminated end. The antenna should be oriented in a line bearing toward the station with which communication is desired. The maximum course deviation should not exceed 10 degrees.

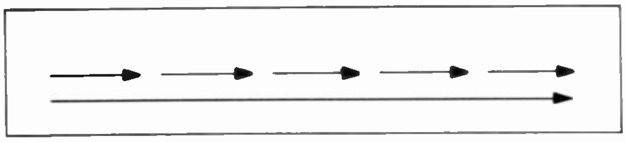


Figure 214. Vectorial Addition of Radiation from the Components of a Long Length of Wire.

Wave-Antenna Phenomenon

Assuming that the velocity of wave travel along a wire is equal to that in space (equal to the velocity of light), the radiation from any point on the wire will arrive at any other point on the wire in the direction of wave travel with the same velocity as the remaining energy travelling along the wire. Thus, the radiation from each component along the wire adds in phase to the radiation given off by the rest of the line. Figure 214 shows vectorially how these components add up in line. Since the radiation resultant is proportional to the length of the wire, the length may be used to represent the resultant.

In practical cases where a long wire is terminated in its characteristic impedance and is fed with power at its resonant frequency, the current flow will be unidirectional, in the direction of the terminated end. The propagation velocity of the wave, created by this current flowing along the antenna, is reduced to about 85% of the value of the propagation velocity in free space for each wave length of antenna, or, in other words, there is a phase discrepancy of 15% per wave length, due to:

1. The radiation resistance of the antenna
2. The ohmic resistance of the antenna
3. The resistance of the terminating resistor and the ground-return circuit

Due to the above factors, the phase of each individual component of the wave travelling toward the terminated end becomes successively retarded. Hence the intensity of the radiation from each component section of the antenna is successively weaker along the antenna from the input end to the terminated end. The vectorial addition in space of the radiated field components, from the individual sections of the wave antenna, produce a blimp-like lobing pattern, which is tilted in the direction of the terminated end of the antenna. See figure 215. The sharpness, or directivity of the lobing pattern depends to a great degree upon the resistivity of the ground-return circuit. It follows, therefore, that the best directivity is obtained from a wave-antenna installation located on poor ground (rocky or sandy terrain), where the resistivity is high. Conversely, poor directivity is obtained when the antenna is located above salt-water marsh land.

After the wave has travelled some distance from the antenna, its electric field becomes perpendicular to the earth. As the lower portion of this field passes over the ground, it induces a current in the ground, which

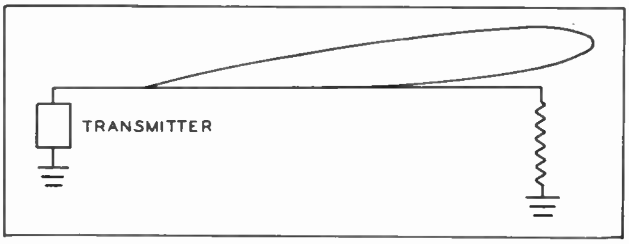


Figure 215. Resultant Radiation Pattern from a Horizontal Long-Wire Antenna. Proper termination results in a unidirectional effect.

in turn tends to attenuate the energy flow. The net result is that the electric-field-wave front tends to tilt toward the direction of travel, so that at some distance from the antenna a horizontally polarized component of the travelling wave exists. See figure 216. This phenomenon, which is most effective on ground waves at low frequencies, accounts for the signal voltages induced in a horizontally polarized beverage receiving antenna when vertically polarized waves are being transmitted by a long-wave antenna.

Beverage Antennas for Transmitting

Three types of beverage antennas for transmitting are illustrated in figure 217, A, B, and C. The antenna conductors in each application are supported on wooden poles, provided with crossarms. The pole height is 12 to 20 feet. The terminating resistances in each application should be capable of dissipating approximately one third of the applied power.

Figure 217A shows a single-wire beverage, constructed of #6 B. & S. wire, and terminated in its characteristic impedance of 300 to 500 ohms for a corresponding pole height of 12 to 20 feet. This antenna may also be used for reception.

Figure 217B shows a four-wire beverage. The conductors are spaced 6 feet apart on the wooden crossarms. The distance between crossarms is also 6 feet. Thus the wires form a 6-foot square cage. Each antenna is terminated in its characteristic impedance of 235 ohms, corresponding to a height of 15 feet. The low-impedance termination allows greater dissipation of power in the high-resistive ground circuit, which results in sharper directivity of the lobing pattern.

Figure 217D shows an alternate method of coupling to the transmitter when it is some distance away from the antenna by means of a balanced, open-wire transmission line.

The three-wire beverage represents an economic compromise in beverage transmitting-antenna construction. See figure 217C. The conductors are spaced 5 feet apart in the form of an equilateral triangle. The value of the terminating resistor is 300 to 500 ohms.

If wooden-pin-type insulator supports are used on the wooden cross-arms, they should be of the treated fireproof variety. Since a power of two to ten kilowatts is applied to the antenna, these precautions are necessary to prevent fire hazards caused by insulator breakdown.

Beverage Antennas for Receiving

Receiving beverage antennas generally consist of a one or two-conductor system. The primary differences between the transmitting and receiving types of beverage antennas are the methods of termination and, in some cases, the orientation. The physical construction of receiving antenna systems is similar to that of the transmitting types.

The simplest receiving system is the single-wire terminated beverage, as shown in figure 217A. If the antenna is used exclusively for receiving, a low-wattage, 500-ohm carbon resistor is suitable for termination for an antenna height of 10 to 15 feet (correct value can be found by using a carbon potentiometer). This antenna receives signals arriving from the direction of the terminated end.

It cannot be too highly emphasized that a good grounding system at both ends of the antenna is necessary for efficient operation of any of the beverage systems. Although the grounding points are located at either extremity of the antenna, care should be taken to insure that no interfering noise sources are within 500 feet of either ground system. For this reason, it may be necessary to locate the receiving terminal of the antenna at some distance from the receiving site, as a camp area usually contains a number of noise sources. This, of course, necessitates the use of a long

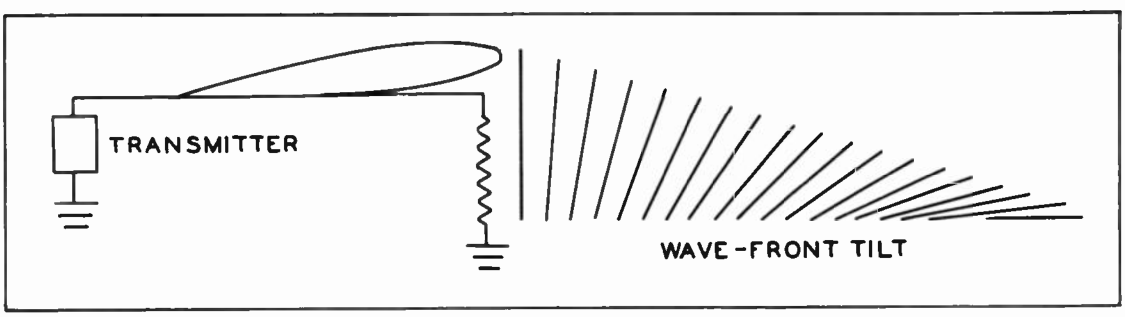


Figure 216. Effect of Ground upon the Polarization of Ground Waves at Low Frequencies.

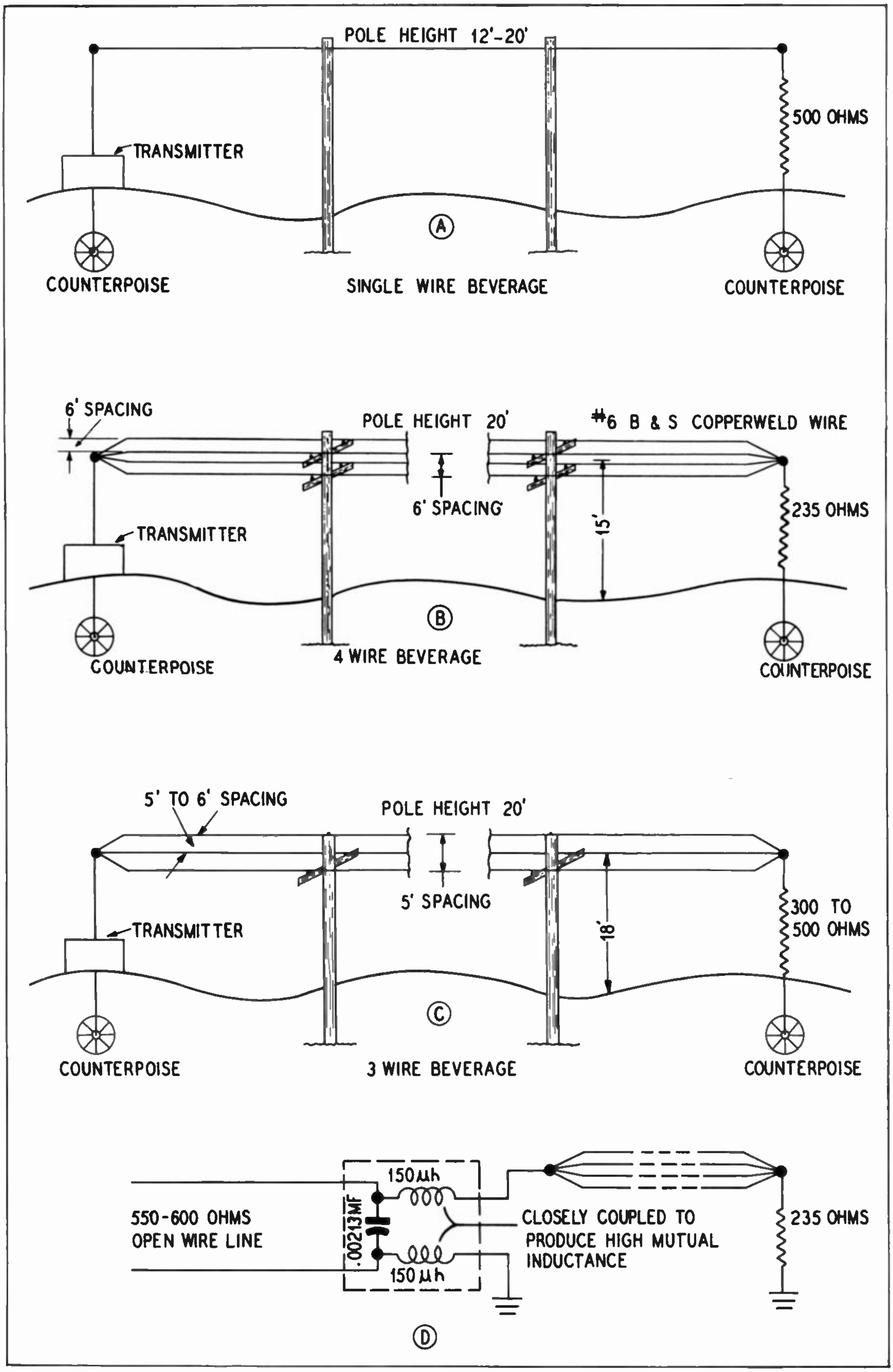


Figure 217. Four Typical Beverage Antennas for Transmitting Purposes.

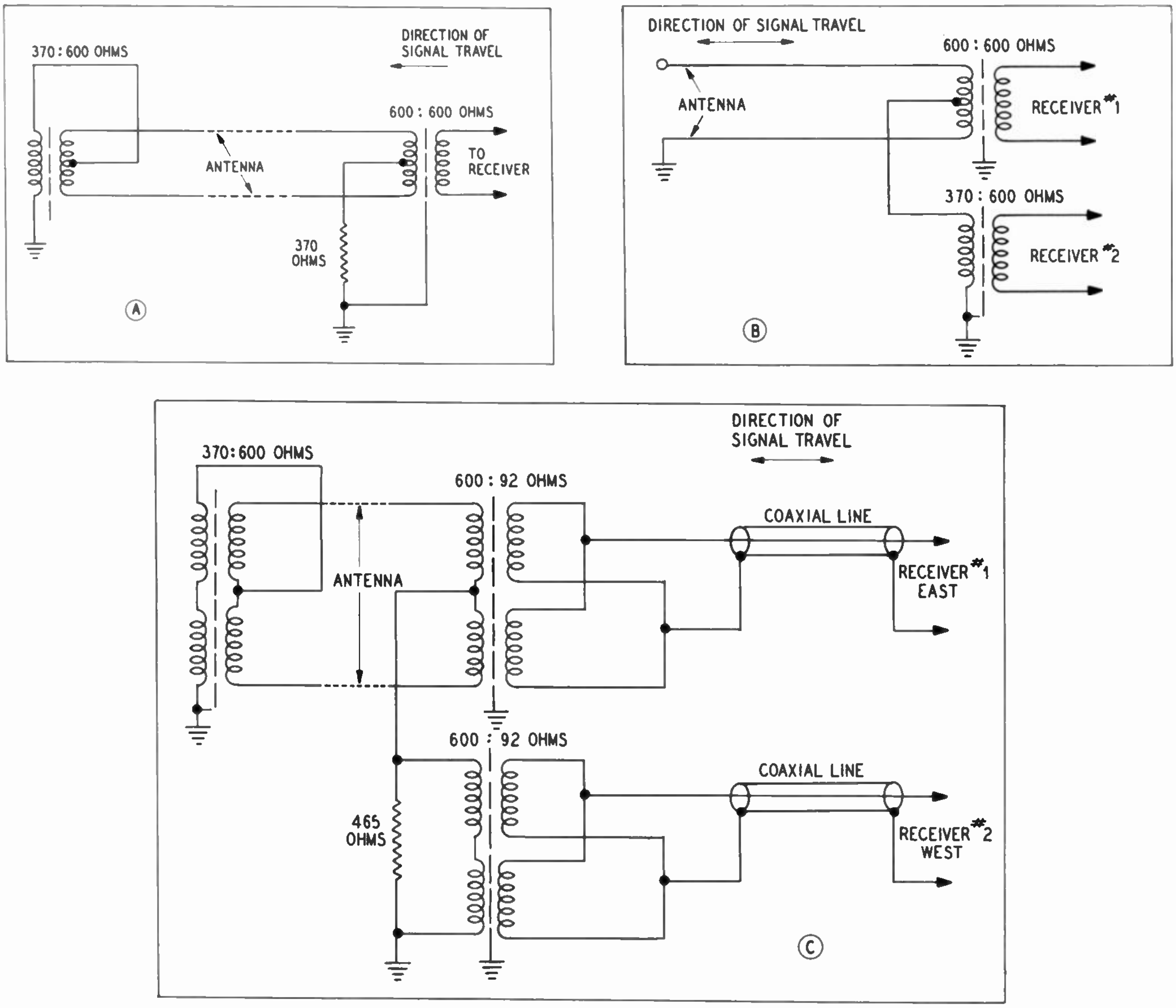


Figure 218. Three Typical Beverage Antennas for Receiving Purposes.

transmission line, which must be properly balanced to ground. Minimum lengths of feeder lines should be striven for in planning such an installation.

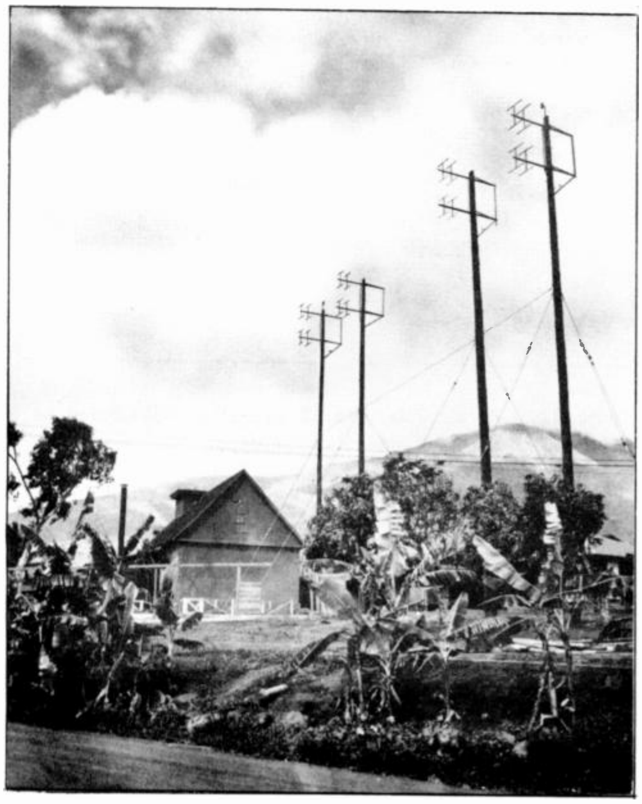
Figure 218A shows a refinement of the single-wire beverage. The antenna is laid out in a direction opposite that of the transmitted signal source. The transmitted waves, arriving in the direction shown, develop signal voltages between the pair of antenna wires and ground. These signals are properly balanced to ground in the 370 : 600-ohm transformer, and sent back down the antenna toward the receiver transformer. The antenna acts as a balanced, 600-ohm line. The current flowing in the line toward the receiver is fed through the balanced coupling transformer, then through another transmission line to the receiver. The 370-ohm resistor dissipates the signal energy arriving from directions opposite that of the transmitting source.

Figure 218B illustrates a simple arrangement for bidirectional reception of transmitted signals. One end of the beverage is connected to ground, while the other is free. The signals are balanced to ground by transformer coupling, which in turn feeds the signals to two receivers through a pair of balanced transmission lines.

Figure 218C illustrates a bidirectional receiving system feeding two receivers. A coaxial line transfers the signal energy from the antenna coupling circuit to the receivers. The two receivers are receptive to signals arriving from the same or opposite directions.

V-H-F AND U-H-F ANTENNAS

The physical size of an antenna element varies inversely with the frequency, so that at 100 mc. a full-wave radiator is 3 meters long, while at 300 mc. it is



Combinations of Horizontally Polarized Stacked Dipoles and Reflectors for Directive V-H-F Radio-Telephone-Line Operation.

only 1 meter long. Obviously the smaller antennas are relatively easy to construct and adjust. Since line-of-sight communication is employed almost exclusively on frequencies above 30 mc., high power is not necessary because the signal field strength depends upon the antenna height and the distance. Since low and medium powers are used, the antenna system must have the proper physical construction for maximum electrical efficiency. Accurate construction and adjustment of coupling circuits and matching sections are relatively easy at very high and ultra high frequencies, so that these systems generally operate in a very efficient manner.

The use of v-h-f communication equipment in mobile installations for field use has, to a great extent, superseded the use of h-f equipment. The latter operates at considerably reduced antenna efficiency, particularly when using a whip-type antenna. For the same length of antenna as the h-f whip, the v-h-f antenna will operate at maximum efficiency. In many cases, the efficiency of h-f whip antennas is less than 5%.

Additional information on the transmission characteristics are given under the subject, Propagation of Radio Waves, on page 1.

A very important characteristic of v-h-f signals is their polarization, in that both the transmitting and receiving antennas must be similarly polarized for good reception. An important factor to consider when operating in these frequency ranges is that greatly extended distances can be realized by using directive (multielement) arrays at substantial heights above ground.

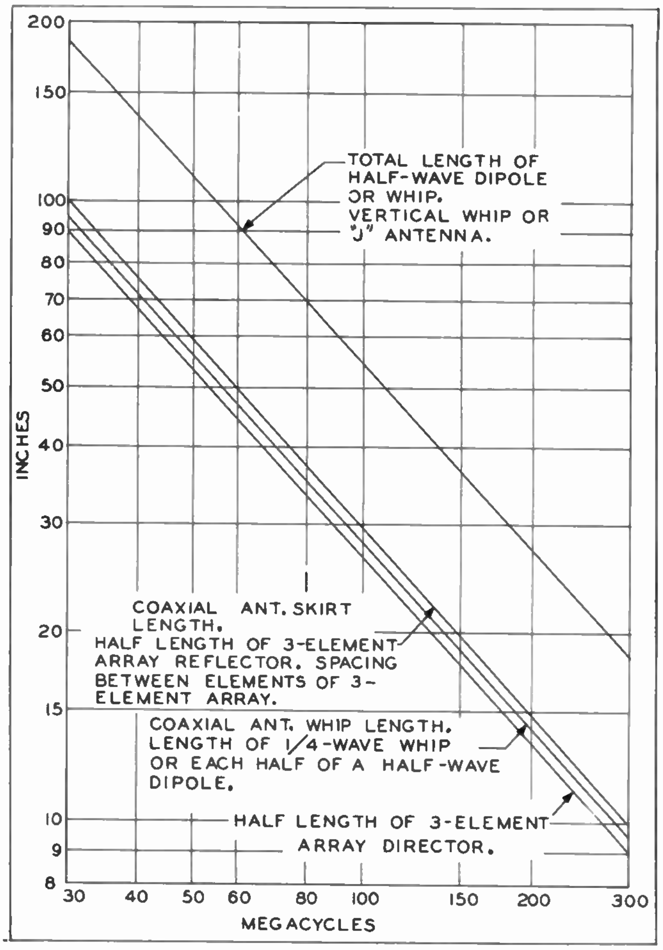
In calculating the length of a half wave in the v-h-f range, a slight modification must be made due to a greater degree of end effect or the changed ratio of diameter to element length. The formula below provides a close approximation, which can be used as a basis for construction.

$$\text{Length (inches)} = \frac{5550}{\text{freq. (mc.)}}$$

To further aid in determining the dimensions of various elements of a v-h-f array, the following chart is given.

CHART 12

CHART FOR DETERMINING CORRECT LENGTH OF V-H-F ANTENNA ELEMENTS



For open-wire lines operating in the v-h-f range, the following formula is applicable.

$$\text{Length (inches)} = \frac{5760}{\text{freq. (mc.)}}$$

A complete discussion of all types of v-h-f and u-h-f antennas is beyond the scope of this course; however, the principle of developing elaborate arrays in these

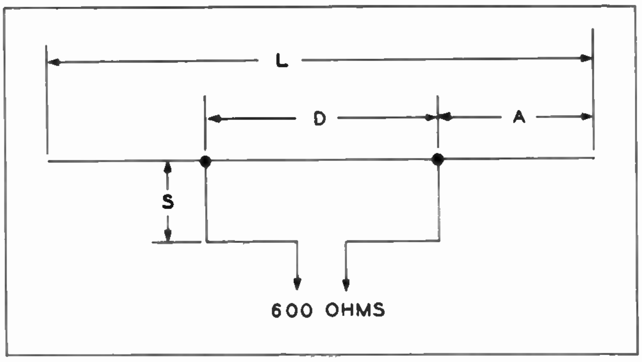


Figure 219. "T"-Matched Antenna.

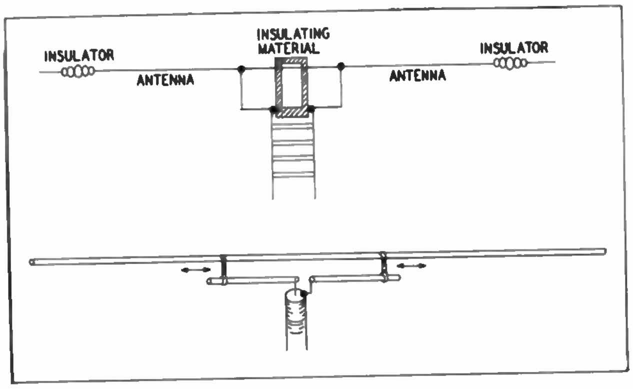


Figure 220. Arrangement for Supporting the Center of a "T"-Matched Antenna.

frequency ranges differs but little from that discussed under h-f arrays.

In recent years, the greatly extended use of the higher frequencies for communication purposes makes it necessary for students of radio and electronics to familiarize themselves with the associated techniques. The more common types of antennas for these frequency ranges are discussed briefly in the following pages.

"T-Matched" Antenna

A delta-matched feeder system is widely used to connect an open-wire, untuned transmission line to a half-wave antenna. The difficulty encountered in the proper adjustment of this system has led to the use of another similar feed method. This feeder arrangement is called the "T" match. See figure 219. The transmission line divides at a point near the antenna and each wire extends parallel to the antenna for a short distance before making a right-angle bend and connecting to the antenna.

The following formulas may be used to calculate the dimensions of a "T"-matching section for a 600-ohm line:

$$L(\text{feet}) = \frac{475}{\text{freq. (mc.)}}$$ where L = length of antenna $\left(\frac{0.95\,\lambda}{2}\right)$

$$D\ (\text{feet}) = \frac{114}{\text{freq. (mc.)}}$$ where D = distance along antenna between the points where the line connects to it

$$A\ (\text{feet}) = \frac{180.5}{\text{freq. (mc.)}}$$ where A = distance from end of antenna to nearest tap

$$S\ (\text{inches}) = \frac{114}{\text{freq. (mc.)}}$$ where S = spacing between antenna and the parallel wire of "T" match

A method of supporting the center of the "T" match is shown in figure 220. Two insulating strips of paraffined wood or ceramic material are used to maintain the spacing at the center, and to carry the weight of the transmission line. An approximate right-angle bend is made at each end of the "T", adjacent to where the wires connect to the antenna. By using sufficiently heavy wire (#12 or larger), this bend can be made self-supporting.

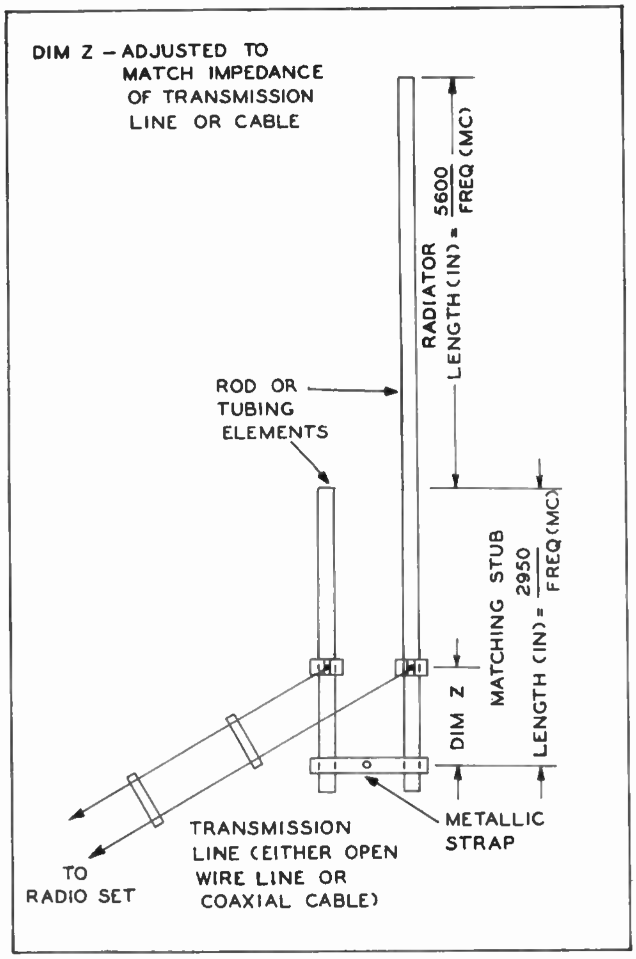
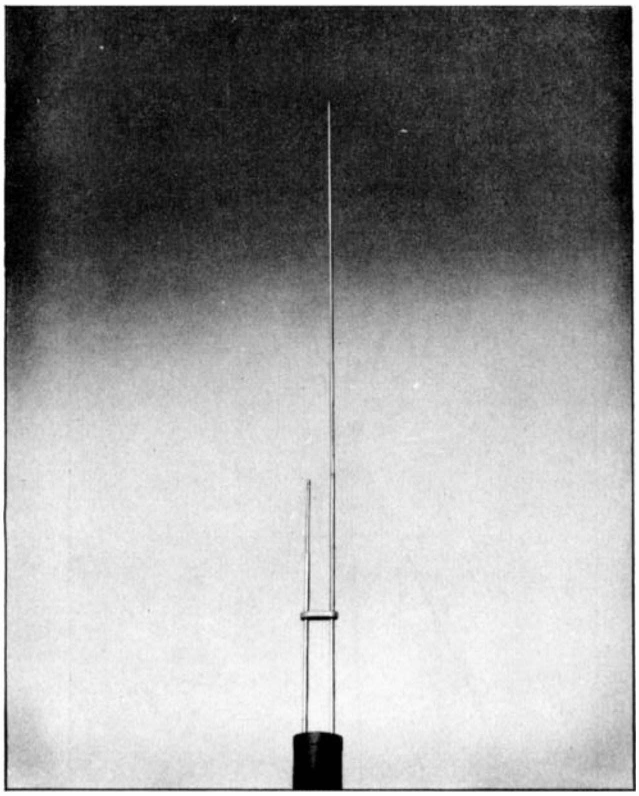
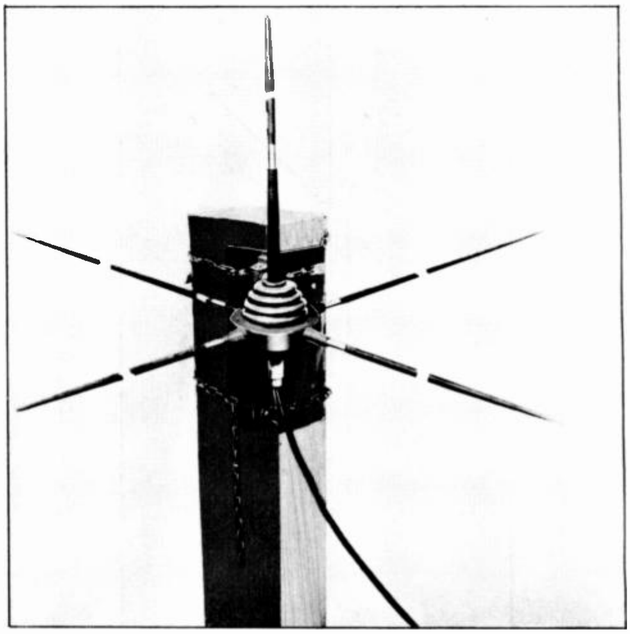


Figure 221. "J" Antenna.

In practical applications, the matching section consists of tubing, with adjustable straps connecting it to



J-Type Antenna.



V-H-F Ground-Plane Antenna on a Wooden Mast.

the antenna. The elements may consist of 3/8-inch to 1 1/4-inch diameter tubing. In the u-h-f range, it is advisable to use silver-plated tubing, because most of the r-f current travels along the surface of the conductor.

"J" Antenna

A vertical type of antenna, which is used in v-h-f applications where a 2-wire feed system is employed and general coverage is desired, is the J antenna. This type of antenna finds wide use on police-radio vehicular installations, and to some extent on shipboard installations. The antenna consists of a half-wave vertical radiator and a quarter-wave matching section. An open-wire, 600-ohm line is tapped onto the matching section. See figure 221.

The quarter-wave stub acts as a matching transformer. The 600-ohm line is tapped on at the point which produces a minimum of standing waves on the untuned transmission line. It may be grounded at the center of the shorted end for protection from lightning. The stub can be resonated by sliding the shorting bar up and down while exciting the antenna from another antenna located some distance away.

Sleeve and Ground-Plane-Type Antenna

For the upper end of the v-h-f band and for u-h-f applications when broad-band coverage is desired, a

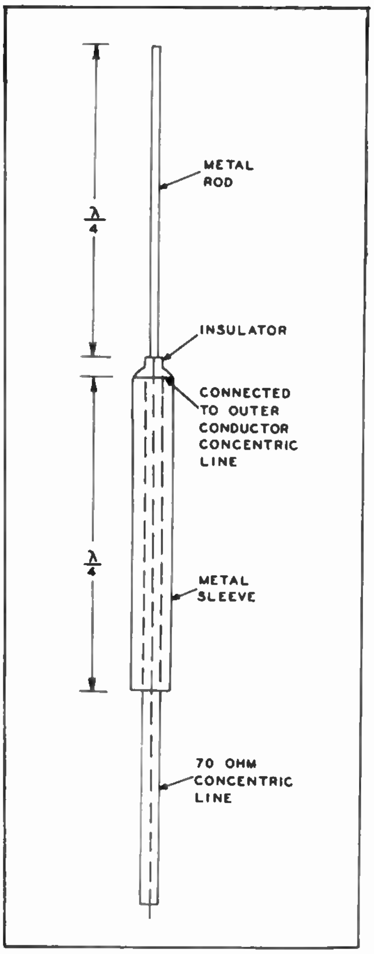


Figure 222. "Sleeve" or Coaxial-Type Antenna.

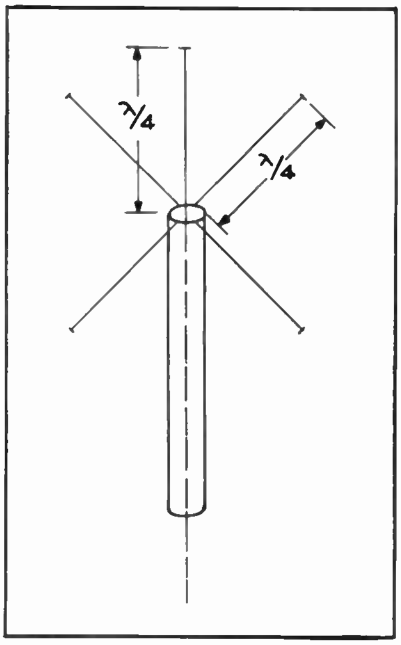


Figure 223. Ground-Plane Vertical Antenna.

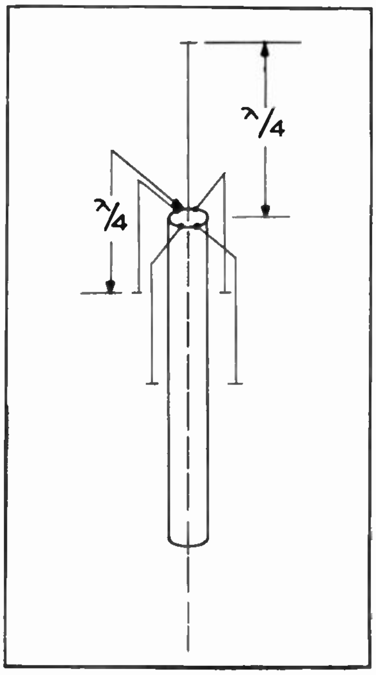
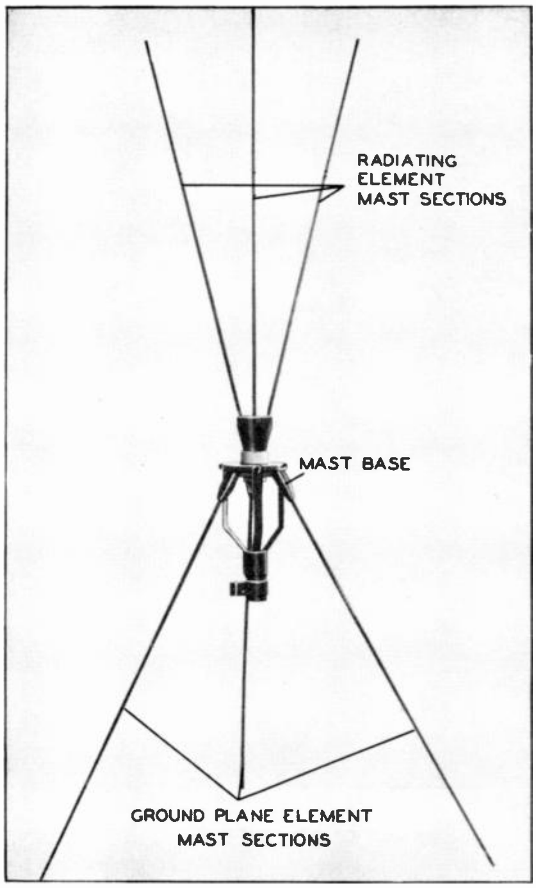


Figure 224. Bent Ground-Plane Vertical Antenna for Use with a Low-Impedance Coaxial Cable.

single vertical half-wave radiator is commonly used. The lower half of the system consists of a metallic sleeve through which a concentric feed line is run. This type of antenna produces a vertically polarized wave of nondirectional characteristics and with a fairly low angle of radiation. The sleeve or coaxial-type antenna is shown in figure 222. Note that the upper radiating portion is a quarter wave length, and is not covered by the grounded sleeve which makes up the other quarter



Three-Element, Omnidirectional, Broad-Band, Ground-Plane, V-H-F Communications Antenna.

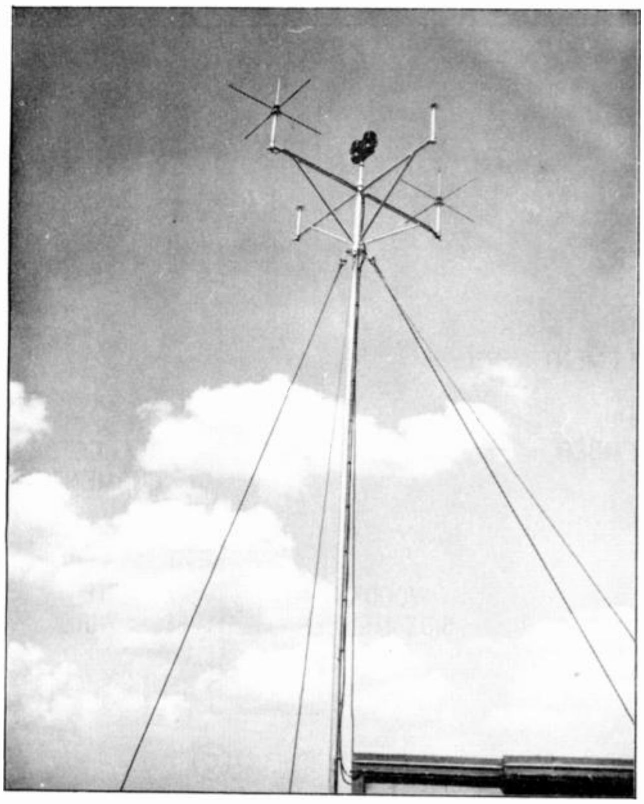
wave length of the radiating element. This antenna is fed with 70-ohm coaxial or concentric line.

To increase the low-angle radiation, a number of grounded elements are added, to make up an antenna called the ground-plane coaxial type. See figure 223. The radiation resistance of this antenna is approximately 21 ohms; therefore, to obtain a proper impedance match, the impedance of the first quarter wave length of the coaxial line may be about 35 ohms and the impedance of the remainder may be the normal 70 ohms.

An adaptation of the ground-plane type may be constructed, so that standard 70-ohm line may be employed. See figure 224. The ground-plane elements are bent close to the supporting rod to give about 70 ohms at the feed point. If they are bent out at a slight angle, 50-ohm coaxial line may be used.

Folded-Dipole Antenna

In the v-h-f range, matching the impedance of the antenna and transmission line is more of a problem than at the lower frequencies. A means of effectively overcoming this is the development of the folded-dipole antenna. Essentially, this antenna may be considered as two half-wave antennas, closely spaced, paral-



Combinations of Horizontally Polarized Stacked Dipoles and Reflectors for Directive V-H-F Radio-Telephone-Line Operation.

lel to each other, and shorted at their ends. One of the elements is center-fed as a conventional half-wave antenna. See figure 225. Assuming that the elements have equal diameters, the impedance at the feed point is four (the square of the number of elements) times that of a conventional dipole, or 288 ohms. Therefore, a 300-ohm transmission line, such as "twinex", may be used without noticing any appreciable impedance mismatch; thus, the need for an impedance-matching device is eliminated.

The total length around the loop formed by the antenna may be calculated by the following formula:

$$\text{Length (feet)} = \frac{955}{\text{freq. (mc.)}}$$

By using three half-wave elements, evenly spaced (see figure 226), the impedance at the point of feed (being a function of the number of elements) is now nine times that of a conventional dipole and therefore, can be fed by a transmission line with an impedance of approximately 600 ohms. The impedance-step-up ratio also depends upon the ratio of diameters of the elements, being inversely proportional to the diameter of the driven or broken element and directly proportional to the diameter of the unbroken element or elements.

The spacing between the elements is not a critical factor, but the ratio of spacing to the radius of the driven element also determines the impedance-step-up ratio. In order to maintain broad-band characteristics,

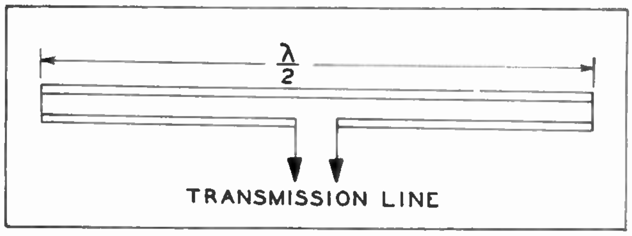


Figure 225. Folded-Dipole Antenna.

it is recommended that the impedance-step-up ratio not be increased above 10 by means of the spacing ratio. If a ratio of more than 10 is desired, the number of elements should be increased.

In parasitic arrays, a problem of impedance matching is encountered when a conventional dipole is used as the driven element. The radiation resistance (input impedance) of the dipole is lowered as the number of parasitic elements in the array is increased. In the basic three-element parasitic array using a conventional dipole as the driven element, the input impedance is approximately 8 ohms. To eliminate the need for an impedance-transformation device, a folded dipole may be used as the driven element. See figure 227. In this case, the radiation resistance is increased by a factor of four or more, depending upon the design of the folded dipole. This impedance may be easily matched by using common commercial transmission lines.

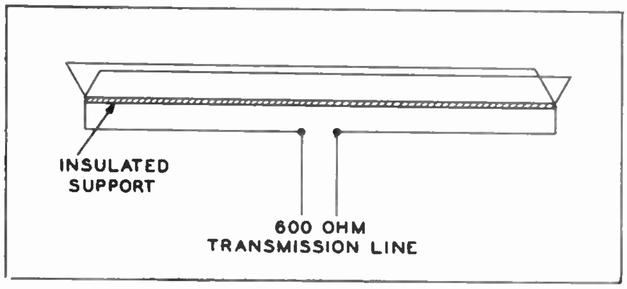


Figure 226. Three-Element, Folded-Dipole Antenna.

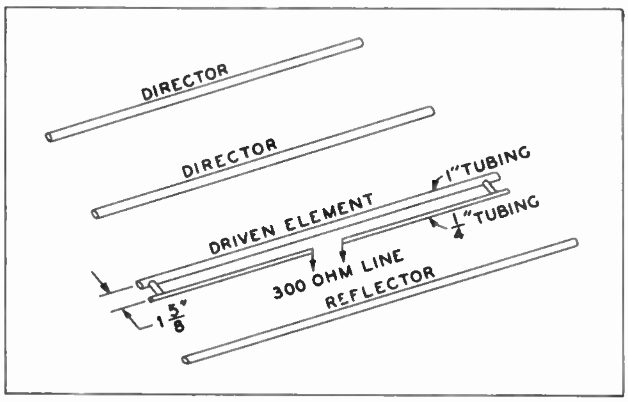


Figure 227. Use of a Folded Dipole as the Driven Element of a Parasitic Array.

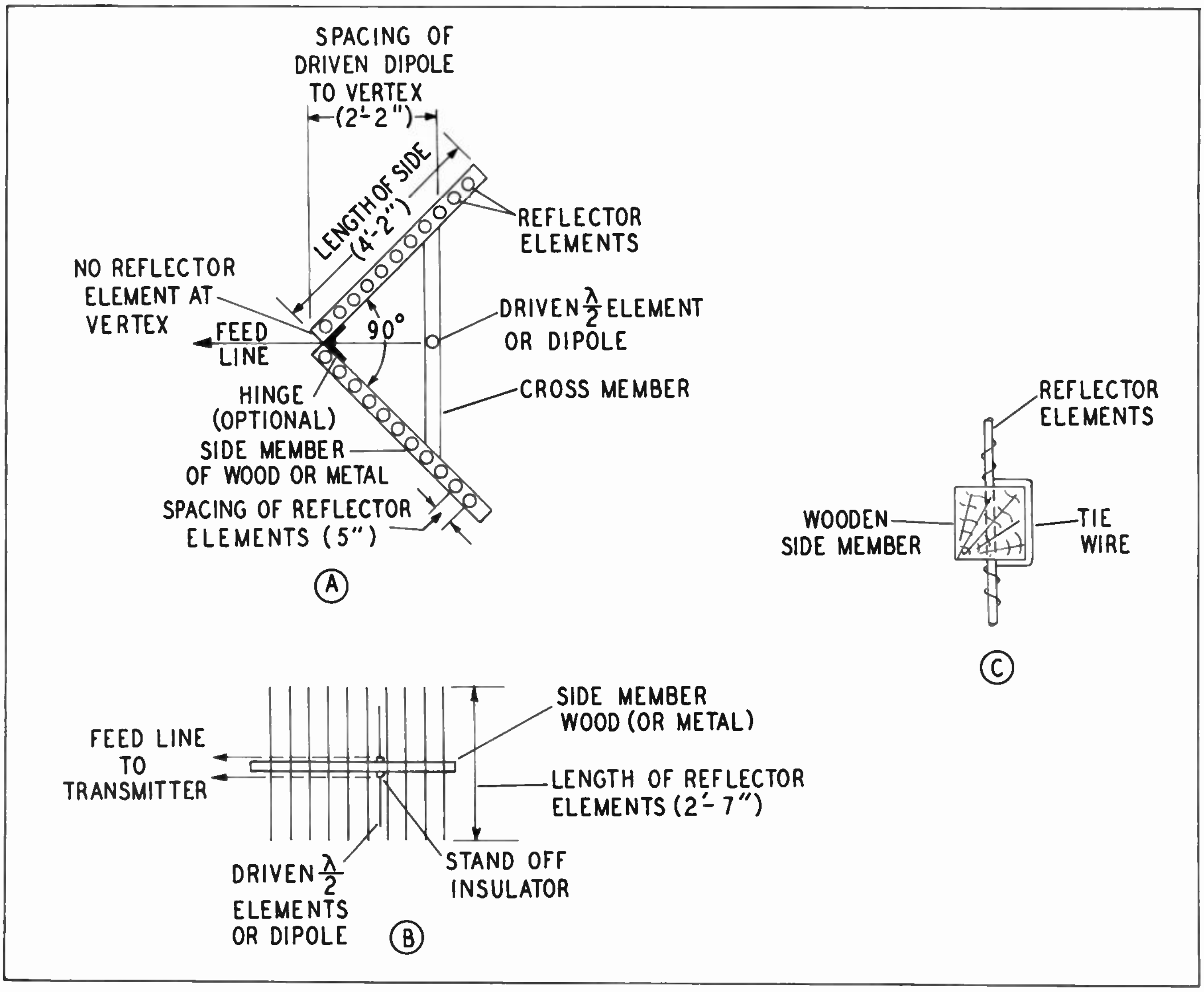


Figure 228. Corner-Reflector Antenna.

Frequency Band	Length of Side	Length of Reflector Elements	Number of Reflector Elements	Spacing of Reflector Elements	Spacing of Driven Dipole to Vertex
224—230 mc. (1¼ meters)	4'2"	2'7"	20	5"	2'2"
112—116 mc. (2½ meters)	8'4"	5'2"	20	10"	4'4"
112—116 mc. (2½ meters) (alternate)*	6'8"	5'2"	16	10"	3'6"
56—60 mc. (5 meters)	16'8"	10'4"	20	1'8"	8'8"
56—60 mc. (5 meters) (alternate)*	13'4"	10'4"	16	1'8"	6'11"

Dimensions of square-corner reflector for 224, 112, and 56 megacycles. Alternate designs are listed for 112 and 56 megacycles. The designs marked with an asterisk (*) have fewer reflector elements and shorter sides, but the effectiveness is only slightly reduced. There is no reflector element at the vertex in any of the designs.

Corner-Reflector Antenna

The corner-reflector type of antenna is well suited for very-high-frequency work where extreme directivity is desired. It is actually a primary form of half-wave antenna with a reflector. The reflector consists of two plane surfaces placed at an angle of 90°; the driven element or antenna is set on a line bisecting this 90° angle. The spacing of the driven element from the vertex of the 90° angle should be 0.5 wave length and the reflector elements should be spaced about 0.1 wave length apart. See figure 228. In some applications, the driven element is made in the form of a folded dipole, so that a 450-to-500-ohm, open-wire line can be used as the feeder.

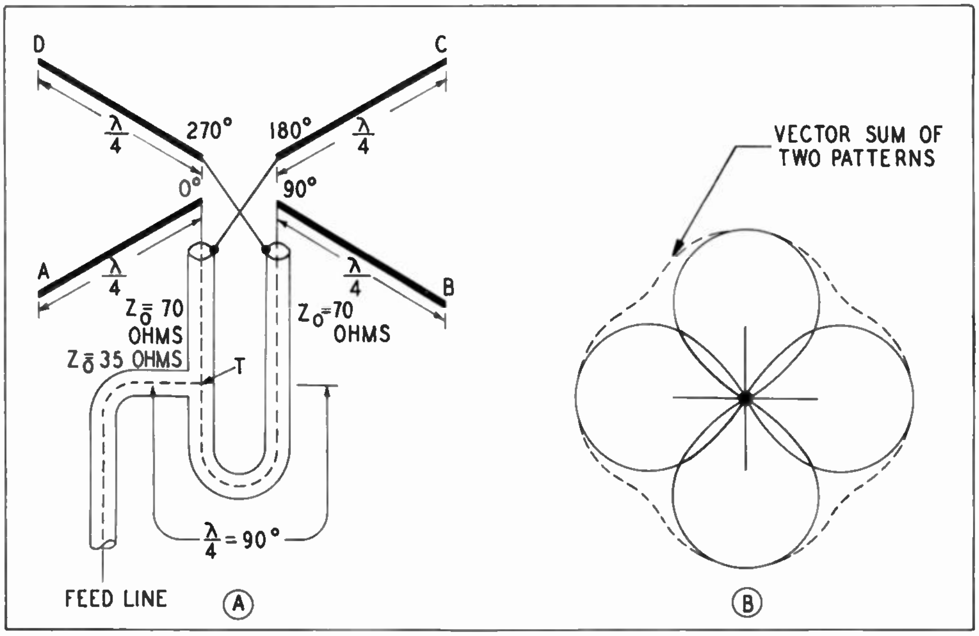


Figure 229. Turnstile Antenna, Showing the Method of Feed and the Resultant Radiation Pattern.

The corner-reflector antenna has approximately a 10-to-1 gain in the forward direction over that of a single half-wave dipole. The amount of radiation toward the back and sides is about 1000 times less than that in the forward direction.

Turnstile Antenna

This type of antenna is used where the prime consideration is a uniform, omnidirectional pattern, and finds wide use in television transmitter installations. Adjacent radiating elements are fed 90° out of phase. See figure 229A. The vector sum of the fields from both dipoles at any angle is nearly equal to the field strength when measured broadside to one dipole. Therefore, a nearly circular horizontal pattern is produced, as shown in figure 229B.

As can be seen in figure 229A, element A is fed from the center conductor of one concentric line and element C is fed from the outer conductor of the same line. Similarly, element B is fed from the center conductor of the other concentric line and element D is fed from the outer conductor of this line. The characteristic impedance of each transmission line matches the input impedance of each of the crossed dipoles; hence, standing waves are not present on the transmission line. In effect the two branches of the transmission line are fed in parallel at the tapped point T. The transmission line feeding this point must have one half the characteristic impedance of the other two lines or the impedance must be transformed by a matching section to prevent standing waves.

Coaxial-Dipole Antenna

The inherently high input impedance of a coaxial type of dipole antenna favors its use in multielement stacked arrays. Figure 230A shows the basic layout of this type of antenna. The outer conductor is of copper or brass tubing 1½ inches to 3 inches in diameter. The inner conductor is of copper or brass tubing ⅜ inch to ½ inch in diameter. Ceramic or polystyrene spacers

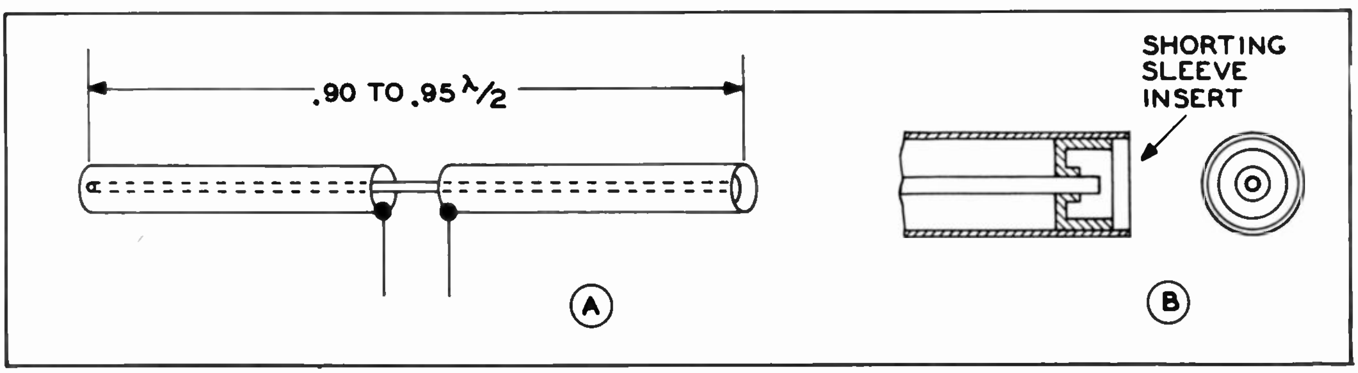


Figure 230. Coaxial-Dipole Antenna.

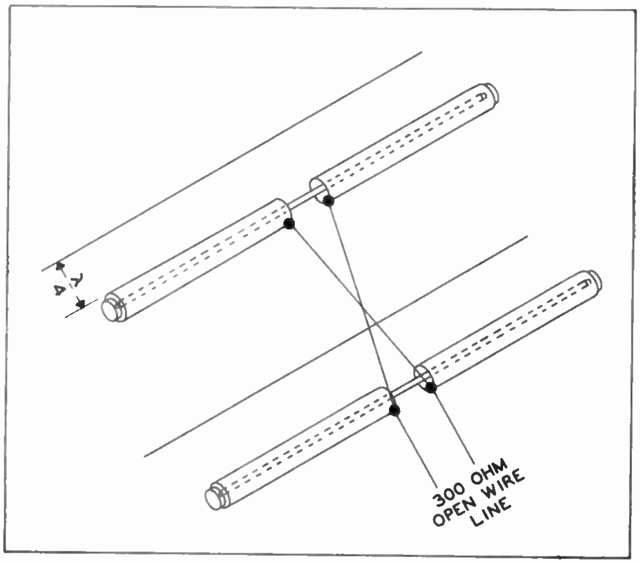


Figure 231. Broadside Array Consisting of Two Coaxial-Dipole Antennas with Parasitic Reflectors. This array produces a highly directional pattern.

may be used to align the conductors. Both ends of the inner and outer conductors are shorted with a sleeve insert. See figure 230B.

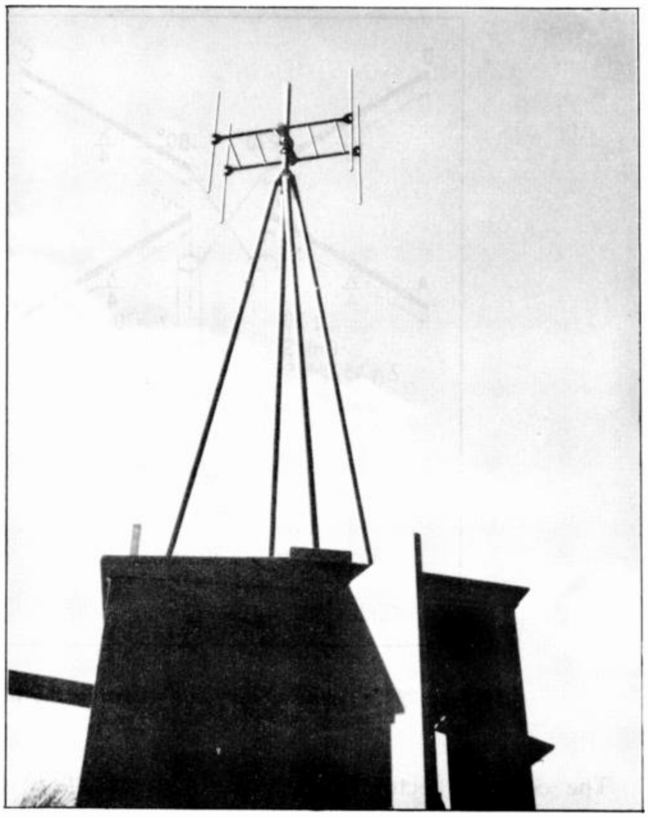
The antenna is resonated by moving each shorting-sleeve insert an equal distance toward the center of the antenna. If the position of the shorting-sleeve insert is less than 1/16 wave length from the ends after tuning, the antenna input impedance at point X will be over 1000 ohms. The shorting-sleeve inserts may be fixed in their final positions by drilling a number of holes through the outer conductor into the flange of the sleeve insert and securing them with self-tapping screws. Spot welding or sweating on the inserts with solder is preferable to the use of screws.

Two coaxial-type dipoles, spaced a half wave length apart, with a transposed open-wire line, and using two single-wire, half-wave, parasitic reflectors a quarter wave length behind the excited array, produce a highly directional broadside pattern. The input impedance of this array (see figure 231) is approximately 300 ohms.

SPECIAL-APPLICATION ANTENNAS

Direction-Finder Antenna Systems

The necessity for the improvement of navigational aids, due to some extent to the exigencies of past wars, has brought forward various new developments in radio-direction-finder antennas A brief and comprehensive description of each is given in the following paragraphs. It should be noted that, while their physical aspects differ, the basic underlying principles are the same in all cases.



Vertically Polarized (Bidirectional) Antenna Array on a Rotatable Mount. This array is used for direction-finding operation in the V-H-F band.

The conventional commercial direction finder (D/F) consists of four basic components; that is, a sense antenna, a loop antenna, a receiver, and a power unit. Both naval and military direction finders consist of the same basic components with slight modifications.

Figure 232 illustrates in block-diagram form how the four basic components are utilized in the common loop method of direction finding.

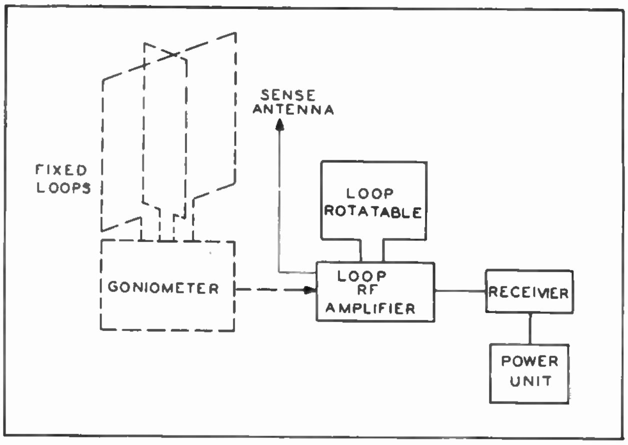


Figure 232. Block Diagram of a Loop Direction-Finding System, Showing the Basic Components.

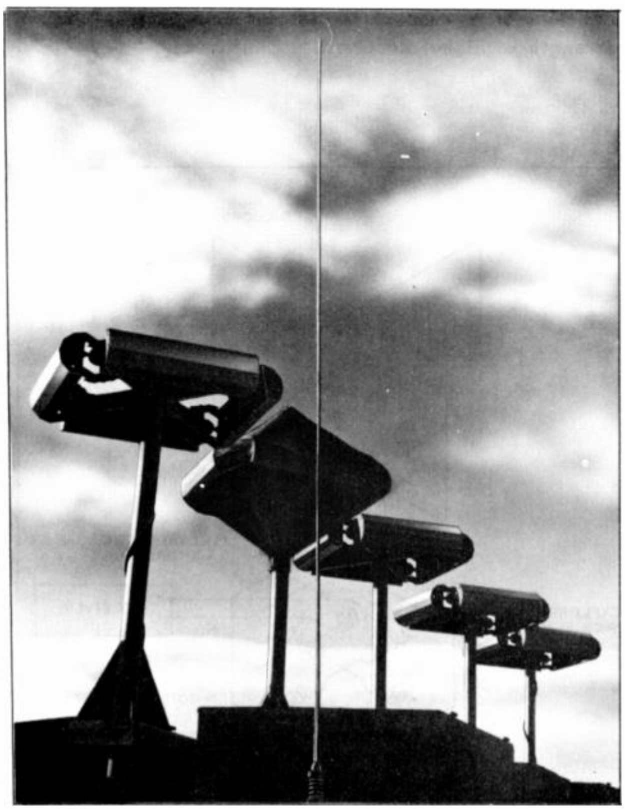
Loop Antenna

The loop antenna consists of several turns of wire on a rectangular form, which may be either fixed or rotatable. To obtain a greater signal voltage in the loop several turns of wire are preferable to a single turn. However, there is a limit to the number of turns which can be used; this limit is determined by such factors as distributed capacity between the turns and between the turns and ground, frequency of operation, etc.

The length, in wave lengths, of wire composing a loop antenna has no direct bearing on the resonant frequency of the loop, because the reactive components exist in a lumped form. The resonant frequency depends upon the lumped inductance and the distributed capacity of the loop, just as the resonant frequency of a coil depends upon these factors and not directly upon the number of feet of wire composing the coil.

The distributed capacitance of a coil of wire, which is considered as a single capacitance connected across the terminals of the coil, will provide resonance at a certain frequency. This distributed capacity is detrimental to the operation of the coil as a resonant circuit at other frequencies because it by-passes the lower frequencies and chokes out the higher frequencies.

A loop antenna which is like any other coil, has inductance which is desirable and distributed capacity which is undesirable. The inductance and distributed capacity are increased by using more turns, greater lengths per turn, and less spacing between the turns.



Array of Horizontal Loop Antennas Used to Produce a Field Pattern for the Guidance of Blind-Landing Aircraft.

From the foregoing discussion, it is obvious that the inductance and distributed capacity are opposed to one another from an efficiency standpoint. While more turns increase the inductance, fewer turns reduce the capacity and while less spacing increases the inductance, more spacing decreases the capacity.

There is a critical spacing beyond which additional spacing does not greatly reduce the distributed capacity. For example, the gain of a loop antenna two feet square is not increased appreciably when the wire spacing is increased more than about one eighth of an inch. For a loop antenna four feet square, the critical spacing is somewhat less than a quarter of an inch and for a loop eight feet square, it is approximately three eighths of an inch.

As the number of turns on the loop is increased, the distributed capacity becomes greater. At first this increase in capacity is quite rapid but as more and more turns are added to the loop, the ends of the loop are spread farther apart and the increase of capacity does not keep pace with the increase of inductance.

When a receiving loop antenna is turned so that its flat side is toward the transmitting station, the strength of the signal received is minimum. See figure 233. Under these conditions, the advancing radio waves strike both sides of the loop at the same instant and induce exactly equal and opposite currents, which balance each other out completely; hence, there is no signal for the receiver except that due to loop capacity. (See discussion of sense antenna on page 144.) It is obvious, therefore, that the strongest signal is delivered by a loop which has its edge pointed directly toward the transmitting station.

In using a loop antenna, the signal strength from a nearby station remains approximately the same until the loop is turned almost exactly at right angles to the direction of the station. Then the signal strength shows a sudden and decided decrease during the last few degrees of loop movement. The variation of signal strength with loop movement is shown in figure 233A for various angles of the loop.

On the other hand, the signal from a distant station shows a very gradual increase as the edges of the loop are brought into line with the direction of the radio waves. But during the last few degrees of loop movement (the movement that brings the loop directly in line with the station), there is a decided and sudden increase in signal strength. The variation of signal strength with loop movement is shown in figure 233B.

Loop Antenna with Goniometer

The original loop-type antenna for direction-finding operation employs two loops, mounted with their planes at right angles and in fixed positions. Each loop is resonated with a condenser, the two condensers being operated by one control. Each loop is connected in

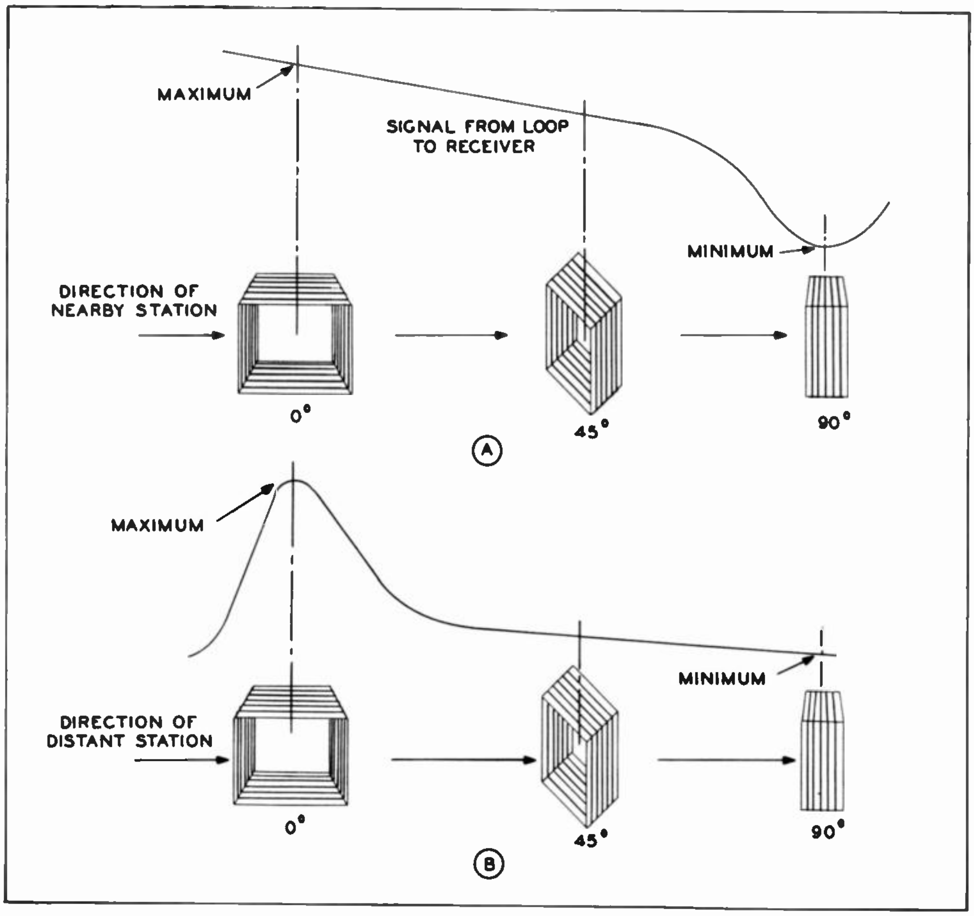


Figure 233. Loop Antenna Oriented to Various Positions with Respect to Nearby and Distant Stations, Showing Variation in Strength of Signal Received.

series with two coils. The four coils for the two loops are arranged in the form of a square, and is called a goniometer. See figure 234. Within the square is a small pickup or "exploring" coil, which is connected to the input circuit of a radio receiver. The pickup coil is attached to a compass dial and its position with reference to the dial indicator shows the two possible directions from which the signal is being received, once the true north position has been predetermined and the loops have been installed accordingly.

Sense Antenna

The radio-wave energy reaching a loop antenna affects the antenna conductors not only in their function as a loop (inductance) but also as a capacity antenna; therefore, when the loop is oriented to the position of minimum signal, the capacity-antenna effect still exists. An auxiliary capacity antenna (vertical whip) may be used in such a manner that a signal voltage of opposite phase to the signal voltage from the loop's capacity effect is introduced into the receiver, thus cancelling out the latter signal and allowing the reading of a distinct minimum.

A goniometer-loop combination may be fitted with

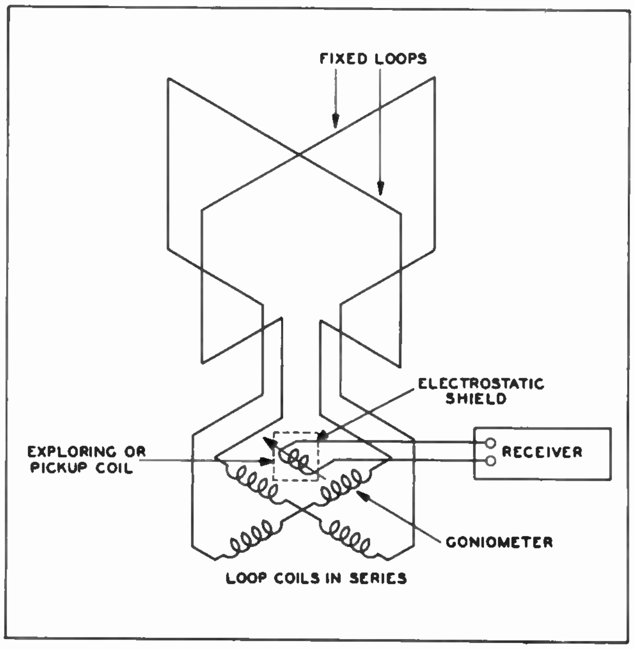


Figure 234. Schematic of Loop Antenna and Associated Goniometer.

a sense antenna (vertical whip) which will increase its response to signals coming from one direction and decrease its response to signals coming from the opposite (180°) direction, thus enabling the operator to determine from which of the two directions the signal is being received. Note that this principle may be used when employing the movable loop, previously described.

Limitations of Loop-Type Antenna

The efficiency of the loop antenna is considered to be very low by most authorities on the subject.

The loop-type direction-finding method is beset with several inherent limitations, some of which are very serious. One of the most peculiar of these limitations, called "night effect," is a phenomenon which occurs about sunset and lasts through the night. This night effect greatly disturbs the course direction, and is due to the fact that the strength of the reflected sky wave is much greater at night and the angle at which it returns to the earth varies due to random changes in the ionosphere.

The loop antenna is composed of four sides, two vertical and two horizontal. When it is used for transmission, the vertical pair radiate vertically polarized waves while the horizontal pair radiate horizontally polarized waves; when the loop is used for reception, they receive in the same order. It is the horizontally polarized component which is the cause of the difficulty outlined in the preceding paragraph. The horizontally polarized waves emitted by the horizontal legs travel up to the ionosphere, where they are refracted and reflected back to the earth. Here they combine with the now horizontally polarized ground wave and the resultant signal depends upon the instantaneous phase relationships. This results in distortion of the course signals. The night effect increases with frequency, so that the usefulness of a loop as a directional antenna decreases as the frequency is raised above three megacycles. It is obvious, therefore, that since a radio wave is sometimes refracted during its transmission and since it is difficult to separate the vertically and horizontally polarized waves at great distances, accurate readings are not always possible.

One other limitation of the loop is known as the "shore effect." This effect is usually associated with coastal D/F installations, and is generally due to the fact that a radio wave has a slightly higher velocity over water than over land. The error which this introduces into the loop D/F system (indicated in figure 235) is not as serious as that of "night effect." The U. S. Navy division of the coastal geodetic survey has compiled a list of "correction-factor" constants for D/F frequencies and localities, which can be used by navigators to make the necessary corrections.

Often, errors due to extraneous voltages being induced in a loop antenna are another cause for worry and, hence, is another limitation which one should be aware of at all times.

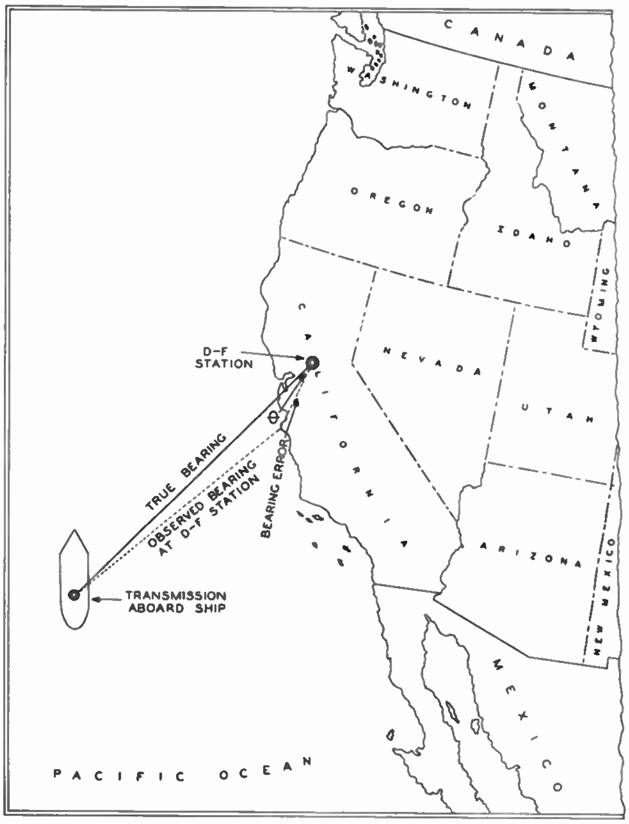


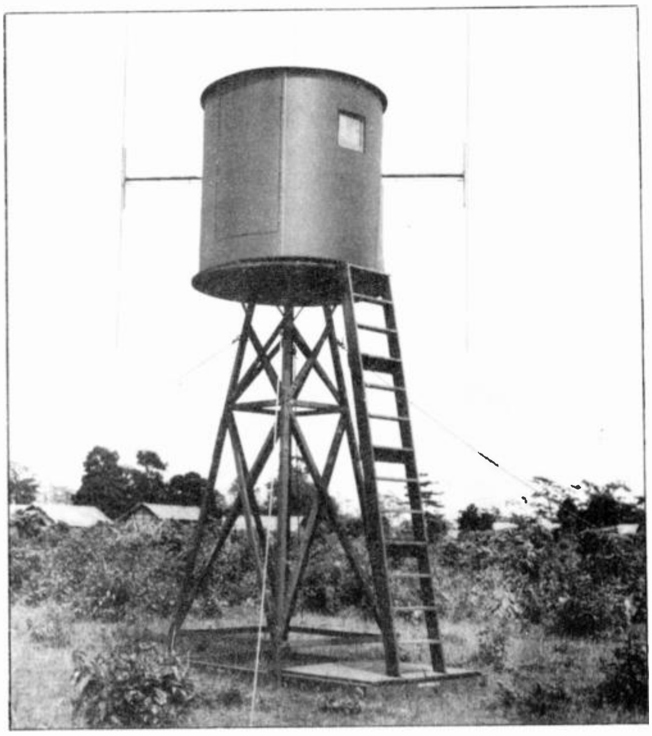
Figure 235. "Shore-Effect" Distortion in Loop Direction-Finding System.

The use of the loop is restricted to the medium and high-frequency ranges, because the size of a loop on the lower frequencies is too great.

In determining the site for a loop-type antenna, it is well to consider the effects of surrounding objects upon its operation. Metallic objects, such as wires, guard rails, and masts, in the vicinity of a loop antenna will have r-f currents induced in themselves by passing radio waves which are reradiated and combine with the original wave to introduce a distortion known as quadrantal error. This distortion causes an apparent deviation in the direction of arrival of the received wave, and may cause an indistinct null point, thus reducing the accuracy of the bearing determination.

When the loop antenna is used in shipboard and aircraft installations, it is physically impossible to remove it from the effects of surrounding metallic objects. Therefore, compensation must be made when taking bearings aboard ships and aircraft. This compensation may be in the form of a characteristic chart peculiar to the particular installation or it may be a compensating device attached to the rotary mechanism of the loop antenna. Whichever method of compensation is employed, it must be checked regularly for accurateness, or serious errors in operation will result.

It is also possible, and considered general practice, to compensate at least partially for the large errors in



Radio-Direction-Finder Array Mounted on a Rotatable Structure.

bearing which are caused by closed-loop circuits of surrounding metallic objects, such as the loop formed by a stack and wire stay on board a ship. By forming another closed-loop circuit of other surrounding metallic objects, an equal and opposite effect to that produced by the stack-and-wire-stay closed-loop circuit can be introduced into the loop antenna and compensation is accomplished. This is especially practical in shipboard installations when large quadrantal errors are common. Another common practice is to break the continuity of induced current paths in surrounding objects, by inserting insulators at proper intervals along their lengths. These two methods of compensation together with the proper location of the loop antenna reduce the quadrantal error to the point where it may be taken into account by the characteristic chart or compensating device previously mentioned.

Adcock System of Direction Finding

The Adcock system of direction finding is a great improvement over the conventional loop method in that it eliminates to a great extent almost all of the inherent limitations of the loop antenna. This system of direction finding is now standard for various U. S. Government agencies and civilian airlines.

The Adcock radio range stations, as they are commonly known, are usually located at about 200-mile intervals along a prescribed air route. The four basic units which make up the system are a medium-power transmitter having two r-f channels, five towers with counterpoises, a power unit, and a radio receiver. The Adcock system consists of four corner towers and a fifth tower located in the exact center of the square formed by the other towers. The fifth tower is utilized for voice broadcasts of weather and other pertinent information which may be of aid to safe navigation of the craft in flight.

Reasonable care must be exercised in choosing a site for an Adcock station. A satisfactory site should be clear of all surrounding objects and hills; in short, it should be as nearly flat as possible. The antenna towers should be installed at a considerable distance from railroad tracks, overhead power lines, telephone cables, or any other obstruction, in order to avoid any possibility of wave distortion. Distant hills should not exceed 1.5° to 2.5° in altitude at a distance of three to five miles from the center of the four tower installation, as checked with a theodolite (transit).

Orientation of the four towers is dependent on the course desired. The dimensions of a typical Adcock-tower installation are shown in figure 236. While the towers appear to be rather high, they are really very short for the frequency on which they operate. If the electrical height of a tower for frequencies between 200 and 400 kc. is calculated, it will be found that the height of the towers shown is actually a small fraction of a wave length.

In aviation, the plane in flight is always the first consideration regardless of anything else. Therefore, the height of the tower, which affects radiation efficiency, is sacrificed in order to eliminate the hazard which tall towers would present to a plane in flight. On the other hand, if it were possible to disregard this hazard, the height of the towers for a quarter wave length would be so great as to require guy wires. These guy wires would cover the field between the towers and, hence, would distort the transmission pattern and the resultant course.

Typical Radio-Range Installation, Showing Tower Locations and Counterpoises.

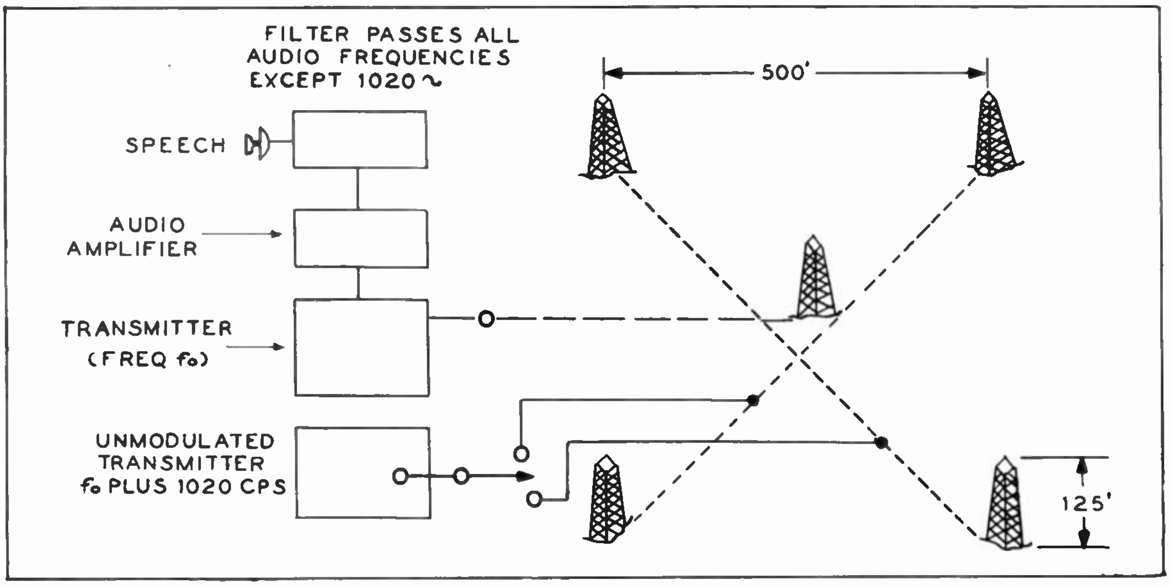


Figure 236. Physical Arrangement of Simultaneous Adcock Radio Range.

Great care must be taken in the laying out of an Adcock radio range. Usually the allowable tolerance in the distances between the fixed Adcock dipoles or towers is extremely small, about plus or minus 1½" being allowable and plus or minus one tenth of one degree when the central angles formed by the four towers are measured with a theodolite from the exact center of the square formed by the towers. The reason for all this accuracy is to maintain a symmetrical layout and a well-balanced feeder-line system, and to insure the minimum of difficulties that may arise if the installation is not laid out accurately.

Since the Adcock system of direction finding was developed for the purpose of eliminating the horizontal polarization error, which was discussed previously under loop antennas, various modifications have been added to further reduce any possible effects of horizontally polarized waves. Figure 237 shows various forms of the Adcock antenna system.

The four corner towers are insulated from ground. The largest portion of the resistance of these towers is made up of ohmic resistance and dielectric loss. The average radiation resistance computed for such an array is found to be about 0.06 ohm, while the total resistance is actually about 1.5 ohms.

The capacity of a tower is not uniform, and is much greater at the base than at the top.

Energy is fed to each of the four towers by a buried transmission line running from the tone-modulated transmitter, which is housed at the center of the ground plot. The energy is fed so that the r-f currents are of equal strength and 180° out of phase in diagonally opposite towers, in order to obtain the familiar figure-eight pattern previously discussed under loop-type antennas. Figure 238 shows the field pattern and the typical operational characteristics of an aural type of radio-range beacon, which is based on the Adcock system.

The radio-range-beacon system described above is also known as the simultaneous-range-transmitter (SRA) system. This system is in use today, and is installed in well over one hundred stations throughout this country, and is used in several foreign countries by American International Airlines.

Since the system has two independent r-f channels, controlled by a matched set of zero-temperature-coefficient crystals ("A" cut) that assure a frequency separation of 1020 cycles between the carriers, it affords a means for the simultaneous transmission of voice and direction-guidance signals for airfield approach work. Interference between the speech modulation and "A-N" course-guidance signals (1020 c.p.s.) is avoided by the insertion of a band-rejection filter in the input to the speech modulation circuit, which eliminates the speech frequencies in the neighborhood of 1020 c.p.s. A combination band-pass filter is used in the output circuit of the aircraft receiver, so that the pilot may select either the course-guidance signals or the speech weather broadcast or, if he wishes, he may listen to both signals simultaneously.

Usually the weather-broadcast transmitter has an output of 400 watts, and is capable of being modulated 70% with voice. The coded ("A-N") c-w transmitter has an output of 300 watts. The latter transmitter is provided with an automatic switching and keying arrangement for shifting the transmission from one Adcock-antenna pair to the other, and for keying one of them with the letter A (· —) and the other with the letter N (— ·).

The voice-signal transmission is omnidirectional, as indicated in figure 238A, while the coded c-w signal is transmitted in accordance with the figure-eight di-

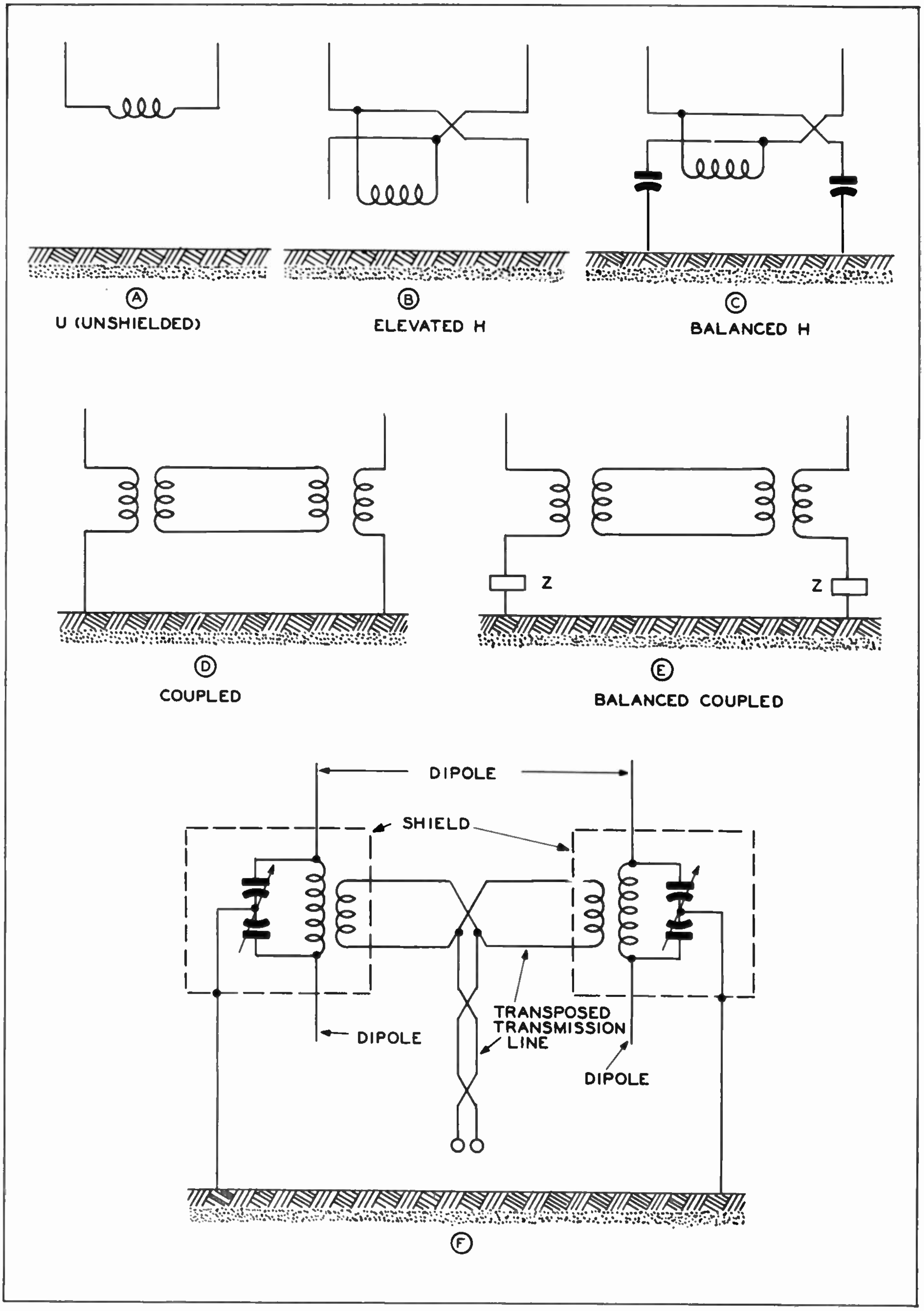


Figure 237. Various Forms of Adcock Antenna Systems.

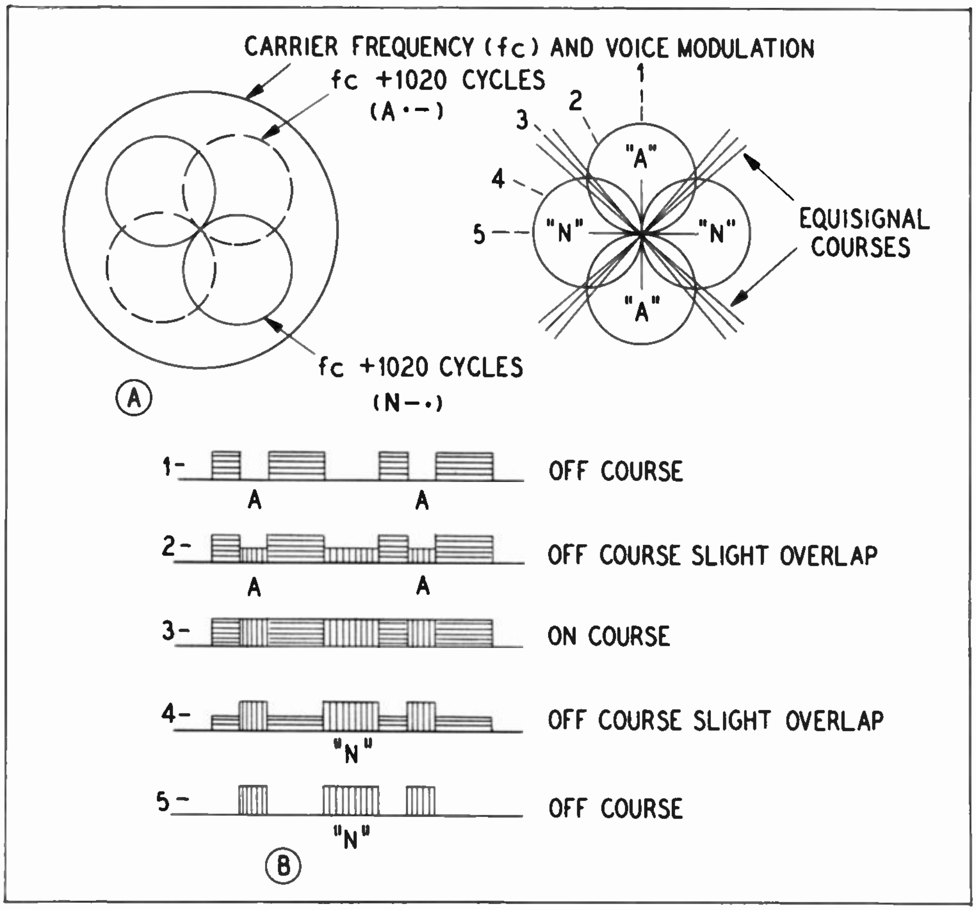


Figure 238. Field Patterns and Typical Operational Characteristics of the Aural-Type Radio Range.

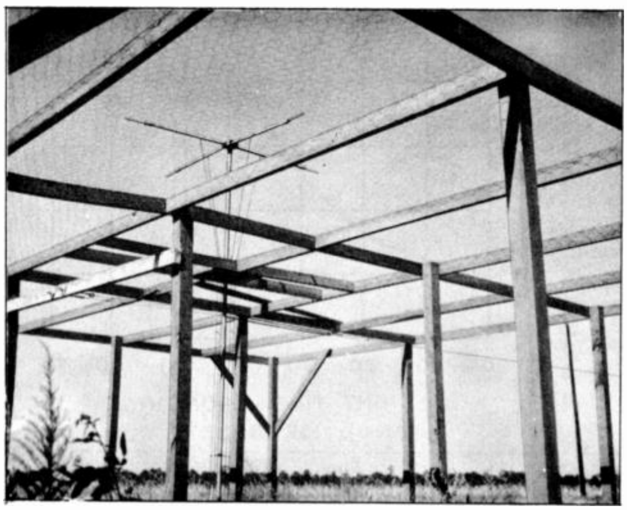
rectional pattern, as shown in figure 238B. The voice signal is received uniformly in all directions while the coded c-w signal is received nonuniformly in all directions.

Although the antenna used for radio-range reception on an aircraft appears to be a simple structure, course errors may result if the antenna is not designed according to certain principles laid down by the men who developed the radio-range beacon. The principles and the mathematics involved are beyond the scope of this discussion; the reader may refer to a good aeronautical radio engineering text for a detailed explanation of the complexities involved.

The Adcock radio range system just described usually includes in the same "shack" a "Z"-marker transmitter. The antenna for this transmitter is located either in the attic of the shack or on a pole approximately ¼ wave length above ground, a short distance from the building.

As an aircraft approaches the radio-range station, the signal, "A-N," heard in the receiver grows very loud, then suddenly disappears, and reappears again as the craft passes to the other side of the station. This space or region where the "A-N" signal disappears is called the "cone of silence" and is the region where the coupling between the range antennas and the receiving antenna is zero.

The "Z" or "cone-of-silence" marker, as it is also commonly known, is a low-powered 75-mc. transmitter, which is amplitude modulated with a 3000 cycle,



Typical Field Installation of a Z-Marker Antenna, Showing the Chicken-Wire-Type Counterpoise.

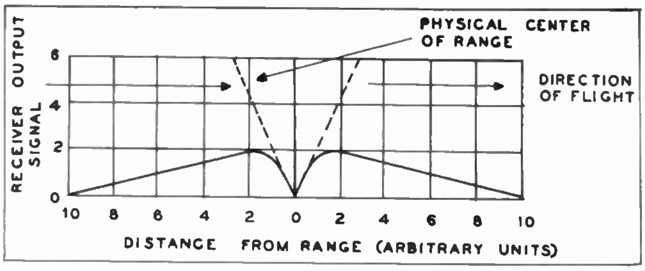


Figure 239. Relative Field Intensity of a Radio Range as Received with an Ideal Non-directional Antenna. Note the cone-of-silence region.

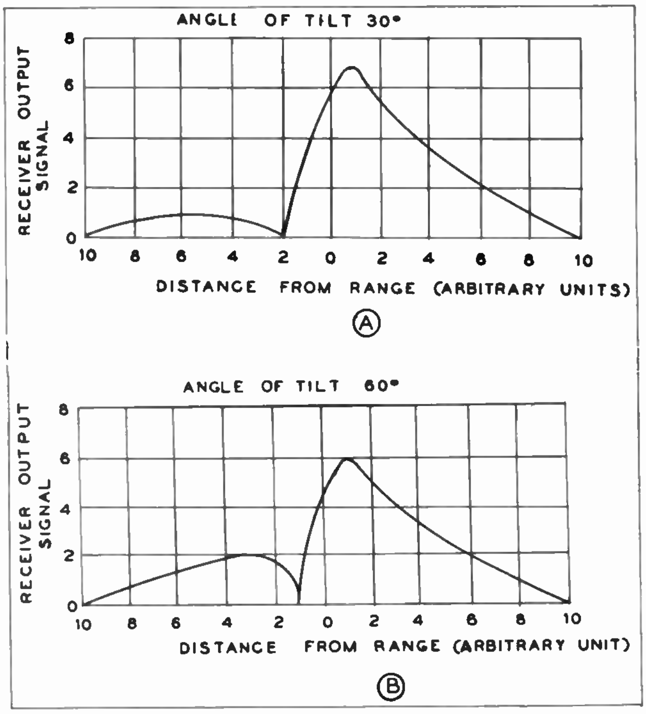


Figure 240. Distortion Introduced in the Cone-of-Silence Region When the Receiving Antenna is Tilted to 30° and 60°.

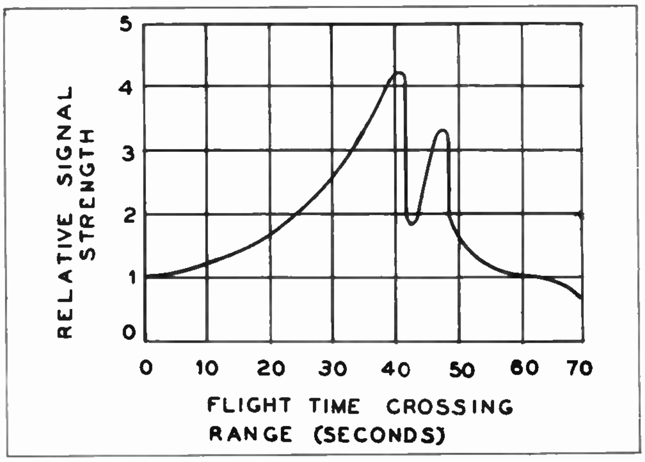


Figure 241. Distortion in the Cone-of-Silence Region Caused by the Presence of Nearby Railroad Tracks.

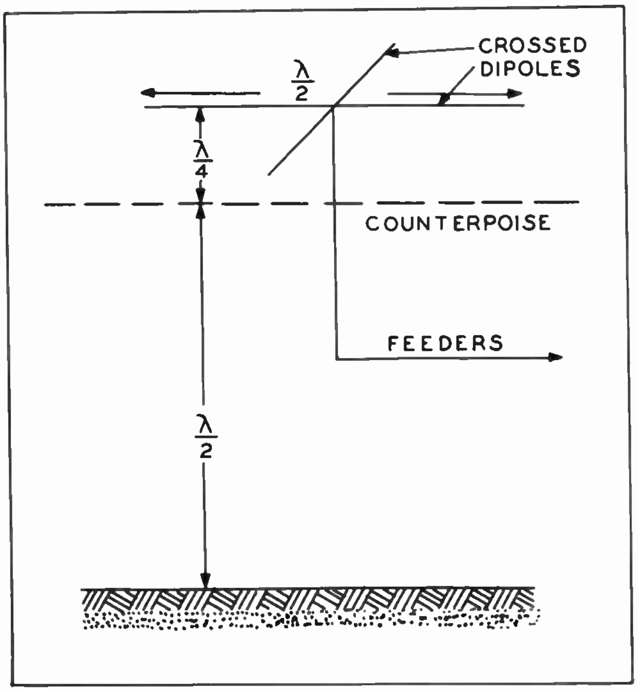


Figure 242. "Z"-Marker Antenna, Showing Placement with Respect to Ground.

steady tone. The output of the transmitter is fed to a turnstile antenna array which radiates vertically an oval-shaped, circularly polarized pattern from the center of the range. This serves to indicate to the pilot the exact center of the range.

Because of the special radiation pattern desired, it is obvious why the site selected for a radio range should be clear. The radiation pattern must be as nearly perfect as possible so that the pilot will know *precisely* when he is over the range transmitter, for this gives him a reference point from which to begin his "approach" procedures.

Figure 239 shows the relative field intensity of a radio range as received with an ideal nondirectional antenna. This figure illustrates graphically the increase in signal strength as the craft approaches the range, the sudden disappearance of the signal, and its reappearance on the opposite side of the cone of silence.

Figure 240 shows the distortion in the relative field intensity due to the inclination of the receiving antenna.

Figure 241 shows the distortion of the cone of silence caused by the presence of nearby railroad tracks.

The "Z"-marker antenna consists of two horizontal half-wave antennas crossed at their centers and placed a quarter wave length above a wire mesh counterpoise, which in turn is placed one half wave length above ground. Figure 242 shows the placement of the "Z"-marker antenna with respect to ground.

The dipoles are fed 90° out of phase with each other, to provide a circularly polarized radiation field in the vertical direction. A delta-matching section completes the feed system to each dipole.

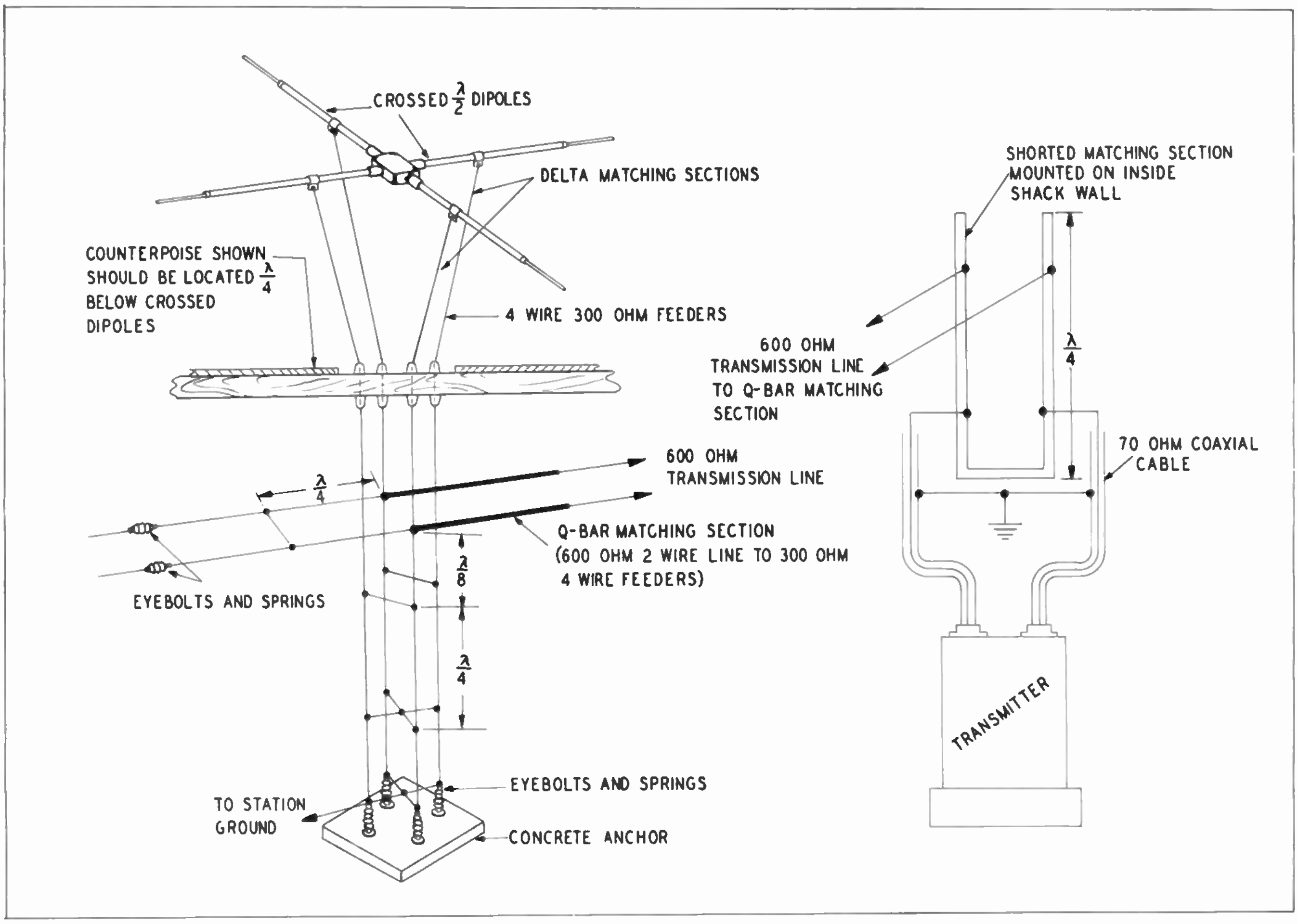


Figure 243. Outdoor Installation of "Z"-Marker Antenna.

Figure 243 shows a typical outdoor-installation layout in more detailed form than is shown in figure 242. Figure 244 shows a typical shack installation.

Two 70-ohm coaxial cables, with shields tied together and grounded, are brought to a shorted quarter wave length matching section which is mounted on the wall of the shack. See figure 245. A 600-ohm transmission line is tapped off the matching section at the proper place, and is led off to the antenna some distance out in the range field. Here the 600-ohm line is matched to a Q-bar section connected to a four-wire, 300-ohm vertical transmission line. In both shack and outdoor installations, connection is made directly to two of the four wires and through a 90° phase-shifting stub to the other two. The transmission lines are connected to the dipoles through delta-matching sections, as shown.

Microwave Antennas

Antennas designed for operation in the super-high-frequency range, 3000 to 30,000 mc., function in accordance with the same basic principles of operation as do the lower-frequency antennas. However, due to the small physical size of the radiating elements, full advantage can be taken of directive arrangements for efficient line-of-sight operation.

Due to the complexity of design and construction of these arrays, only their general features are considered.

Since the radiation properties of microwave frequencies approach those of light waves, their propagation can be directed by reflecting surfaces placed in their path. These reflecting surfaces can be properly spaced elements acting in parasitic fashion, additional driven elements properly spaced and oriented, or a parabolic-shaped reflecting device.

Since parasitic and driven-type arrays are discussed on pages 88 and 93, information on only the parabolic-reflector-type array is given in the following paragraphs.

A radiating device, placed at the focal point of a parabolic-shaped metal plate, provides the r-f energy for reflection from the concave side of the parabolic reflector. See figure 246.

The parabolic reflectors which have found practical use in the past few years are illustrated in figure 247. The reflectors are usually fabricated from solid plate

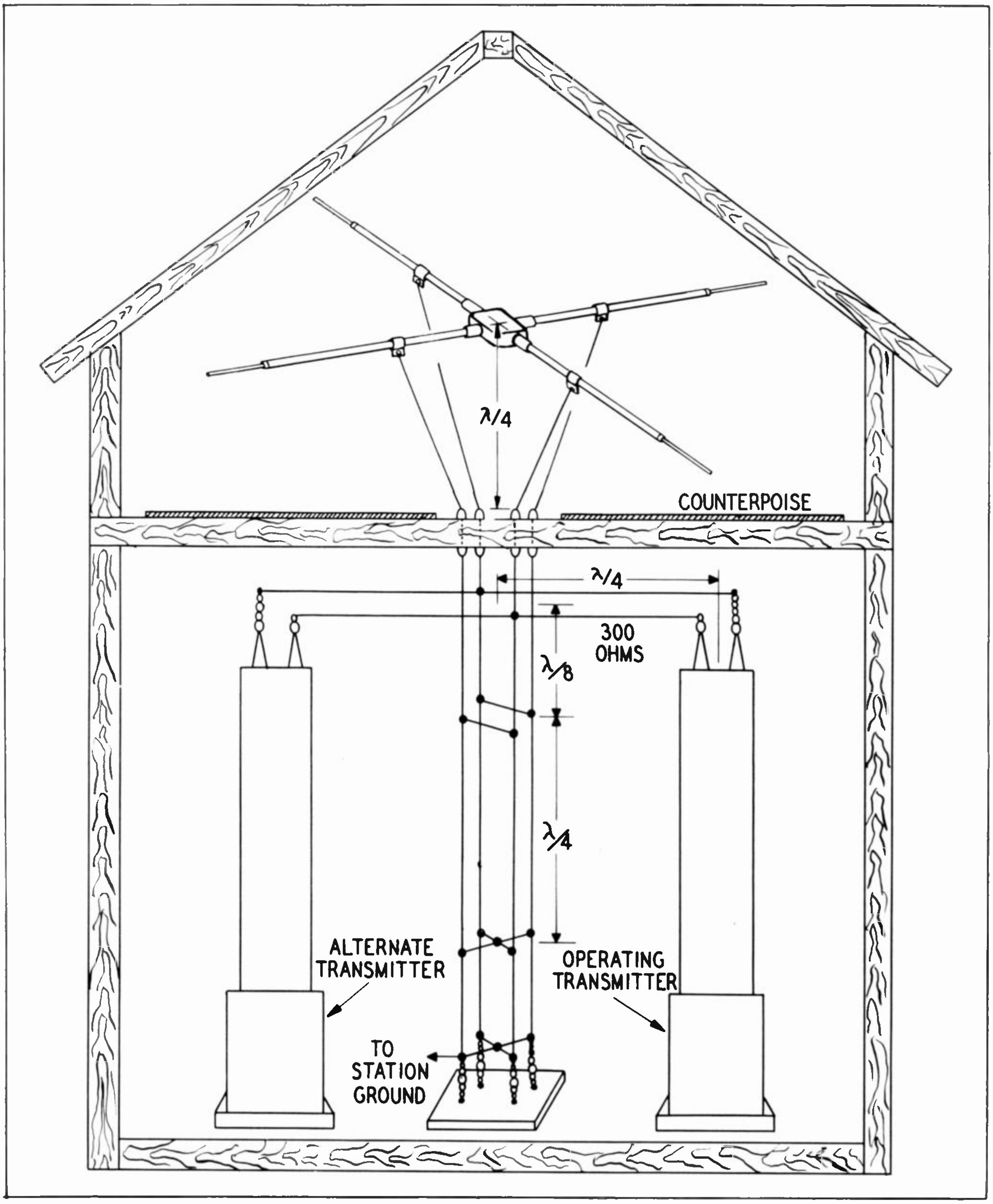


Figure 244. Shack Installation of "Z"-Marker Antenna.

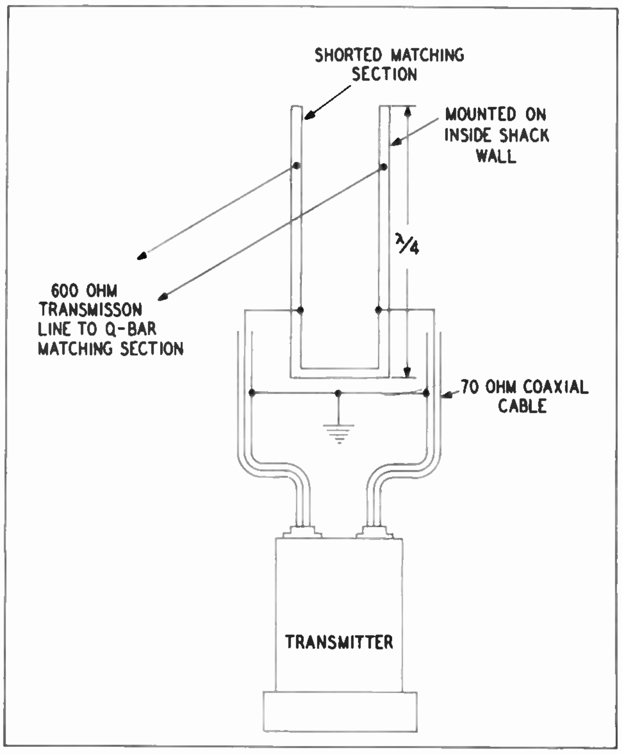
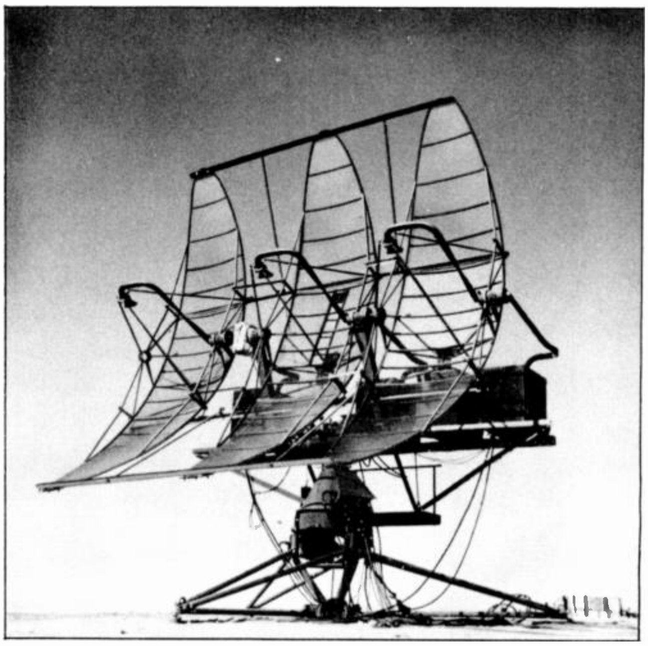


Figure 245. "Z"-Marker Outdoor Installation, Showing Details of Feed.



Array of Orange-Peel Paraboloids with Sectional Horn Feeds for Height-Finding Equipment.

or screen-type metal with necessary supports and, in many instances, they are placed on rotatable mountings. The reflector can be shaped and driven in a way to provide the desired radiation pattern.

The two types of transmission lines applicable at these frequencies are coaxial lines and wave guides. They may be used in a front or rear-feed system.

In a front-feed system, the coaxial line or wave guide approaches the parabolic reflector from the front, and directs the spray of r-f energy into the reflector. In a rear-feed system, the coaxial line or wave guide projects through the parabolic reflector and an additional reflector is placed ahead of the radiating element, to help direct a greater portion of the r-f energy toward the parabola. Figure 248 illustrates the typical systems of feed for microwave antennas with parabolic reflectors.

The requirements of the feed system are: (1) it must be shaped and located so that it directs energy toward the reflector and (2) it must properly terminate the transmission line to keep the standing-wave ratio near unity.

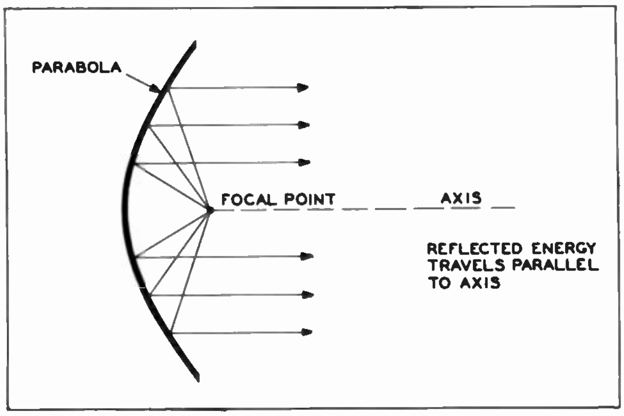
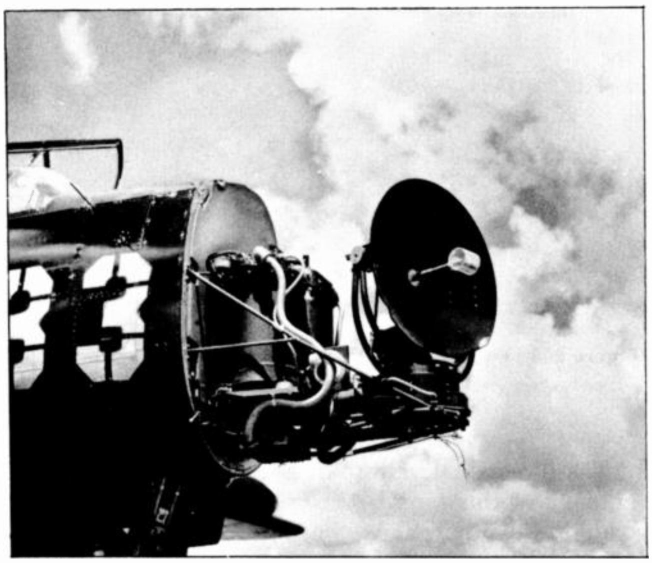


Figure 246. Principle of Parabolic Reflection.



Aircraft Installation of a Coaxial-Line-Fed Dipole with a Paraboloid Reflector on a High-Speed Rotating Mount.

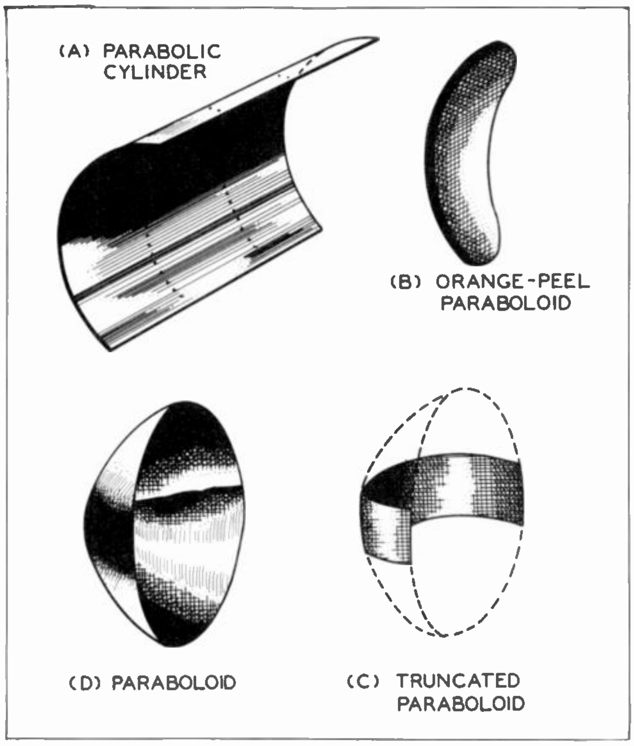
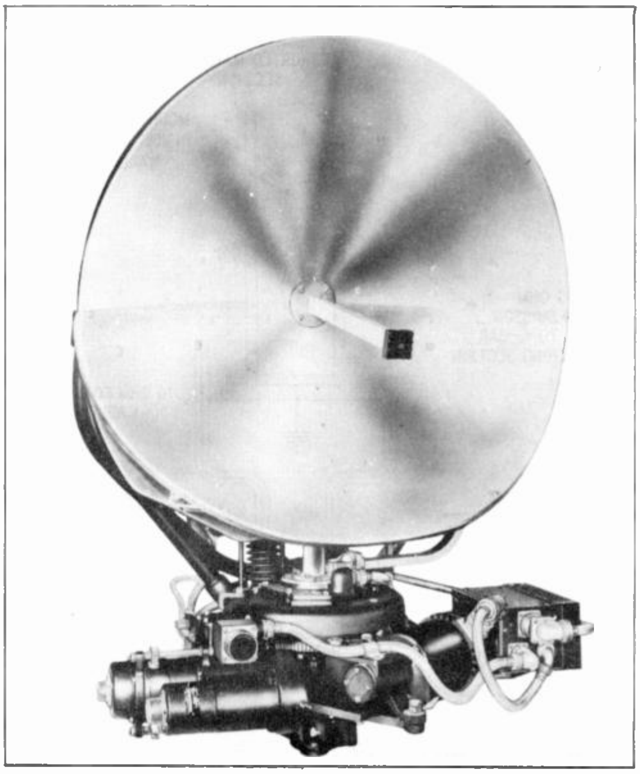


Figure 247. Examples of Parabolic Reflectors used with Microwave Antennas.



Waveguide-Reflex-Horn Antenna with a Parabolic, Cosecant-Squared Reflector on a Rotating Mount.

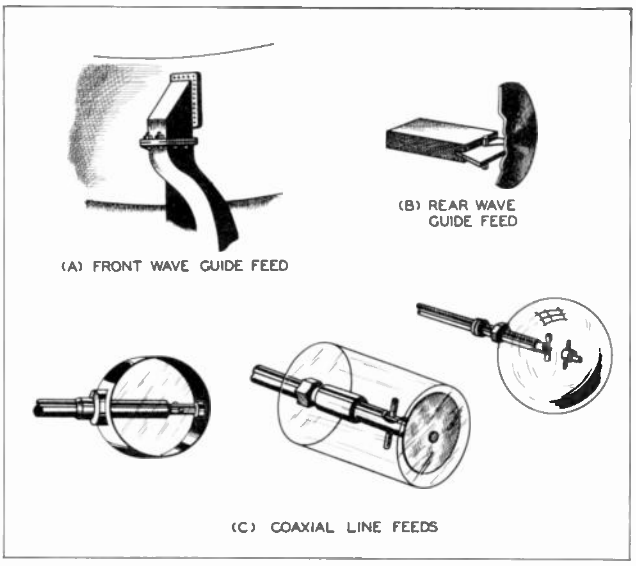


Figure 248. Various Methods of Feeding Microwave Antennas Having Parabolic Reflectors.

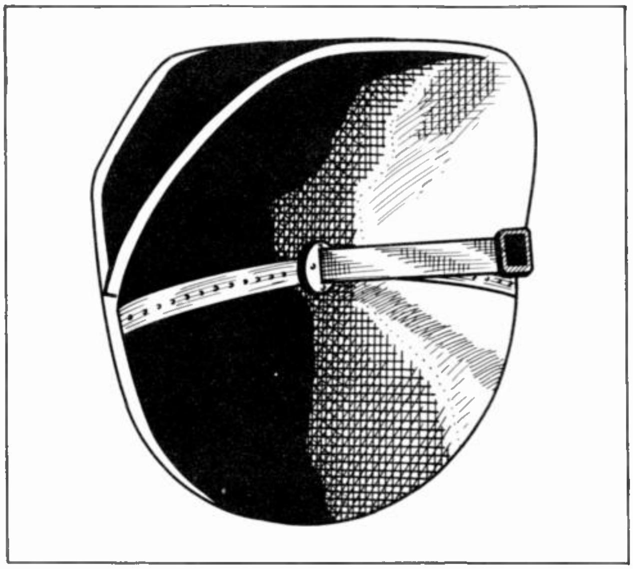


Figure 249. Special-Purpose Parabolic Reflector Used to Obtain a Dispersed Beam (Cosecant-Squared Pattern).

The directional pattern of a transmitting microwave antenna of this type is very narrow in one plane and wide in the other plane. Since in many microwave antenna applications the same array is used for both receiving and transmitting, the directivity of the pattern can be considered essentially the same.

A variation in the normal pattern from a parabolic reflector is obtained by bending the top of the reflector forward. See figure 249. This type of pattern is especially useful when it is desired to lay down a field of uniform intensity on the earth's surface from an aircraft.

EXAMINATION No. 4

True or False

1. Directional antennas of the rhombic type are useful for long-distance communication. ....

2. A good signal-to-noise ratio is desirable when a rhombic antenna is used for transmission. ....

3. It is not necessary to use a good reflecting plane for the half-rhombic antenna. ....

4. The strongest radiation from a half-rhombic antenna is in a horizontal plane. ....

5. A terminated nonresonant half-rhombic antenna has a unidirectional radiation pattern. ....

6. A properly terminated full-rhombic antenna has a relatively high angle of radiation and has a narrow operating frequency range. ....

7. The tilt angle of a full-rhombic antenna, which is one-half the angle formed by adjacent sides, is determined by subtracting the angle that the main forward power lobe makes with the wire of an individual side from 90°. ....

8. A decrease in rhombic-antenna leg length must be accompanied by a subsequent increase in antenna height to maintain the same angle of radiation. ....

9. A terminating resistor used in rhombic applications should be able to dissipate about one-fourth of the transmitter power. ....

10. A "curtain" rhombic antenna is employed where a narrow band of frequencies is to be covered. ....

Multiple Choice
(Underline the correct answer.)

1. The starting point in the design of a rhombic antenna is the
   a. type of terrain involved.
   b. materials available.
   c. time of year.
   d. distance to be covered and frequencies to be used.

2. The input impedance of a single-wire rhombic antenna is approximately
   a. 75 ohms.
   b. 300 ohms.
   c. 750 ohms.
   d. 1200 ohms.

3. A balanced 4-wire line is sometimes used with a rhombic receiving antenna because it
   a. is less receptive to distant noise pickup.
   b. is an exponential form.
   c. can be terminated more easily.
   d. facilitates tuning.

4. By adding a series coil and capacitor at the lower end of a short vertical antenna, the current distribution will approximate the sine-wave distribution on a quarter-wave vertical antenna, and there will be an increase in radiated power due to
   a. a closer impedance match between the line and the antenna.
   b. a more efficient ground system.
   c. an effective increase in radiation resistance.
   d. a reduced loading effect on the transmitter-output circuit.

5. When top-loading a short vertical antenna, an increased amount of current flow in the radiating (top) portion of the antenna may be obtained by
   a. increasing the top loading of the antenna.
   b. inserting a parallel-resonant coupling circuit between the transmitter and the antenna.
   c. inserting a quarter-wave matching stub at the antenna.
   d. spreading the feeder lines.

6. The tilt angle of a half-rhombic antenna, for optimum results, must be constructed to be
   a. greater than the wave angle.
   b. at least 10 degrees.
   c. less than the wave angle.
   d. the complement of the angle that the main forward power lobe makes with the wire.

7. The purpose of the terminating impedance of a rhombic antenna is to
   a. produce a unidirectional radiation pattern.
   b. balance the currents in the legs of the antenna.
   c. dissipate one-third of the applied power.
   d. minimize capacity effects of the antenna to ground.

Continued on Next Page

8. The problem of maintaining a constant input impedance of a rhombic antenna with respect to the terminating impedance over a wide frequency range can be solved by

a. adding a series variable inductance at the termination end.
b. using stainless-steel wire for the terminating impedance.
c. grounding the terminating impedance at its center.
d. using a multiple-wire, or "curtain," rhombic.

9. The height of a rhombic antenna modifies the radiation patterns in the vertical and horizontal planes, and also affects the over-all gain, particularly if

a. the antenna is operating on a high frequency.
b. an extremely low angle of radiation is desired.
c. the rhombic has short-length sides.
d. long-distance coverage is required.

10. A long-wave beverage antenna operates more efficiently over poor terrain, such as rocky or sandy ground, because

a. all radiation from the antenna is in a vertical direction from ground.
b. it operates isolated from ground by at least two wave lengths.
c. the ground attenuation is a vital factor in increasing its directive properties.
d. it aids in attenuating local man-made noises.

Subjective

1. List three ways in which the effective height of a vertical quarter wave length antenna may be increased.

2. Why is a counterpoise an important part of the antenna system when using a vertical antenna?

3. Why must there be some modifications made on terminated rhombic-type antennas when it is desired that they be used for reception as well as for transmission?

4. What advantage has the folded-dipole antenna over a single-dipole antenna?

5. With a horizontally polarized antenna, how is it possible to receive signal energy being transmitted by a long-wave beverage antenna which transmits vertically polarized waves?

CONSTRUCTION AND MEASUREMENT INFORMATION

ANTENNA MASTS AND TOWERS

Types and General Uses

There are many types of antenna structures to be found in the field. The materials and the size of the structure naturally depend upon the application.

For most light-weight use in the field, that is, somewhere below the 90-foot class, most of the antenna structures are of the mast-section type. These consist of several sections which, when fitted together, form the over-all structure. These fitted mast sections are of various designs and materials. One commonly used mast-section structure is the very light mast which consists of ten 3-foot aluminum sections forming an over-all 30-foot structure. This type of mast is generally used for v-h-f antenna; its installation is simple, and can be accomplished with a minimum of effort. Another type of aluminum structure consists of two telescoping mast sections which, when extended, reach a height of 25 feet.

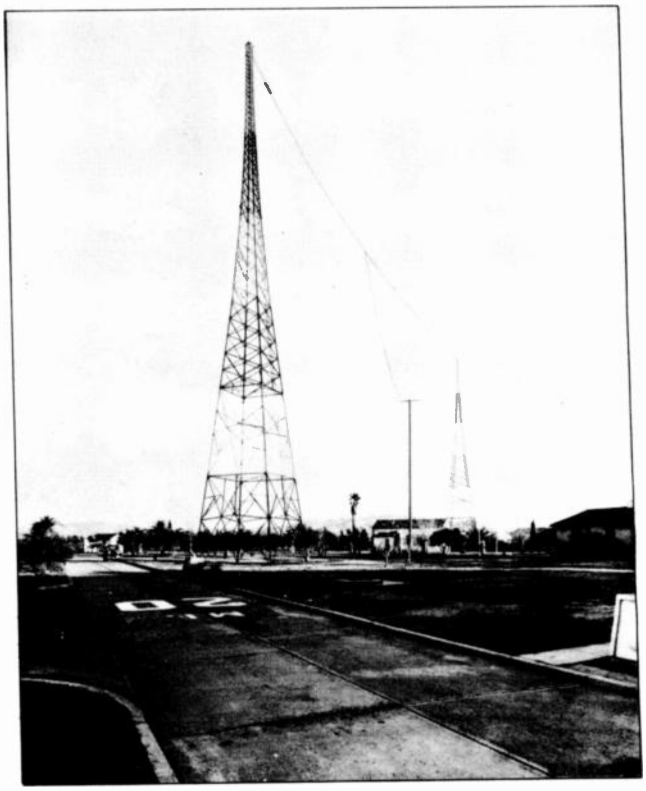
One of the most common types of sectional antenna structures in the light intermediate class consists of eleven 5-foot, hollow steel sections which, when assembled, form a 40-foot structure with a 15-foot gin pole. This type of structure is widely used where a strong, and yet light-weight, antenna structure is required. Another type of mast-section structure, comparable to the above-mentioned type, is composed of eight 6-foot, plywood sections, fastened together by metal couplings.

In the fixed-tower classification, the construction and materials of the antenna structures are widely diversified. A common base-insulated tower which is in general use as a vertical radiator is the 180-foot, windcharger type. This consists of nine 20-foot steel lattice sections, triangular in shape, braced by guys at 5 different levels, 3 guys to each level. This type of tower is suitable for use with transmitters in the 1 kw., medium-frequency category.

A self-supporting, 125-foot, insulated tower called the "Blaw Knox" tower is commonly used for 400-watt radio range work. This type of antenna tower is equipped with a ladder to the top, and is furnished with lighting of standard construction including prismatic-type fixtures.

In the heavy-intermediate class, there are two main types of towers which are used as antenna supporting structures in the field. These are either of the 75-foot or the 90-foot type, and both are of the noninsulated variety. These towers are extremely light, of triangular lattice-braced construction, and are designed to be assembled on the ground and raised as a unit.

One of the most common heavy-duty structures used in the field is the 73-foot, 7-inch rhombic tower. This type is designed for supporting heavy rhombic or other heavy antennas. The tower consists of lattice-braced galvanized steel, which is designed for complete assembly on the ground.



Four-Sided Supporting Structures for a Horizontal Half-Wave Communications Antenna and Transmission-Line Pole Support.

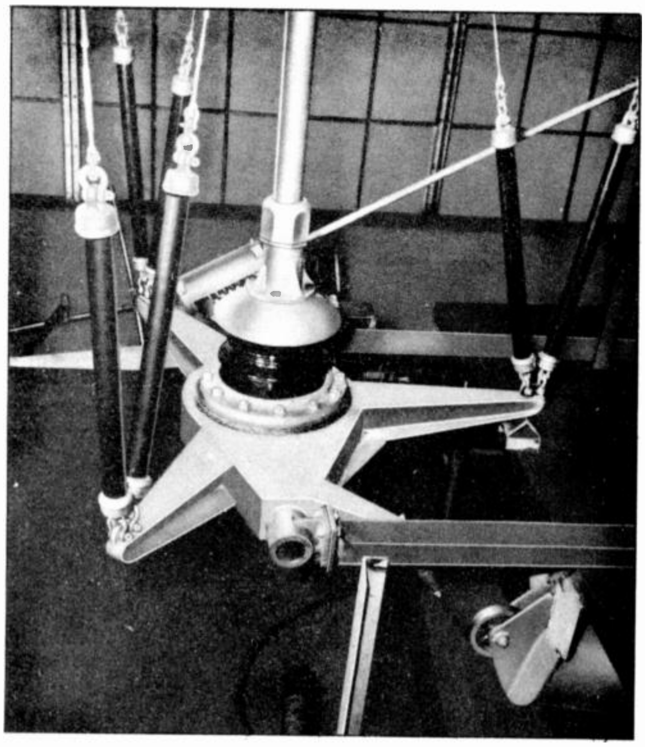
Erection of Antenna Structures

To simplify the discussion of the methods of erecting antenna supporting structures, the structures are grouped into the following three main classifications, according to the method of erection:

1. Short Structure: 20—50-foot; using the "brute force" method.
2. Medium-Height Structure: 50—90-foot; using the "manual-gin-pole" method.
3. Tall Structure: 90—200-foot; using the "falling-gin-pole" method.

Erection of Short Structure

The short structure can be erected by a 3-man team. The method of erection employed can be called the "brute-force" method. Because of the light weight of the structure, no special pivoting base or block-and-tackle equipment is required. Side and rear guy wires should be firmly anchored and tied before the lifting process is begun. See figure 250. To erect the structure, one man raises the mast, the second man holds his foot against the base of the mast. The third man sights along



Base-End Tilting Mechanism of a Stayed, Tilting-Whip Antenna Used on Naval Vessels.

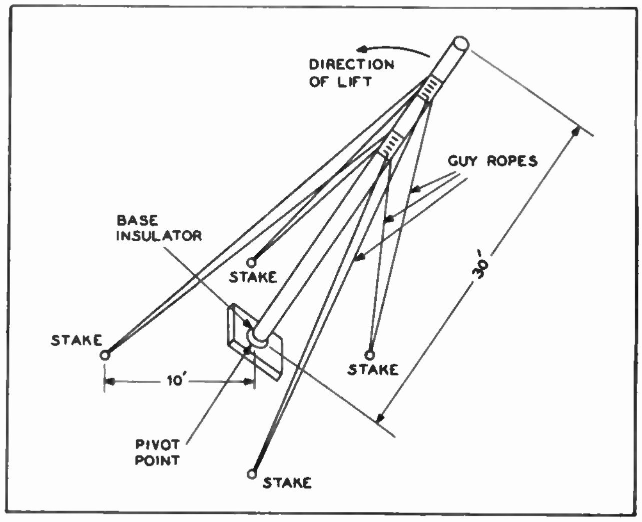


Figure 250. Brute-Force Method of Erection for Short Mast Structures.

Erection of Medium-Height Structure

The medium-height structure can be erected by a 3-man team. The method of erection employed is called the "manual-gin-pole" method. The gin pole itself is a single mast section, and is pivot-hinged at a right angle to the main mast section. Two pulleys are required; one is attached at the top end of the gin pole, and the other at a ground stake located at a distance from the pivot point equivalent to the height of the gin pole. See figure 251. A rope is threaded through the pulleys in block-and-tackle fashion. All guy ropes

the length of the mast, to ascertain that it is being properly aligned by the guy wires at all times during the lifting process, thus avoiding excessive strain on the base insulator and the mast sections.

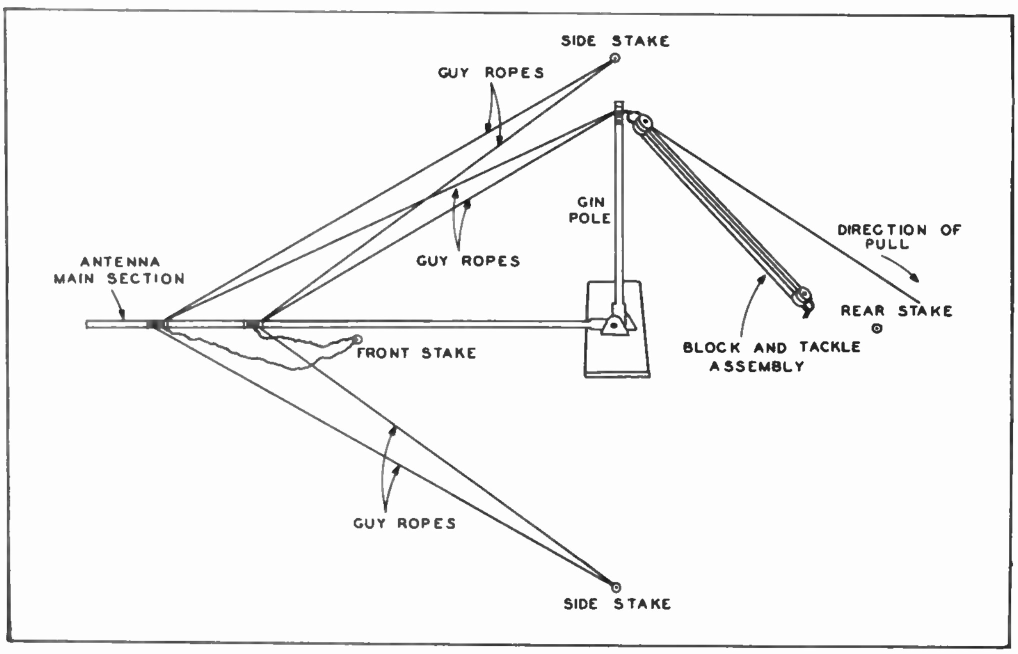


Figure 251. Manual Gin-Pole Method of Erection for Lightweight, Intermediate-Height Structures.

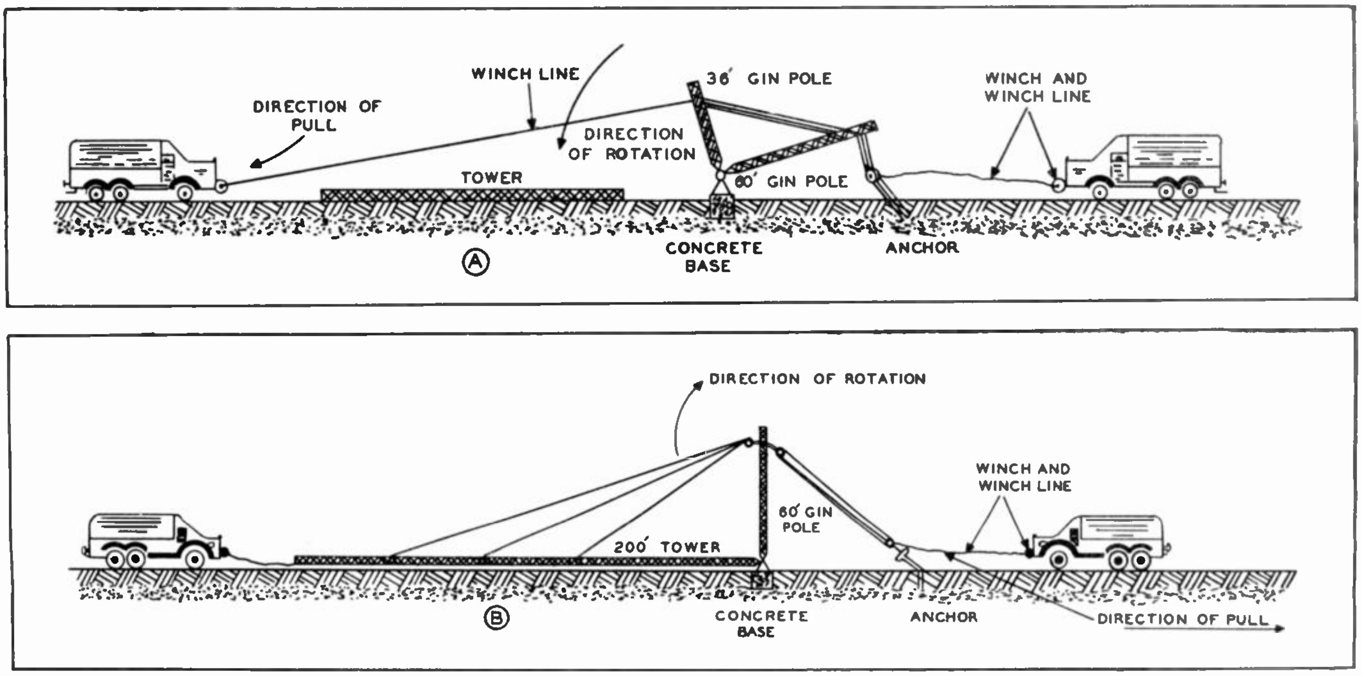


Figure 252. Falling Gin-Pole Method of Erection for Tall or Heavy Structures.

should be fastened and staked before the lifting process commences. As one man pulls the gin-pole pulley rope to start lifting the structure, another man steadies the mast and aids in lifting, progressing from the top of the structure toward the base. An even pulling motion must be maintained by tightening the guy wires equally at all times during the lifting process. This method of erection is practical, depending upon the material of the structure, for lengths up to 100 feet. Materials such as aluminum, plywood, straight-grain fir, and other light-weight materials, when used in mast sections, lend themselves to the above method of erection.

Erection of Tall Structure

The erection procedure for a tall structure requires heavy-duty equipment and the services of approximately six men. The method is called the "falling-gin-pole" method, and consists of two major operations; first, the erection of the gin pole (see figure 252A), and second, the erection of the main structure (see figure 252B).

In an operation of this magnitude, a fully equipped and specially trained crew of men, with each man performing a specific job, is required. The physical hazards peculiar to operations of this type demand that careful attention be given to guying details during the raising, and to the security of the guys and the guy-wire tensions after erection.

It is recommended that the inexperienced investigate all details of this method, referring to War Department technical manuals and commercial publications on this subject. IMPORTANT! Observe all precautions noted.

Mast and Pole Data

The mechanical problems encountered in the actual construction of an antenna system are by no means an insignificant part of antenna work.

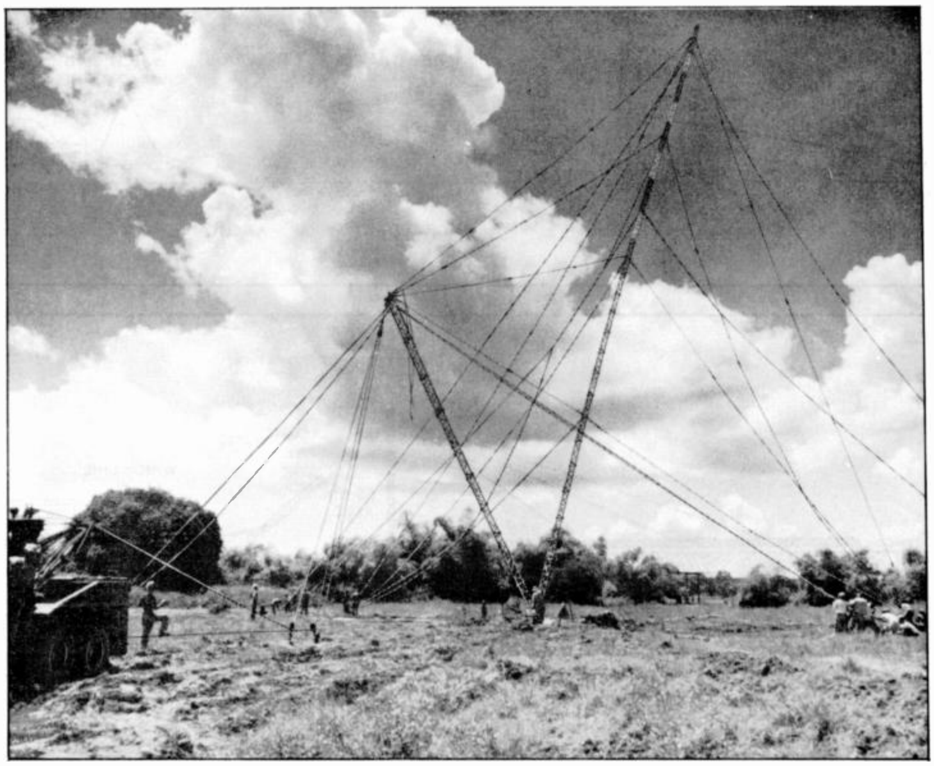
In general practice, a specific antenna kit, including all required materials and instructions pertinent thereto, is provided for an installation project; for those cases in which separate materials must be assembled, the following information is given below.

Note: Detailed specifications on mast and pole work are not within the scope of this manual, and will therefore be dealt with only in a general way; for complete information on these items, refer to War Department Technical Manual TM 11-486 or the technical manual pertaining to the particular type of antenna kit.

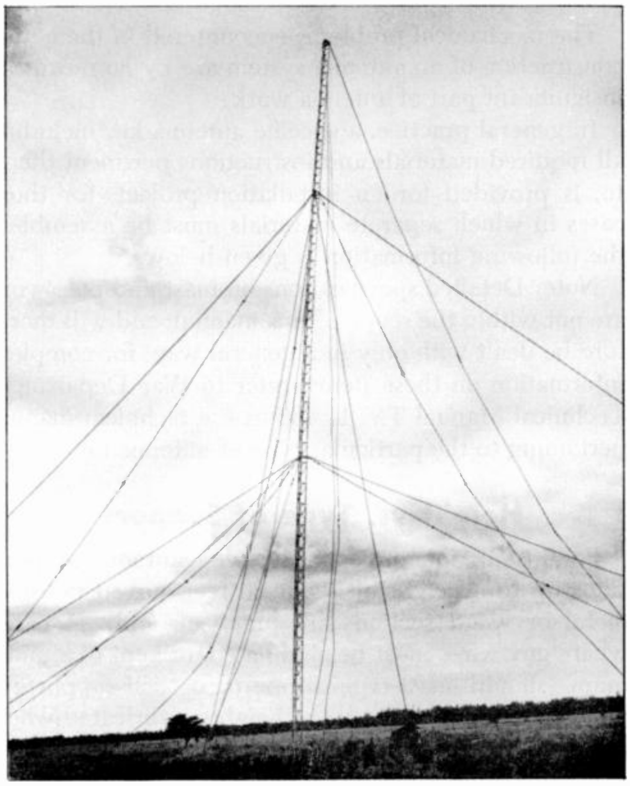
Height vs. Type of Support

For installation projects involving antenna suspensions up to a height of about 60 feet, guyed poles of metal or wood sections are practical. Only in cases where guy wires must be eliminated, or kept to a minimum, should mast-type supports or self-supporting poles be employed for these heights; fabricated-wood or metal-section poles are entirely satisfactory, provided they are sufficiently guyed.

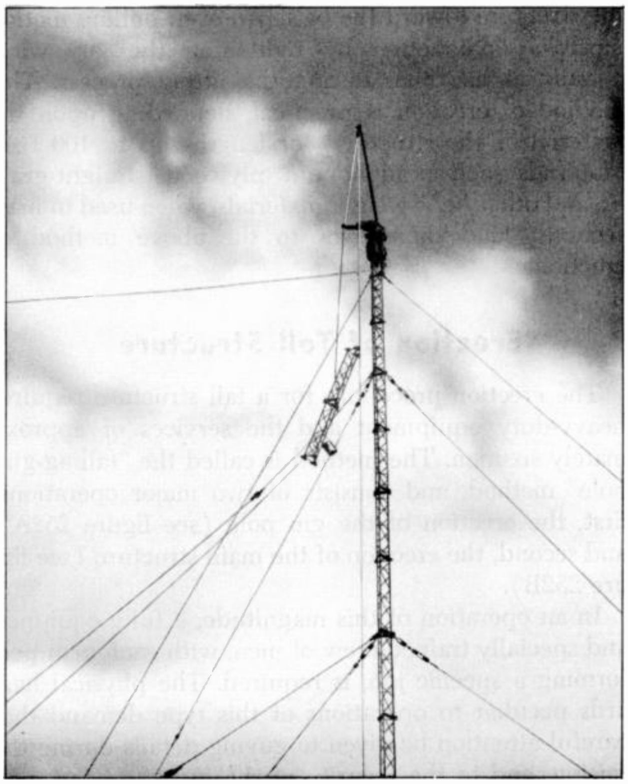
For heights of 80 to 100 feet, either three-sided or four-sided lattice-type masts are recommended as most practical. At these heights, the masts can be made self-supporting, although by guying, the dimensions of the



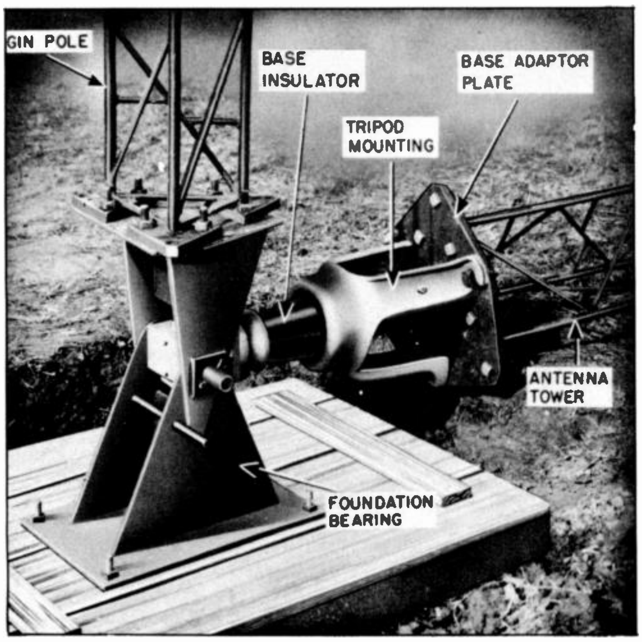
Erection of a Tall Structure, Using the Falling-Gin-Pole Method (Intermediate Stage).



Erection of a Tall Structure, Using the Falling-Gin-Pole Method (Final Stage).



Method of Assembling a Sectionalized, Heavy-Duty-Type Antenna Structure.



Position of Gin Pole and Tower before Erection, Showing Detail of Tower Base and Hinge Assembly.

cross sections may be reduced without danger from high winds.

For heights above 100 feet, a well-guyed, four-sided, lattice-type mast is required. For such installations special attention must be given to the guying system and its associated strain insulators.

The best woods for antenna supports are cedar, pine, and fir, although other woods which grow tall and have straight grain (preferably not white woods), such as redwood, are also suitable. It is most important to apply a preservative to the portion of the pole inserted in the ground. All bark should be removed, and the pole should be treated up to a point at least 2 feet above the probable ground line as soon as possible thereafter. Two commonly used preservatives are creosote and osmoplastic B. The latter is a mixture of coal tar, pentachloraphenol, and sodium fluoride thinned with benzol. Certain precautions should be observed when handling these preservatives, as they are poisonous. Gloves should be worn when applying and handling these materials. The preservative should be applied to the timber with a paint brush and after applying, the hands should be washed thoroughly with a moderately strong soap.

The life of a wood structure can be increased several hundred percent by protecting it from the elements with a coat or two of paint. Apply a primer coat of flat white, and when dry, apply a second coat of outside paint or aluminum paint; aluminum paint is the best from the preservation standpoint.

When installations of heavy structures are to be made, the project should be handled by a construction crew having the equipment and training for such work. The bases of masts for such installations must be seated in concrete foundations. In ordinary soil, a hole of suitable size is made, and a steel plate is placed in the bottom of the hole. After the mast is erected, the hole is filled with the cement mixture. In very soft, wet soil, the hole is made, and heavy piles are driven in, leaving the tops of the piling flush with the bottom of the hole. The steel plate is placed over the piling; after the mast is erected, the hole is filled with the cement mixture.

In some installation work, the stepping of poles is advantageous; when frequent inspections of aerial-mounted apparatus is required, and when climbing equipment is not available, pole steps are recommended. Do all stepping work on the ground, before the poles are erected. Use wood pole steps (see figure 253) for the first three steps at the ground end of the pole. Install the first step approximately 36 inches from the ground line. The fourth, and all successive steps, should be of the spike-head type. Steps should be installed on both sides of the pole, and should be staggered so as to allow 18 inches between successive steps.

Storm Loading

All sorts of climatic conditions are encountered in the field. They must be considered before attempting to make a permanent, or even a temporary, antenna installation, since these conditions influence the extent to which the system is loaded. The weight and tension that a specific type of structure can withstand in addition to the normal weight imposed by the an-

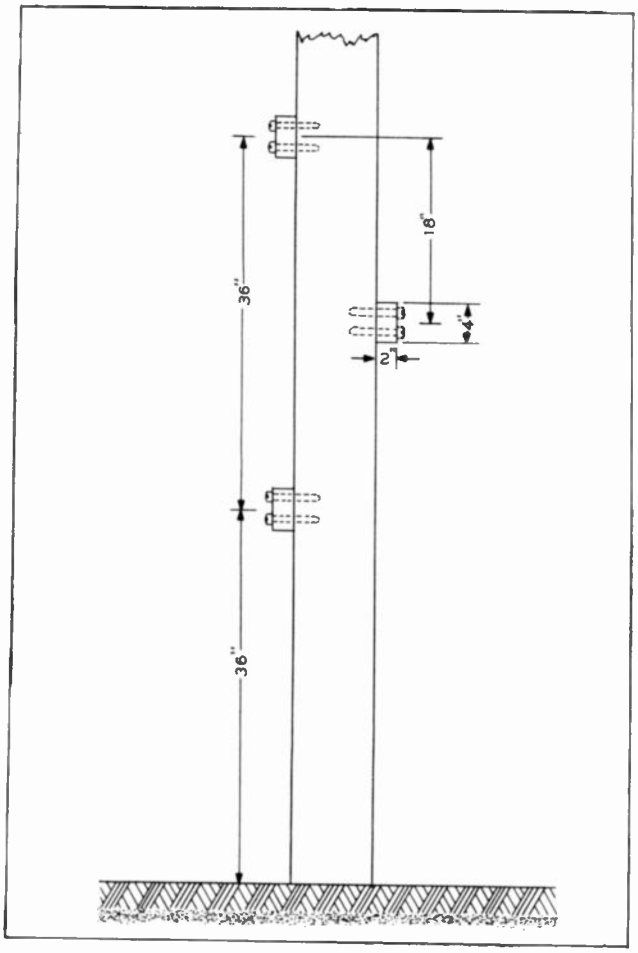
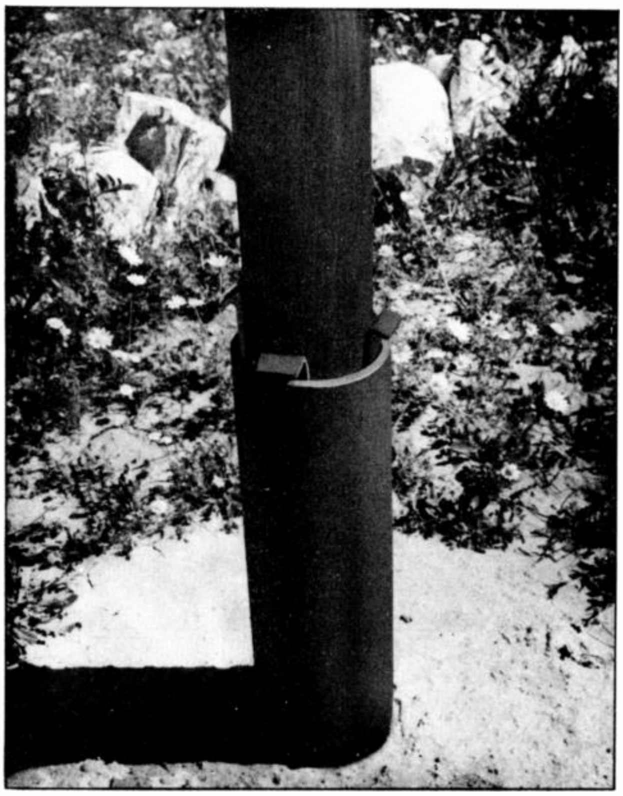


Figure 253. Step Arrangement for Wood-Pole Antenna Masts.



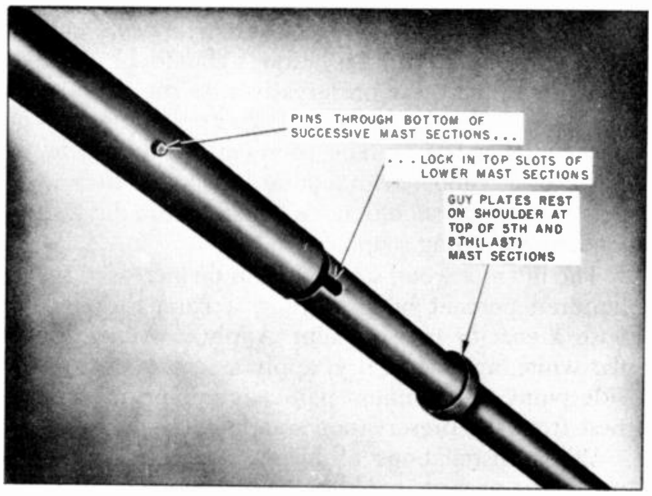
Special Base for Wooden Supporting Structure to Prevent Rapid Decay and Disturbance by Termites.

tenna system, without buckling or collapsing is called storm loading. In many instances, structural systems incorrectly designed for the loading have caused disruption of communication service in the field. For example, on Okinawa, during the typhoon in the fall of 1945, quite a few antenna structures were destroyed and communication facilities subsequently interrupted. This could not be considered a case of poor planning because the wind reached a velocity of 160 knots, which is far from normal. This is an extreme case, illustrating the precautions that must be observed when considering structural loading.

In addition to wind velocity, temperature, and precipitation in the form of either rain or ice, must be considered in designing and installing the structures. When an antenna installation is to be made in an area where the ice and temperature conditions are not known, a general rule to follow is to use heavy-loading construction in latitudes above 40°, medium loading between latitudes 30° and 40° and light loading in latitudes below 30°; this rule is not ironclad, for the elevation of the antenna site must also be considered. Even if the installation is to be below 30° latitude, high winds and icy conditions in mountainous regions must be taken into account.

The types of storm loading are classified as follows:

1. Light Loading: A wind velocity of about 70 miles per hour on the exposed wire surfaces at a minimum temperature of 30° F.



Detail of Mast-Section Lock which Prevents Undesirable Rotation of Antenna Array after Orientation.

2. Medium Loading: A wind velocity of about 60 miles per hour on the exposed wire surfaces covered with ¼″ radial thickness of ice at a minimum temperature of 15° F.

3. Heavy Loading: A wind velocity of about 60 miles per hour on the exposed wire surfaces covered with ½″ radial thickness of ice at a minimum temperature of 0° F.

Sag Measurements

The sag is always measured at the center of the span. See figure 254. Measurements may be made by the oscillation method. This makes use of the fact that there is a direct relation between the sag of a suspended member and its period of oscillation. After the line has been pulled up to approximate tension, select a span which contains no connectors or splices and which is free from contact with trees or other objects. Then go through the following steps:

1. Strike the line sharply with the hand at a point about 2 or 3 feet from a pole, and start a stop watch simultaneously.
2. Hold the fingers lightly against the line, and, as the return wave is felt, count "one"; upon the second return, count "two," and so on.
3. In spans with estimated sags of 50 inches or less, count the number of oscillations, or return waves, occurring within 10 seconds.
4. In spans with estimated sags of more than 50 inches, measure the time in seconds for three complete oscillations.
5. Compare the observed results with the chart below, and make the necessary sag adjustments.

CHART 13

Number of Oscillations in 10 Seconds	Sag (Inches)	Time, in Seconds, for 3 Oscillations	Sag (Inches)
10	12	6¼	50—54
9½	13—14	6½	55—58
9	15—16	6¾	59—62
8½	17	7	63—67
8	18—19	7¼	68—71
7½	20—22	7½	72—77
7	23—26	7¾	78—82
6½	27—30	8	83—87
6	31—36	8¼	88—93
5½	37—43	8½	94—99
5	44—50	8¾	100—104
		9	105—111
		9¼	112—117
		9½	118—123
		9¾	124—130
		10	131—138

Wire Messengers

In large antenna installations where a considerable number of transmission lines of the coaxial type are used, it becomes necessary to have a means of support for these lines. The use of wire messengers meets this requirement. When it is required to span a road, ravine, waterway, etc., the use of messengers becomes imperative.

In selecting the type of messenger, careful consideration must be given to the type and size of wire for the weight to be supported. Loading conditions are also an important factor to consider in determining messenger supports.

In most field work, stranded, soft-drawn galvanized steel wire will most closely meet the requirements for messenger work. The following chart indicates carrying capacity for the specified wire types and sizes.

CHART 14

Wire Type	Wire Size Nominal Dia. (Inches)	Breaking Load (Pounds)	Remarks
Soft-drawn galvanized steel	3/16	2400	7-.065-inch strands
	5/16	6000	7-.109-inch strands
	3/8	11,500	7-.120-inch strands
	7/16	18,000	7-.144-inch strands
	7/64	790	Single wire, high strength, light work
Galvanized iron	1/8	645	Use only as field expedient

There are several methods of suspending the cables from the messengers. In emergencies when regular hangers are not available, the cable may be suspended from the messenger by tying a clove hitch around the cable and joining the ends of the tie in a square knot. Field wire may be used for the tie work. The ties should be spaced about six feet apart. The cable and messenger should be tied together on the ground, then raised into position, and the messenger tensioned. Wire hangers may be fabricated from #12 AWG galvanized steel wire, if available. See figure 255.

Tension Bridges

A tension bridge is a means of reinforcing a joint or connection in a cable, to prevent unnecessary strain at that point. Two general methods of bridging are illustrated in figure 256.

Choosing Antenna Site for Optimum Operation

The location of an antenna installation is of extreme importance when top efficiency is to be obtained. In choosing the proper antenna site, the fullest advantage of the existing terrain must be taken. In the case of highly directive antennas, such as the rhombic, this factor is extremely important, for a poor antenna site will cause a sharp drop in antenna efficiency and, therefore, a reduction in over-all operating performance.

Low-Frequency, Medium-Frequency, and High-Frequency Antennas

1. If possible, the antenna should be erected over flat terrain, with no large obstructions, such as buildings or hills, in the immediate area.
2. In the case of terminated long-wire antennas and nonresonant rhombics, the terrain immediately in front of the terminated end should be level for at least one mile.

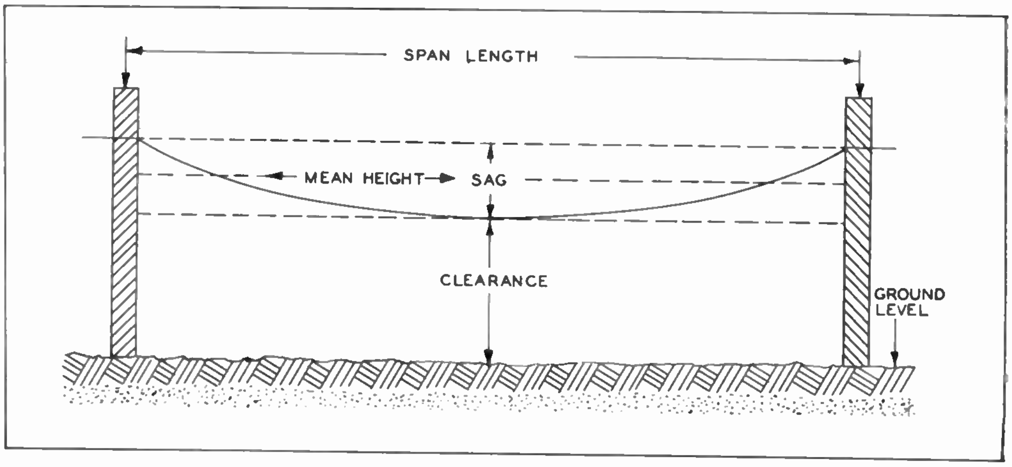


Figure 254. Measurement of Antenna Sag.

3. If the antenna must be erected over ground where there are differences in elevation at the various pole sites, it should be erected with the antenna wires level. Their elevation should be the average of the elevation of the four pole sites plus the recommended height above ground.

4. If possible, avoid having such obstructions as hills and large buildings directly in line with the main power lobe of the proposed antenna.

5. Because of possible high absorption losses, the antenna should not be erected over a heavily wooded area.

V-H-F Antennas

In v-h-f communication circuits, the proper choice of antenna sites becomes of paramount importance. It must be remembered that tactical conditions will primarily dictate the antenna site, but full advantage must be taken of the available location, as previously stated. When a v-h-f radio relay link system of the multi-channel type is to be installed, careful planning of sites for the relay links must be undertaken.

The following considerations are important in the choice of an antenna site for v-h-f antennas and for antennas in the upper end of the high-frequency band:

1. Dense wooded areas must be avoided.

2. If vertically polarized antennas are to be used, several sites, a short distance apart in the same cleared area, should be tried, and the location that gives the best operation should be used.

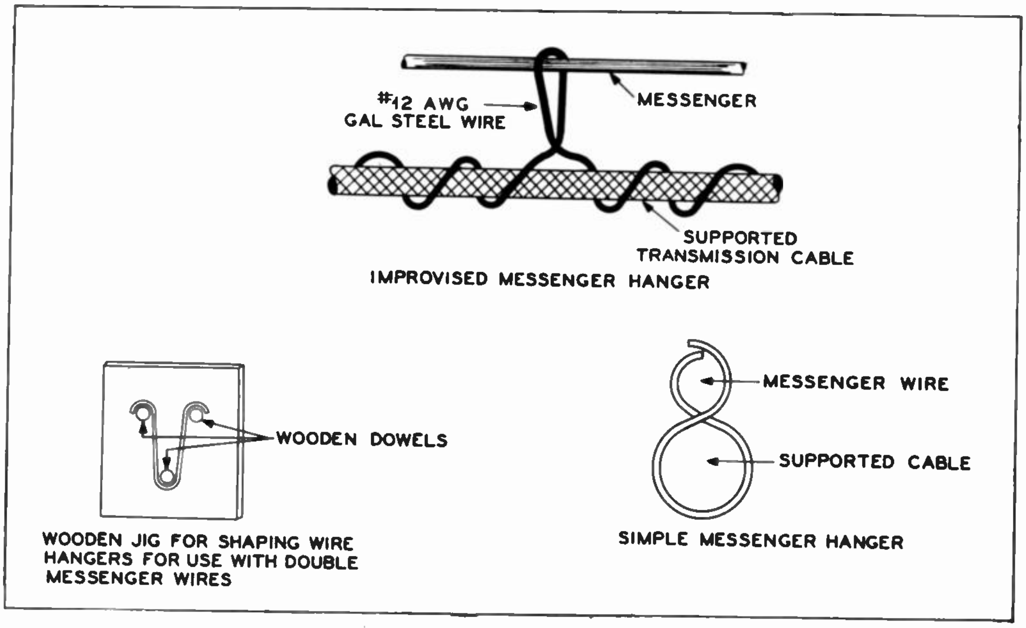


Figure 255. Improvised Messenger Hangers.

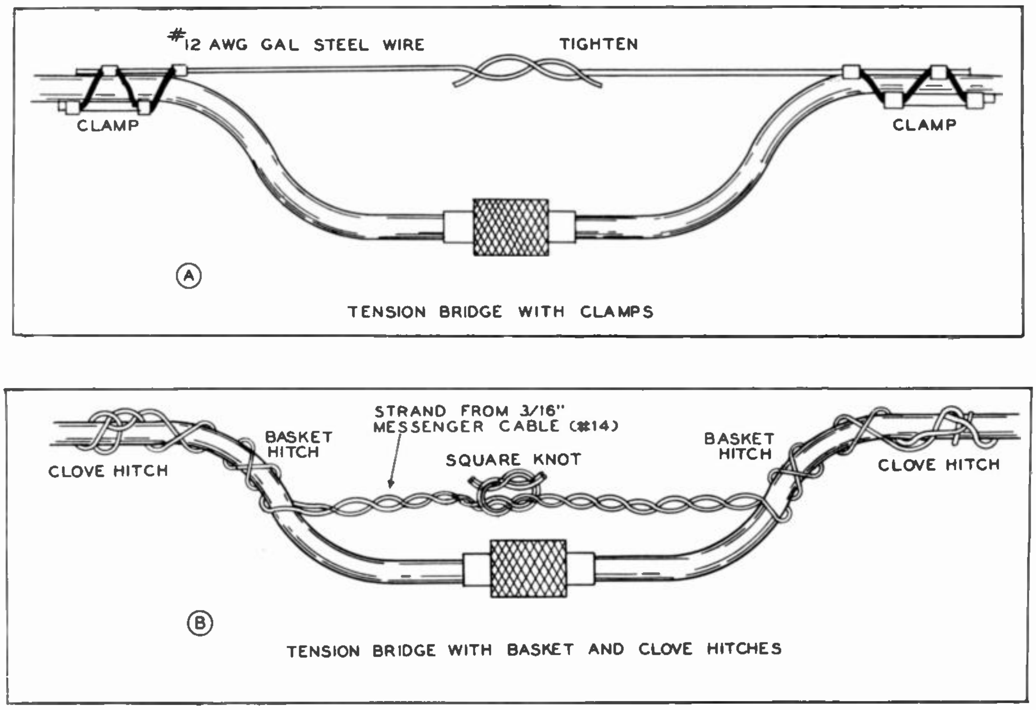


Figure 256. Method of Improvising Tension Bridges.

3. In flat country, the antenna masts should be located as high as possible, and any depressions in the ground should be avoided.

4. In mountainous and hilly country, the antennas should be located on the forward side of the hills, and high enough to provide line-of-sight paths.

5. In mountainous terrain, in a situation where the straight-line path between stations crosses the peak of a nearby hill, best results can be obtained by orienting the antenna so that it points, at a slight angle, off to the side of the straight-line course.

6. In transmission over sea water, when using vertical polarization, the antenna height has no appreciable effect on the efficiency in the lower end of the v-h-f band, but height does have an effect in the high end of the band. When a horizontally polarized antenna is used, the higher the mast, the better the signal, regardless of frequency.

The problem of correct layout for an antenna installation for the desired direction of transmission requires a knowledge of the following factors:

1. The longitude and latitude of the proposed transmitting location.

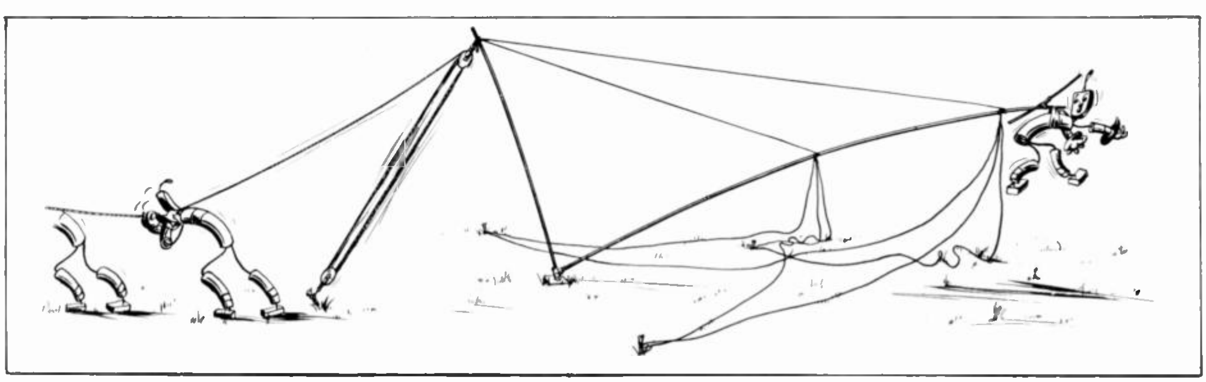
2. The longitude and latitude of the receiving location, or locations.

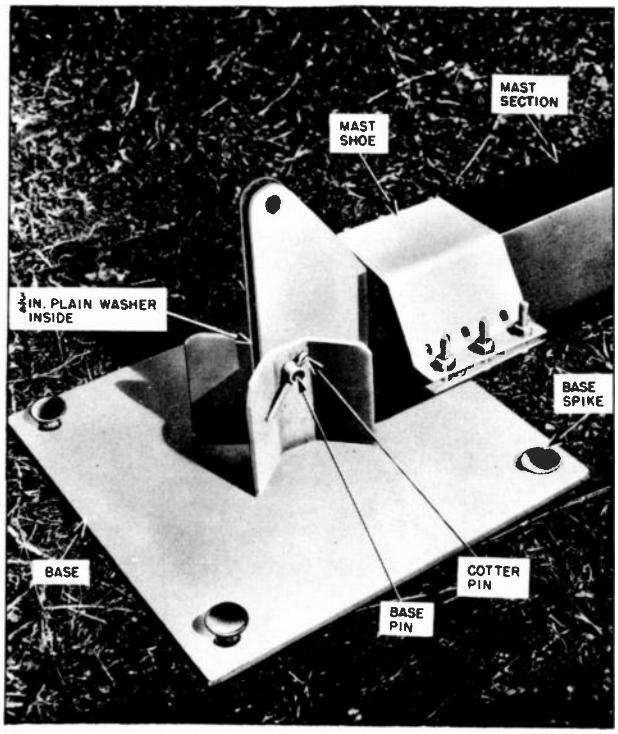
3. The direction of true north from the transmitting location.

Information on the longitude and latitude of a location is generally available from civil or military agencies. The direction of true north from the transmitting site may be determined by any one of several methods:

1. The line of a shadow from a vertically placed object (such as a pole, or building with straight vertical sides), at noon.

2. A magnetic compass and the magnetic declination for the particular location.





Detail of Special Base Plate and Hinge Assembly for a Light-Weight, Mast-Section-Type Antenna Structure.

3. The direction of a line to the north polar star.

The determination of true north by the "shadow" method is accurate only if the exact standard time for the particular longitude is known. In the northern latitudes, the direction of the shadow at noon points to true north, while in the southern latitude, true north is exactly opposite to the direction of the shadow.

When determining true north by the compass method, the compass should be mounted on a solidly placed tripod, near eye level. A sighting stick, consisting of a narrow, straight, wooden stick, with *a nail in a vertical position* at each end, should be made. When the compass needle stops oscillating, the direction of magnetic north can be determined by laying the stick along the line of the compass needle, and sighting toward the north. In order to determine true north, the magnetic declination for the particular location must be known. This can be found on navigation maps of the area, such as loran, coast and geodetic survey, or marine navigation maps. The sighting stick must be rotated to the right or left by an amount equal to the magnitude but opposite to the direction of the declination for the particular location. For example, in the area between New York City, N. Y. and Philadelphia, Penna. the magnetic declination is 9° 30′ west. Thus, if a magnetic compass was used for determining true north in this location the true north reading would be 9° 30′ to the east of the indicated compass reading. Therefore, the sighting stick should be rotated 9° 30′ to the right of the compass needle direction for the true north indication.

The simplest method of determining true north is by sighting the direction of the north polar star. A straight rod, or pipe, about 8 or 10 feet long, should be mounted on a solid, exactly vertical, supporting structure. This sighting device should be pivoted so that it can be moved upward or downward, and to the right or left. After a sighting has been made on the north polar star, drop a plumb line from the end pointing toward the star; this locates the point on the ground which is exactly in line with the sighting point and the north polar star. The same result can be accomplished by dropping a pebble from the far end of the sighting device.

After the direction of true north is determined, a line should be staked out for a distance of 10 or 20 feet.

The next operation is to determine the exact required bearing of the antenna toward the desired receiving location with respect to true north.

The required bearing of the antenna can be determined by one of three methods:

1. Calculating by spherical trigonometry.

2. Determining the direction of the receiving location by the great circle route on a global atlas.

3. Laying out the direction of true north and the receiving location on an azimuthal map.

Knowing the longitude and latitude of the transmitter and receiver favors the use of spherical trigonometry for extreme accuracy. By this method the exact bearing and distance can be determined.

A large global atlas can be used to determine the required antenna bearing by running a string from the proposed transmitting location on the globe to true north (previously determined), and by running another string from the transmitting location to the receiving location. Both strings must lay along a great circle route. The angle formed at the transmitting point by the strings on the globe is the bearing angle to be used for orienting the antenna. The axis of the major lobe of any directive or nondirective antenna arrangement, should lay along this line.

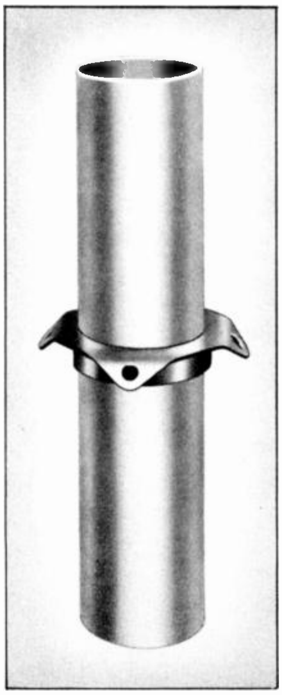
In using the azimuthal map, two straight lines are drawn from the transmitting point; one to true north and the other to the receiving location. The angle formed by the two lines is the bearing angle for the antenna orientation. The azimuthal type of aerial navigation map has a high degree of accuracy.

In the layout of antenna installations, such as large rhombics or Adcock range antennas, extreme accuracy must be attained. In these operations, the facilities of a local engineering agency should be utilized.

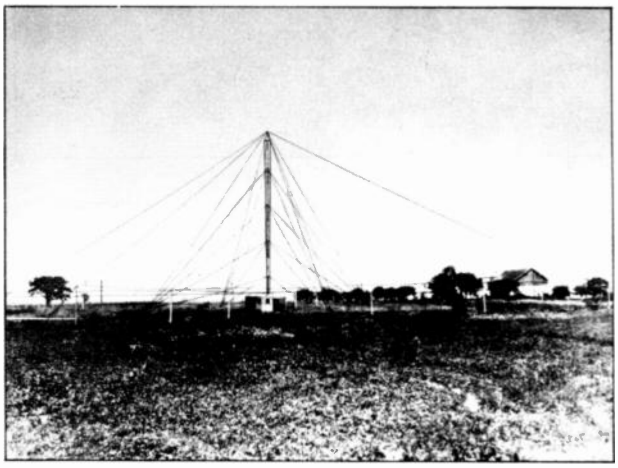
GUYS AND ANCHORS

Guying of Structures

The purpose of guy wires is to add strength to an upright structure in such a direction as to overcome the horizontal stress created by the pull of a horizontal antenna (back-guying) and to prevent swaying of the

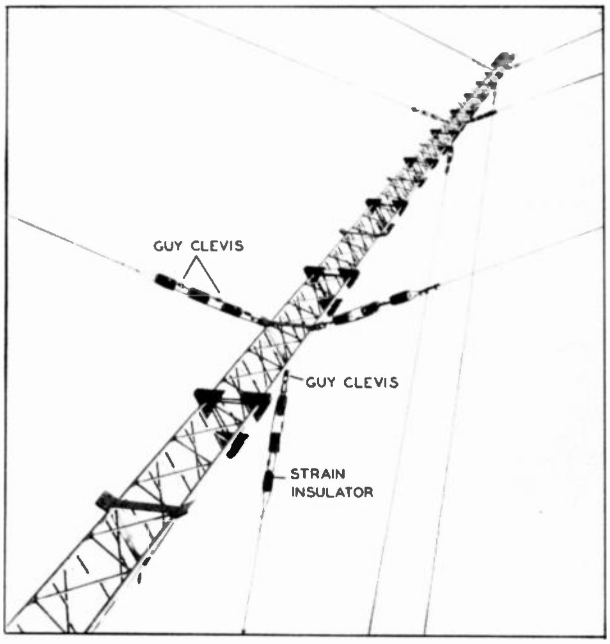


Cut-Away Section of Antenna Mast with Guy Plate Installed.



Typical Method of Guying a Medium-Height Structure.

structure in any direction in the presence of a high wind. The latter guying properties, will be partially lost if the guys do not provide equal amounts of pull in different directions. This effect can be avoided by attaching guy wires at points of equal height on the structure (120 degrees apart when using three-point guying or 90 degrees apart when using four-point guying), by staking the guys at equal distances from the base of the mast, and by adjusting them to the same tension.



Attachment of Guys to Steel Tower.

Guying systems are usually available in kit sets; after a visual inspection and a tightness check of the clamps, the guys can be quickly and easily attached to the structure and anchored according to the instructions included. When guy kits are not furnished, and guys must be made on location, it is recommended that, wherever possible, they be fabricated in a shop where the proper facilities are available. The following hints on the fabrication of guying systems will be found helpful.

The size and type of wire to be used for guying a specific structure is dependent upon the height of the structure, the weight and stress of the antenna, and the loading conditions of the locality.

For a safe approximation in determining the size of guy wire to employ, multiply the size of the wire used for the antenna curtain by a factor of 3 or 4 for normal loading areas, and by a factor of 5 to 7 for abnormal loading areas.

The "loading" of aerial communication lines is a term applied to the effects of varied weather conditions, such as wind velocities, temperature, ice formation, etc. In selecting the type and size of wire to be used in a certain locality where loading conditions are not known, an attempt should be made, in advance of construction, to obtain this information from communications or electric light agencies familiar with that area. Where this cannot be done, a general rule to follow is to use heavy loading construction in latitudes above 40°, medium loading construction between 30° and 40°, and light loading in latitudes below 30°. There are, of course, exceptions to this rule, and ingenuity as well as common sense will play an important part in the final decisions.

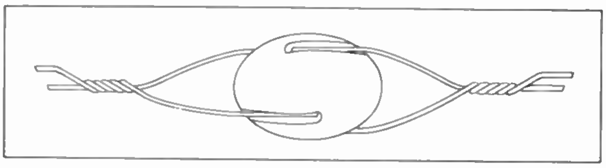
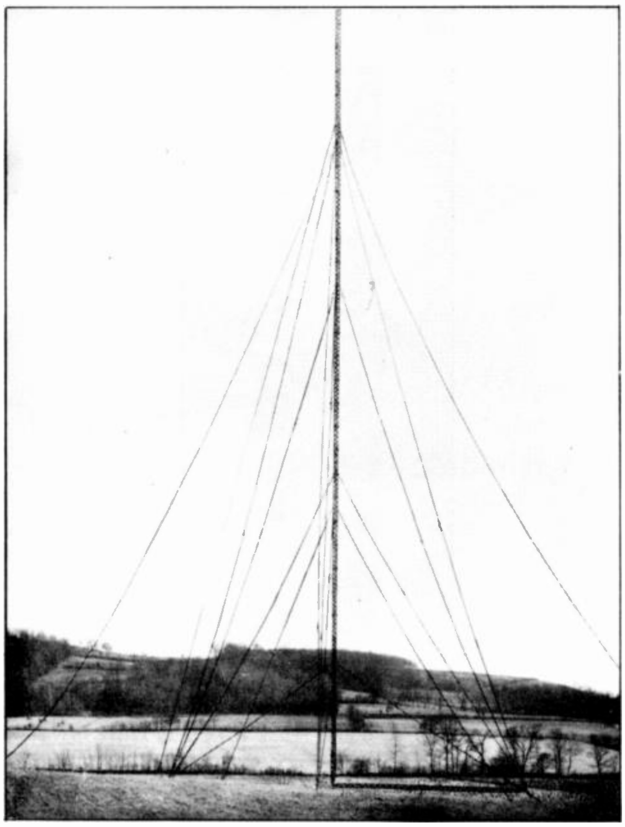


Figure 257. Ball-Strain-Type Porcelain Insulator.



Typical Method of Guying a Tall Structure.

Materials which have proven to be very satisfac:ory for guying are stranded copperweld, galvanized steel, aluminum, and nylon. Material such as untreated steel, hemp, or cotton are not suitable, as they will fail in a very short time.

If more than one size of suitable wire for guying purposes is available, use the heaviest wire, as a safety factor is important in this work.

In installations where light-weight guying for temporary work is required, nylon rope guys are recommended. Nylon rope is strong and flexible, and is moisture- and fungi-repellent. Although it stretches under strain, this fault may be overcome prior to the time of installation, by prestretching it.

Guy wires on antenna structures should be broken up at intervals of less than one quarter wave length of the highest frequency of operation. Ball-strain-type porcelain insulators (see figure 257) are usually used, as they provide a safety factor in case of insulator breakage. The spacing of insulators is more important at the connection of the guy to the eyebolt in the structure than at the anchor tie point. Guys on transmission-line poles do not require strain insulators.

Guy wires should be temporarily tensioned by using come-along grips, and for fixed installation work, turnbuckles should be used near the anchor ties.

Guy wires should never be pulled taut, because in that condition they are more susceptible to breakage under wind pressure. The amount of guy-wire tension applied should never exceed the minimum required to keep the structure in a vertical position, allowing a slight amount of sway.

Figure 258, shows typical guy wire construction. The over-all length and the spacing between strain insulators is dependent upon the application. All connections should be made with care, as the strength of the entire guy wire will depend upon the strength of each joint. Before the structure is raised into position, make sure that there are no kinks in any of the wires; also, during erection operations, make sure that equal and sufficient tension is maintained in all lifting ropes and guys. A well-balanced guying system will keep the tallest, heaviest structure in a steady vertical position under conditions of extreme stress and strain. Guy wires and all connections at clamps, etc., should be checked periodically for signs of wear or loosening. Guy-wire tensions should also be tested regularly, and compensations made with turnbuckles or come-along grips when necessary.

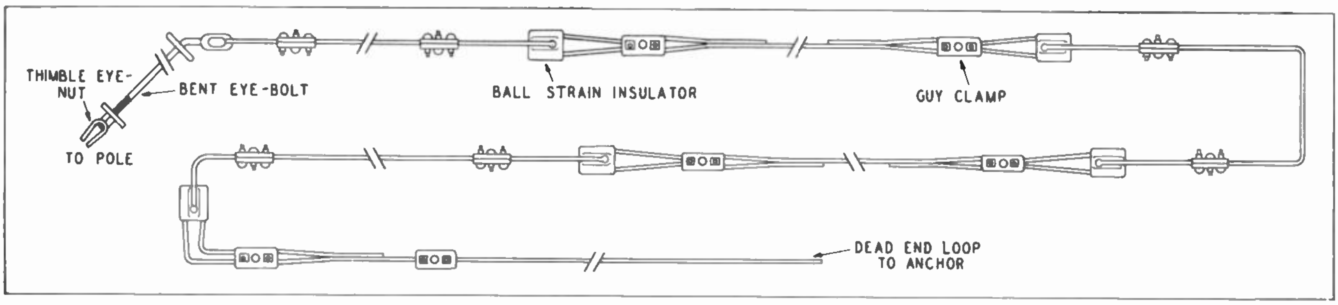
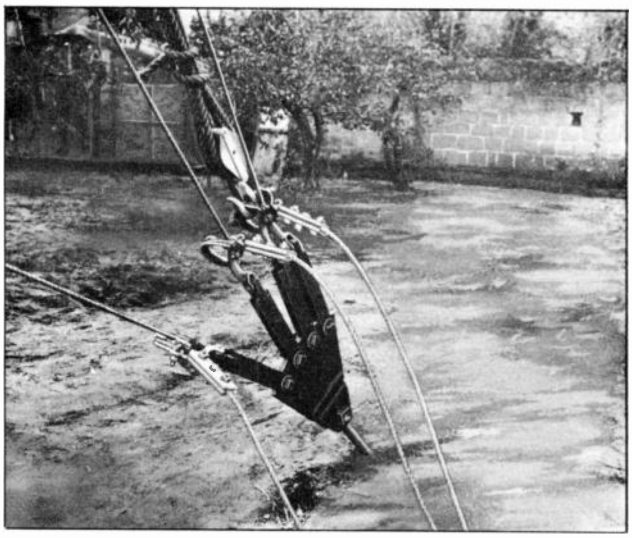
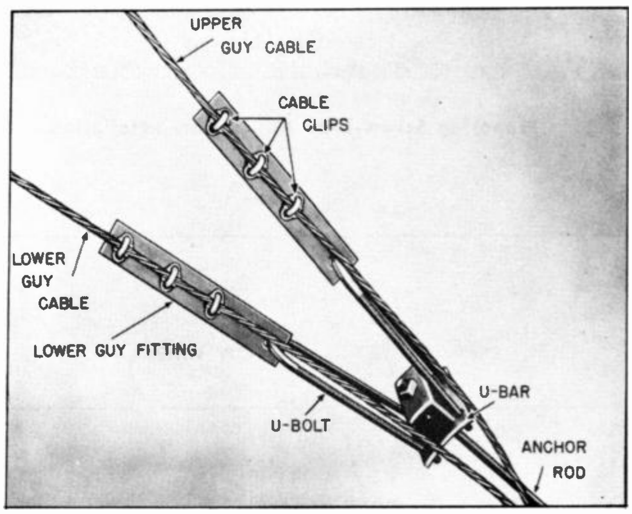


Figure 258. Typical Guy-Wire Construction.



Multiple-Guy Anchor Assembly.



Detail of Guy-Wire Connection to Anchor Rod.

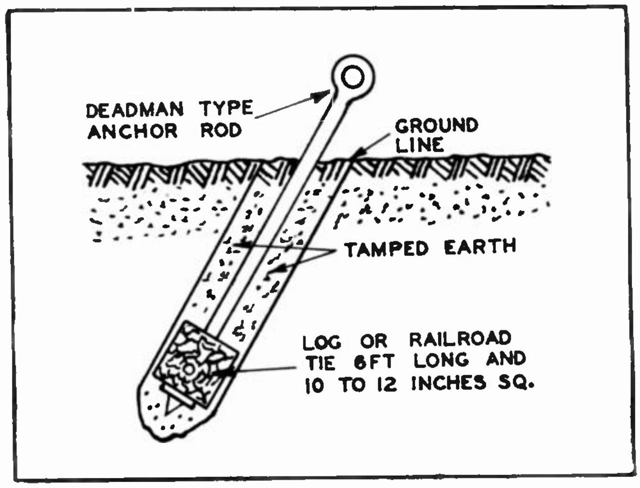


Figure 259. Permanent Deadman-Type Anchor.

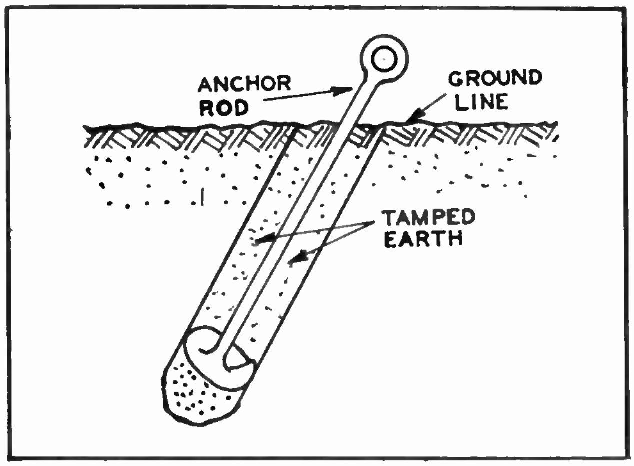


Figure 260. Screw-Type Anchor.

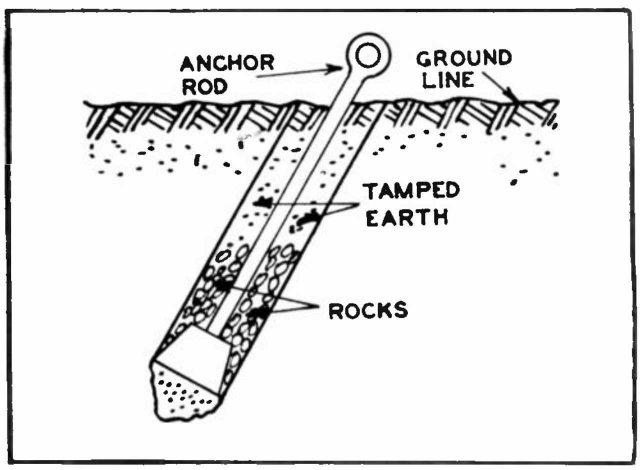


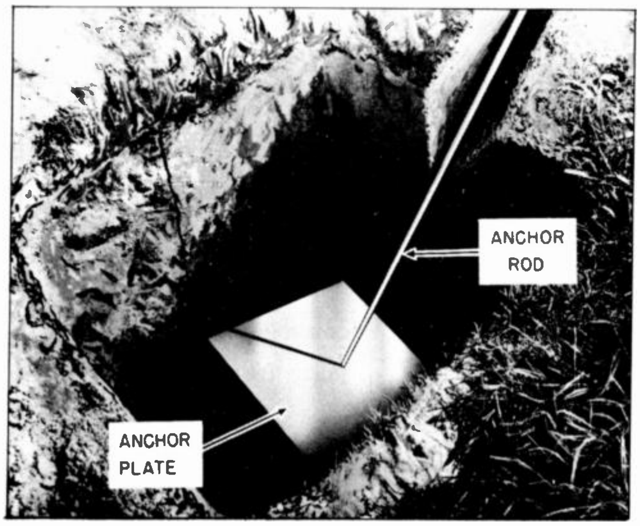
Figure 261. Cone-Type Anchor.

Self-supporting towers should be utilized where conditions permit. Experience has shown that guy wires, in many cases, are a contributing factor to spurious radiations. These spurious radiations affect receiving services in the immediate locality.

Types of Anchors

As may be expected, the kind of anchor used in antenna-structure work depends to a large extent upon the soil conditions encountered.

A permanent type of anchor used in heavy-structure construction is called the "deadman" type of anchor. This consists of a 1¼" galvanized steel rod, 6 or 8 feet long, and a wooden log 1 foot in diameter and 6 to 12 feet in length, the size depending upon the available wood and the type of soil at the anchor location. The rod is screwed and bolted to the log, which is placed



Installation of Flat-Plate-Type Anchor.

Preparing Screw-Type Anchor for Installation.

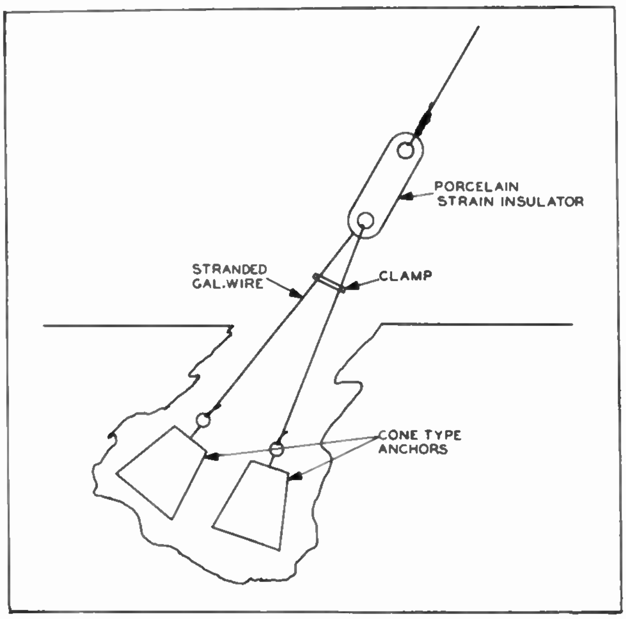


Figure 262. Bridle Arrangement for Cone-Type Anchors.

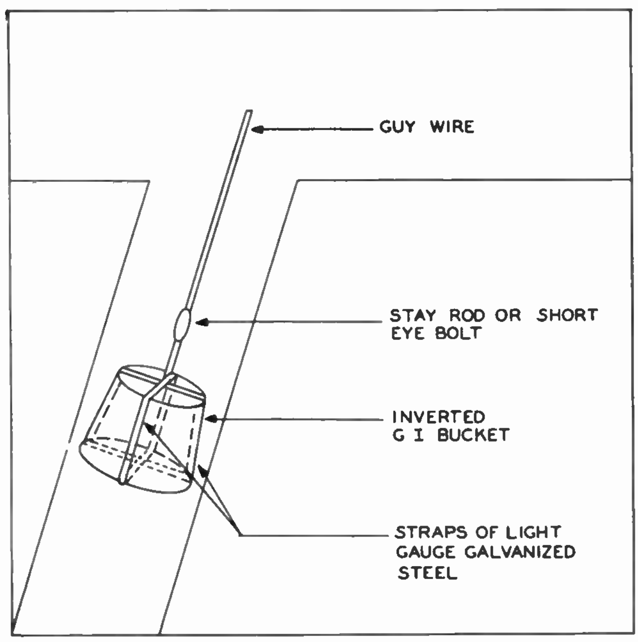


Figure 263. Improvised Bucket-Type Anchor.

5 to 6 feet below tne surface of the earth, with the anchor rod placed at an angle directly in line with the strain of the guy, when connected. See figure 259.

The screw-type anchor is used when the soil is firm. This anchor consists of a 6-foot rod with a plate at the end, so that it can be screwed into the ground. An eyelet at the other end of the rod allows a steel bar to be used when screwing the rod into the ground. See figure 260.

Other types of anchors are furnished with specific antenna kits, such as the cone-type anchor and the expanding-plate anchor. The cone-type anchor is fairly common. When using this anchor, care should be taken to firmly pack the backfill with rock or concrete, to prevent the cone from pulling out. See figure 261.

Where the nature of the soil is such that two anchors are required for the guys, the connection of the anchor

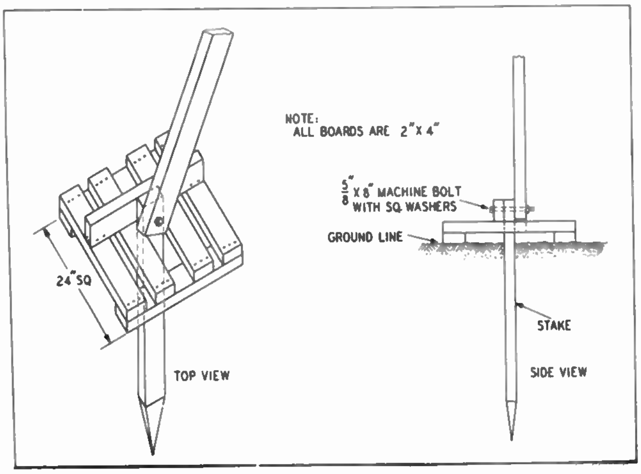


Figure 264. Swamp Footing for Pole Supports.

to the guy must be made in the form of a bridle (see figure 262), with the stranded wire passing from one anchor through the porcelain strain insulator and back to the second anchor, with a clamp at the insulator.

In soft and mucky ground, a satisfactory anchor may sometimes be improvised by using an ordinary bucket. The bucket is inverted and placed in the ground. The suction effect provides sufficient holding strength for normal strains. See figure 263.

Special Bases and Anchors

In swampy or other unstable ground, it may be necessary to provide additional bearing area for supports. Figure 264 shows a method of constructing a "swamp footing" of either 4 x 4 or round poles.

If it is necessary to use rock anchors for the guy wires, a satisfactory scheme, which makes use of materials usually available, is shown in figure 265. This anchor is shown with a single guy wire, but it is also suitable for use with a double guy of the type used with earth anchors.

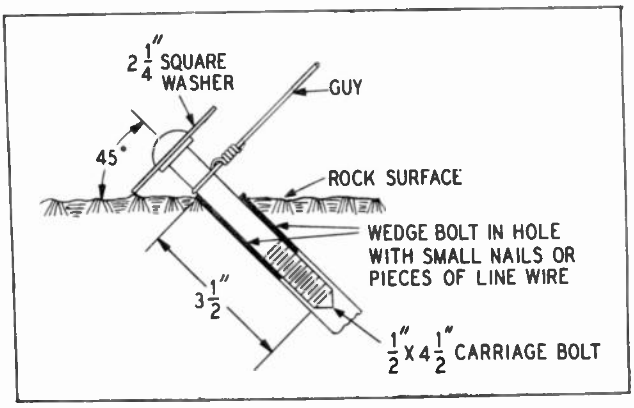


Figure 265. Improvised Rock Anchor.

GROUNDS AND COUNTERPOISES

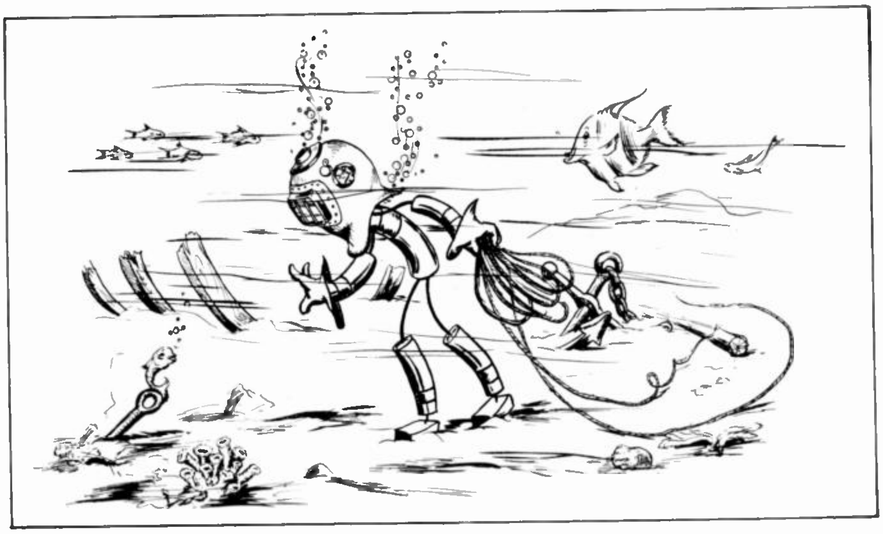
At the lower radio frequencies, one of the prime requirements for optimum operation is a good, low-resistance ground.

Types of Grounds

A water pipe can be used as an emergency ground, but this seldom results in the best possible antenna performance. If a water pipe must be used, a cold-water pipe should be employed. The connection to the pipe is made by scraping the pipe, fitting a ground clamp, and making a good connection to the strap. The connection may be taped for protection against oxidation. See figure 266.

If no water pipe is available, a simple outdoor ground can be made by driving a 6-foot length of pipe into the soil where there is natural moisture. A multiple grounding system that is more efficient can be made by using 4 lengths of pipe arranged at the corners of a 10-foot square, and connecting them all together at the top.

Chemical treatment of the ground where the rods



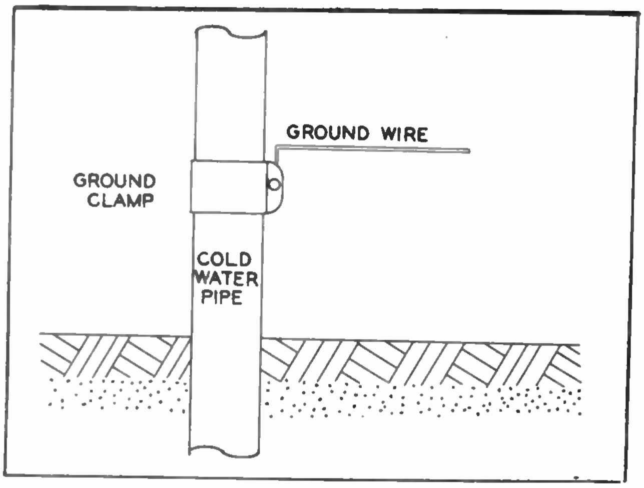


Figure 266. Cold-Water-Pipe Ground.

are driven may be used to decrease the resistance. See figure 267.

A series of conductors buried 1 or 2 feet beneath the surface, and arranged in a radial pattern like the spokes of a wheel reduces losses in the ground in the immediate vicinity of the antenna. See figure 268.

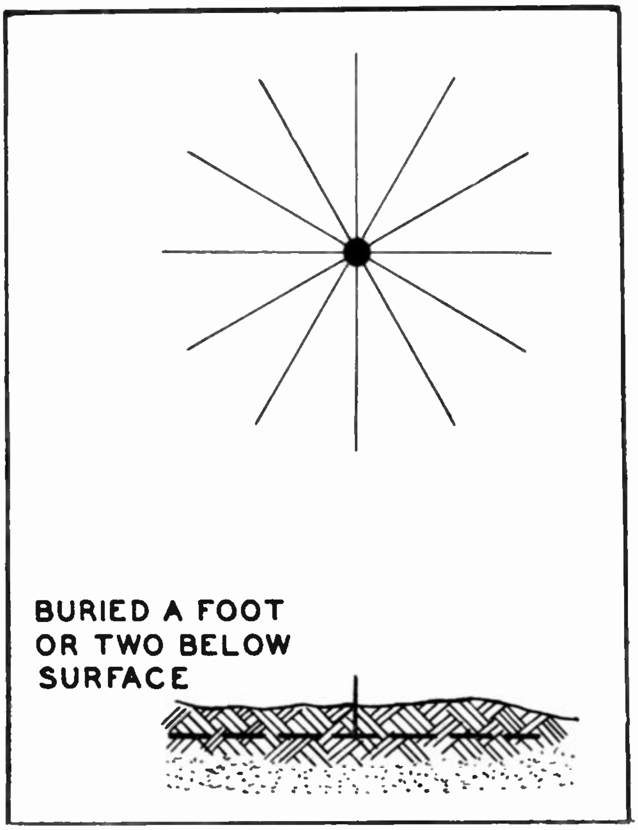


Figure 268. Radial System of Buried Copper Conductor Provides a Good Ground.

Types of Counterpoises

When an extensive radial ground system is not practical because of rocky or sandy soil, a counterpoise, which is a capacitance ground, is used.

Normally, the counterpoise is made as large in area as the location will permit. It is usually made in a circular form, with the ends of the radial wires separated about 5 to 10 feet. At approximately every 10 feet, adjacent wires are jumpered, to prevent any resonance effects. The counterpoise is usually constructed about 6 to 10 feet above the ground, but it should be remembered that the height of the antenna is effectively reduced by an amount equal to the height of the counterpoise. See figure 269.

A practical counterpoise may be made by assembling a large screen of chicken wire or similar material. This screen may be placed on the ground, but better results are obtained if it is placed a few feet above the ground.

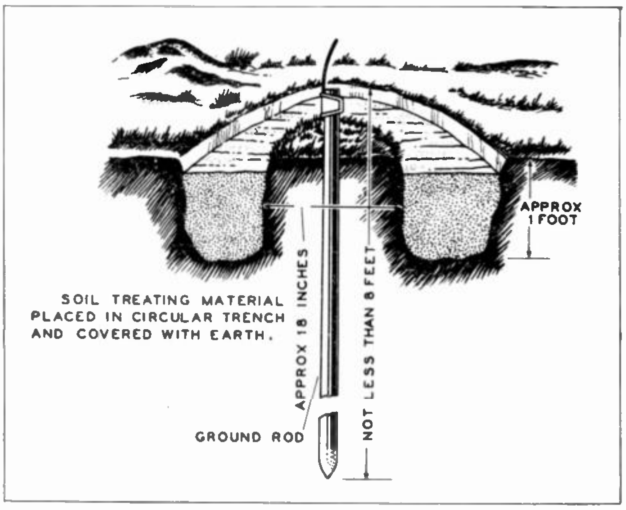


Figure 267. Chemical Treatment of Ground to Increase Conductivity.

TRANSMISSION LINES

Types of Lines

The various types of transmission lines used in the field can be placed into three general classifications, as follows:

1. Open-wire lines.
2. Coaxial cables.
3. Twisted-pair and twin-conductor lines.

Open-Wire Lines

An open-wire transmission line consists of two or more parallel wires spaced by insulators throughout the length of the line. In most applications, 600-ohm (characteristic impedance) lines are constructed of a pair of #6 (B & S) copper wires, spaced 12 inches apart. For practical uses, open-wire transmission lines

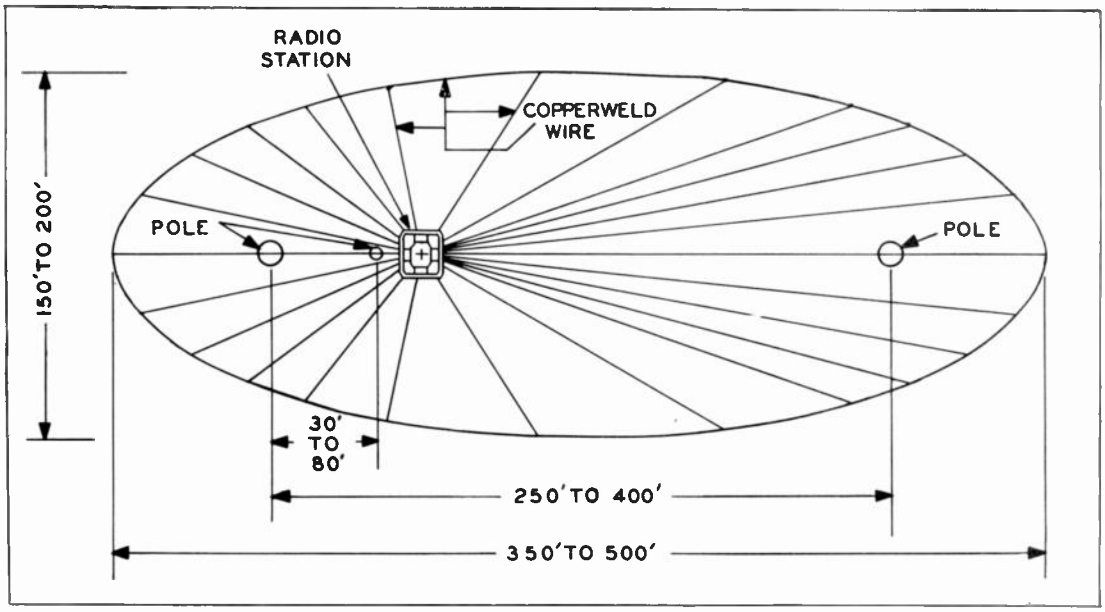
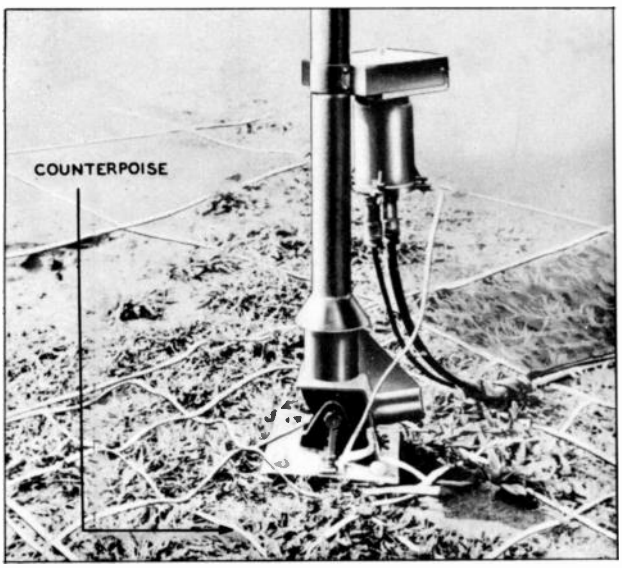
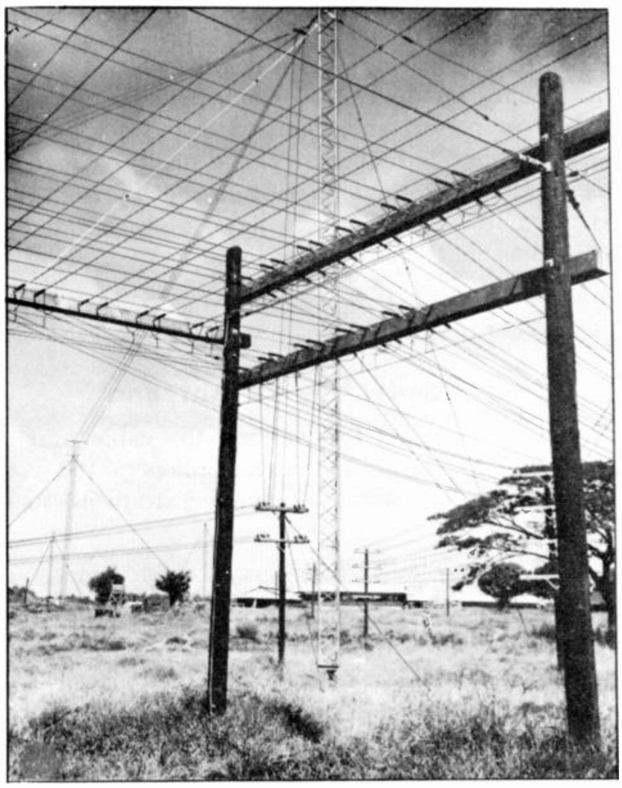


Figure 269. Layout of Typical Counterpoise System.



Counterpoise of Meshed Wire for Light Antenna Structure.

can be constructed so that characteristic impedances of 200 to 800 ohms are obtained. Open-wire lines can be easily balanced to ground and surrounding objects, because of the symmetry of their construction. These lines have a low transmission loss, that is, attenuation per unit length.



Multiple-Transmission-Line Crossarm Supporting Frame.

Coaxial Cables

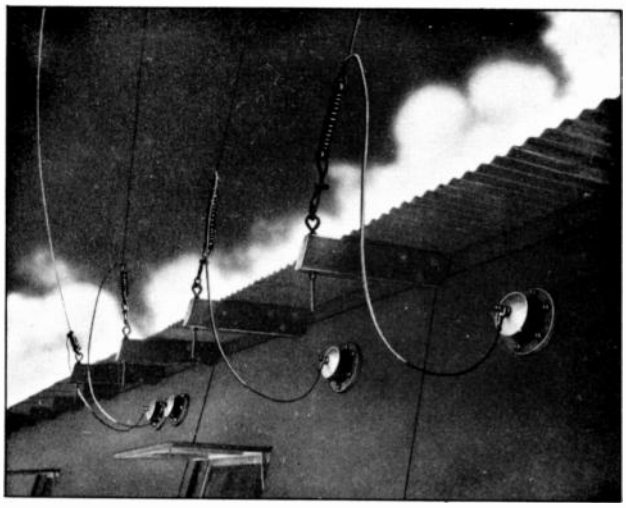
Coaxial transmission lines are made in two general types; one type employs a hollow tube in which a conductor is placed coaxially and supported at intervals by insulators; the other type uses an outer metallic braid enclosing the inner coaxial conductor, which is separated from the braid by solid, flexible insulation. Coaxial cables usually have characteristic impedances ranging from 50 to 200 ohms. The hollow-tubing type (concentric line) is widely used in u-h-f work. These lines have a relatively high transmission loss per unit length, as compared to open-wire lines. In special applications, where a balanced and well-shielded transmission line is required, a special, dual-coaxial cable can be fabricated by strapping two solid-dielectric-type cables together and using their inner conductors as the transmission line and the outer metallic-braid conductor, soldered together at both ends, for the shield. The transmission losses of this dual-coaxial line is similar to single coaxial lines, but the characteristic impedance is doubled.

Twisted-Pair and Twin-Conductor Lines

Twisted-pair line consists of two separately insulated wires twisted together, with or without a metallic-braid covering. This type of line usually has a characteristic impedance ranging from 70 to 150 ohms. These lines have a relatively high transmission loss per unit length. When the line is moist, the losses may be several db greater per unit length than those in a dry line; therefore, this type of line should be used only in emergencies.

Twin-conductor line, which consists of two evenly spaced wires molded into a common insulator, such as vinyl or polystyrene, approaches the qualities of open-wire lines, but, because of the small spacing between conductors, the impedance is much lower. The loss per unit length in these lines is also relatively higher than that in open-wire lines.

Coaxial-Transmission-Line Channelling on Outside and at Entrance to Transmitter Building.



Single-Wire Feed Lines Entering Transmitter Building Through Pyrex Feed-Through Insulators.

Preparation of Coaxial-Type Line For Connection to Antenna

The tools required for working the cable are: a sharp knife, a pair of combination pliers, a 100-watt soldering iron, and a sharp-pointed instrument, such as a scriber.

1. Cut a suitable length of coaxial line.

2. Mark the outer covering with a knife at a point 11″ from the end of the cable. Cut the outer covering completely around the cable; be careful not to cut into, or mark, the braid beneath this covering. Then slit the 11″ piece of covering lengthwise, and remove it.

3. Apply a light backward pressure on the end of the shield, to loosen it. Using a sharp-pointed instrument, unbraid the shield carefully, for a distance of 10 inches from the end. See figure 270. Be careful not to damage the dielectric beneath the shield.

4. Twist the loosened ends of the shield to form a pigtail conductor.

5. Mark the dielectric carefully, 4 inches from the end, by pressing the knife blade directly in to a depth of about 1/16″, continuing around the cable.

Caution: Do not scratch the inner conductor with the knife, or it will break later.

6. Repeat this marking of the dielectric, at small intervals, out to the end, without touching the inner conductor with the knife blade. The dielectric can now be broken at each mark by gently bending it back and forth.

7. Remove each small section of dielectric, in turn, by pulling it with the pliers while twisting in the same direction that the wire (if stranded) was twisted during manufacture. Do not allow the remaining dielectric to become wet or soiled.

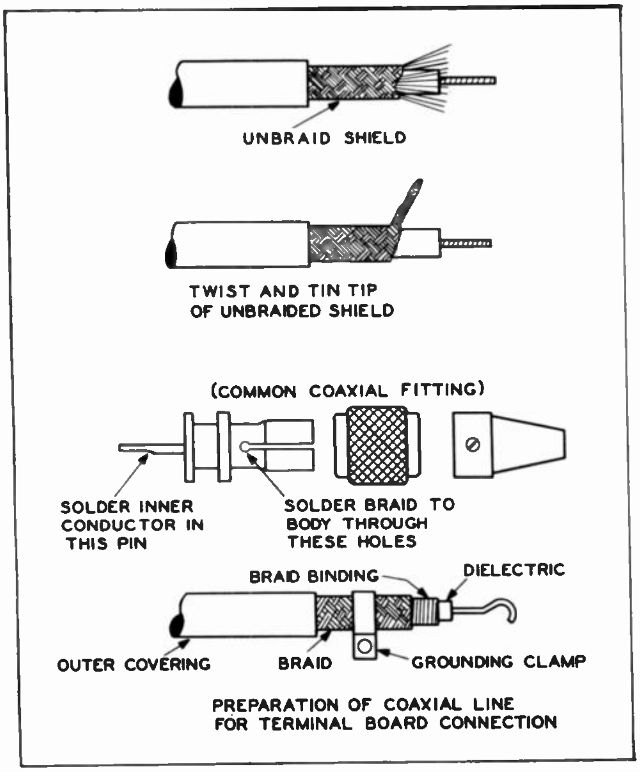


Figure 270. Preparation of Coaxial Line for Soldering.

Soldering of Coaxial Fittings

1. The length of cable to be stripped depends upon the fitting used. Cut the outer braid at the desired point with a knife, circling the covering. See figure 271. Then split the covering lengthwise and remove it.

2. For installations where the coaxial line does not terminate in a plug, unravel the outer copper-braid conductor shield for the required distance from the end of the stripped outer covering. Then twist the outer braid to form a ground lead.

3. After marking the desired length of dielectric to be stripped, follow the same procedure as in removing the outer covering, and remove the dielectric from the center conductor.

4. Tin the center conductor and the end of the twisted outer braid.

5. If a special jam-nut is provided, fan out the outer braid, slip on the join-nut and fitting, and push the outer braid into the fitting, allowing about ¼" of braid to extend past the jam-nut when tightened. Using a knife, trim the braid off flush with the jam-nut.

6. Disassemble the coaxial fitting, and fit over the conductor, seating the inner conductor into place. Solder the outer braid lead to the fitting, and tighten the entire assembly. Bind the outer insulating covering with lacing cord, approximately 1" from the end

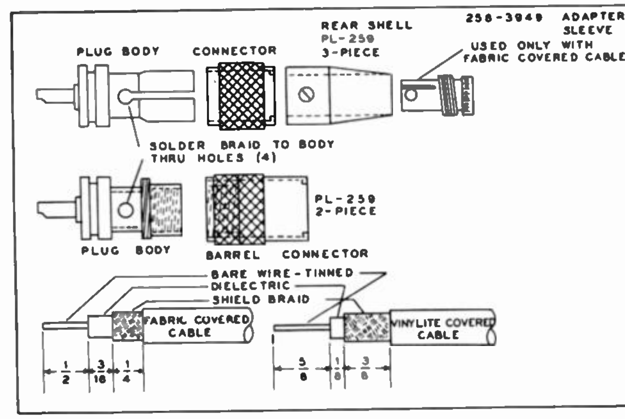


Figure 271. Soldering of Coaxial Fittings.

of the fitting, and treat with lacquer or radio speaker cement.

Improvised Lines

In general, field wires are poor substitutes for coaxial cable, and should be used as emergency r-f transmission lines only when the signals are sufficiently strong to withstand appreciable loss. The higher the frequency used, the greater the transmission losses. A good spaced-wire line can be improvised for the v-h-f band, when coaxial cable cannot be obtained, by using two conductors of any available type of insulated wire, separated by wood blocks or some other insulating material, at two foot intervals. Paired wire such as W-110B or W-143 may be used. The wire can be fastened to the separating blocks by means of tape, string, or wire. A twisted pair may be used as a 150-ohm, quarter-wave matching section between the spaced line (impedance 400 to 500 ohms) and a half-wave antenna (center impedance of 50 to 70 ohms). See figure 272.

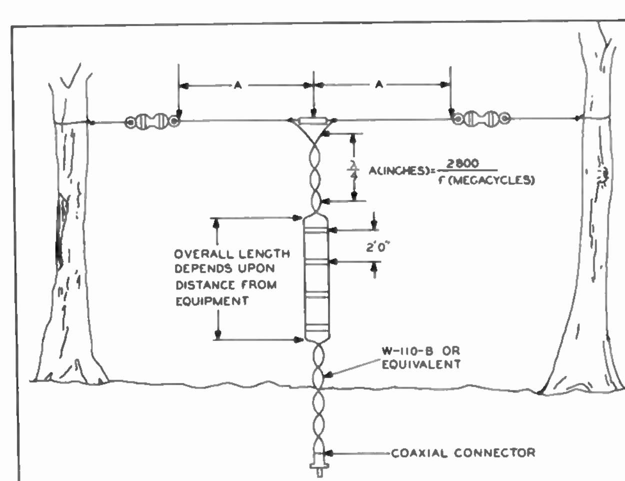


Figure 272. Improvised Transmission Line.

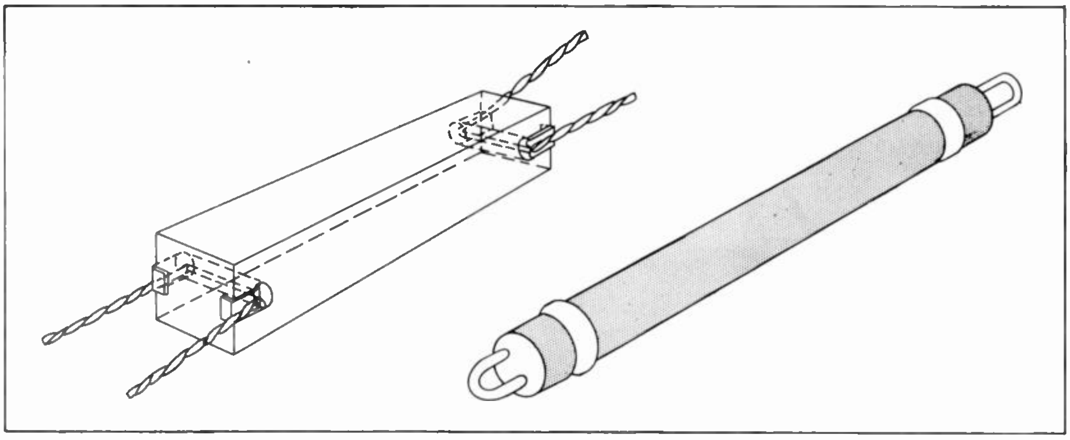


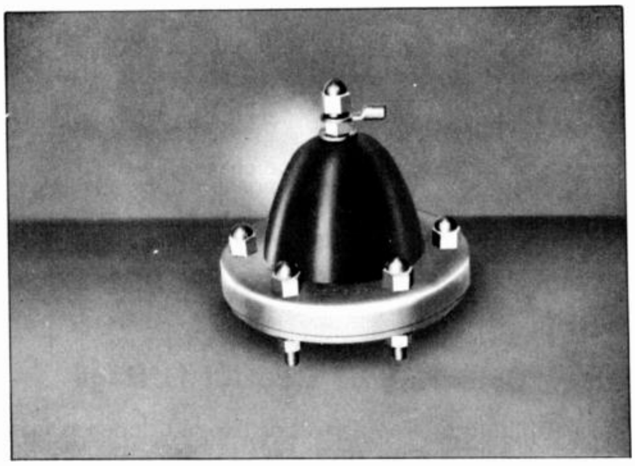
Figure 273. Two Types of Strain Insulators for Antenna Ends.

Insulators

Insulators for antennas and transmission lines are designed in various shapes and for many different uses. There are strain insulators, which are used to tie single-wire supports to specific tie points. These are made of hard rubber, isolantite, or ceramic, and are made in rectangular or cylindrical shapes with holes at each end. See figure 273. Some strain insulators have eyebolts at the ends, for tie points. Another type of insulator is called the spreader type, and usually consists of an isolantite body, 5/8" in diameter and 2¾" long, with a catch at each end. See figure 274. This type of insulator is used for spacing an open-wire type of transmission line to a half-wave antenna.

Feed-through insulators serve the purpose of providing a good insulating surface for feeding transmission lines through a wall. These are usually shaped like a bowl, and are made of porcelain or ceramic. See figure 275.

Standoff type insulators are used for supporting a transmission line away from a wall or siding. These



Bowl-Type, Ceramic, Stand-Off Insulator.

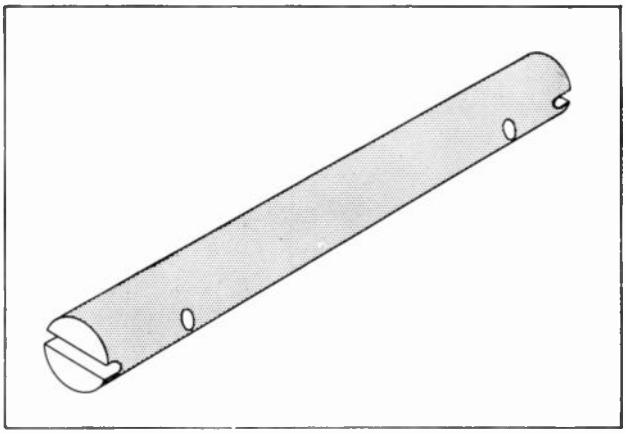


Figure 274. Spreader Insulator.

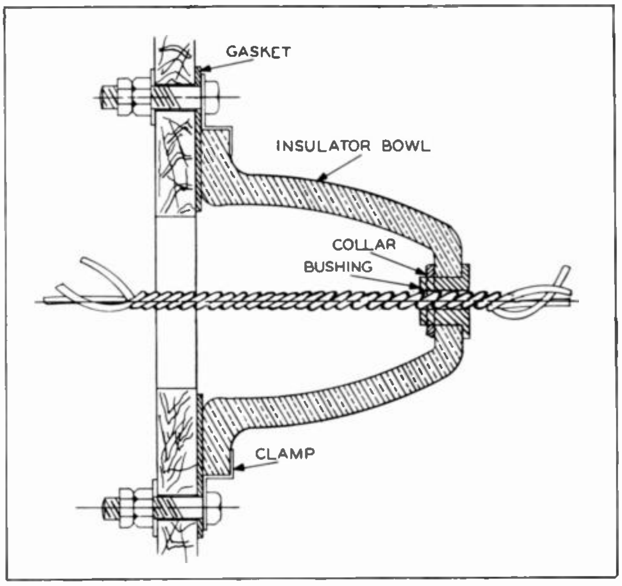


Figure 275. Bowl-Type Feed-Through Insulator.

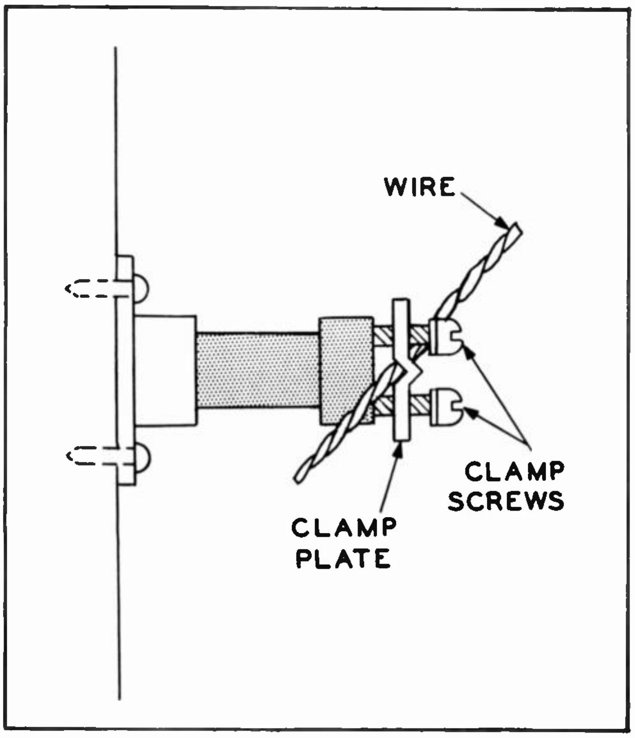


Figure 276. Horn-Type Stand-Off Insulator.

insulators have a base in which holes are drilled for mounting, and a top clamping arrangement through which the transmission line is fed and secured. See figure 276.

SHORT CUTS IN ANTENNA AND TRANSMISSION-LINE WORK

With large guy wires, it is difficult to make tight joints at the insulators, even though pliers are used. A simple tool can be made for this purpose from a strap of heavy iron with a single hole drilled about ½" from one end. The wire is passed through the insulator, given a single turn by hand, and then held with a pair of pliers at the point shown in figure 277. By passing the wire through the hole in the iron strap and rotating the strap as shown, the wire can be twisted quickly and neatly.

Manufactured spreaders for transmission lines are usually made of ceramic material. These are inexpensive, and stand up well in the weather; however, cases may arise where improvised spreaders are desirable. Spreaders may be fabricated from bakelite, hard rubber, cellulose acetate, or similar materials. None of these materials stand up as well as ceramic when used outdoors, but where a special size of spreader is needed, some other material must be used. Figure 278 illustrates two methods of fabricating improvised feeder spacers.

Concentric or coaxial line having air insulation between conductors can be constructed in cases where rigidity and extremely low loss is desired. Isolantite beads, or spacers, designed to pass a given size of wire (the center conductor) through a center hole, and having an outside diameter slightly less than the inside diameter of standard sizes of metal tubing, are available. The beads are strung on the wire and fastened at suitable intervals, then the assembly is drawn through the tube, which must be clean on the inside. To fasten the beads in place the wire should be given a slight crimp on each side of the bead. This will prevent the beads from sliding on the wire.

METHODS OF ESTABLISHING ANTENNA RESONANCE

Extreme accuracy in calculating and setting the dimensions of an antenna is only necessary when the antenna is used at one specific frequency. A few of the more commonly used methods of establishing antenna resonance after construction are described below. By noting the different aspects of each method, the one which should be used for a specific installation can be determined.

Standing-Wave-Observation Method

In an antenna system having a tuned transmission line, the position of standing waves appearing on the line is dependent upon the condition of resonance of the antenna to which the line is connected. By locating the points at which the standing-wave-current minima (more pronounced than current maximum) occur on the transmission line, it is possible to determine the degree and direction of nonresonance of the associated antenna.

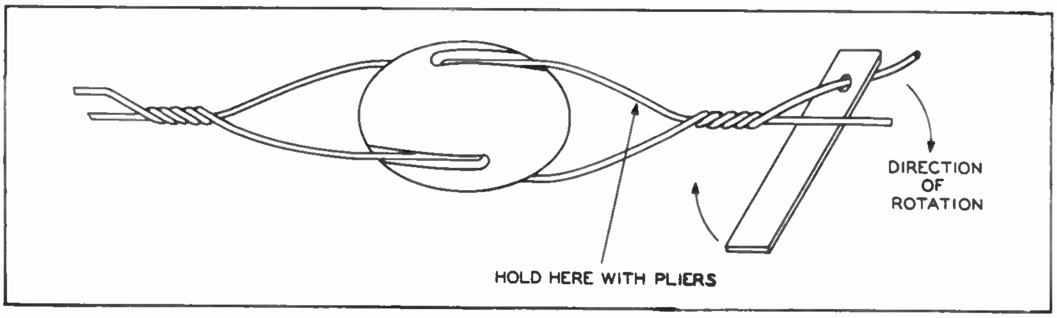


Figure 277. Simple Lever Method for Tightening Guy Wire at Ball-Strain Insulator.

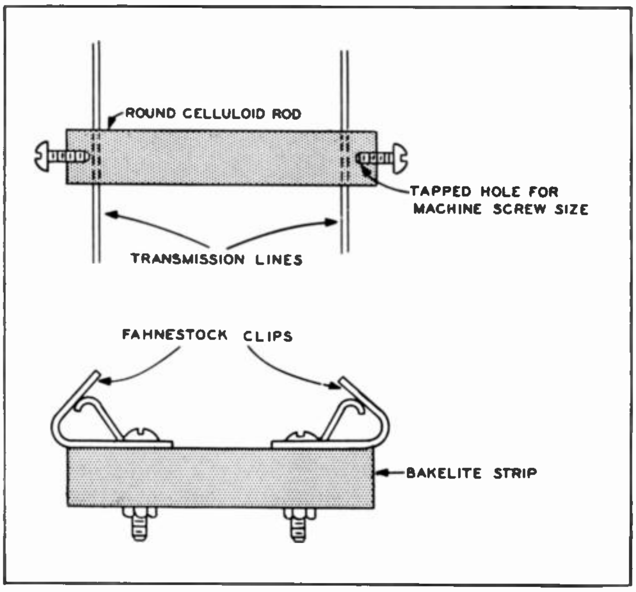


Figure 278. Improvised Feeder Spacers.

This method of resonating an antenna system calls for a current-measuring device, such as an r-f thermomilliammeter with adjustable brass or copper straps, or a microammeter with loop pickup and diode rectifier, and a method of determining the actual physical lengths equivalent to fractions of a wave length.

Initially, it is important to accurately determine the physical length of transmission line which corresponds to an electrical one-quarter wave length at the applied frequency.

$$L\ (\lambda/4,\ \text{in feet}) = \frac{246}{\text{frequency (mc.)}}\ K$$

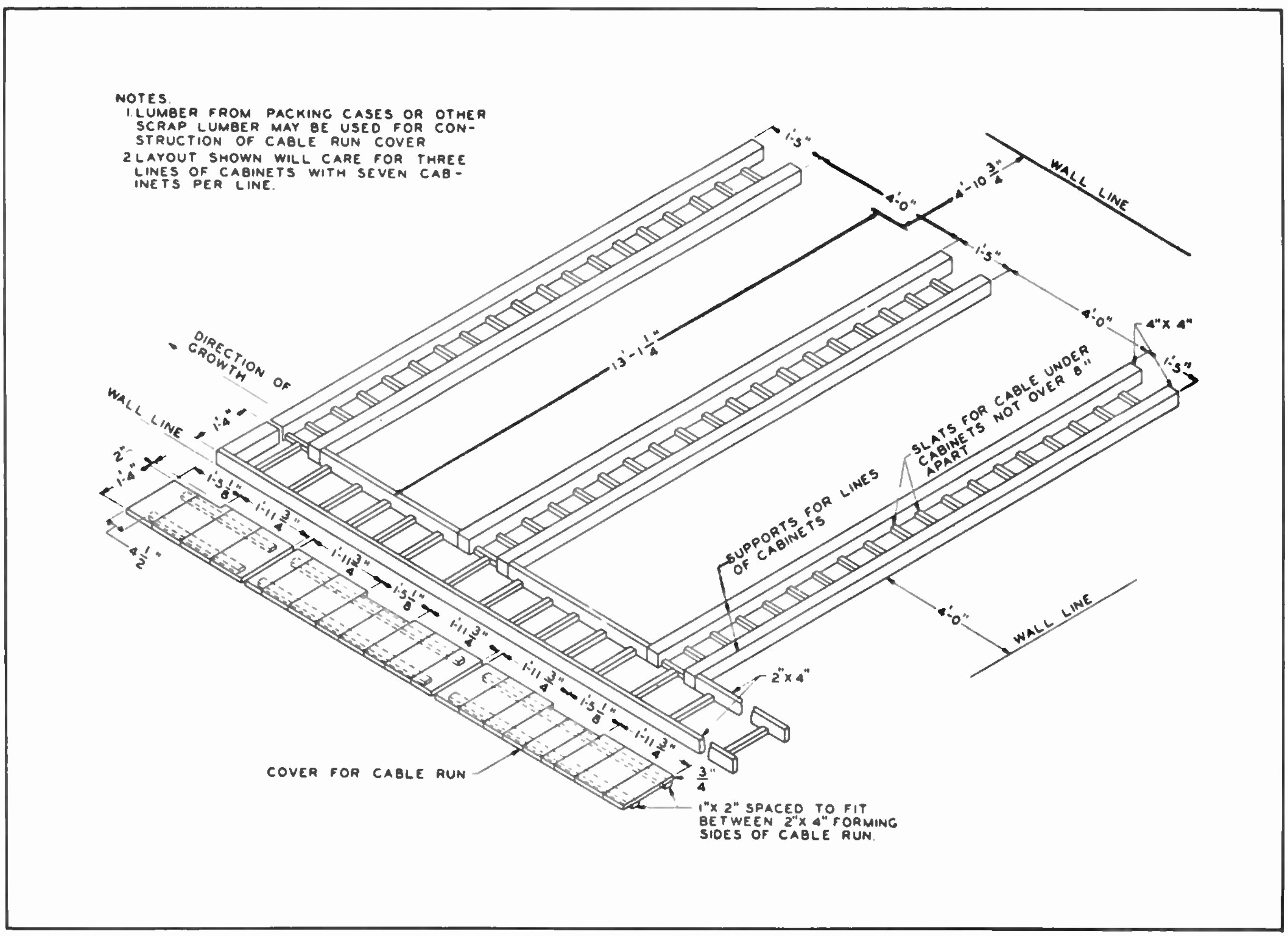
Where K (velocity factor) has the following approximate values:

For parallel open-wire line—0.975

For air-insulated concentric lines—0.85

For rubber-insulated concentric and twisted-pair lines—0.60

For parallel tubing—0.95



Plan for Improvised Transmission-Line-Cable Run.

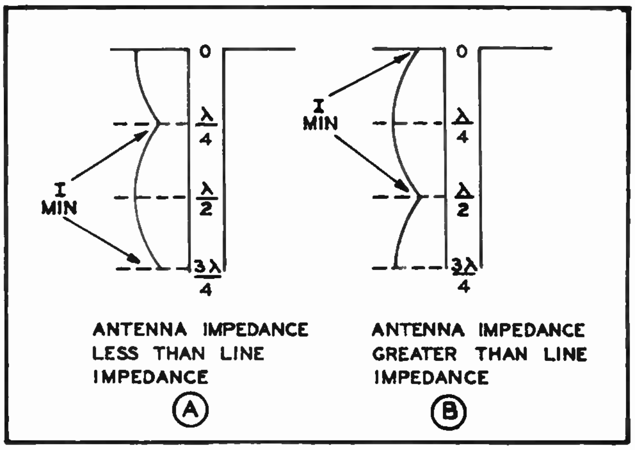


Figure 279. Standing-Wave Method of Determining Transmission-Line Match to Antenna.

Therefore, if it is desired to measure standing waves of current along a parallel open-wire line being fed by a 6-megacycle signal, substituting in the formula above gives the approximate measuring-point distance λ/4 from the antenna.

$$L = \frac{246}{6} 0.975 = 39' 11\frac{3}{4}''$$

Note: To obtain the physical equivalent length of a half-wave section or full-wave section, multiply L by 2 or 4, respectively.

Now that the first measuring point has been located, the next step should be to attach the current-measuring device first at that point, then at a point one-half wave length farther down the line. If the current minima or maxima occur at multiples of one-quarter wave length from the antenna (see figure 279A and B), the antenna is resonant.

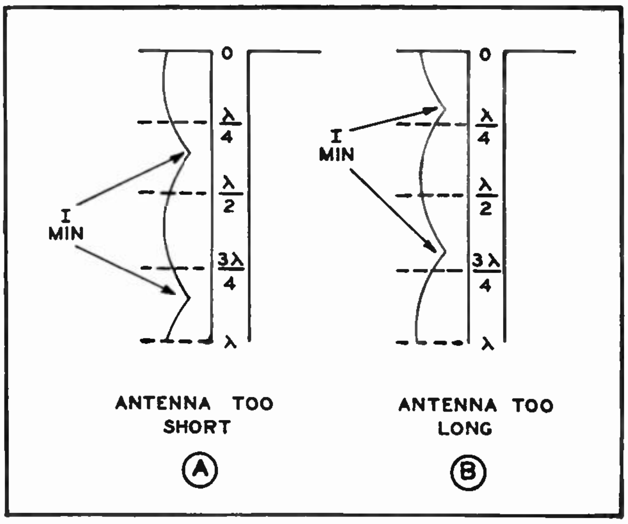


Figure 280. Standing-Wave Method of Determining Transmission-Line Match to Antenna.

If the current minima or maxima occur at points other than multiples of one-quarter wave length from the antenna, but at points between these distances, the antenna is operating off the resonant frequency. See figure 280A and B. When the antenna is either too short or too long, the first current minimum or maximum will occur at a point less than one-quarter wave length from the antenna.

The antenna length should be increased or decreased, as required, to give a standing-wave distribution indicating a condition of resonance. This method will provide a rough approximation of the amount of antenna-length compensation required for a certain percentage of error in standing-wave distribution.

Grid-Dip-Oscillator Method

A very reliable method for determining the specific radio frequency to which a length of antenna will resonate makes use of a variable-frequency r-f oscillator, with a d-c milliammeter connected in series with the grid-leak resistor. Instead of the meter, a magic-eye tube may be used. For constructional details of a grid-dip oscillator, see page 180.

The grid-dip oscillator is coupled to the antenna, with the antenna erected in its proper operating position, and with its transmission line disconnected. As the grid-dip-oscillator frequency is varied over the frequency band desired, the grid meter will show a sharp dip at the resonant frequency. Rock the tuning control back and forth to ascertain the location of the point which gives maximum dip; then, using an accurate frequency-measuring device, such as an SCR-211-( ) Frequency Meter, find the frequency of the grid-dip oscillator.

If the frequency measured is below the desired resonant frequency of the antenna, it will be necessary to reduce the antenna length and recheck its resonant frequency as previously described. Conversely, if the frequency measured is above the desired resonant frequency of the antenna, it will be necessary to increase the antenna length and recheck its resonant frequency.

Matching-Transformer Method

When it is required to check the resonant frequency of a loftily mounted antenna, and test equipment such as a grid-dip oscillator is not available, the method outlined below may be used. This method is based upon the fact that the addition of a resonant length of feeder line to an antenna does not affect the operation of the antenna.

With a transmitter output circuit of the series-resonant type, the resonant length of feeder line required should be an electrical quarter wave length. With a parallel-resonant output circuit, the resonant length of feeder line should be an electrical half wave length or an even multiple thereof (λ, 3/2 λ, etc.).

First, construct the resonant length of feeder line, observing the specifications given above. Then, with

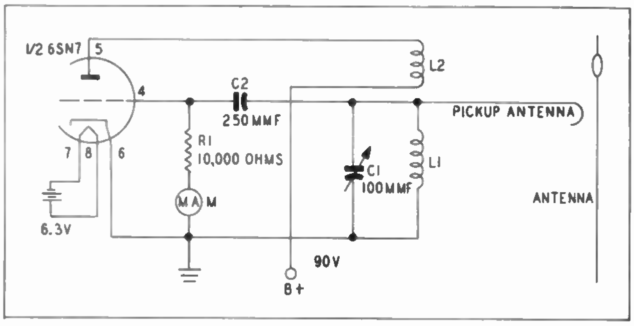


Figure 281. Schematic of Grid-Dip Oscillator.

the feeder line disconnected from the antenna, and very loosely coupled to the transmitter, adjust its tuning to give maximum feeder current. (Use the loosest coupling which will give a satisfactory reading.) Note the setting of the tuning control or controls.

Connect the feeder line to the antenna in an end-fed manner. Then, without changing the amount of coupling, adjust the tuning of the feeder line to give maximum feeder current. Regardless of what maximum reading is obtained in this case (it will be much lower), note the setting of the tuning control or controls.

If the capacitor or capacitors are found to be set at lower capacity than before, the antenna is too long. If the capacitor or capacitors are found to be set at higher capacity than before, the antenna is too short. If the capacitor setting or settings are found to be the same with the antenna connected or disconnected, the antenna is exactly the correct length. With a little experience, the proper amount of antenna-length compensation for error in capacitor setting can be judged satisfactorily.

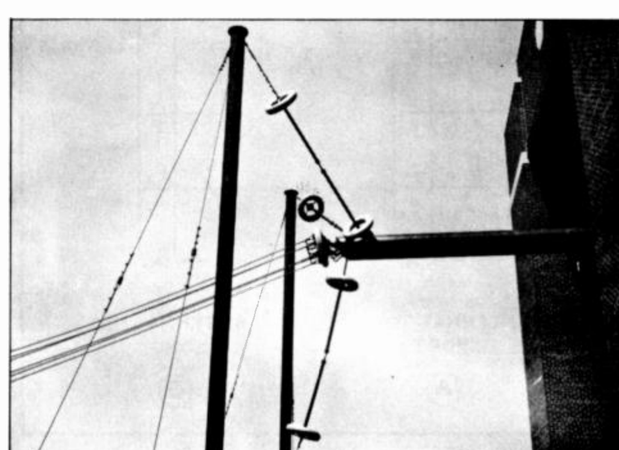
CONSTRUCTIONAL DETAILS OF GRID-DIP OSCILLATOR

R1 = 10,000 ohms
C1 = 100 mmf., variable
C2 = 250 mmf., mica
L1, L2 { Inductance depends upon frequency being measured (may be calculated from engineering charts for range of frequencies used).
M = 0–5 d-c milliammeter

One of the most accurate methods for determining the true resonant frequency of an antenna is the grid-dip-oscillator system. The oscillator is used to check the resonant frequency while the antenna length is adjusted until the desired frequency is obtained. The oscillator may be of any design; the circuit shown in figure 281 is a tickler feed-back type. Half of a 6SN7 is used, but any triode with similar characteristics is satisfactory. A plate supply of 90 volts is employed. R1 and C2 make up the grid leak combination across which the grid bias for the oscillator is developed. The meter (M), which is an 0–5-ma. meter, is in series with the grid-leak resistor and indicates the grid current. C1 is a variable 100-mmf. condenser which, with L1, forms the oscillator tank circuit. The value of L1 depends upon the frequency coverage desired, and its specifications may be found by using appropriate engineering charts. L2 is the tickler, or feed-back coil, and usually contains about 15% of the number of turns of the grid coil. The pickup antenna consists of a rod 2 to 3 feet long.

Before checking the resonant frequency of the antenna, the feeders should be removed and, in the case of a dipole, the two halves of the antenna should be connected together.

When using the oscillator, the rod is brought close to the antenna being tested; then C1 is tuned to the point which gives minimum grid current, as indicated by the meter. This shows that the antenna is acting as a resonant load and is absorbing part of the radiated energy from the pickup antenna. With the coupling loosened, to prevent overloading, the frequency of the oscillating circuit is then measured by an accurate frequency meter. If the frequency measured is lower than the desired frequency, the antenna is shortened a bit, and checked again. This procedure is repeated until the antenna has the correct physical length to resonate at the desired frequency. If the antenna to be measured cannot be reached by the pickup rod, a coaxial line or twisted pair, with a pickup loop attached to it, may be used. The pickup loop can be hooked to one of the insulators supporting the antenna, so that it will be at a high-voltage point. To make sure that the pickup line does not resonate to the desired frequency, the pickup loop is decoupled considerably from the antenna, and the tuning condenser C1 is tuned to make sure that there is no dip within reasonable range of the operating frequency.



Down-Lead Extension Shown in Lowered Position.

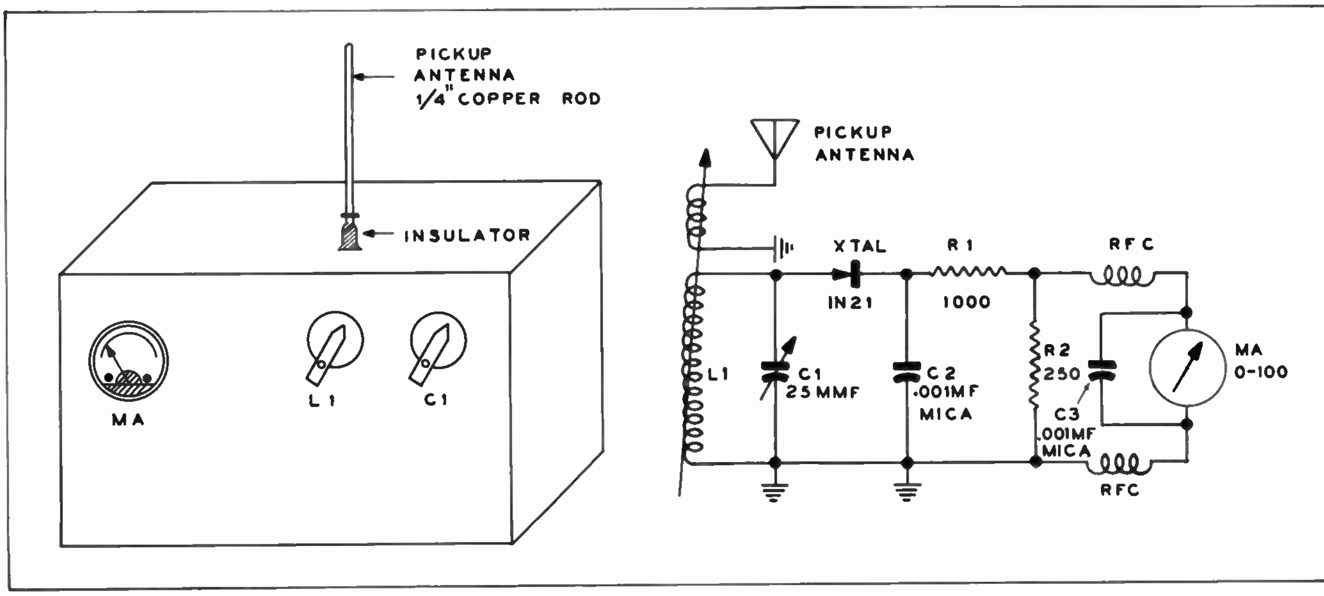


Figure 282. Field-Strength Measurement Device (for V-H-F Range).

CONSTRUCTIONAL DETAILS OF A FIELD-STRENGTH METER

In the discussion of antenna field strength, the use of a receiving device that gives a relative indication of field strength was mentioned.

The use of some kind of field-strength measuring device is essential if the antenna system is to be adjusted to produce maximum radiation. Basically, the field-strength meter consists of a pickup antenna, a tuned input circuit, a crystal rectifier, and some kind of indicating device such as a microammeter. The field-strength meter will only give relative measurements, but is very useful in the v-h-f range, and for determining the beam pattern when using directional antennas.

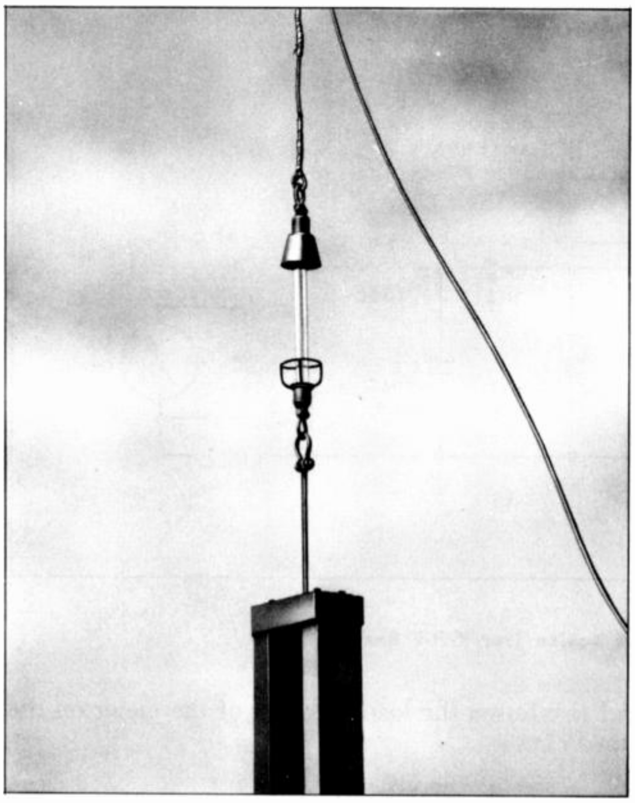
When using the field-strength meter, care must be taken to make the field-pattern checks at least several wave lengths away from the antenna, and at heights corresponding with the desired angle of directivity. When checking for harmonics and spurious radiations, the field-strength meter may be operated a couple of hundred feet from the antenna.

Figure 282 shows a field-strength measuring device especially suitable for measurements in the v-h-f range. The input or antenna coil shown, which is of the variometer type, may be changed for different frequency ranges. The data on winding the coils may be found in any radio handbook. The amount of energy introduced into the tuned circuit is determined by the amount of coupling between the primary and secondary. Capacitor C1 is tuned for maximum indication of the meter at one particular location of the pickup antenna. Resistors R1 and R2 make the response of the crystal more linear with variations in radiated power, and also lessen the loading effect of the meter on the tuned circuit.

C1 = 25 mmf., variable
C2 = .001 mf., mica
C3 = .001 mf., mica
L1 = variocoupler (adjustable coupling)
XTAL = 1N21 type
R1 = 1000 ohms
R2 = 250 ohms
MA = 0-100 microammeter
Pickup antenna = 2′ or 3′ of ¼″ copper rod

ANTENNA MULTICOUPLER UNIT FOR RECEIVING SERVICES

In many receiving-station installations, it is necessary to feed several receivers operating on different frequencies and connected to the same antenna. In this type of installation, interference may occur between receivers, because of radiation from the high-frequency oscillators. A unit called a multicoupler is used to reduce this effect. This is a distributing amplifier system which affords some isolation for each receiver. The usual unit used in the field has a 200-ohm or 600-ohm balanced input circuit, and also a 75-ohm unbalanced input circuit. The input circuit is untuned, so that a wide band of frequencies may be covered. The usual multicoupler is used in the 3-to-20-megacycle range, and is most efficient at about 10 megacycles. Most multicoupler units are about 25% efficient, and are usually used at receiving sites where the diversity type of reception is employed. Where tactical conditions permit the erection of individual receiving antennas, the use of a multicoupler unit is not recommended. See figure 283 for a simplified circuit of a multicoupler unit.



Antenna Down-Lead Support for Windy Locations with Pyrex Insulator and Anti-corona Discs.

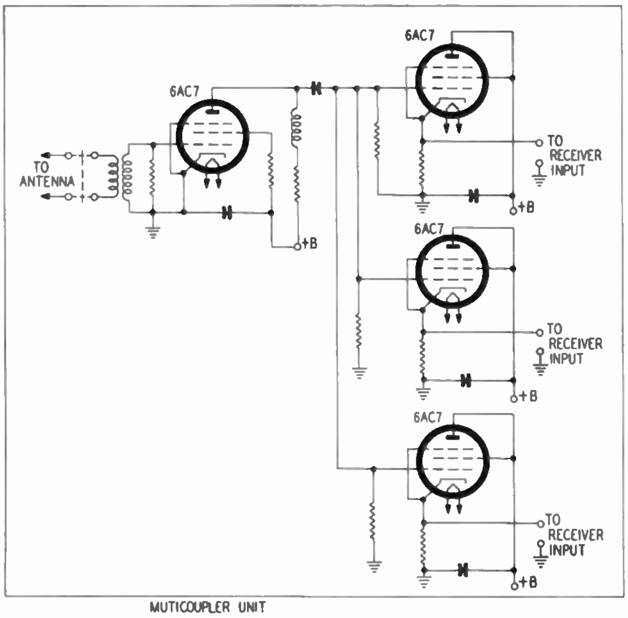


Figure 283. Simplified Schematic of a Multicoupler Unit.

FARADAY ELECTROSTATIC SHIELDS

In transferring energy from the final tank coil in a transmitter, consideration must be given to the stray capacitance which exists between the antenna coupling coil and the tank coil. This stray capacitance causes harmonic energy to be coupled into the antenna system. (The harmonic radiation is most severe from tank circuits having a high L-to-C ratio.) The undesirable capacitive coupling can be eliminated by the use of an electrostatic shield between the two coils; this is called a Faraday shield. It consists of a comb of metal which has parallel conductors, insulated from each other except at one end, where all are joined. This construction, which eliminates any closed loops, is used to prevent any inductive current flow in the shield, which would cause heating and consequent power losses. If the shield is used between two coils which are coupled end-to-end, the shield should be flat, and if it is used between two concentric coils, it must be concentric between the two coils. See figure 284 for the various methods of using a Faraday shield.

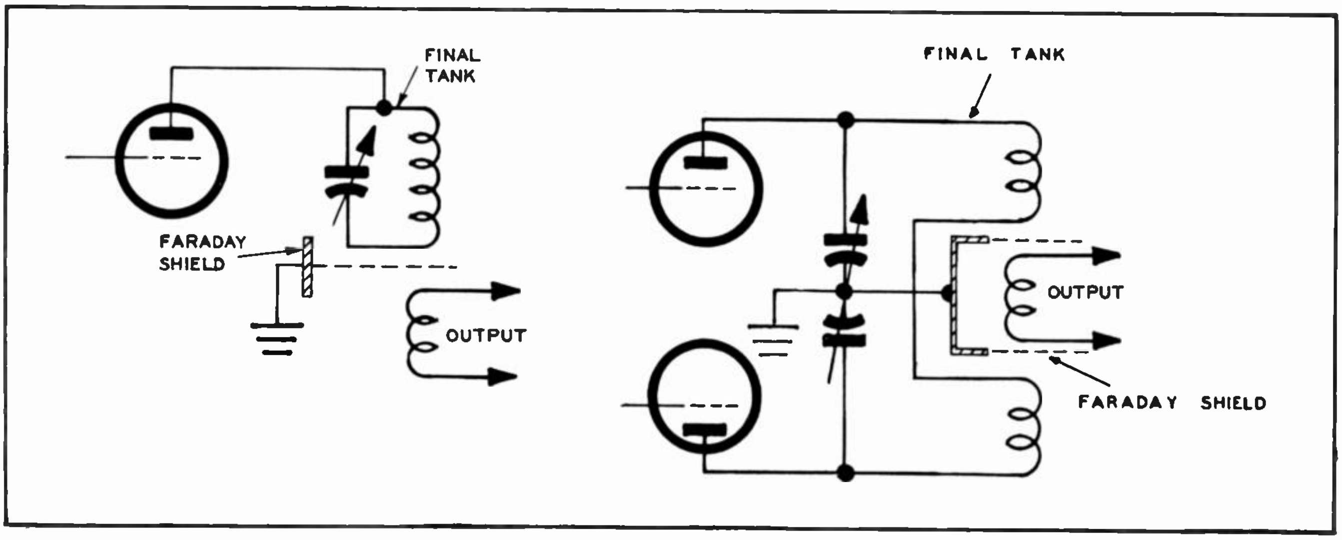


Figure 284. Various Methods of Using a Faraday Shield.

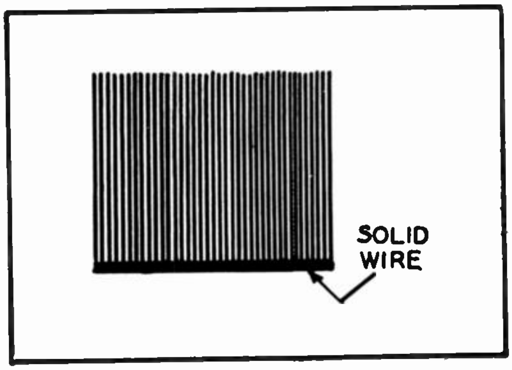


Figure 285. Faraday-Shield Construction.

The shield is usually constructed by winding #22 to #14 bare wire on a flat or round form which has been covered by a sheet of celluloid or heavy paper. The winding is coated with either collodion or coil dope and then the entire wire is cut in a straight line parallel to the axis of the coil. The adjacent ends of each loop of the coil are soldered to a straight wire. See figure 285.

FOUR-WIRE LINES AS MATCHING TRANSFORMERS

The four-wire type of line has found wide application where a low-cost, low-impedance line is desired. This type of line finds its greatest application as a quarter-wave matching transformer between any two points of different impedance, especially between a nonresonant feedline and an antenna current loop. When used in this way the four-wire line has the advantage of being light in weight, making it especially useful where a matching section must be supported from an antenna several half waves long. The following chart indicates the impedance of a nonresonant line and the required "Q" section impedance, which is the 4-wire line acting as a matching transformer. As is shown, the required "Q" section impedance changes with antenna length.

CHART 15

Nonresonant Feed Line (2 Wire)			Required "Q" Section (4-wire line) Impedance, in Ohms, for Various Antenna Lengths			
Wire Size	Space (Inches)	Imped. (Ohms)	$\frac{\lambda}{2}$	$\frac{2\lambda}{2}$	$\frac{3\lambda}{2}$	$\frac{4\lambda}{2}$
12	1.25	410	175	193	202	211
14	1.25	440	184	200	210	219
12	1.50	440	184	200	210	219
14	1.50	465	181	206	216	225
12	2.00	465	187	206	216	225
14	2.00	495	193	212	223	232
12	4.00	550	203	224	234	245
14	4.00	575	207	228	240	250
12	6.00	600	212	234	245	256
14	6.00	625	216	238	250	261

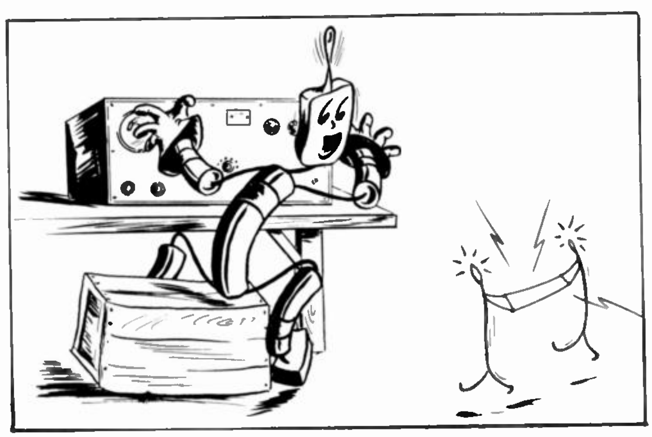
After the required "Q" section (4-wire line) impedance has been found in the preceding chart, the correct spacing of the 4-wire line to give the required impedance can be found in the chart below.

CHART 16

Impedance (Ohms)	No. 12 Wire Spacing (Inches)	No. 14 Wire Spacing (Inches)	No. 16 Wire Spacing (Inches)
175	1.415	1.120	
184	1.495	1.185	
187	1.535	1.215	
193	1.630	1.280	
200	1.720	1.361	1.065
202	1.820	1.440	1.128
206 207	2.020	1.600	1.255
210 211 212	2.120	1.630	1.319
216	2.30	1.825	1.430
219	2.420	1.920	1.503
223 224 225	2.662	2.110	1.629
228	2.910	2.310	1.830
232	3.075	2.435	1.930
234	3.150	2.497	1.981
238	3.320	2.625	2.081
240	3.420	2.721	2.160
245	3.640	2.881	2.289
250	4.040	3.204	2.541
256	4.360	3.460	2.740
261	4.650	3.683	2.920

PHANTOM ANTENNAS

It is often desirable to test a transmitter without radiating unnecessary signals (FCC Sec. 22, Art. 525) or to couple to the transmitter a load equivalent to the antenna, for measurement of power output. For this purpose, a "phantom," or "dummy," antenna is used. In its simplest form, for frequencies up to 50 megacycles the phantom antenna may be a lamp of suitable wattage rating connected across a portion of the final tank coil. When normal loaded plate current is obtained, the brilliance of the lamp is compared with



another of similar rating operating on 110 volts, and the power roughly estimated. By controlling and measuring the current and voltage to the comparitor lamp and matching its brillance with the phantom load, a more accurate determination can be made of power consumed in the dummy load.

At the higher frequencies the inductive and capacitive reactance of a tungsten lamp has a detuning effect on the tank circuit, and a special noninductive resistance must be used. Above 50 megacycles, resistive loads can be made from carbon-filament lamps, carbon resistors, or special noninductive resistances made for the purpose. By connecting an r-f ammeter of suitable range in series with the resistance, the power dissipated can be found from the formula $P = I^2R$. (If carbon-filament lamps are used for this purpose, their resistance when hot must be known.)

Where it is desired to simulate the reactive conditions of a transmission line, a resonating tuned circuit may be coupled to the final tank, with a resistance incorporated to dissipate the required amount of power. Figures 286A and B show two phantom circuits, with an r-f ammeter of suitable range in series with the resistance, for computing the power dissipated in the load resistor. In these circuits, the resistance should approximate the value of resistance into which the tank circuit works, i.e., the impedance of the transmission line.

Where the power of the transmitter exceeds one

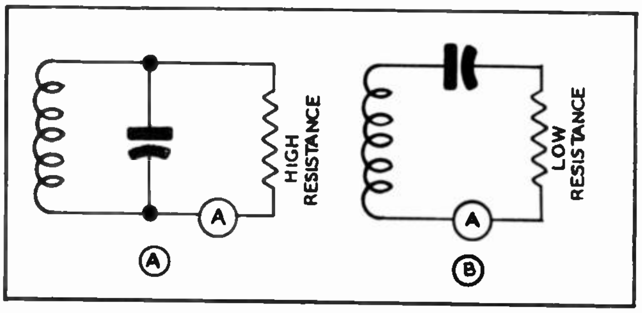


Figure 286. Two Types of Phantom Antennas with Meters for Measuring Power Output.

kilowatt, and the resonant type of phantom antenna is used, the components, and particularly the capacitor, must have an adequate voltage rating with a safety factor. Capacitors should be protected by a spark gap, as very high voltages are often encountered. For such high-power applications, condensers of the ceramic pillar type of construction are generally preferred. The voltage strain may be divided by connecting several such condensers in series.

Instead of connecting the phantom load across the final tank coil, it may be connected in place of the feeders or in place of the antenna. However, to insure that the coupling circuit absorbs normal power, the resistance should approximate the load it replaces.

INDEX

ANSWER SHEET

EXAMINATION No. 1

True or False

1. True
2. False
3. False
4. True
5. False
6. True
7. True
8. True
9. False
10. False

Multiple Choice

1. c.
2. a.
3. c.
4. b.
5. c.
6. d.
7. d.
8. b.
9. a.
10. c.

Subjective

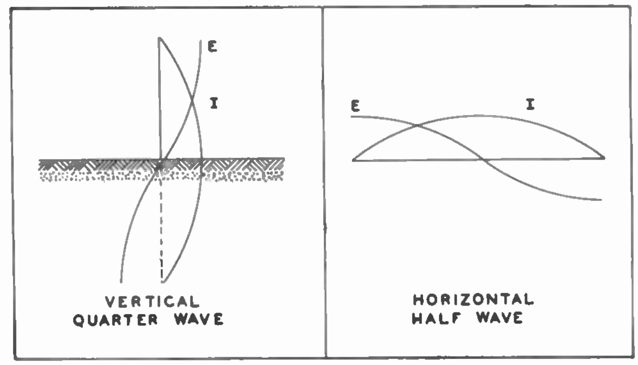
1. a. Length of antenna.
   b. Number of elements.
   c. Height above ground, ground effects or conductivity of ground.
   d. Capacitive effects to ground and across insulators (end effects).
   e. Orientation with respect to ground.
   f. Method of feed.
   g. Surrounding objects other than ground.
2. Using formula,

$$L\ (\text{feet}) = \frac{492 \times 0.95}{f\ (\text{mc.})}$$

$$L\ (\text{feet}) = \frac{468}{1.6}$$

$$L\ (\text{feet}) = 292\ \text{feet}$$

3.



4. a. Effective height.
   b. Shape.
   c. Physical length.
   d. Presence of nearby objects.
5. a. Identify character of noise by listening test.
   b. Remove all immediate, possible sources of man-made noise.
   c. Determine whether noise is internal or external to receiver.
   d. If noise is internal, check receiver.
   e. If noise is external, check shielding and bonding of equipment.
   f. Reduce receiver bandwidth.
   g. Improve directivity of transmitting and receiving antennas.
   h. Increase transmitted power.

EXAMINATION No. 2

True or False

1. True
2. True
3. False
4. True
5. True
6. True
7. True
8. True
9. False
10. True

Multiple Choice

1. b.
2. d.
3. b.
4. a.
5. a.
6. d.
7. c.
8. a.
9. b.
10. c.

Subjective

1. A parallel open-wire-type transmission line has a high characteristic impedance when the size of the wire is small with respect to the spacing between the wires, and low when the size of the wire is large with respect to the spacing between them.

   A concentric-type transmission line has a high characteristic impedance when the inside diameter of the outer conductor is large with respect to the outside diameter of the inner conductor, and low for the opposite condition.

2. a. The standing waves shift along the length of the line with the voltage leading the current from the terminated end.
   b. The standing waves shift along the length of the line with the current leading the voltage from the terminated end.
   c. The standing waves shift along the length of the line with the current lagging the voltage, and there is a relative change in maximum and minimum amplitudes.
3. a. Transposition.
   b. Equalization of line lengths.
   c. Series capacitance in feeder line.
   d. Balancing device, such as "bazooka."
4. A current-fed antenna is one which is fed power at a low-impedance point along its length, such as a center-fed half-wave resonant antenna.

   A voltage-fed antenna is one which is fed power at a high-impedance point along its length, such as an end-fed half-wave resonant antenna.
5. a. Balanced or unbalanced condition of line.
   b. Impedance variations of coupling circuit over operating frequency range.
   c. Frequency and power of coupled signals.
   d. Type of antenna to be used.
   e. Method of feed to be used at antenna.

ANSWER SHEET

EXAMINATION No. 3

True or False	Multiple Choice
1. False	1. d.
2. True	2. a.
3. True	3. d.
4. False	4. c.
5. True	5. a.
6. False	6. c.
7. False	7. d.
8. True	8. b.
9. True	9. d.
10. False	10. b.

Subjective

1. Self-resonant element is same length as driven element. Tuned element is either shorter (director) or longer (reflector) than driven element.
2. Adjust director length to resonate at highest frequency.
   Adjust reflector length to resonate at lowest frequency.
3. A collinear array consists of many half-wave dipoles in line, end to end, which are excited in phase. The radiation-pattern maximum is at right angles to the axis of the elements.
   A broadside array consists of many half-wave dipoles lying parallel to one another, which are excited in phase. The radiation-pattern maximum is broadside to the plane of the elements.
   An end-fire array consists of many half-wave dipoles lying parallel to one another, which are excited out of phase. The radiation-pattern maximum is in the plane of the elements.
4. To take better advantage of the low-angle radiation pattern of a long single-wire antenna, the array should be tilted downward from the horizontal at the terminated end.
5. Wave angle desired.
   Terrain conditions.
   Space available.
   Height of available supporting structures.
   Type of available feeder system.
   Termination required for directivity and power-handling capability.

EXAMINATION No. 4

True or False	Multiple Choice
1. True	1. d.
2. False	2. c.
3. False	3. a.
4. True	4. c.
5. True	5. a.
6. False	6. d.
7. True	7. a.
8. True	8. d.
9. False	9. c.
10. False	10. c.

Subjective

1. a. Increase the physical length of the radiator beyond a quarter wave length.
   b. Place a lumped inductance in series with the vertical quarter-wave-length antenna, at its base.
   c. Terminate the straight vertical portion of the antenna in a flat-top arrangement.
2. Because radiated power = total power less the power dissipated in the ground.
   $Pt = I^2 Ra + I^2 Rg$
   where Pt = total power
   I = antenna current
   Ra = radiation resistance
   Rg = ground resistance
3. Since reception may occur in other than the normal direction, the currents induced in the antenna by the received signal will not add in correct phase at the receiver to produce maximum gain.
4. Broader frequency response.
   High input impedance; suitable for feed by "Twinex."
5. When the vertically polarized waves leave the long-wave antenna, their electric field is perpendicular to the ground. As the lower portion of this field passes over the ground, it induces a current in the ground, which, in turn, tends to attenuate the energy flow. The net result is that the electric-field wave front tends to tilt in the direction of wave travel so that at some distance from the antenna a horizontally polarized component of the travelling wave exists.