THE A.R.R.L. ANTENNA BOOK

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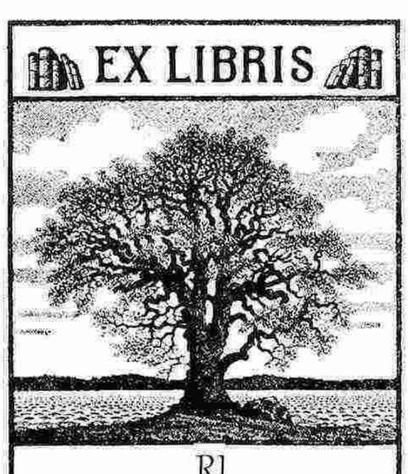
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THE A.R.R.L. ANTENNA BOOK

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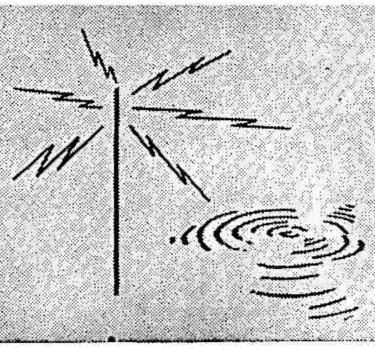


1. WAVE PROPAGATION

NATURE OF RADIO WAVES — POLARIZATION — REFLECTION — REFRACTION — THE IONOSPHERE — THE TROPOSPHERE — GROUND-WAVE PROPAGATION

THE choice of a suitable antenna for radiation at a given frequency is determined by the nature of radio waves and their behavior in traveling through space over different paths.

Radio waves are electromagnetic waves whose frequencies of alternation range from the region just above the upper limit of audible frequencies at approximately 15,000 c.p.s. to the lower limits of heat and light wave frequencies at about one million megacycles. The speed of travel for radio waves is substantially the same as the speed of light, 300,000 km. or 186,000 miles per second in vacuum. The speed will vary in accordance with the nature of the medium traversed. Similarly to light waves, radio waves can be polarized, reflected, refracted and diffracted.

The energy in a radio wave is divided equally between traveling electrostatic and electromagnetic fields. The electrostatic lines of force are always at right angles to the corresponding magnetic lines of force, as shown in Fig. 1. The plane containing the set of crossed lines represents the *wave front.* The direction of the wave travel is always perpendicular to the wave front.

The *intensity* of the wave is usually expressed in microvolts per meter, which is a measure of the dielectric stress produced by the electrostatic component, or the voltage induced in a conductor one meter long when held at right angles to the magnetic component.

Polarization

The direction of the lines of force in the electrostatic field is taken as the direction of polarization of the wave. If the direction of the electrostatic lines is perpendicular to the earth, the wave is said to be *vertically polarized;* while if the electrostatic lines are parallel to the earth, the wave is *horizontally polarized.* An antenna which generates a vertically polarized wave is itself said to be vertically polarized, while generators of horizontally polarized waves are themselves said to be horizontally polarized. The polarization of a high-frequency antenna is the same as its position with respect to the earth's surface; that is, a vertical antenna is vertically polarized and a horizontal antenna is horizontally polarized.

Waves of low frequency traveling along the ground usually maintain their polarization in the same sense as generated at the antenna. At high frequencies the polarization of the wave may be altered during travel. In such cases the polarization may vary quite rapidly, and is often circular or elliptical because the wave is divided into several components which follow different paths. A horizontally polarized wave traveling in contact with conductive earth suffers very rapid attenuation, because the electrostatic field is short-circuited. The ground acts as a conductor at frequencies up to about 10 Mc., but is more like a dielectric at higher frequencies.

As a result of the alterations during travel, the energy taken from the wave by the receiving antenna will normally be greatest when the antenna polarization is the same as that of the arriving wave. Therefore, the polarization of the antenna is of considerable importance. It should be noted, however, that at high frequencies the

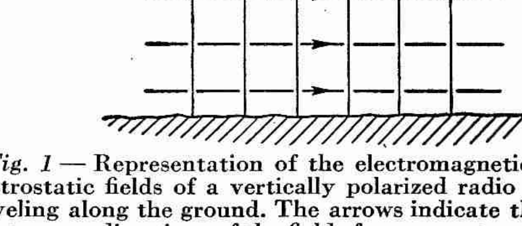


Fig. 1 — Representation of the electromagnetic and electrostatic fields of a vertically polarized radio wave traveling along the ground. The arrows indicate the instantaneous directions of the fields for a wave travelling perpendicularly out of the page toward the reader. Reversal of the direction of *one* set of lines would reverse the direction of travel, but there is no change in direction when both are reversed.

polarization of the receiving antenna should be related to the arriving wave, regardless of the polarization of the generating antenna. It has been found that arriving waves at 7 Mc. and higher tend to be horizontally polarized, so that on the average a horizontally polarized receiving antenna will be the more effective. At 3.5 Mc. the polarization of the arriving wave may be of either type; there is some evidence of a shift between day and night conditions. The polarization of arriving waves is chiefly vertical on 1.75 Mc.

Reflection

Radio waves may be reflected from any sharply defined discontinuity of suitable characteristics and dimensions in the medium in which they are traveling. Any good conductor differing in dielectric constant from that medium meets the requirements, if its dimensions are at least comparable to the wavelength. Therefore, the radiation from an antenna may be reinforced in a given direction if a similar element is suitably placed in the field of the antenna. In addition, the surface of the earth forms such a discontinuity, as do also the boundaries between ionospheric layers of differing dielectric constant and the boundaries between dissimilar air masses in the lower atmosphere. At certain frequencies radio waves are readily reflected from these discontinuities as well as from smaller bodies, such as a ship or an airplane.

Refraction

As in the case of light, the radio wave is bent when it moves obliquely into any medium having a different refractive index from that of the medium which it leaves. Because the velocity of propagation differs in the two regions, that part of the wave front which enters first travels faster or slower than the part which enters the new region last, resulting in a turning or refraction of the wave front. Refraction may affect the wave in either the troposphere (lower atmosphere) or the ionosphere, or both.

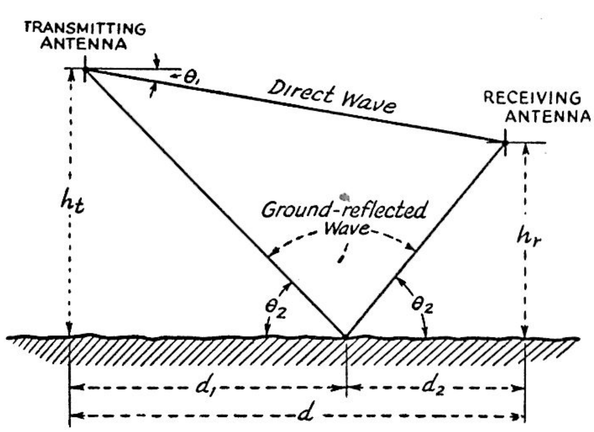


Fig. 2 — Diagram showing direct and ground-reflected components of the space wave. Neglecting the curvature of the earth and the effect of refraction in the atmosphere, resultants of the space wave may be computed according to the following formulae:

$$\text{Tan } \theta_2 = \frac{h_t + h_r}{d} = \frac{h_t}{d_1} = \frac{h_r}{d_2}$$

$$\text{Tan } \theta_1 = \frac{h_t - h_r}{d}$$

Height is calculated to the center of a dipole antenna.

Diffraction

When a wave grazes the edge of an object in passing, it tends to be bent around the object. This effect, called *diffraction*, results in the extension of the range of waves which normally follow a line-of-sight path, so that such waves may be received at some distance below the brow of a hill or around the edges of an obstruction.

Types of Waves

In general, radio waves may be classified according to the paths they follow in traveling as *ionospheric waves*, *tropospheric waves* and *ground waves*.

The ionospheric wave, often called the "sky wave," is that part of the total radiation which is directed toward the ionosphere (the upper atmosphere, above 60-mile heights). It may or may not be returned to earth by the effect of refraction and reflection in the *upper* atmosphere, where differing layers of dense ionization exist.

The tropospheric wave is that part of the total radiation which undergoes refraction and reflection in regions of abrupt change of dielectric constant in the *lower* atmosphere (troposphere), such as the boundaries between air masses of differing temperature and moisture content.

The ground wave is that part of the total radiation which is directly affected by the presence of the earth and its surface features. Attention is called to the fact that this definition includes certain components which may not at once be recognized as belonging to a ground wave. Besides the *surface* or *earth-guided wave* there is also a *space wave*, which is not to be confused with the inospheric wave so long described as the "sky" wave. The space wave is itself the resultant of two components, the *direct wave* and the *ground-reflected wave*, as shown in Fig. 2.

The Ionosphere

Principal dependence for communication between distant points on the frequencies below 30 Mc. is placed upon the ionospheric wave. This wave leaving the transmitting antenna travels upward from the earth's surface at such an angle that it would simply continue out into space if its path were not bent sufficiently to bring it back to earth. The medium which causes such bending is the *ionosphere*, a region in the upper atmosphere where free ions and electrons exist in such quantity as to cause a change in the refractive index. Their presence is accounted for by the effect of ultraviolet radiation from the sun. The ionosphere includes a series of densely ionized layers existing at different heights. Each layer consists of a central stratum of ionization which tapers off in density both above and below.

The higher the degree of ionization, the greater the bending *on any given frequency.* The atmospheric pressure is also a factor, since greater density resulting from the higher pressures tends to work against the ionization effect. Thus, the greater the height of the ionized layer, the more favorable the conditions for refraction.

For a given density of ionization the amount of refraction becomes less as the frequency of the wave becomes higher. The bending, therefore, is smaller at high than at low frequencies, and, if the frequency is raised to a sufficiently high value, the bending eventually will become too slight to return the wave to earth even when it enters the ionosphere at a very small angle to the plane of the ionized layer. Therefore, at this and higher frequencies, long-distance communication becomes impossible.

A simplified illustration of the paths taken by high-frequency waves encountering the ionosphere is shown in Fig. 3, where the effect of a single layer is considered. A wave of moderate frequency entering the layer will be bent back to earth, provided the angle which it makes with the layer is small enough. As the angle at which the wave enters is increased, the wave returns to earth nearer to the transmitting point. As the angle is still further increased, a *critical angle* will be reached at which the wave just manages to be bent back to earth. Waves entering at still higher angles will not be bent enough and, passing through the layer into space, become useless for communication. Energy radiated at angles above this critical angle obviously is wasted.

Layer Height and Critical Frequencies

By using a frequency low enough so that waves which enter the ionosphere at the maximum angle of 90 degrees (i.e., waves going vertically from the transmitting antenna to the ionosphere) are returned to earth, it is possible to measure the height of the ionosphere. This is done by measuring the time taken by the wave to go up and back, when the distance can be readily calculated. The distance so found is the *virtual height,* or the height from which a pure reflection would give the same effect as the refraction which actually takes place.

If the transmitting frequency is gradually increased while height measurements of this type are being made, eventually a frequency range will be encountered where the virtual height increases rapidly, until finally the wave does not come back. The frequency just above that at which vertical reflection ceases is known as the *critical frequency.* As the frequency is further increased beyond the critical frequency, the wave must enter the ionosphere at progressively smaller angles in order for it to be bent back to earth. At the lowest practicable angles — about 4 or 5 degrees above the horizontal from the transmitting point — long-distance transmission is possible at frequencies up to about 2.5 times the critical frequency. Thus, the critical frequency is a measure of the ability of the ionosphere to return high-frequency waves to earth.

Multiple Layers

Measurement of critical frequencies has indicated the presence of several ionized layers rather than only one. Thus, a critical frequency at, say, 5000 kc. may be determined for a layer at a certain height; yet as the frequency is raised above 5000 kc. new refractions appear to return from a higher layer. When the critical frequency from this new layer is reached, a further increase in frequency may discover the effect of refraction in a third and still higher layer, until finally the last critical frequency is passed and no further return of the waves can be recorded.

Two such layers are recognized as having a permanent existence. The lower one, called the *E* layer, maintains a virtual height of 70 to 75 miles throughout the day and from season to season. The critical frequency of the *E* layer varies with the altitude of the sun, however, showing daily maxima at noon with minima occurring after midnight, the daily maxima being greater in summer than in winter. Because the *E* layer is relatively low and therefore under relatively high pressure and subject to a high degree of ionization, there is considerable absorption of energy from waves passing through it in the daytime.

The upper permanent layer is designated in daytime as the F_2 layer; at night it is known as the *F* layer. Through the day there is an intermediate layer, F_1, appearing at about sunrise and fading out at night. This layer generally is absent in winter. Its virtual height reaches about 140 miles during the middle of the day and is virtually constant from season to season. Its critical frequency varies much as does that of the *E* layer. The F_2 layer shows considerable variation both in virtual height and in critical frequency during the day and from season to season. In winter the virtual height may be as low as 140 miles, while in summer it may be as high as 200 to 250 miles. The critical frequency is much higher in winter than in summer, and in winter the maximum tends to occur near noon while in summer it is reached in late afternoon. It is the F_2 layer which is responsible for returning 14- and 28-Mc. waves to earth in the daytime.

The *F* layer averages about 185 miles in virtual height during the period of darkness, while its critical frequency drops off rapidly from the daytime F_2 value, reaching a minimum at midnight. It is effective for night transmission of 14-Mc. signals.

Some investigators have reported the presence of other layers, the most important being one designated as the *D* layer and having a virtual height of about 37 miles. The *D* layer appears to affect daytime broadcast signals at considerable distances. Its appearances are irregular.

Skip Distance

At frequencies above the critical frequency the ionospheric wave will not be returned to earth near the transmitter. Even those waves which barely meet the conditions for refraction, those just below the critical angle, will return to earth at some considerable distance from the transmitter. The region lying between the end of the useful ground wave and the point where the highest-angle waves return to earth is known as the skip-distance zone, because all ionospheric waves "skip over" the region and, since it is beyond the range of ground waves, no signals are heard.

The skip-distance zone depends upon the frequency employed by the transmitter and the state of the ionosphere. The zone will be wider as the frequency is raised above the critical frequency. For a given frequency, the skip distance will depend upon the time of day and the period in the various cycles affecting ionization. There is, of course, no skip distance below the critical frequency for a particular layer, since all ionospheric waves return to earth below that frequency.

The region over which the ionospheric-wave signals can be heard beyond the skip zone also depends upon the frequency. The smaller the range of angles at which the wave can be refracted, the narrower the useful region will be. Beyond the distance at which the wave making the smallest angle with the ionosphere is returned to earth there will be another silent zone, resulting from the second skip.

Multiple Reflection

Waves which strike the earth's surface after having been refracted in the ionosphere usually will be reflected upwards again, especially if the arriving angle is not too near the horizontal. Nearly horizontal waves, since they must travel a greater distance along paths adjacent to the surface, suffer greatly from absorption. A considerable part of their energy is consumed in ground losses, since the ground is not a perfect conductor.

On reflection from the ground the waves again travel to the ionosphere, and if conditions are suitable they will be refracted once more and returned to earth a second time. This process, known as multiple reflection, may continue until the energy in the wave is completely absorbed. Most long-distance transmission is of this "multi-hop" type, since the height of even the F_2 layer is such that the greatest possible distance that can be covered in one hop, with a wave entering the ionosphere at the smallest angle, is less than 3000 miles. The energy taken from the wave in traveling through the ionosphere is less than that absorbed when the wave strikes the ground, so that as a general rule the smaller the number of hops the better. Therefore, the wave should enter the ionosphere at a low angle for minimum attenuation. Energy absorption in the ionosphere is least at the higher frequencies, and this, plus the fact that high-frequency waves are reflected from ionized layers at greater heights, accounts for the fact that long-distance transmission is more readily possible on the higher frequencies.

It should be borne in mind that in multi-hop transmission the ionosphere conditions may vary greatly over the transmission path. In east-west transmission, for instance, the wave may start out in full daylight and complete its journey in darkness, while in north-south transmission it may leave the transmitter in winter to arrive at a receiver in summer. These differences in time and seasons play an important part in determining the distance over which satisfactory transmission is possible.

Variations in the Ionosphere

Since ionization depends upon ultraviolet radiation from the sun, conditions in the ionosphere may be expected to vary in accordance with changes in the sun's radiation. Besides the daily variation depending upon the height of the sun in the observer's sky, there are at least three other regular cycles in ionization. One is a period of 28 days, which corresponds with the period of the sun's rotation. The effect of this cycle is particularly evident in the 14- and 28-Mc. bands. For a short period in each 28-day cycle, transmission conditions reach a peak, usually followed by a fairly rapid drop to a lower level, and then slowly build up to the next peak.

The cycle of longest period yet observed covers about 11 years, corresponding to a similar cycle of sunspot activity. The effect of the 11-year cycle is to shift up or down the critical frequencies for *F*- and F_2-layer transmission. At a sunspot minimum the critical frequencies are lowest, and hence long-distance transmission must take place on lower frequencies. At this time the 28-Mc. band is very seldom useful for DX work. The 14-Mc. band is good in the daytime but is seldom useful at night. At a sunspot maximum, following a minimum by approximately 6 years, the 28-Mc. band is good for long-distance work in the daytime and the 14-Mc. band is useful throughout most of the day. The most recent sunspot maximum is considered to have occurred in 1938.

Superimposed upon the conditions resulting from the 11-year cycle are the yearly or seasonal variations, which depend, like the daily variation, upon the earth's path around the sun and the angle at which radiation from the sun enters the ionosphere. The wintertime conditions are most favorable and summer least favorable for long-

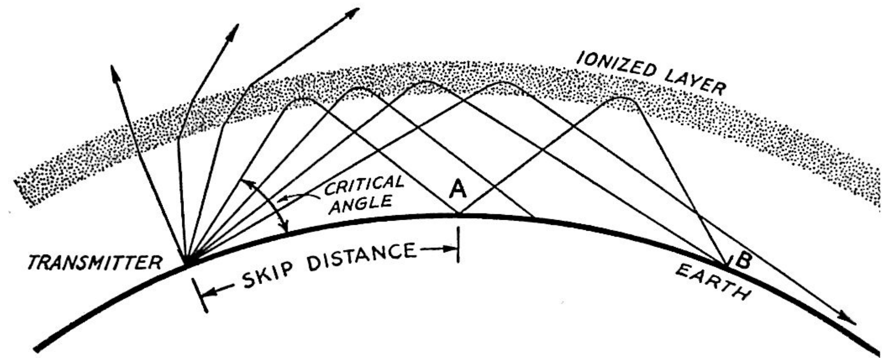


Fig. 3 — Showing behavior of high-frequency waves on encountering the ionosphere. Waves leaving the transmitter at angles above the critical are not bent enough to be returned to earth. A high-angle wave which returns at A may be reflected upward from the ground and re-refracted to appear at point B (two-hop transmission). Such a wave will not be as strong at the receiving point as one which makes the journey from the transmitter to B in one hop.

distance communication. Because of the varying length of the day in different seasons, however, the best all-around conditions for long-distance transmission usually are found in the late fall and early spring.

Daily variations on 14 and 28 Mc., depending upon the time in the sunspot cycle, have been described above. On lower frequencies the effect is chiefly that greater distances can be covered at night than in the daytime, although at a sunspot minimum the 7-Mc. band becomes better for long-distance night transmissions.

Fading

Since ionosphere conditions are not constant, it is to be expected that refraction effects will not be perfectly uniform. As we have seen, there is a gradual change in the transmission efficiency with the time of day. In addition, waves entering the ionosphere at different angles will be refracted differently. Because of the differing lengths of the paths involved, a group of such waves may arrive at the receiving antenna, at times in phase so as to aid each other and at other times with phase differences which partially or wholly oppose. Furthermore, the polarization of the incoming wave may shift, while the receiving antenna polarization remains fixed. Any of these effects may cause the received signal strength to vary over a wide range. This variation may be quite rapid, especially at the higher frequencies. In addition, the transmission conditions may not be alike for waves of slightly different frequencies, so that in the case of voice-modulated transmission, involving side-bands differing slightly from the carrier in frequency, the carrier and various side-band components may not be propagated in the same relative amplitudes and phases they had at the transmitter. This effect, known as *selective fading,* causes severe distortion of the signal, especially in the case of frequency-modulated signals received over other than line-of-sight paths. This distortion results from the fact that the instantaneous frequency of the f.m. wave is subject to continual variation, so that when two waves reach a receiving antenna by different paths they differ in instantaneous frequency. The result is a combined wave in which components of both amplitude and frequency modulation make up a new modulation at a frequency which is not harmonically related to the modulation impressed at the transmitter, but which depends upon the differences in transit time for the different paths traveled by the waves. The resulting distortion is greatest at high modulation frequencies and with high depths of modulation.

Fading may be entirely different at two receiving points only a short distance apart. By the use of antennas separated by a wavelength or two, feeding separate receivers, it is possible to take advantage of this to overcome the effects of amplitude fading, but not of selective fading. Simultaneous use of inputs from antennas of differing polarization also will often serve the same purpose. Such a receiving arrangement is known as a "diversity" system.

Magnetic Storms

During the sunspot maxima, and for some time following, occasional severe disturbances in the ionosphere may develop, affecting variously the propagation of radio waves on all frequencies. These disturbances are marked by corresponding abnormal conditions in the earth's magnetic field and by more frequent and spectacular displays of the visual phenomenon known as the aurora, extending further from the polar regions than is the normal case.

The effect of magnetic storms on low-frequency waves is to increase the daytime signal strength above normal while the intensities at night are subnormal, comparable to the daytime levels. On the higher frequencies long-distance communication frequently becomes impossible, the signals dropping sharply in strength without warning. A peculiar effect appears on the very-high frequencies in which voice transmissions are next to impossible, while abnormal distances may be covered with c.w. signals or tone-modulated keyed carriers. At times even c.w. carriers appear to be modulated by a characteristic noise, similar to tone modulation. Best results in v.h.f. transmission and reception with directive antennas is obtained during these "aurora skip" periods if the array is pointed in a northerly direction, without regard to the directions of stations contacted. It is as though the auroral curtains were serving as

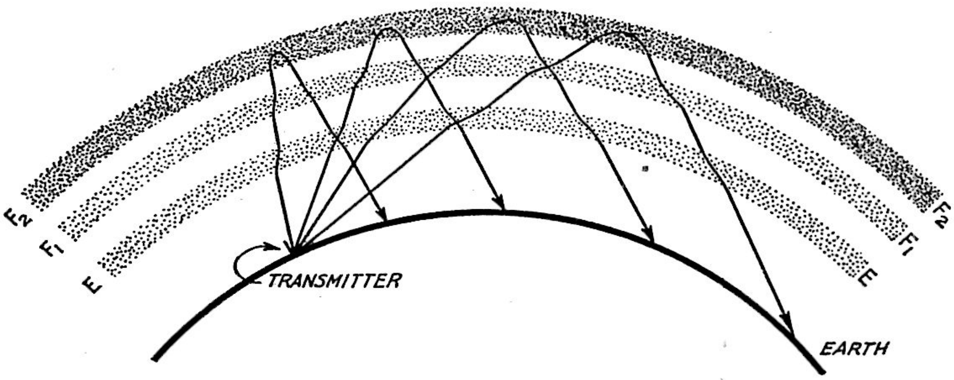


Fig. 4 — F_2 layer transmission at high frequencies (14 and 28 Mc.). The waves are partially bent in going through the two lower layers, but not sufficiently to return to earth.

global reflectors. Distances of the order of 500 miles are then attainable at 50 Mc.

Sporadic E-Layer Refraction

Observers using frequencies between 14 and 60 Mc. have become familiar with an exceptional propagation effect which is attributed to the "sporadic *E* layer." Actually, this is not a continuous layer, but appears to consist of scattered patches or clouds of relatively dense ionization at a height approximately the same as that of the *E* layer. Such clouds, varying in density, are present in random positions nearly all the time. Their effect is to raise the critical frequency to a value sometimes twice that which can be returned from any of the regular layers by normal refraction. This effect is responsible for the only known type of ionospheric transmission on the very-high frequencies. Distances of about 500 to 1400 miles are possible, provided that the ionized cloud is situated about midway between transmitter and receiver or is of very considerable extent.

On 50 Mc., sporadic-*E* transmission usually is most effective in the early summer months (May and June) and is infrequently observed in winter. In contrast to regular ionospheric transmission, there appears to be no correlation of the conditions with respect to the time of day. Two-hop transmission is relatively infrequent, since two clouds of ionization seldom are favorably situated for a second reflection. One or two occurrences have enabled amateurs on the East and West Coasts to communicate by means of 50-Mc. waves.

The presence of sporadic-*E* refraction on the 14- and 28-Mc. bands is indicated by abnormally short skip, a typical case being when 14-Mc. signals from a transmitter only 100 miles away arrive with a strength usually associated with distances of this order on 7 and 3.5 Mc.

Propagation in the Troposphere

Just as ionospheric transmission has little usefulness for the very-high frequencies, so the tropospheric wave is of relatively slight importance on the lower frequencies. The principles discussed in this section and the one on "Ground-Wave Propagation" to follow will, therefore, have their principal bearing upon the very-high and ultrahigh frequencies.

The lower atmosphere is a theatre of warring air masses whose movements determine our weather. Masses of air hundreds of miles in area, miles in depth and millions of tons in weight may remain at rest for a time over a region, becoming affected by the surface temperature and humidity characteristic of the region. When eventually they are moved by the forces of atmospheric circulation, often at tremendous speeds, they may travel over regions quite different from their origin, while retaining for some time their original characteristics as warm-dry or warm-moist, cold-dry or cold-moist. When they meet dissimilar air masses, the lighter, warmer and drier air overruns the heavier masses. Boundaries between dissimilar masses are created, called *fronts* by the weather analyst. The front represents a discontinuity in the dielectric constant of the troposphere, which serves to refract and reflect radio waves in much the same manner as the ionospheric layers but at much lesser heights. The result is the return to earth of 50- and 144-Mc. signals, and possibly those of higher frequencies as well, at distances appreciably beyond the range of ground-wave propagation, sometimes up to 400 miles.

The most common of these tropospheric discontinuities is known as the *temperature inversion.* Normally, the temperature of the lower atmosphere decreases at a constant rate with increasing height. When for any reason this *lapse rate* of approximately 3 degrees F. per 1000 feet of elevation is altered, a temperature inversion is said to take place. Some of the types of temperature inversion are the *dynamic* inversion, resulting from the overrunning of a warm air mass by a colder mass; the *subsidence* inversion, caused by the sinking of an air mass heated by compression; the *nocturnal* inversion, brought about by the rapid cooling of surface air after sunset; and the *cloud-layer* inversion, caused by the heating of air above a cloud layer by reflection of the sun's rays from the upper surface of the clouds. Similar sharp transitions in the water-vapor content of the atmosphere may also bring about refraction and reflection of v.h.f. waves.

Tropospheric wave propagation is marked by characteristic fading phenomena. The governing conditions are much less stable than those in ionospheric transmissions, but are increasingly predictable as knowledge of weather conditions and air-mass movements is advanced. Hourly and seasonal variations are observed. Best conditions often prevail in the evening and just before sunrise. Conditions are generally poorest at mid-day when the atmosphere is relatively stable. Seasonally, the summer usually offers better conditions, and there is a peak period in the late spring and early summer corresponding with the best period for sporadic *E*-layer propagation. Effects are heightened at locations along the sea coasts by the on-shore breezes.

Because of the effect of shifting angles of advancing fronts and the differences in extent of the fronts, ability to vary the angle of principal radiation from a v.h.f. antenna may enable the operator to gain maximum advantage from prevailing tropospheric conditions. An antenna which is so mounted and fed as to be entirely flexible in orientation, not only at all angles with respect to the horizon and the direction of maximum propagation but also in a range of at least one wavelength in height above ground, will serve best in tropospheric wave propagation. A device which would automatically orient the antenna in response to changing propagation conditions is still the dream of the v.h.f. operator, but not beyond the realm of possibility.

Ground-Wave Propagation

At the present time the most reliable means of propagation of all frequencies above 30 Mc. is by the ground wave, though the range is confined to distances only slightly beyond the length of the line of sight from the transmitting antenna to the receiving antenna because of the rapid absorption of ground waves at the very-high frequencies.

The distance to the horizon over level terrain, including normal refraction and diffraction effects slightly beyond the horizon, is expressed by the formula

$$D = 1.41\sqrt{x}$$

where x is the height in feet of the center of the transmitting antenna and D the distance in miles. When both the transmitting and receiving points are elevated, the maximum line-of-sight distance will be the sum of the distances computed by the formula for each location. The actual range of the space wave, however, is greatly affected by diffraction caused by intervening hills and other irregularities of terrain, as well as by the presence of reflecting surfaces at suitable points behind the transmitter and receiver. Such reflectors may consist either of earth contours or of artificial metallic elements arranged in the form of a directive antenna array. There is evidence to support the theory that the presence of a relatively consistent local convection current or an updraft, such as is usually found on the windward side of a ridge or mountain range, may affect propagation to a measurable degree. Although this is properly a tropospheric effect, it bears a more direct relation to topography.

The considerations of antenna orientation for effective ground-wave propagation are the same as discussed in the section on tropospheric propagation. The height of the center of the antenna in wavelengths above the surface is of primary importance. Because the effect of the ground-reflected component of the wave is important in aiding or in distorting the direct wave, a range of adjustment in height of the center of the antenna is particularly desirable. Further reference to Fig. 2 will show the effect of the ground-reflected component on phase angles when refraction and earth curvature are neglected and the intervening terrain between transmitter and receiver is smooth and level. Since the actual conditions are usually far more complex, the formulas given may be taken only as an approximation, and in practice the amateur will be rewarded by experimentation with antenna height and orientation, checked by reports from a remote receiver, as well as by field-strength measurements wherever possible.

Space-wave calculations are of particular importance in the case of horizontally polarized waves at very-high frequencies. The surface wave has but little effect on such waves. A formula which will apply to most practical computations of field strength for horizontally polarized waves at very-high frequencies can be written as

$$\text{Space wave} = \frac{2E_o}{d} \sin 2\pi \frac{h_t h_r}{\lambda d}$$

where the notation is as given in Fig. 2. E_o is the field that would be produced if the antenna were in free space and the currents were the same as those actually present, and λ is the operating wavelength.

Since the curvature of the earth introduces two effects that operate in opposite directions, this formula can be used where there is a moderate amount of earth curvature. This is explained by the fact that the curvature makes the effective heights of the transmitting and receiving antennas which must be used less than their actual heights, resulting in an actual received field strength less than the field that would be calculated for the same antenna height neglecting curvature. At the same time, the wave reflected from the slightly spherical ground diverges more than would be the case if the reflection took place from a plane surface, thereby reducing the intensity of the ground-reflected wave arriving at the receiving antenna. This reduces the extent to which the ground-reflected wave can cancel the direct wave, and so tends to increase the strength of the receiving field.

Besides the factors affecting the space wave with its direct ray and ground-reflected components, the attenuation of the surface wave or earth-guided wave must be considered. This involves both the conductivity and dielectric constant of the earth within the path and the presence or absence of irregularities of surface and of wooded areas and man-made structures, as in cities, which tend to reduce the effective conductivity of the earth. These effects at the very-high frequencies are too complicated for reduction to a formula, and are best evaluated by a field-strength survey.

The conductivity and dielectric constant of earth vary widely. The depth to which ground currents of appreciable amplitude exist ranges from about 5 feet at the very-high frequencies to 50 feet or more at broadcast frequencies and below. Therefore the earth constants are not particularly sensitive to surface conditions, such as recent rainfall. A number of types of terrain are listed in the order of their relative conductivity: sea water, fresh water, rich moist loam, clay, rocky soil, sand. If the surface is not level, or if it be wooded or contain many buildings, the effective conductivity is reduced.

Antennas and Wave Propagation

From this discussion of wave travel it should be apparent that one of the functions of the antenna is to send a wave into the propagating medium in such a way that it will have the best chance of being returned to earth at the receiving point. This is chiefly a matter of the angle at which the wave encounters reflecting and refracting discontinuities, although in some cases polarization may be of importance. It must be recognized that the desirable conditions will change with frequency.

The desirable type of "send-off" for waves of different frequencies can be summarized as follows, by the various amateur bands:

1.75-Mc.: Low-angle radiation is indicated for the longer distances. High-angle radiation may cause fading toward the limit of the ground-wave signal, because the downcoming waves add in random phase to the ground-reflected and surface waves. Vertical polarization is to be preferred.

3.5 Mc.: As at 1.75 Mc., waves at all angles of radiation usually will be reflected, so that no energy is lost by high-angle radiation. It is true again, however, that the lower-angle waves will in general give the greater distance. Polarization on this band does not appear to be of great importance.

7 Mc.: Under most conditions, angles of radiation up to about 45 degrees will be returned to earth; during the sun-spot maximum, still higher angles are useful. It is best, however, to concentrate the radiation below 45 degrees. Polarization is not important, except that losses probably will be higher with a vertically polarized antenna.

14 Mc.: For long-distance transmission, most of the energy should be concentrated at angles below about 20 degrees. Higher angles are useful for comparatively short distances (300–400 miles), although 30 degrees is about the maximum useful angle. Aside from the probable higher losses with vertical polarization at the antenna, the polarization may be of any type.

28 Mc.: Angles of 10 degrees or less are most useful. As in the case of 14 Mc., polarization is not important so far as the ionosphere is concerned.

50 Mc.: The lowest possible angle of radiation is most useful for all types of transmission. Vertical polarization has been chiefly used for line-of-sight and tropospheric transmissions, although horizontal polarization is also successful. In any event, in both these types of transmission the *same* polarization should be used at both transmitter and receiver. For sporadic *E*-layer transmission there is no evidence to favor any particular type of polarization.

Higher frequencies: The relatively small amount of data indicates that, as in the case of 50-Mc. optical and tropospheric transmission, either horizontal or vertical polarization may be used so long as the same type is employed at both ends of the circuit. Concentration of low-angle radiation in a preferred direction by means of suitable arrays of reflector, radiator and directors, or radiator and parabolic reflector, become increasingly desirable and physically practicable at the very-high and higher frequencies.

Wherever possible the location of any antenna should be chosen only after careful experimentation. Often a shift of only a few inches in the position of a v.h.f. antenna with respect to surrounding objects will result in a marked change in the pattern of field intensity. Since any reflecting surface that tends to concentrate an appreciable portion of the radiated energy along the horizontal increases the intensity of the ground wave, advantage should be taken of any natural reflectors that might aid in a favored direction. Conversely, careful location may do much to lessen the effects of obstacles in a desired direction.

2. ANTENNA FUNDAMENTALS

CURRENT AND VOLTAGE DISTRIBUTION — HARMONIC OPERATION — ELECTRICAL LENGTH — RADIATION PATTERNS

THE strength of the field radiated from a section of wire carrying radio-frequency current depends upon the length of the wire and the value of the current flowing in it. For a given power input to the wire, the current will be highest when the reactance of the wire at the frequency of the r.f. current is zero, just as the current in a circuit consisting of a coil and condenser is highest when the net reactance of the circuit is zero — in other words, when the circuit is resonant.

The shortest length of wire which will resonate to a given frequency is one which is just long enough to permit an electric charge to travel from one end to the other and then back again in the time of one r.f. cycle. If the speed at which the charge travels is equal to the velocity of light, or 300,000,000 meters per second, the distance which it will cover in one cycle will be equal to this velocity divided by the frequency in cycles per second, or

$$\lambda = \frac{300{,}000{,}000}{f}$$

in which λ is the wavelength in meters. Since the charge traverses the wire twice, the length of wire needed to permit the charge to travel a distance λ in one cycle is $\lambda/2$, or one-half wavelength. Therefore the shortest *resonant* wire will be a half wavelength long.

The reason for this length can be made clear by a simple example. Imagine a trough with barriers at each end. If an elastic ball is started along the trough *from one end*, it will strike the far barrier, bounce back, travel along to the near barrier, bounce again, and continue until the energy imparted to it originally is all dissipated. If, however, whenever it returns to the near barrier it is given a new push just as it starts away, its back-and-forth motion can be kept up indefinitely. The impulses, however, must be *timed* properly; in other words, the rate or frequency of the impulses must be adjusted to the length of travel and the rate of travel. Or, if the timing of the impulses and the speed of the ball are fixed, the length of the trough must be adjusted to "fit."

In the case of the antenna, the speed is constant, so we have the alternatives of adjusting the frequency to a given length of wire, or the length of wire to a given frequency. The latter is usually the practical condition.

By changing the units in the equation just given, and dividing by 2, the more useful formula

$$l = \frac{492}{f\ (\text{Mc.})}$$

is obtained. In this case l is the length *in feet* of a *half* wavelength for a frequency f, given in megacycles, when the wave travels with the velocity of light. This formula is the basis upon which several significant lengths in antenna work are developed. It represents the length of a half wavelength in space, or when no factors which modify the speed of propagation exist.

Current and Voltage Distribution

If the wire in the first illustration had been infinitely long the charge, or electrical potential (voltage) and the current — an electric current is simply a charge in motion — would both decrease slowly with distance from the source. The slow decrease would result from dissipation of energy in the form of radio waves and in heating the wire because of its resistance. When the wire is short, however, the charge is reflected when it reaches the far end, just as the ball bounced back from the barrier. With radio-frequency excitation of a half-wave antenna, there is of course not just a single charge but a continuous supply of energy, varying in voltage according to a sine-wave cycle. We might consider this as a series of charges, each of slightly different amplitude than the preceding one. When a charge reaches the end of the antenna and is reflected, the direction of current flow reverses, since the charge is now traveling in the opposite direction. However, the next charge is just reaching the end of the antenna, so we have two currents of practically the same amplitude flowing in opposite directions. The resultant current at the end of the antenna therefore is zero. As we move farther back from the end of the antenna the magnitudes of the outgoing and returning currents are no longer the same because the charges causing them have been supplied to the antenna at different parts of the r.f. cycle. There is less cancellation, therefore, and a meas-

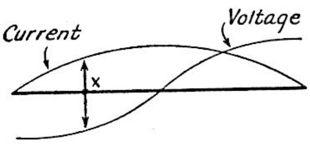


Fig. 201 — **Current and voltage distribution on a half-wave wire. In this conventional representation the distance at any point (X, for instance) from the wire, represented by the heavy line, to the curve gives the relative intensity of current or voltage at that point.**

urable current exists. The greatest difference — that is, the largest resultant current — will be found to exist a quarter wavelength away from the end of the antenna. As we move back still farther from this point the current will decrease until, a half wavelength away from the end of the antenna, it will reach zero again. Thus in a half-wave antenna the current is zero at the ends and maximum at the center.

The voltage, or electrical potential, along the wire will behave differently; it is obviously greatest at the end since at this point we have two practically equal charges adding. As we move back along the wire, however, the outgoing and returning charges are not equal and their sum is smaller. At the quarter-wave point the returning charge is of equal magnitude but of opposite sign to the outgoing charge, since at this time the polarity of the voltage wave from the source has reversed (one-half cycle). The two voltages therefore cancel each other and the resultant voltage is zero. Beyond the quarter-wave point, away from the end of the wire, the voltage again increases, but this time with the opposite polarity.

It will be observed, therefore, that the voltage is maximum at every point where the current is minimum, and vice versa. The polarity of the current or voltage reverses every half wavelength along the wire, but the reversals do not occur at the same points for both current and voltage; the respective reversals occur, in fact, at points a quarter wave apart.

The distribution of current and voltage along the wire follows, for all practical purposes, a sine curve. The phenomenon of standing waves is easily observed by inserting an ammeter at various points along the wire to measure the current, or by using a voltage-sensitive device such as a neon lamp to indicate the voltage maxima and minima.

A maximum point on a standing wave is called a loop (or anti-node); a minimum point is called a node.

Harmonic Operation

If there is reflection from the end of a wire, the number of standing waves on the wire will be equal to the length of the wire divided by a half wavelength. Thus if the wire is two half waves long there will be two standing waves; if three half waves long, three standing waves, and so on. These longer wires, each multiples of a half wave in length, also will be resonant, therefore, to the same frequency as the single half-wave wire. When an antenna is two or more half waves in length at the operating frequency it is said to be harmonically resonant, or to operate at a harmonic, the number of the harmonic being the number of standing waves on the wire. For example, a wire two half waves long is said to be operating on its second harmonic; one three half waves long on its third harmonic, and so on.

Harmonic operation is often utilized in antenna work because it permits operating the same antenna on several harmonically-related amateur bands. It is also an important principle in the operation of certain types of directive antennas.

Electrical Length

The electrical length of a linear circuit such as an antenna wire is not necessarily the same as its physical length in wavelengths or fractions of a wavelength. Rather, the electrical length is measured by the *time* taken for the completion of a specified phenomenon.

For instance, we might imagine two linear circuits having such different characteristics that the speed at which a charge travels is not the same in both. Suppose we wish to make both circuits resonant to the same frequency, and for that purpose adjust the physical length of each until a charge started at one end travels to the far end, is reflected and completes its return journey to the near end in exactly the time of one r.f. cycle. Then it will be found that the physical length of the circuit with the lower velocity of propagation is shorter than the *physical* length of the other. The *electrical* lengths, however, are identical, each being a half wave.

In alternating current circuits the instantaneous values of current or voltage are determined by the instant during the cycle at which the measurement is made (assuming, of course, that such a measurement could be made rapidly enough). If the current and voltage follow a sine curve, which is the usual case, the time, for any instantaneous value, can be specified in terms of an angle, the sine of which gives the instantaneous value when multiplied by the *peak* value of the current or voltage. A complete sine curve occupies the 360 degrees of a circle, and represents one cycle of a.c. current or voltage. Thus a half cycle is equal to 180 degrees, a quarter cycle to 90 degrees, and so on.

It is often convenient to use this same form of representation for linear circuits. When the electrical length of such a circuit is such that a charge, *traveling in one direction,* takes the time of one cycle to traverse it, the length of the circuit is said to be 360 degrees. This corresponds to one wavelength. On a wire a half wave in electrical length the charge completes a one-way journey in one-half cycle, and its length is said to be 180 degrees. The angular method of measurement is quite useful for lengths which are not easily-remembered fractions such as ½ and ¼ wavelength, or multiples of such fractions.

Velocity of Propagation

The speed or velocity at which electromagnetic waves travel through a medium depends upon the dielectric constant of the medium. At radio frequencies the dielectric constant of air is unity, so that the waves travel with the velocity of light in a vacuum. This is also the velocity of the charge traveling along a wire.

If the dielectric constant is greater than 1, the velocity of propagation is lowered. Thus the introduction in appreciable quantity of insulating material which has a dielectric constant greater than 1 will cause a slowing down of the speed of the wave. This effect is frequently encountered in practice in connection with both antennas and transmission lines, and causes the electrical length of the line or antenna to be somewhat greater than the actual physical length.

Length of a Half-Wave Antenna

The electrostatic capacity at the ends of a half-wave antenna is higher than might be expected, because of the presence of the insulators which support the antenna. For ordinary antenna systems this "end effect," for the reason described in the preceding section, causes the physical length of the antenna to be about 5 per cent less than the length of a half wave in space. The percentage varies slightly with different installations, but as a good average the length of a half-wave antenna may be taken to be

$$l\ (\text{feet}) = \frac{492 \times 0.95}{f\ (\text{Mc.})}$$

or

$$l\ (\text{feet}) = \frac{468}{f\ (\text{Mc.})}$$

This formula is sufficiently accurate, for all practical purposes, for finding the physical length of a half-wave antenna for a given frequency, but does not apply to antennas longer than a half wave in length.

The current at the ends of the antenna does not quite reach zero because of the end effect, as there is some current flowing into the end capacity. Similarly, the voltage at the center does not pass through zero, but drops to some low, but finite, value at the point where the reversal in polarity takes place. This is because the resistance of the antenna is not zero, and therefore some energy is consumed; hence there must be some voltage present to force the current to flow.

Antenna Resistance

The energy supplied to an antenna is dissipated in the form of radio waves and in heat losses in the wire and nearby dielectrics. The radiated energy is the useful part, but so far as the antenna is concerned it represents a loss just as much as the energy lost in heating the wire is a loss. In either case the dissipated power is equal to I^2R: in the case of heat losses, the R is a real resistance, but in the case of radiation R is an assumed resistance, which, if it had actually been present, would have dissipated the same power that actually disappears by radiation. This fictitious resistance is called the radiation resistance. The total power loss in the antenna is therefore equal to $I^2(R_0 + R)$, where R_0 is the radiation resistance and R the real resistance, or ohmic resistance.

Since the current varies at different parts of the antenna, it is necessary to specify the point at which it is measured. The current, radiation resistance and ohmic resistance are always measured at a current maximum, or loop. For a half-wave antenna in free space — that is, entirely removed from any objects which might affect its operation, including the earth — the radiation resistance is equal to about 73 ohms. This value is modified by the presence of conductors or dielectric materials in the field of the antenna, and by the presence of the ground. The ohmic resistance depends upon the size of the conductor and the material of which it is made. The resistance of copper wire of size No. 14 or larger is quite small at high frequencies, compared to the radiation resistance, so that most of the energy loss in a half-wave antenna is by radiation. Because of this, well over nine-tenths of the energy supplied to the antenna is radiated in the form of electromagnetic waves. In other words, a high-frequency antenna is more than 90 per cent efficient.

Antenna Impedance

The impedance of an electrical circuit is equal to the voltage divided by the current. If in an a.c. circuit the voltage and current are in phase — that is, reach their positive maxima and negative maxima together — the impedance is resistive only. If reactance is present, however, the maxima of current and voltage do not coincide and the current and voltage are said to be out of phase. The difference in phase is measured by the fraction of a cycle separating corresponding points on the voltage and current waves, and, since this is a matter of time, can again be expressed in degrees.

In the half-wave antenna the current and voltage are approximately 90 degrees out of phase, as we have already seen, except at the center where the standing wave of voltage is changing polarity. At this point the voltage and current are in phase, and the impedance is resistive only. At all other points along the antenna the impedance is largely reactive. As shown by Fig. 201, the voltage increases and the current decreases as we move away from the center of the antenna and, since impedance is equal to E/I, the impedance progressively increases, reaching equal maximum values at the ends.

If the antenna is some multiple of a half wave in length, as in Fig. 202, the impedance reaches its lowest value (and is resistive) at each current loop, and its highest value at each voltage loop. The

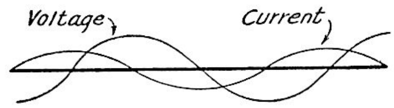


Fig. 202 — **Harmonic operation of a long wire. The wire is long enough to contain several half waves. The current and voltage curves cross the heavy line representing the wire to indicate that there is a reversal in the direction of the current, and a reversal in the polarity of the voltage, at intervals of a half wavelength. The reversals of current and voltage do not coincide, but occur at points a quarter wavelength apart.**

impedance thus goes through regular cycles just as do the standing waves of current and voltage.

The antenna impedance is important in connection with methods of feeding power to the antenna, since the impedance at the point at which the power is introduced determines whether the power must be supplied at high voltage and low current, low voltage and high current, and so on.

Radiation Patterns

The radiation from an infinitesimally small length of wire carrying a radio-frequency current would be distributed equally in all directions. The section of wire could be considered as a point source of radiation at the center of a sphere of any desired radius, and the field strength would be the same at every point on the surface of such a sphere.

We can consider a wire of appreciable length to be made up of a chain of such elemental point radiators, and find that when this is the case the field strength is no longer uniform at equal distances in any direction from the wire. This comes about because the waves radiated by the elemental lengths do not add in the same way in different directions with respect to the wire.

To illustrate this, let us take two point radiators, or elemental lengths of wire, and separate them by a half wavelength. Each radiates equally well in all directions, but we shall confine ourselves only to one plane, that of the page. If the currents are of equal intensity and in phase, the fields about each at a given instant might look like the pattern shown in Fig. 203. Because of the separation between the radiators, the fields along the line X-Y passing through the two points always oppose each other, so that the net field strength is zero along that line. This is a direct consequence of the time taken by the field to reach a point a

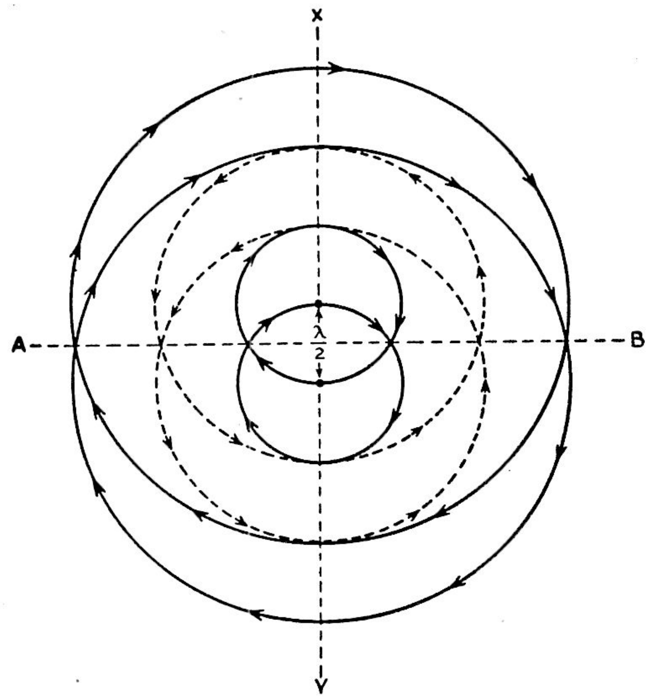


Fig. 203 — **Interference between waves from two separated radiators causes the resultant directional effects to differ from those of either radiator alone. The two radiators shown here are separated one-half wavelength. The radiation fields of the two cancel along the line X-Y but, at distances which are large compared to the separation between the radiators, add together along line A-B. The resultant field decreases uniformly as the line is swung through intermediate positions from A-B to X-Y.**

half wavelength away. On a line A-B perpendicular to that joining the radiators, the opposite condition exists. Here the fields are always in phase, or adding, so that the resultant field strength along such a line is practically twice the field of either radiator alone.

The situation is much more complex when a wire consisting of a series of infinitesimally small radiators is considered, since it is necessary to take into account the effect of the radiation from each elementary length, which includes not only an allowance for varying current values in different parts of the wire, but also phase differences. Formulas for relative intensity of radiation in any direction from wires of any length are available, however. The solutions of the formulas give the radiation pattern of the antenna considered. The complete radiation pattern is a solid figure in which the distance from the center to any point on the surface gives the relative intensity of radiation in that direction from the antenna, the antenna being the point at the center. The patterns differ greatly for antennas of different lengths.

The solid pattern of radiation from any straight single wire in free space is always symmetrical with respect to the axis of the wire. Therefore if the pattern is cut by any plane containing the wire axis the cross-section of the pattern will always be the same. The outline of the section of the solid pattern on such a plane gives the plane directive diagram. Such a diagram for a half-wave antenna is shown in Fig. 204. It is usually plotted on polar coördinate paper (paper with radial lines marking the 360 degrees of angle in a circle, and with a linear scale of concentric circles for marking amplitudes). The plane directive diagram is very useful in antenna work, but it must be remembered that this type of diagram shows only two dimensions of a three-dimensional figure. The third dimension always must be specified in practical work.

If a plane is passed through the doughnut-shaped solid pattern of a half-wave antenna at right-angles to the axis of the wire, the cross section of the solid pattern will be a circle. In this plane, therefore, the radiation is of equal intensity in all directions.

Although the actual antenna wire is represented in Fig. 204, it is important to keep in mind that in any directive diagram or radiation pattern the antenna is represented simply by a point at the center of the pattern. Every plane which is passed through the solid pattern to get a plane directive diagram must therefore pass through the center of the pattern.

The points on the pattern where the radiation is zero are called **nulls,** and the curved section from one null to the next on the plane diagram, or the corresponding section on the solid pattern, is called a **lobe.**

Radiation and Induction Fields

In addition to the radiation fields already described, there are also magnetic and electric fields about an antenna which correspond to the ordinary magnetic field about a coil carrying current, or between the plates of a charged condenser. In other words, these induction fields result from the self-inductance and self-capacity of the antenna. The strength of the induction fields is inversely proportional to the square of the distance from the antenna, while the radiation fields die away directly with the distance. The two kinds of fields have equal intensity at a distance equal to the wavelength divided by 2π, or slightly less than 1/6 wavelength. At about 3/8 wavelength the induction field is negligible compared with the radiation field.

The induction field is of little importance because it decreases so rapidly with distance. However, in making field strength measurements in the vicinity of an antenna its existence must be kept in mind and the antenna not approached too closely if the strength of the radiation field only is to be measured.

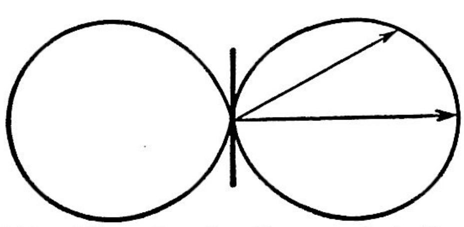
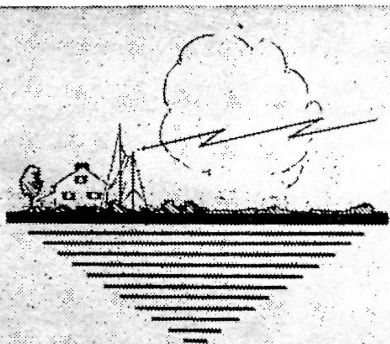


Fig. 204 — **Plane directive diagram of a half-wave antenna. The solid line shows the direction of the wire, although the antenna itself is considered to be simply a point at the center of the diagram. The length of the arrow represents the relative field strength in that direction.**
***The "doughnut"* form of the solid directive pattern can be visualized by imagining the drawing glued to a piece of stiff cardboard with a short length of wire fastened at the center, in the position occupied by the solid line, to represent the antenna. Then twirling the wire rapidly will give a representation of the actual solid pattern.**

Reciprocity

The various properties of an antenna apply both to transmitting and receiving, subject to some qualifications when the path of the waves between the transmitting and receiving points involves propagation through the ionosphere. Thus, the more efficient the antenna for transmitting, the more effective it will be for receiving. The directive properties will be the same for both transmission and reception, and, in the case of directive antenna systems, the gain will be the same on both transmitted and received signals. The current distribution and impedance will likewise be identical whether the energy is fed directly to the antenna from the transmitter or whether it is picked up from passing waves of the same frequency.

In long-distance transmission the observed behavior may sometimes be at variance with this rule because the waves may not take exactly the same paths through the ionosphere when going in opposite directions, and therefore an incoming wave may not strike the antenna at the same angle, in either the horizontal or vertical planes, which gives the best results for a transmitted wave whose destination is the source of the received signal. Thus the two waves may be utilizing different parts of the directive pattern of the antenna, with some departure from complete reciprocity. On the average, however, the reciprocal relation for transmitting and receiving holds quite well even with varying ionosphere conditions.



3. GROUND EFFECTS

REFLECTION FROM THE GROUND — REFLECTION FACTORS — GROUND RESISTANCE — FREQUENCY EFFECTS

THE performance of an antenna, particularly with respect to its directive properties, is considerably modified by the presence of the earth underneath it. The earth acts like a huge reflector for those waves which are radiated from the antenna at angles lower than the horizontal, so that the downcoming waves strike the surface and are reflected by a process very similar to that by which light waves are reflected from a mirror. As in the case of light waves, the angle of reflection is the same as the angle of incidence, so that a wave which strikes the surface at an angle of, for instance, 15 degrees, is reflected upward from the surface at the same angle.

The reflected waves combine with the direct waves, or those radiated at angles above the horizontal, in various ways, depending upon the orientation of the antenna with respect to earth,

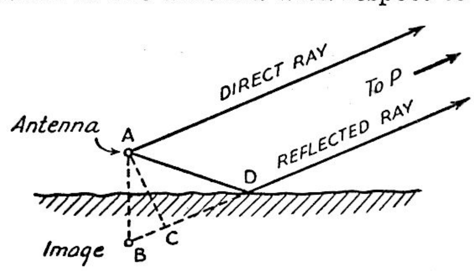


Fig. 301 — At any distant point, P, the field strength will be the resultant of two rays, one direct from the antenna, the other reflected from the ground. The reflected ray travels farther than the direct ray by the distance BC, where the reflected ray is considered to originate at the "image" antenna.

the height of the antenna, its length, and the character of the ground. At some vertical angles above the horizontal the direct and reflected waves may be exactly in phase — that is, the maximum field strengths of both waves are reached at the same time at the same spot, and the directions of the fields are the same — so that the resultant field strength is equal to the sum of the two. At other vertical angles the two waves may be completely out of phase — that is, the fields are maximum at the same instant and the directions are opposite, at the same spot — so that the resultant field strength is the difference between the two. At still other angles the resultant field will have intermediate values. Thus the effect of the ground is to increase the intensity of radiation at some vertical angles and to decrease it at others.

The effect of reflection from the ground is shown graphically in Fig. 301. At a sufficiently large distance, the two rays which converge at the distant point can be considered to be parallel. The reflected ray travels a greater distance in reaching P than the direct ray does, however, and this difference in path length accounts for the effect described in the preceding paragraph. If the path of the reflected ray is exactly a half wave longer than the path of the direct ray, the two waves will arrive out of phase. This corresponds to the condition illustrated in Fig. 203, Chapter 2. If the path of the reflected ray is just a wavelength longer than that of the direct ray, however, the two rays arrive in phase. This is true providing the phase of the reflected wave is not changed in the process of reflection from the ground, which is the case with a perfectly-conducting ground.

Image Antennas

It is often convenient to use the concept of an image antenna to show the effect of reflection. As Fig. 301 shows, the reflected ray has the same path length (AD equals BD) that it would if it originated at a second antenna, of the same characteristics as the real antenna, but situated below

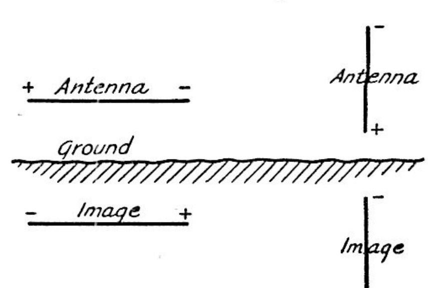


Fig. 302 — Horizontal and vertical half-wave antennas and their images.

the ground just as far as the actual antenna is above it. Like an image in a mirror, this image antenna is "in reverse," as shown in Fig. 302. If the real antenna is horizontal, and is instantaneously charged so that one end is positive and the other negative, then the image antenna, also horizontal, is oppositely poled; the end under the positively charged end of the real antenna is negative, and vice versa. Likewise, if the lower end of a half-wave vertical antenna is instantaneously positive, the end of the vertical image antenna nearest the surface is negative. Now if we look at the antenna and its image from a remote point on the surface of the ground, it will be obvious that the currents in the horizontal antenna and its image are flowing in opposite directions, or are 180 degrees out of phase, but the currents in the vertical antenna and its image are flowing in the same direction, or are in phase. The effect of ground reflection, or the image antenna, is therefore different for horizontal and vertical half-wave antennas.

Reflection Factor

The effect of reflection can be expressed as a factor which, when multiplied by the free-space figure for relative intensity of radiation at a given vertical angle from an antenna, gives the resultant relative radiation intensity at that same angle. The limiting conditions are those represented by the direct ray and reflected ray being exactly in phase and exactly out of phase when both, assuming there are no ground losses, have exactly equal amplitudes. Thus the resultant field strength may be either twice the field strength from the antenna alone, or zero.

The way in which the reflection factor (based on perfectly-conducting ground) varies with antenna height is shown in the series of graphs, Figs. 303 to 320. Figs. 303 to 314 apply to hori-

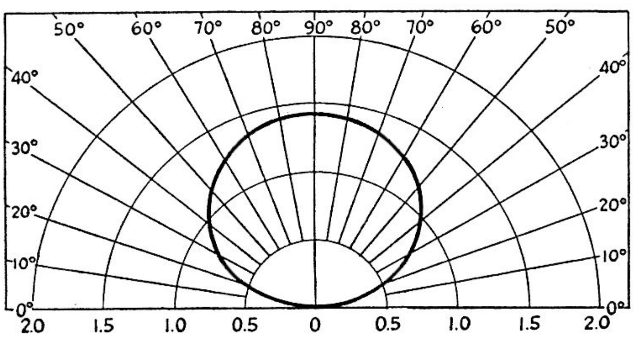


Fig. 303 — Ground reflection factor, horizontal antennas ⅛ wavelength high.

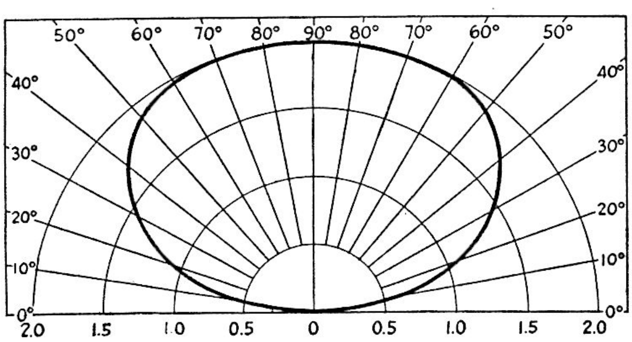


Fig. 304 — Ground reflection factor, horizontal antennas ¼ wavelength high.

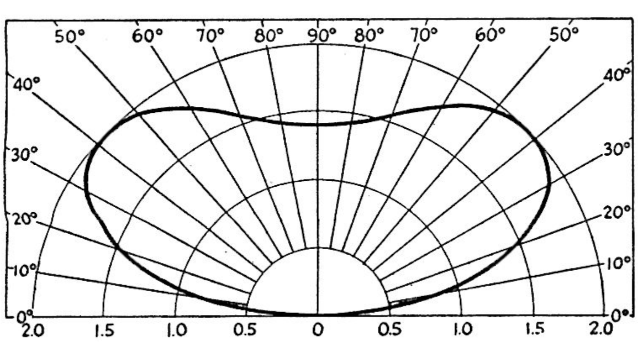


Fig. 305 — Ground reflection factor, horizontal antennas ⅜ wavelength high.

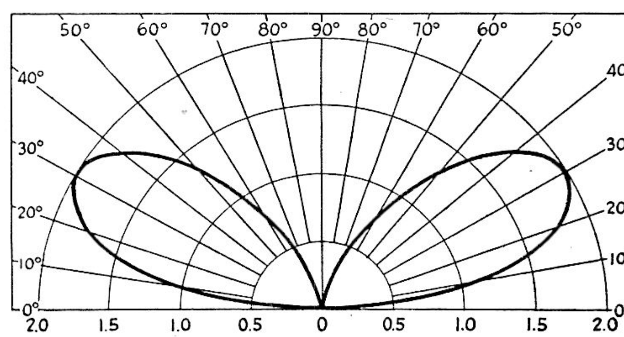


Fig. 306 — Ground reflection factor, horizontal antennas ½ wavelength high.

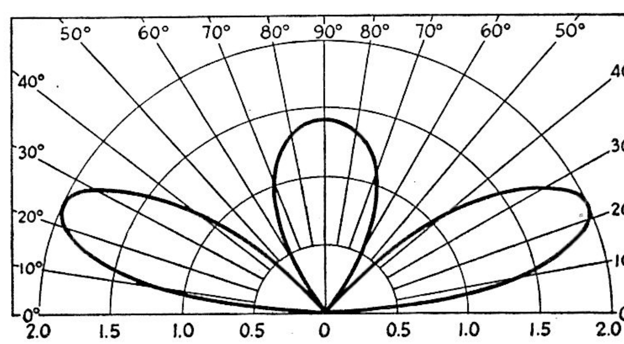


Fig. 307 — Ground reflection factor, horizontal antennas ⅝ wavelength high.

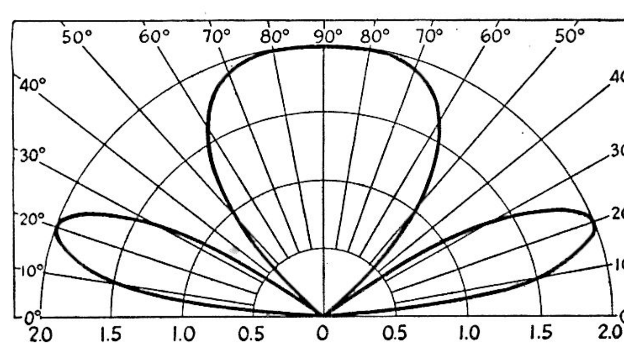


Fig. 308 — Ground reflection factor, horizontal antennas ¾ wavelength high.

zontal antennas of any length, and to vertical antennas an *even* number of half-waves long. Figs. 315 to 320 apply to vertical antennas an *odd* number of half-waves long. Comparing the two sets, it is seen that the positions of nulls (multiplying factor zero) and maxima (multiplying factor 2) are interchanged for the two sets of conditions.

It must be remembered that these graphs are not plots of vertical patterns of antennas, but represent simply multiplying factors representing the result of reflection from the ground. With the distinction between vertical and horizontal antennas noted, the graphs apply equally well to *all* antennas. Also, it should be understood that they apply at vertical angles only. The ground makes no distinction between geographical directions in reflecting waves.

Fig. 321 shows the angles at which nulls and maxima occur as a function of the height of the antenna. This chart gives a rough idea of the ground reflection pattern for heights intermediate to those shown in detail in Figs. 303–320, and also facilitates picking the right height for any desired angle of radiation.

Ground Characteristics

As already indicated, the charts are based on reflection from a perfectly-conducting ground. In practice, the ground does not act like a perfect conductor at high frequencies. The effect of ground losses is to reduce the amplitude of the reflected wave so that the maximum reflection factor is something less than 2 and the null does not reach zero. Also, there may be a shift in phase with reflection which further changes the actual picture.

At all except the lowest angles these effects are small, and no serious error is introduced by assuming that the ground acts like a perfect

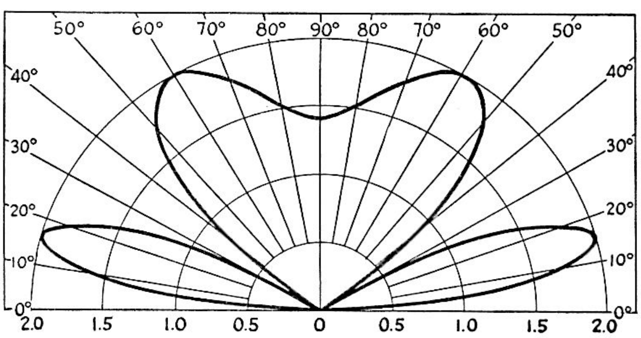


Fig. 309 — Ground reflection factor, horizontal antennas 7/8 wavelength high.

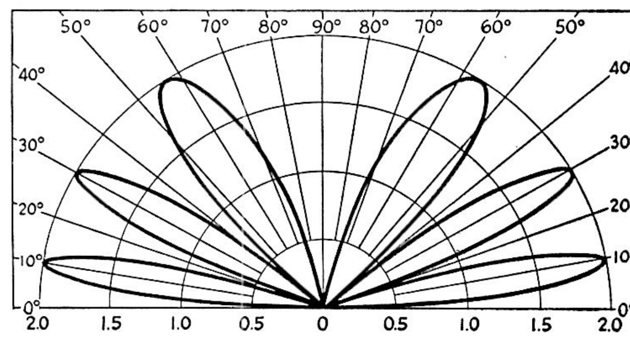


Fig. 312 — Ground reflection factor, horizontal antennas 1½ wavelength high.

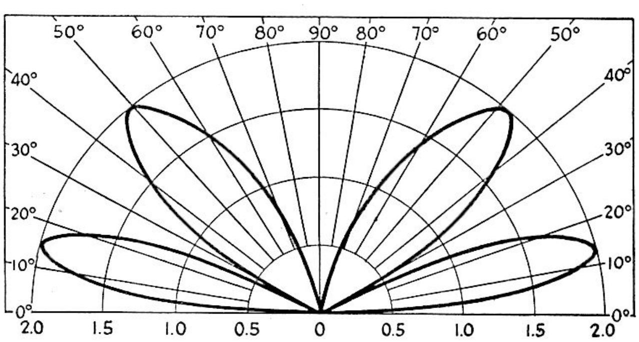


Fig. 310 — Ground reflection factor, horizontal antennas 1 wavelength high.

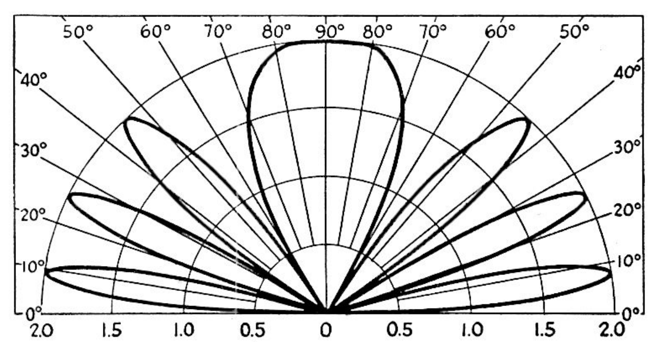


Fig. 313 — Ground reflection factor, horizontal antennas 1¾ wavelength high.

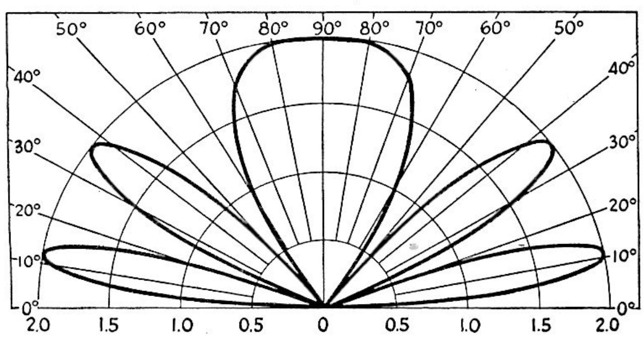


Fig. 311 — Ground reflection factor, horizontal antennas 1¼ wavelength high.

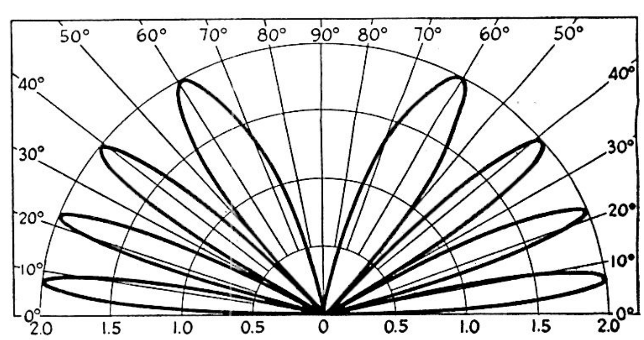


Fig. 314 — Ground reflection factor, horizontal antennas 2 wavelengths high.

reflector. The effect at angles below about 10 degrees is to give increasingly more attenuation than is indicated by the charts, until at about 3 degrees and lower there is no radiation, for all practical purposes. This applies to either horizontal or vertical antennas, so that the reflection factor at the horizontal with a half-wave vertical antenna, which theoretically is 2, actually is zero. Thus the apparent advantage of the vertical antenna at very small angles is not realized at high frequencies.

At frequencies of the order of 1.75 and 3.5 Mc. ground losses are of less consequence, and the charts become more nearly true for all vertical angles.

The "effective reflecting plane" of the ground — that is, the surface from which the reflection is considered to take place at the heights given in the charts — seldom coincides with the actual surface of the ground. Usually it will be found that this plane appears to be a few feet below the surface; in other words, the height of the antenna taken for purposes of estimating reflection is a few feet more than the actual height of the antenna. A great deal depends upon the character of the ground, and in some cases the reflecting plane may be "buried" a surprising distance. Thus in some instances the charts will not give an accurate indication of the effect of reflection. On the average, however, they will give a quite satisfactory representation of reflection effects, with the qualifications with respect to high frequencies and low angles mentioned above.

Ground Reflection and Radiation Resistance

Waves radiated from the antenna directly downward reflect vertically from the ground and, in passing the antenna on their upward journey, induce a current in it. The magnitude and phase

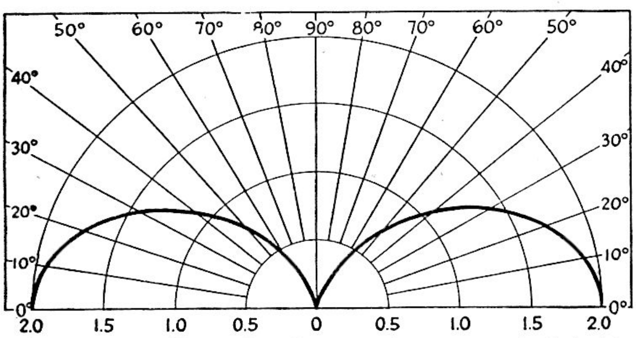


Fig. 315 — Ground reflection factor, vertical half-wave antenna with center ¼ wavelength above ground.

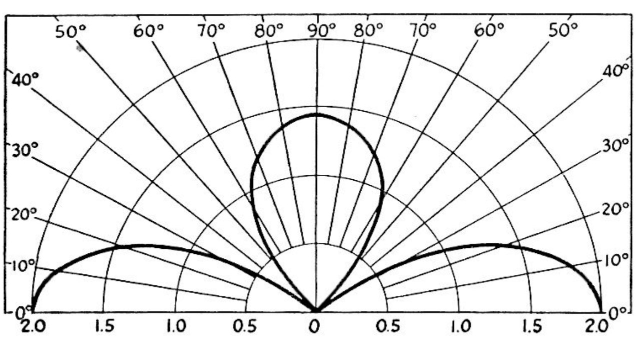


Fig. 316 — Ground reflection factor, vertical half-wave antenna with center ⅜ wavelength above ground.

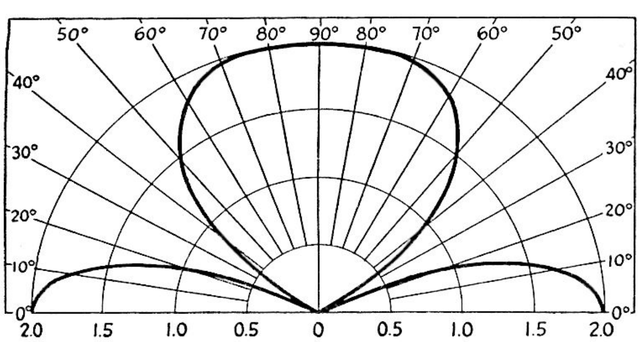


Fig. 317 — Ground reflection factor, vertical half-wave antenna with center ½ wavelength above ground.

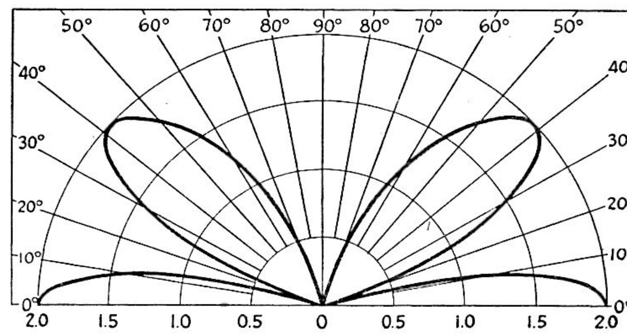


Fig. 318 — Ground reflection factor, vertical half-wave antenna with center ¾ wavelength above ground.

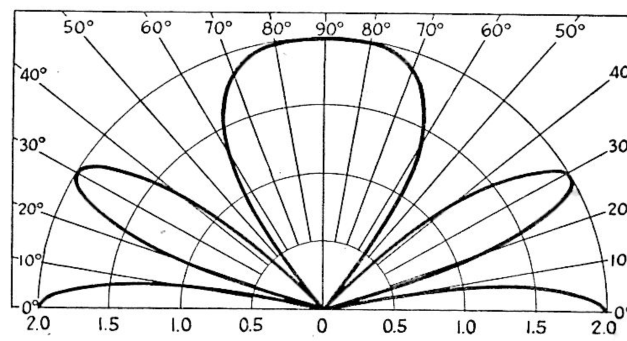


Fig. 319 — Ground reflection factor, vertical half-wave antenna with center 1 wavelength above ground.

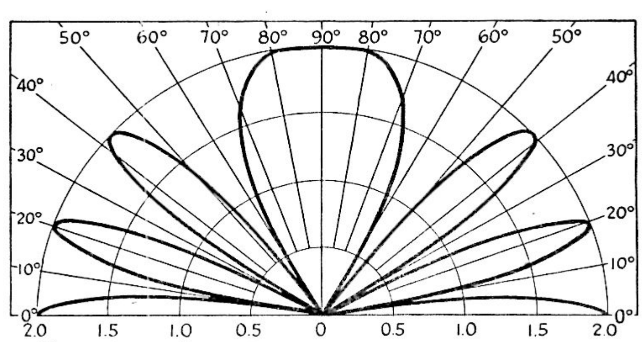


Fig. 320 — Ground reflection factor, vertical half-wave antenna with center 1½ wavelength above ground.

of this induced current depends upon the height of the antenna above the reflecting surface. The total current in the antenna thus consists of two components, one caused by the power from the transmitter, the other caused by absorption of energy from the reflected wave. The second component is of course smaller than the first, but at some heights the two will be more or less in phase, thus giving a higher total current than would result from the same input power to an antenna in free space; at other heights the two would be out of phase and the opposite is true.

The change in current with height, while the input power is constant, is equivalent to a change in the radiation resistance of the antenna. For example, a horizontal half-wave antenna will show a considerable change in radiation resistance as its height is changed, and only at certain heights will the resistance equal the free-space value of 73 ohms. This is shown in Fig. 322.

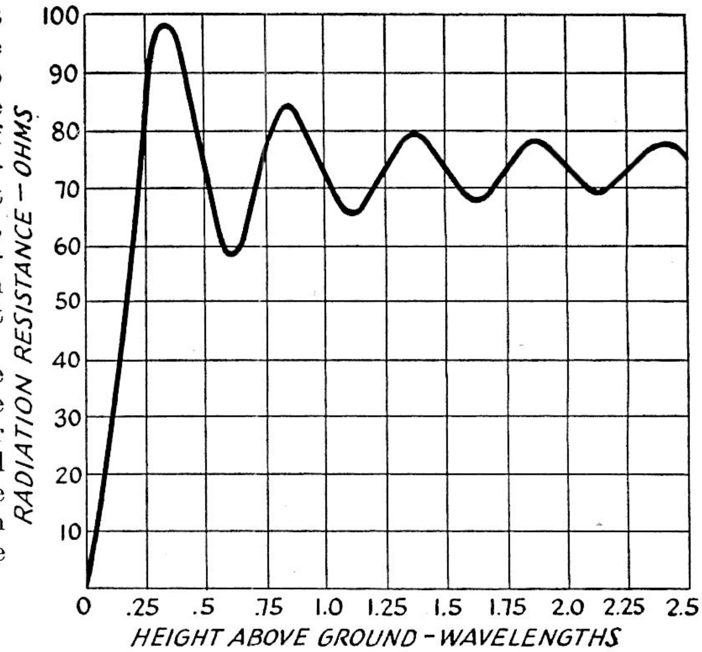


Fig. 322 — Variation in radiation resistance of a horizontal half-wave antenna with height above perfectly-conducting ground.

Ground Screens

The effect of a perfectly-conducting ground can be simulated, in the vicinity of the antenna, by installing a metal screen or mesh underneath the antenna near or on the surface of the ground. Such a screen often will improve the performance of the antenna by reducing losses in the ground near the antenna where, because of the high intensity of the radiation, such losses are most serious. The screen is most effective at the higher frequencies. It should preferably extend at least a half wavelength in every direction from the antenna, although good results have been reported with screens having 25 per cent smaller dimensions.

Besides reducing losses, a ground screen rather effectively establishes the height of the antenna insofar as the radiation resistance is concerned. For this purpose, the height will be the actual height of the antenna above the screen. Since reflection from a screen of reasonable dimensions takes place only at high angles, however, the presence of the screen will not appreciably modify the effect of the actual ground at the lower angles, because the low-angle waves are reflected at considerable distances from the antenna.

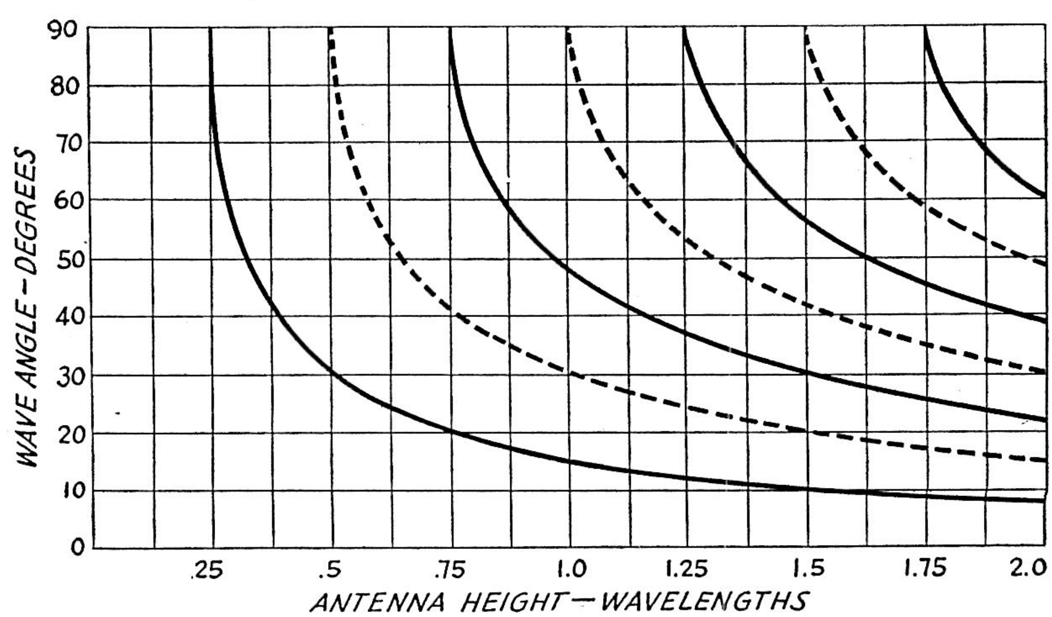
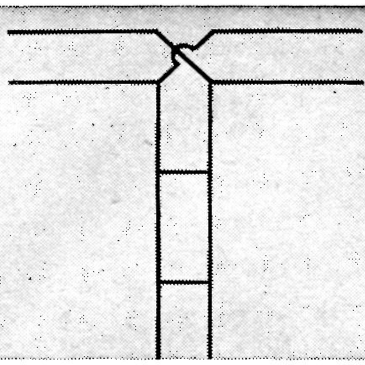


Fig. 321 — Angles at which nulls and maxima (factor = 2) in the ground reflection factor appear for antenna heights up to two wavelengths. The solid lines are maxima, dashed lines nulls, for horizontal antennas or vertical antennas having a length equal to an even multiple of one-half wavelength. For vertical antennas an odd number of half-waves long, the dashed lines are maxima and the solid lines nulls. For example, if it is desired to have the ground reflection give maximum reinforcement of the direct ray at a 20-degree wave angle (angle of radiation) the antenna height should be 0.75 wavelength. The same height will give a null at 42 degrees and a second maximum at 90 degrees.



4. FEEDER SYSTEMS

ANTENNA COUPLING — TUNED FEEDERS — UNTUNED LINES — MATCHING SYSTEMS — ADJUSTMENT

THERE is an unfortunate tendency in amateur circles to describe antenna systems by their method of feed. Such description gives rise to ambiguities and suggests that the performance of the antenna is dependent on the type of feed system used. Such is not the case. *The sole function of any feed system is to transport power from the transmitter to the antenna with a minimum of loss.* There would be no need for feed systems if it were not for the fact that surrounding objects will modify and reduce the effectiveness of any antenna, and it is therefore desirable to have the antenna placed "in the clear," away from houses, wires, metal pipes and poles, and thick trees. In multi-element arrays (to be described later) the transmission line is also used to phase the elements properly.

Types of Feeders

Feed or transmission lines are of two general types, *tuned* and *untuned*. As explained previously, if a line is infinitely long, a current started down it will eventually dissipate and hence there will be no reflection and consequent standing waves. This holds for both a one- or two-wire line. Any line has a *characteristic impedance* which depends on the size and spacing of the conductors. If the line is cut to some finite length and a resistance equal to the characteristic impedance is used to replace the length of line that was running out an infinite length, there will still be no reflections because, for the portion of the line being considered, nothing has been changed. A transmission line terminated in its characteristic impedance, and thus having no standing waves on it, is called an *untuned* or *flat* line.

It is of importance to remember that the line must be terminated in a *resistance;* a reactive component in the terminating load will cause standing waves even though the load impedance (in ohms) is equal to the characteristic impedance. For this reason, any reactive component in the load must be tuned out or canceled before a perfect match can be obtained.

If a line of finite length is not terminated in its characteristic impedance, there will be current and voltage reflections from the end which will combine with the current flowing towards the end to form *standing waves.* If the impedance at the end of the line is higher than the characteristic impedance, there will be a voltage maximum or *loop* at the end of the line and also approximately every half-wavelength in towards the sending end of the line. If the impedance at the end of the line is lower than the characteristic impedance of the line, a current loop will appear at the end of the line and approximately every half-wavelength in towards the sending end of the line. The greater the difference between the impedance of the line and the terminating impedance, the greater the *mismatch* is said to be, and the greater will be the amplitude of the standing waves of current and voltage.

The standing waves cannot exist, of course,

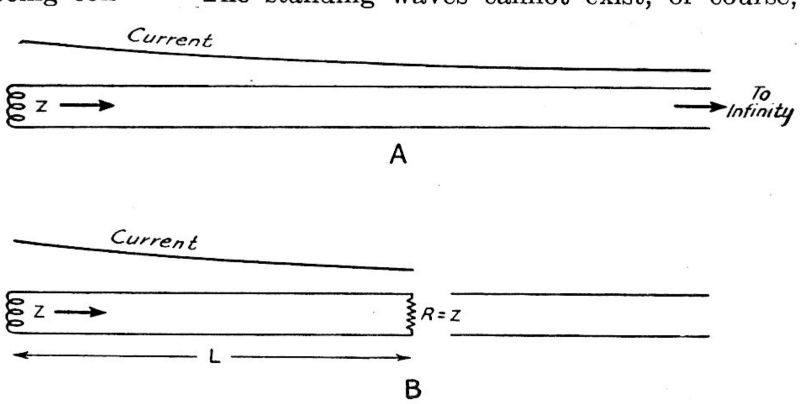


Fig. 401 **— As shown at A, the current distribution is fairly uniform along an infinitely-long line, attenuating slightly because of losses in the line.**

The line can be any finite length, L, as at B, and still have nearly uniform current distribution along it, if it is terminated by a resistance equal to the characteristic impedance of the line.

unless the entire line is of a length resonant to the frequency of the applied energy. For this reason, all lines operated with standing waves on them must be tuned in some fashion, else power could not be put into it. Tuning is normally accomplished by a coil and condenser combination at the transmitter end of the line, and the coil is also used to couple to the transmitter. Lines with

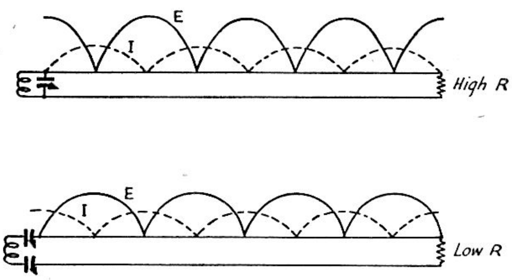


Fig. 402 — A line terminated by other than its characteristic impedance will have standing waves of current and voltage on it. If the termination impedance is higher than the characteristic impedance of the line, a voltage loop will appear at the termination and at every half-wavelength back towards the sending end. A current loop will appear at the termination if the terminating impedance is lower than the characteristic.

The voltage and current loops have been represented in this diagram as they would show up by testing with a neon bulb (for voltage loops) or a bridging ammeter (for current loops) along the line. It should be remembered that any two successive loops along the same wire are out of phase, as are corresponding loops on different wires.

standing waves on them are called *resonant* or *tuned* lines.

With standing waves on the line, the current and voltage distribution will be as shown in Fig. 402. It will be noted that a voltage maximum and a current minimum always appear at the same point, and vice versa.

It was mentioned above that the current (and voltage) loops appear "approximately" one half-wavelength apart. When we mention a half wavelength without qualification we mean a half wavelength in air and, since the velocity of the wave is less along the wire than in air, a wavelength along a wire is slightly less than a wavelength in air. As the impedance of the line is decreased (by using closer spacing or larger conductors, or both), the velocity is decreased due to the increased distributed capacity of the line. Further discussion and actual figures will be given later in this chapter.

Standing-Wave Ratio

If the currents are measured at a current loop and current minimum, or *node*, along a line with standing waves on it, it will be found that the ratio of the loop-current to node-current will be the same as the ratio of the line and terminating impedances. This is called the *standing-wave ratio*. Thus, for example, if a 600-ohm line is terminated by either a 72- or a 5000-ohm resistance, the mismatch and the standing-wave ratio will be 8.3-to-1 in either case. The standing-wave ratio is a direct indication of the degree of mismatch along a line, and is useful in the adjustment of untuned lines.

Any line used to feed an antenna will have no standing waves along it if it is connected to the antenna at a point where the impedance is resistive and matches that of the line. This is normally impractical, except in some special cases to be described later, and the line usually operates with some standing waves on it. This is no particular disadvantage if the line is not more than several wavelengths long and the standing-wave ratio is not higher than about 10-to-1.

Tuned Lines

Resonant lines enjoy widespread use in amateur work because of their flexibility and reliability. Except in a few special cases, the use of a tuned line is the only way that multi-band operation of the same antenna and feed line can be obtained. It is obvious that, since a tuned line can be considered as simply part of the antenna folded back on itself to prevent radiation, power can be put into the system on any frequency that it can be tuned to. For this reason, the amateur interested in multi-band operation and limited in space to only one antenna uses a tuned line for feeding.

Tuned lines are usually connected to the antenna system at one end or at the center although, in an antenna several half-wavelengths long, they may be connected at any voltage or current loop. If the line is connected to the end of the antenna (or any other voltage loop), the line is thus terminated in a high impedance and a voltage loop will appear at the end of the line and every half wavelength back along the line. If the line is connected to the center of a half-wave antenna (or any current loop in an antenna several half-wavelengths long), the line is terminated in a low impedance and a current loop will appear at the end of the line and every half wavelength back along the line. It is thus easy to determine whether a voltage or current loop will appear at the transmitter end of the line. If a voltage loop

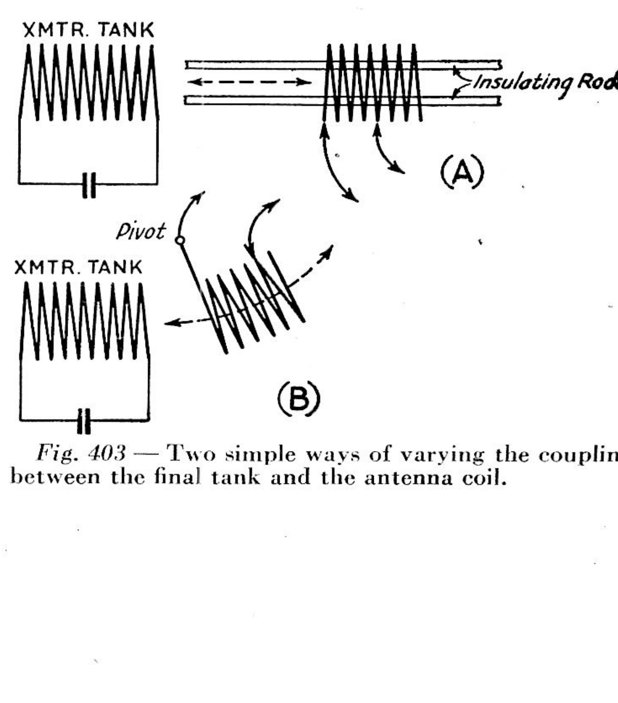


Fig. 403 — Two simple ways of varying the coupling between the final tank and the antenna coil.

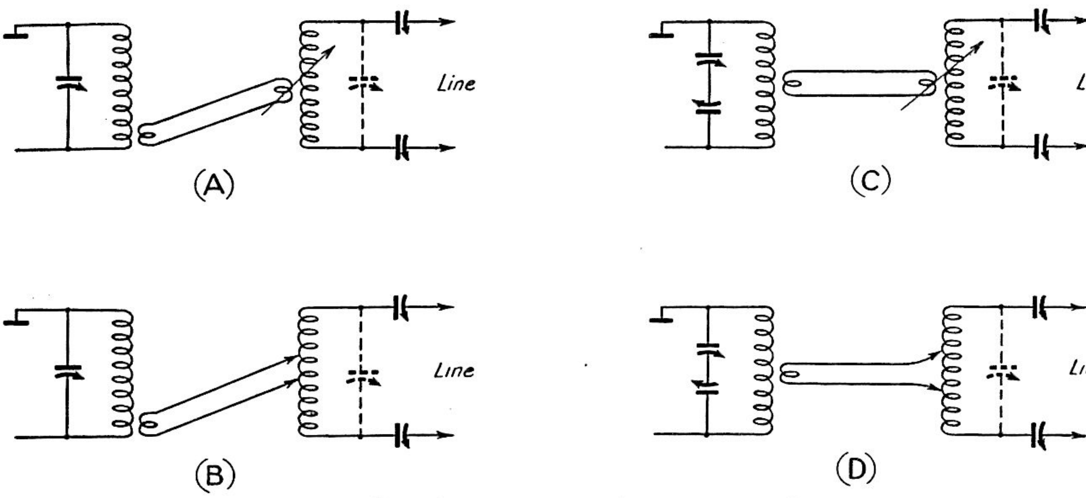


Fig. 404 — Four methods of link coupling the antenna tuning unit to the final amplifier tank. A and B are for unbalanced tanks, and the link is placed near a low-voltage point on the amplifier tank coil. The balanced tanks, at C and D, have the link loop at the center, where the r.f. voltage is low. Coupling is varied by changing the position of the loop with respect to the antenna coil or by moving the taps.

is to appear at the transmitter end of the line, a parallel-tuned circuit will be required to bring the system into resonance, and a series-tuned circuit is required if a current loop is to appear at the transmitter end of the line. The line, of course, does not have to be any exact length, since the tuned circuit will compensate for a good deal of deviation, but it is best to have it as near as possible to some multiple of a quarter wave, since there are some critical lengths where it will be found difficult to bring the line to resonance with either series or parallel tuning. In such a case, a few turns of wire added in each feeder will usually bring the length up to one that can be tuned.

Representative feeder lengths and the type of tuning required are given in Chapter Five, for a half-wave antenna, and they can also be applied to longer antennas of harmonic lengths.

Transmitter Coupling to Tuned Lines

The values of inductance and capacity to use in the antenna coupling system will depend upon the transmitting frequency, but they are not particularly critical. With series tuning, the coil may consist of a few turns of the same construction as used in the final tank; average values will run from two to three turns on 28 Mc. to perhaps 10 or 12 at 3.5 Mc. The coil preferably should be such that the inductance can be varied in case it is not possible to reach resonance with the condensers used. This can be done by shorting-out a few turns of the coil at one end with a jumper connection. The series condensers should have a maximum capacity of 250 or 350 $\mu\mu$fd. at the lower frequencies; the same values will serve even at 28 Mc., although 100 $\mu\mu$fd. will be ample for this and the 14-Mc. band. Since series tuning is used at a low-voltage point in the feeder system, the plate spacing of the condensers will not have to be very great. Ordinary receiving-type condensers are large enough for plate voltages up to 1000, and the smaller transmitting condensers have high enough voltage ratings for higher-power applications. With high-power 'phone it may be necessary to use condensers having a plate spacing of approximately 0.15 to 0.2 inch.

In parallel-tuned circuits the antenna coil and condenser should be approximately the same as those used in the final tank circuit. However, if the line is not of such a length that a voltage loop appears exactly at the antenna tuning unit, it may be found that the antenna tuning circuit cannot be coupled tightly enough to the final amplifier tank to draw the desired amount of power. If this is the case, the ratio of C to L in the antenna tuning circuit should be increased; i.e., the inductance should be decreased by shorting or removing turns.

The simplest and most straightforward method of coupling the antenna tuning circuit to the transmitter final tank coil is to place it alongside the tank coil, with some provision for swinging it or moving it away, to vary the coupling. This has the disadvantage of introducing some capacity unbalance to the transmitter and antenna tuning circuit, as well as requiring that the antenna feed line be run from the lead-in point, where it enters the building, over to the transmitter.

Link Coupling

An alternative system that enjoys widespread use is "link coupling." This allows the antenna tuning unit to be mounted on the wall where the feed line enters the room. A low-impedance line of twisted flexible wire, or No. 14 enamelled, spaced by small ceramic spacers, can be used for the link. The close-spaced open line is better on 28 Mc. and higher frequencies than is the twisted pair, although the twisted pair is normally quite satisfactory on the lower frequencies.

Typical link-coupling circuits are shown in Fig.

404. Variable link coils such as are now available on many manufactured coil sets, can be used at either the final amplifier tank coil or the antenna coil. The fixed links consist of two or three turns of wire wrapped around the plate coil at a low r.f.-voltage point and insulated from the coil. Both the double link and the tapped coil

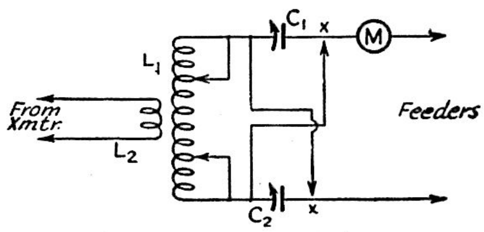


Fig. 405 — Circuit diagram of the antenna tuning unit.

C_1, C_2 — 100-$\mu\mu$fd., 0.07-inch spacing (National TMC-100).

L_1 — 22 turns No. 14, 2¾-inches diameter, 4 inches long (Coto-Coil with variable link).

L_2 — 4 turns rotating inside L_1.

M — R.f. ammeter, 0–2.5 for medium power.

For parallel tuning, clips should be attached at points marked "*x*." Clips left free for series tuning.

system work with the same efficiency: it is somewhat easier to adjust the coupling with the variable link assembly. The link should be wound or tapped on the antenna coil symmetrically at the center of the antenna coil, where the r.f. voltage is least. By thus reducing the capacity coupling, there is less chance of capacity transfer of the harmonic energy and radiation at these undesirable frequencies. The values of antenna tuning condensers and coil are the same as with the straight inductively-coupled system.

To tune the antenna, first loosen the antenna coupling (by swinging out the link or removing the taps from the antenna coil) and tune the final amplifier for minimum plate current. Swing in the link about half-way (or tap on to one turn either side of center) and tune the antenna unit for a maximum rise in plate current. The final amplifier tuning condenser should be tuned for minimum plate current again but the setting should not have changed appreciably from the original no-load setting. The coupling can be increased, by moving in the link (or tapping across more turns), until the final amplifier is drawing rated plate current. When the coupling and tuning adjustments are correct there will be practically no detuning effect on the transmitter tank; that is, the resonance setting (minimum plate current) should be the same both with and without the link in place but, of course, the current values will be different. If such is not the case, it indicates an abnormal amount of capacity coupling caused by unbalance in the system or overcoupling caused by too many turns at one or both ends of the link line. If the final cannot be loaded heavily enough, it indicates that too high an *L-C* ratio is present in the antenna tuning unit, where parallel tuning is being used, and the inductance should be reduced. No trouble should be experienced with series tuning. In general, it is best to use the minimum number of link turns that will give sufficient coupling.

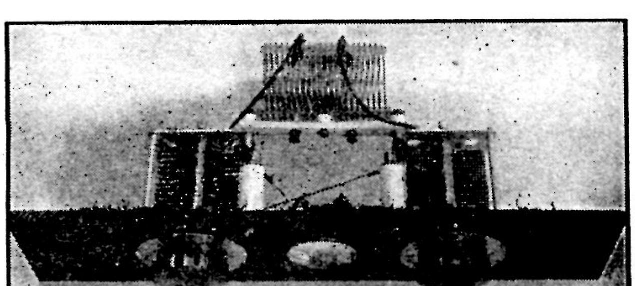


Fig. 406 — A link-coupled antenna tuning unit for use with resonant feed systems. The inductance, with variable link, is mounted on the condenser frames. Clips are provided for changing the number of turns, and for switching the condensers from series to parallel.

There will be some odd lengths of feed lines that cannot be coupled with either a series or parallel circuit, even though the *L-C* ratio is reduced as mentioned above. In such cases, the feeder length should be changed by adding or subtracting about ⅛-wavelength of line or by adding loading coils in the line. Another alternative is to tap the feed line down towards the center of the coil of a parallel-tuned antenna circuit, as shown in Fig. 407. This will work satisfactorily in many cases, but if the line must be tapped too near the center before the system can be loaded properly, it will be found that the center of the coil gets quite warm, indicating considerable loss in the coil. Any heating in the antenna coupling system indicates inefficiency and loss of antenna power, and the coupling system should be checked and changed if possible.

Pi-Network Coupling

A pi-section coupling network is shown in Fig. 408. This is a low-pass filter, and is capable of

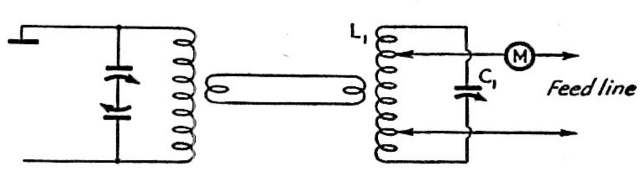


Fig. 407 — In cases where sufficient loading cannot be obtained with either series or parallel tuning, the feeders should be tapped-in on a parallel-tuned circuit.

coupling between a fairly wide range of impedances such as is encountered in going from series to parallel tuning. Suitable constants are given under the diagram. The method of adjustment is as follows: First, with the network disconnected, tune the transmitter tank to resonance, as evidenced by minimum plate current. Then, with trial settings of the clips on L_1 and L_2 (few turns for high frequencies, more for lower), tap the input clips on the final tank coil at points equidistant from the center so that about half the coil is included between them. A balanced tank circuit must be used. Set C_2 at about half scale, apply power, and rapidly rotate C_1 until the plate current drops to a minimum. If this minimum is not the desired full-load plate current value, try a new setting of C_2 and repeat. If, for all settings of C_2 the plate current is too high or too low, try new settings of the taps on L_1 and L_2, and also on the transmitter tank. Do not touch the tank condenser during these adjustments. When, finally, the desired plate current is obtained set C_1 carefully to the exact minimum plate-current point. *This adjustment is important in minimizing harmonic output.*

The pi-network method of coupling is very useful in portable work because it makes it possible to put power into almost any length of wire. For portable application, it is usually used in the unbalanced version (by shorting L_2) and, since single-ended unbalanced amplifiers are generally used, the tank condenser and C_1 become the same condenser. The pi-network coupling is convenient in this application, but it should not be used for fixed-station work because of its lack of harmonic-rejection properties except under critical adjustment conditions.

Feeder Current

The feeder current as read by the r.f. ammeters is useful for tuning purposes only; the absolute value is of little importance when working with tuned lines. When series tuning is used, the current will be high, while but very little current will be indicated in a parallel-tuned system. With a given antenna and tuning system, of course, the greatest power will be delivered to the antenna when the readings are highest. However, should the feeder length be changed, no useful conclusions can be drawn from comparison between the new and old readings. For this reason any indicator which registers the relative intensity of r.f. current can be used for tuning purposes. Many amateurs use flashlight or dial lamps for this purpose instead of meters. They are cheap, and when shunted by short lengths of wire so that considerable current can be passed without burnout will serve very well even with high-power transmitters.

Meters are useful in tuned lines for indicating current balance in the line. There will be a minimum of radiation from the line when the currents are balanced, provided the current readings are taken at the same relative points on each wire of the line. If an unbalance of more than 10 per cent is indicated, it is well to spend some time in adjusting the line. Unbalance in the line can be caused by unequal feeder lengths, unequal feeder capacity to ground or, in any unsymmetrical antenna system (like the Zepp and unlike a center-fed), incorrect length of antenna. Radiation from the tuned feed line is not particularly serious except where the feed line runs close to absorbing objects or where one is trying to obtain good directivity and wishes to reduce spurious radiation and reception.

Line Spacing

For effective cancellation of radiation, the spacing between the two wires must be small in comparison to the wavelength; a separation of 0.01 wavelength or less is desirable. For 14 Mc. and lower, the wires need not be closer than six inches, the length of the popular "feeder spreaders" manufactured for this purpose. Four inches is an optimum spacing for 28 Mc. and higher.

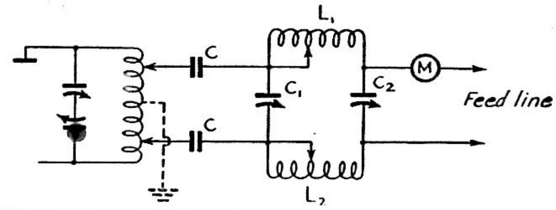


Fig. 408 — A pi-section network for coupling to a tuned line. C_1 and C_2 may be 100 to 250 $\mu\mu$fd. each, the higher-capacity values being used for lower-frequency operation (1.8 and 3.5 Mc.). Plate spacing should in general be about half that of the final tank condenser. For operation from 1.8 to 14 Mc., L_1 and L_2 should each be 15 turns of No. 12 or 14 wire wound on a 2½-inch diameter to occupy 3-inches winding length, and tapped every 3 turns. Approximate settings are 15 turns for 1.8 Mc., 9 turns for 3.5 Mc., 6 turns for 7 Mc., and 3 turns for 14 Mc.

C is a blocking condenser of 0.001 μfd. or so.

From the practical standpoint, too-close spacing is undesirable, especially with long sections of line. The wires inevitably swing with respect to each other when there is wind; if the spacing is close, this means that insulating spreaders must be installed at frequent intervals to prevent the wires from touching, and this in turn increases the weight of the line. Swinging also causes a varying detuning effect, since the change in spacing represents a change in capacity which reacts on the transmitter, and is evidenced by periodic variations in loading.

For work on communication frequencies, the 6-inch spacing represents a compromise which works out well in practice.

When it is necessary that two or more open transmission lines run near each other, they should be separated by a distance not less than ten times the line spacing, if mutual coupling is to be avoided.

Untuned Lines

As explained earlier in this chapter, standing waves will not exist on a transmission line terminated in the characteristic, or surge, impedance. Such lines may resemble the resonant lines in physical construction, but their operation and adjustment are different. In contrast to the resonant lines, non-resonant or untuned (or "flat") lines may be of any desired length. They are excellent for feeding an antenna at some distance from the transmitter but have the disadvantage that their use normally restricts the antenna to one band.

The surge impedance of a line consisting of two parallel conductors depends upon the inductance and capacity of the line per unit of length. In turn,

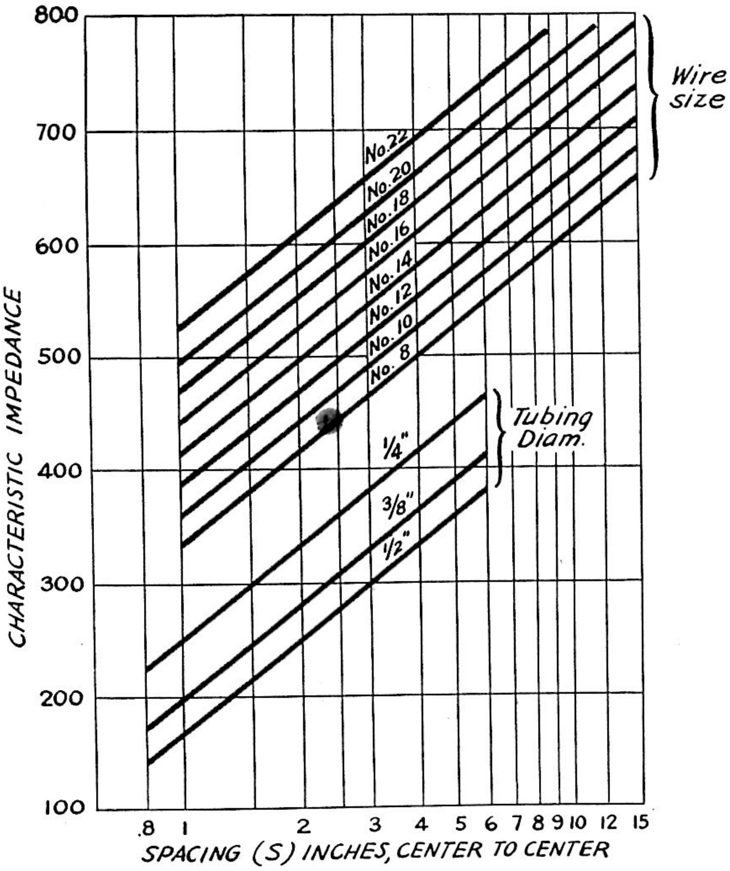


Fig. 409 — **The characteristic impedances of typical spaced-conductor transmission lines.**

these quantities depend upon the size of the conductors, their spacing, and the dielectric constant of the medium between the conductors. When the dielectric is air, the surge impedance of two parallel conductors is given by

$$Z = 276 \log \frac{b}{a}$$

where Z is the surge impedance in ohms, b the spacing, center to center, and a the radius of the conductor. The quantities b and a must be measured in the same units (inches, cm., etc.). Surge impedance as a function of spacing and wire size is plotted in chart form in Fig. 409.

A less common form of transmission line consists of a wire located axially in a metal tube, the two being insulated from each other. This type of line is useful for special applications where the radiation must be reduced to negligible proportions, and where low impedance is required. The surge impedance of such a concentric or coaxial line is given by

$$Z = 138 \log \frac{b}{a}$$

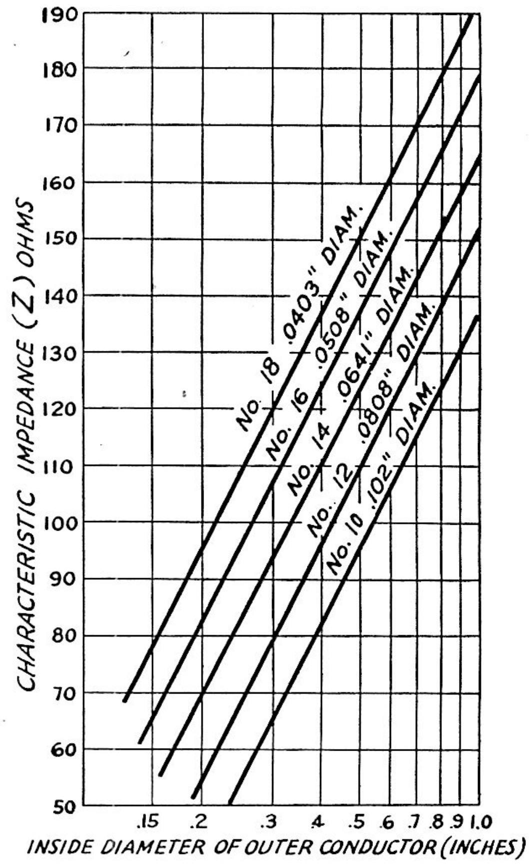


Fig. 410 — **The characteristic impedances of typical concentric lines.**

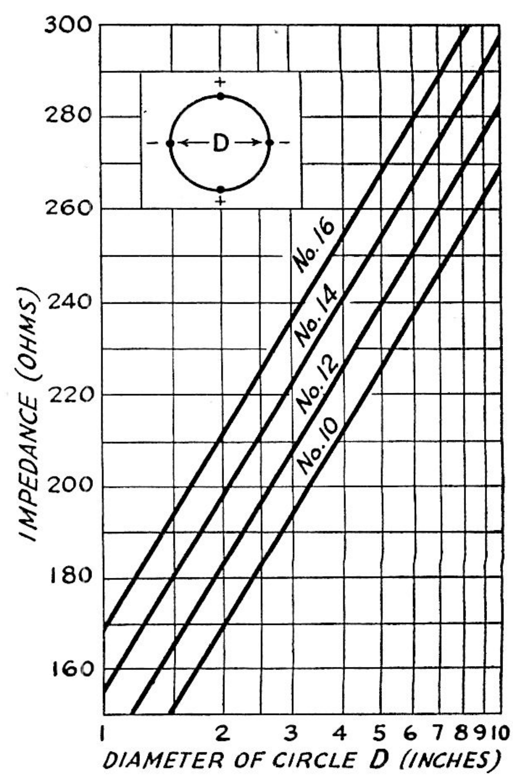


Fig. 411 — **The impedance of a 4-wire line. Opposite wires (not adjacent ones) are connected together at each end of the line.**

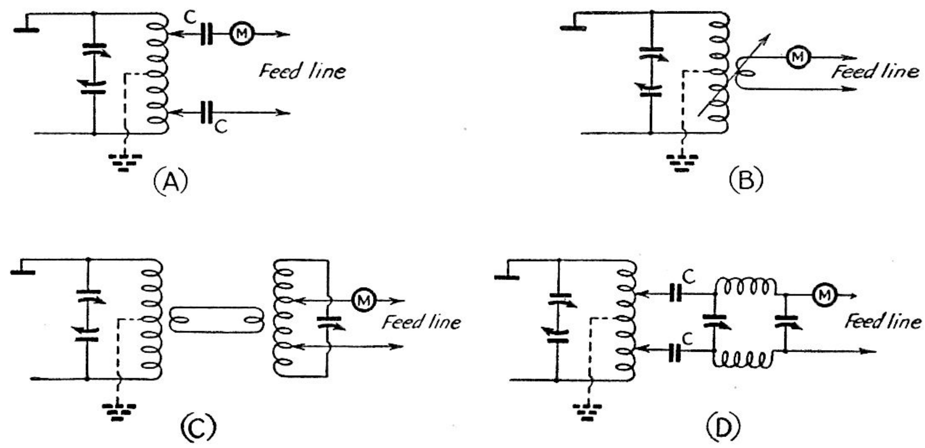


Fig. 412 — Methods of coupling an untuned line to the final amplifier plate tank. The antenna tank in C can be similar to the plate tank, while the constants for the network at D are similar to those in Fig. 408.

where Z is the impedance in ohms, b is the inside diameter of the outer conductor and a is the outside diameter of the inner conductor. The formula is correct for air dielectric and approximately so for a line having ceramic insulators so spaced that the major portion of the insulation is air. Fig. 410 gives impedance values for typical conductors. Well-designed concentric lines are hermetically sealed at both ends and filled with dehydrated air or an inert gas such as nitrogen, to prevent the condensation of moisture inside the line.

Because it is impractical to go below certain impedance values with a two-wire line, and where it is not desirable to use metal tubing (as in a low-frequency Q-match system, described later), it is possible to obtain a low-impedance line with four or more wires. The four wires can be equally spaced on the periphery of a circle, opposite wires being paralleled. In actual practice, disks of bakelite or small plastic "coasters" are used for spacers, the four holes for the wires being drilled in the form at the proper points and the wires are then threaded through and tied. Fig. 411 gives impedance values for normal spacing and the usual sizes of wire.

Still another type of line is simply a single wire. The surge impedance of such a line made of No. 14 wire will be approximately 500 ohms. This type of line has the disadvantage that no provision is made for cancelling radiation as in the case of the two-wire line. However, if the line is not too long, the radiation will be relatively small because the current in the line is small compared to the antenna current. If the line is tied into the antenna at a point where the impedance is 500 ohms, no standing waves will appear. A chart giving representative lengths of antennas and the point of attachment of a single-wire feeder is given in Chapter Five.

Low-Impedance Line

It can be seen from the formula for the characteristic impedance of a two-wire line that the closer the spacing and the larger the wires, the lower will be the impedance. It happens that the impedance of a two-wire line composed of twisted No. 14 rubber-covered wire of the type used in house wiring will be approximately that of the center of a half-wave antenna itself, thus simplifying the method of connecting the line to the antenna. Such discrepancy as may exist between line and antenna impedance can be compensated for by a slight fanning of the line where it connects to the two halves of the antenna, as explained in Chapter Five. The twisted pair line is a convenient type to use, since it is easy to install and the r.f. voltage on it is low because of the low impedance. This makes insulation an easy matter. The losses are somewhat higher than those in spaced lines with air insulation, however, and will increase with frequency. Special twisted line for transmitting purposes, having lower losses than ordinary rubber-covered wire, is available.

Since it is difficult to examine a low-impedance line for standing waves, the easiest way to check the performance is with an auxiliary length of line. The current can be read in each leg of the line and recorded. Then an auxiliary quarter-wavelength of line is added to the line and coupled to the transmitter as before, making sure to load the transmitter to the same input. The current in the line, read at the transmitter end, should be very nearly the same as before. For a final check, an auxiliary eighth-wavelength piece of line can be added. If the readings are quite close in the three cases, there are no standing waves on the line, and it is properly terminated. If the readings are not close, the termination *at the antenna end* must be adjusted.

A very rough check for the proper operation of a low-impedance line is to let the transmitter run for 5 or 10 minutes, feeding the line. If, after this time, there are no spots along the line warmer than other spots, it is safe to assume that no serious standing waves are present.

Transmitter Coupling to Untuned Lines

Similar coupling methods are used with all types of two-wire untuned lines, whether of high or low impedance. Several systems are shown in Fig. 412. Inductively-coupled methods are preferable to direct coupling when a single-ended or unbalanced tank feeds a balanced transmission line; this avoids line unbalance which might occur with direct coupling. In the direct-coupled circuits, the fixed condensers are useful only when the output amplifier plate supply is series-fed to the plates. These condensers, when used, should have a rating somewhat above the maximum plate voltage used and should have a capacity of 500 μμfds. or more. The current rating should be higher than any current encountered in normal operation, which can be calculated by

$$I = \sqrt{\frac{W}{Z}}$$

where I is the current in amperes, W is the power output in watts and Z is the impedance of the line.

The taps or coupling coil (Fig. 412-A and 412-B) should be placed symmetrically about the center or r.f. ground point on the coil. The taps or coupling should be adjusted to make the final amplifier draw normal plate current; if the line is operating properly the taps will not affect the setting of the plate tank condenser. In the case of the method shown at Fig. 412-C, the coupling tank is first adjusted to resonance with the plate tank circuit, using very loose coupling; the taps are then set at trial positions and the current in the line measured. The tap positions and coupling between the coils are adjusted to give maximum line current with normal tube plate current. No portion of the coupling tank should heat during operation; any heating indicates losses and incorrect adjustment.

The filter network shown at D is the same as that already described in connection with resonant transmission lines (Fig. 408), its adjustment when used with non-resonant lines being identical.

Methods of coupling the single-wire feeder to the final amplifier are shown in Fig. 413. It is important to note that, in Fig. 413-B, the antenna coil must be grounded for satisfactory operation. It may be grounded directly to a physical ground or to the transmitter, but the former is preferable and less likely to cause trouble. In both methods, the feeder is tapped up on the coil until normal plate current is drawn, with all circuits tuned to resonance.

There is no adjustment at the transmitter end of an untuned line that will reduce the standing waves on an improperly-terminated untuned line and, for this reason, the line should be matched at the antenna as carefully as possible in every case.

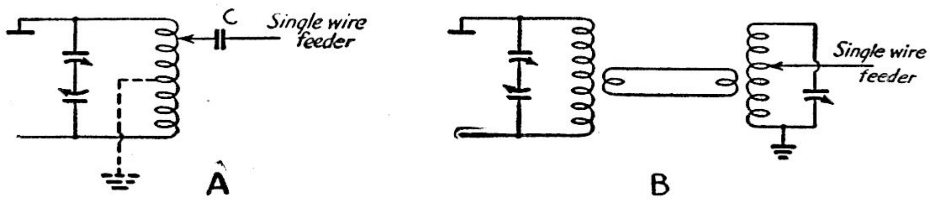


Fig. 413 — Methods of coupling the single-wire feeder to the final tank circuit. It is important to ground the set (A) or the antenna tuning circuit (B).

Matching the Line

In the untuned lines just described, impedance-matching depends upon connecting the line to appropriate point on the antenna. Twisted-pair lines and concentric lines can be made to match the impedance of an antenna at a current loop (55–100 ohms) and can thus be connected directly to the radiator, but in most cases it is necessary to use some type of impedance-matching transformer between the line and the antenna. The "transformer" ordinarily used does not resemble the ordinary coupled r.f. transformer, but is simply a section of transmission line.

Delta Match

Because of the extremely close spacing required, it is impracticable to construct an open-wire line that will have a surge impedance low enough to work directly into a half-wave antenna. Such wire lines usually have impedances between 400 and 700 ohms (see Fig. 409), 600 ohms being a widely used value that can be obtained with No. 12 wire spaced 6 inches. An open-wire line can be matched to half-wave antenna by "fanning out" the end of the line and tapping on to the antenna at critical points. Fig. 414 shows how this is done. The section E is fanned to have a gradually increasing impedance so that its impedance at the antenna end will be equal to the impedance at the antenna section C, while the

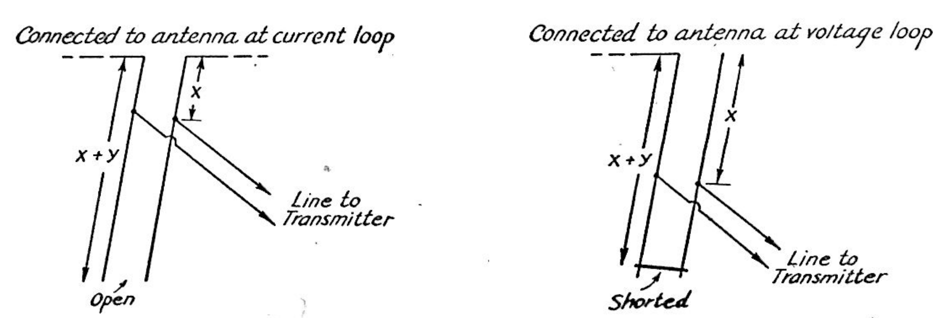


Fig. 415 — Quarter-wave matching sections. The distances X and $X + Y$ can be found from the graph in Fig. 416.

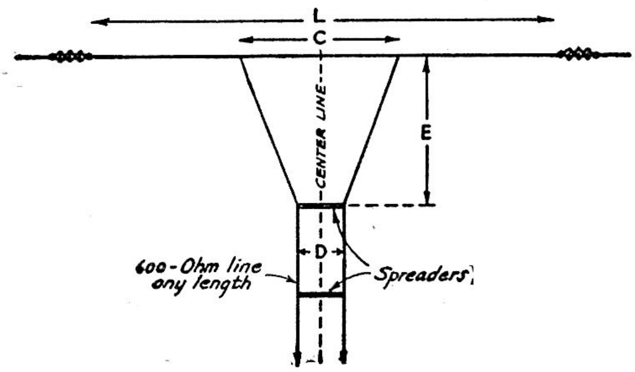


Fig. 414 — Delta match for a half-wave antenna. It is important that the matching section, E, come straight away from the antenna without any bends. Formulae for calculating the lengths C and E are given in Chapter Five.

impedance at the lower end matches that of the transmission line.

Formulas for calculating the lengths C and E for matching a 600-ohm line at any frequency are given in Chapter 5. Performance of the line and match can be checked by examining the line for standing waves, their presence indicating that a mismatch is present. A neon bulb will serve as a rough indication of standing waves along the line, or an r.f. galvanometer can be used as described later.

Quarter-Wave Matching Sections

A widely-popular form of matching transformer is the quarter-wave matching section. Two methods of using them are shown in Fig. 415. If the quarter-wave section is connected to a voltage loop of the antenna, it is necessary to short the matching section, while the section is left open if it is connected to a current loop of the antenna.

The length of the quarter-wave open-wire matching section can be calculated from

$$L \text{ (feet)} = \frac{240}{\text{Freq. (Mc.)}}$$

This will give an approximate length, and the section should always be tuned after it has been put in place.

The exact length of the matching section and the position of the line taps must be determined experimentally, since it will depend upon the impedance of the line as well as the antenna impedance at the point of connection. The impedance of the line is not important — the quarter-wave section can be used to match practically any

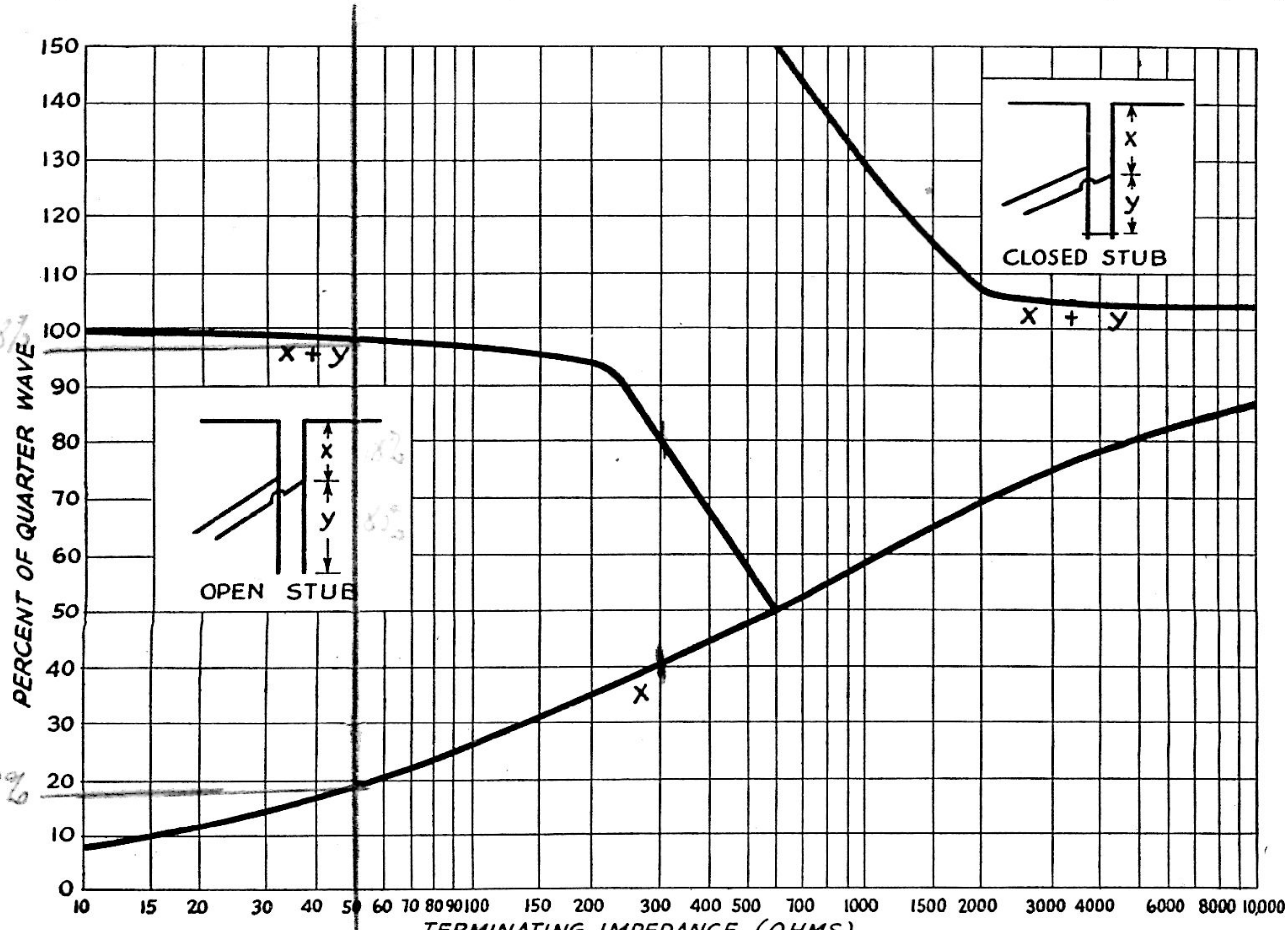
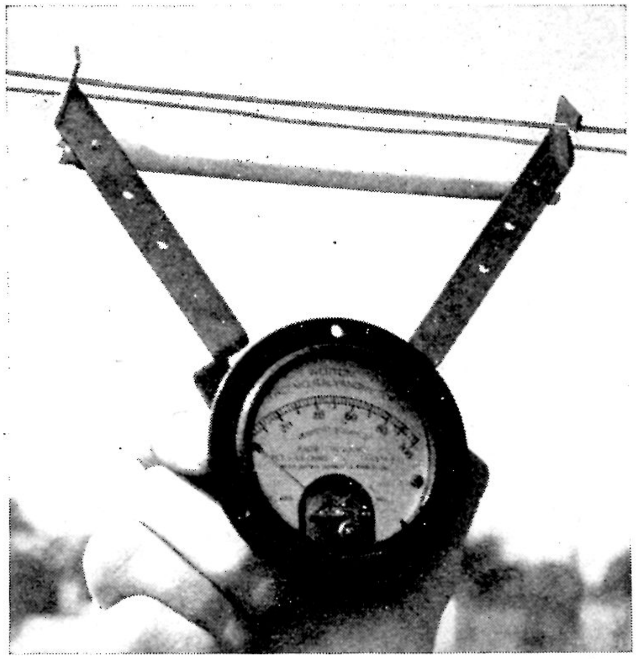


Fig. 416 — An experimentally-determined chart showing the point of attaching the feed line to a quarter-wave matching section and the modification of length of the section for various impedances. The chart holds only for a 600-ohm line. "x" is the distance from impedance to feeder; "$x + y$" is the total length of the matching section. (Courtesy *Radio-REF.*)



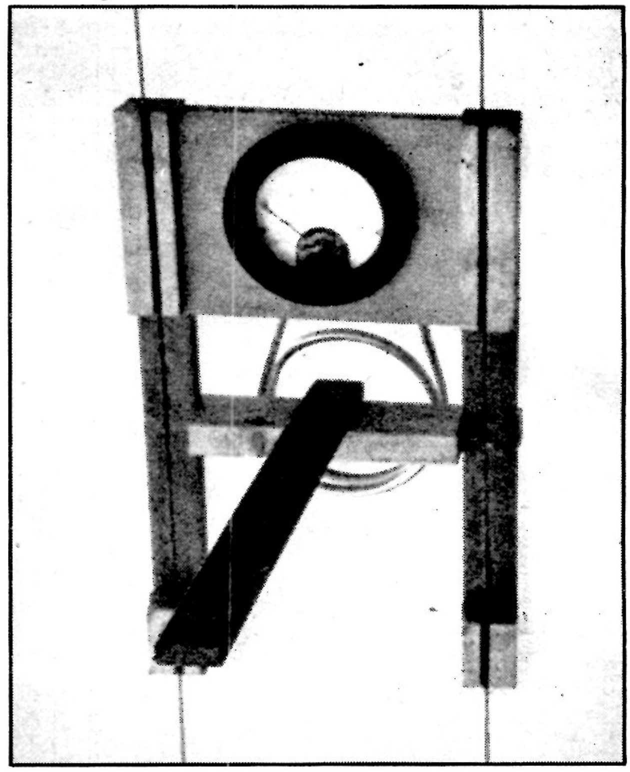


Fig. 417 — Two gadgets for measuring line current when adjusting untuned lines. The one shown at the left is hung across one wire (after the insulation has been scraped away), while the loop method at the right indicates the average between the two feed wires.

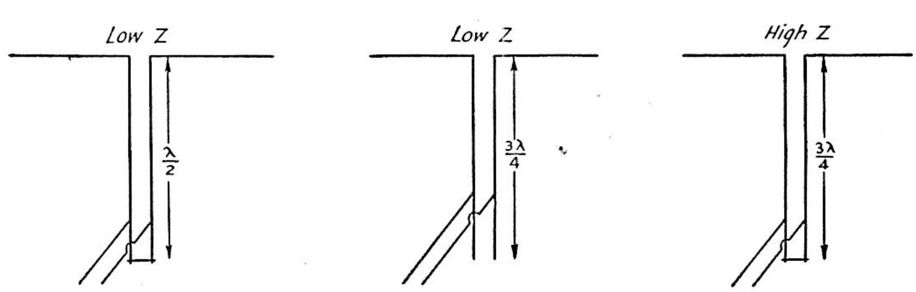
line impedance. The lower the impedance of the line, the nearer to the current loop on the matching section will be the proper point of connection.

Although flashlight and other small lamps can be used to adjust a quarter-wave section (or "matching stub"), a thermomilliammeter is the ideal instrument for proper tuning. It can be rigged as shown in Fig. 417, so that it can be shunted across sections of the line or antenna.

The first step in adjusting the matching section is to bring it and the antenna into resonance. This can best be done by exciting the antenna from a temporary antenna at least a half-wavelength away (the transmitter being on the proper frequency, of course) and adjusting the length of the stub until maximum current is obtained in the shorting bar. The shorting-bar current can be read by shunting the thermomilliameter across it or, if the current is very low, by using the meter as the shorting bar. After the maximum current has been obtained, the temporary antenna can be removed and the feed line tapped on to the stub about ⅛ wavelength from a current loop. The line is coupled to the antenna and the meter (or flashlight bulb) is used to examine the line for standing waves (difference in current along the line). The line is tapped at various points on the matching stub until a place is found that gives the minimum standing-wave ratio. The stub-length can then be increased slightly (by one or two inches on 14 Mc., for example) and the line again examined for standing waves. After slight readjustments of stub length and line-tap position, the line will be perfectly "flat" and there will be no standing waves along its length. If a meter is used to check the current, both wires of the line should be checked to make sure the current is the same in each side. If it isn't, look for capacity unbalance of the line (one side closer to ground or surrounding objects than the other) or a sharp bend in the line.

It should be kept in mind that if the antenna and stub are tuned to resonance independently by excitation from an auxiliary antenna, it will never be possible to match the line exactly. This is because there is always a reactive component along the stub except at the ends. However, by making the closed stub slightly longer (or an open stub slightly shorter), the reactive *component can*

Fig. 418 — Longer lengths than quarter-wave can be used for matching stubs. A half-wave section used to match a low impedance must be closed, while a three-quarter-wave section is open if matching a low impedance and closed if matching a high impedance.



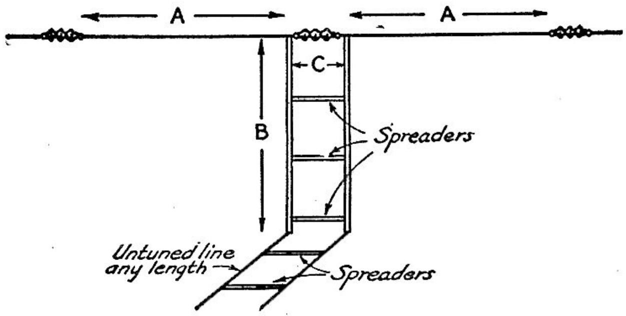


Fig. 419 — The "Q" match used with a half-wave antenna. Formulae for calculating the lengths and spacing are given in the text.

be eliminated at the point where the line is tapped on, and a perfect match will ensue. Some slight standing waves along the line are of little consequence as far as power transfer to the antenna is concerned. It is more important to keep the currents in the line balanced at all times, to minimize radiation from the line. Fig. 416 is a chart of stub lengths and tapping points for various impedances.

When the connection between matching section and antenna is unbalanced, as in any end-fed system, it is important that the antenna be the right length for the operating frequency if a good match is to be obtained. The balanced center-fed system is much less critical in this respect, any deviation in the correct length of the antenna being made up in the matching stub.

A matching stub does not necessarily need be a quarter-wave long. It can be made any multiple of a quarter-wavelength, and it is often more convenient to adjust a half-wave or three-quarter-wave stub. Application of these lengths is shown in Fig. 418.

The "Q" Antenna

The impedance of a two-wire line of ordinary construction (400 to 600 ohms) can be matched, without tapping, to the impedance of the center of a half-wave antenna by the use of a quarter-wave line of special characteristics. The matching section must have low surge impedance and therefore is commonly constructed of large diameter conductors of aluminum or copper tubing, with fairly close spacing. This type of antenna can be purchased in kit form and is known as the "Q" antenna. It is shown in Fig. 419. The important dimensions are the length of the two halves of the antenna, A, the length of the matching section, B, and the spacing between the two conductors of the matching section, C, and the impedance of the untuned transmission line connected to the lower end of the matching section.

The required surge impedance for the matching section is

$$Z_s = \sqrt{Z_1 Z_2}$$

where Z_s is the impedance of the matching section, and Z_1 and Z_2 are the impedances being matched (line and antenna impedances). A quarter-wave section matching a 600-ohm line to the center of a half-wave antenna (72 ohms), for example, should have a surge impedance of 208 ohms. The spacings between conductors of various sizes of tubing and wire for different surge impedances are given in graphical form in Fig. 409. With half-inch tubing, for example, the spacing should be 1.5 inches for an impedance of 208 ohms.

The length, B, of the matching section should be equal to a quarter wavelength, and is given by

$$L \text{ (feet)} = \frac{234}{\text{Freq. (Mc.)}}$$

the factor being smaller because of the decreased velocity along the close-spaced line compared to the open line. For a four-wire matching section, a factor of 238 should be used.

The Q-match system can also be applied to antennas longer than a half wavelength. Fig. 420 gives the impedances necessary to match various long-wire antennas to representative lines.

The height above ground will also affect the resistance at the current loops of any antenna (see Chapter Five) and should be considered when designing the matching section.

Corrective Stubs

A method of matching, or correcting, that resembles the quarter-wave matching section previously described is the so-called "corrective stub." It consists of an open or closed stub that can be connected to the line at a convenient point, and it will eliminate the standing waves on the line from that point back to the transmitter end. It will have no effect on the line between the

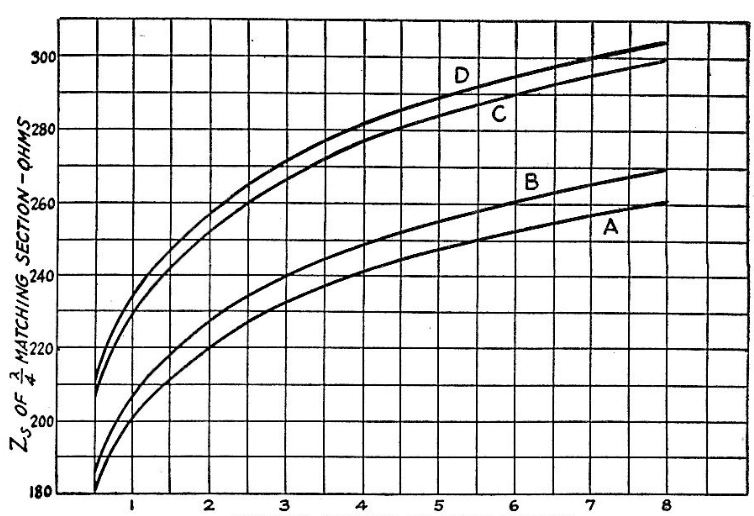


Fig. 420 — Required surge impedance of "Q" matching sections for radiators of various lengths. Curve A is for a line impedance of 440 ohms, Curve B for 470 ohms, Curve C for 580 ohms and Curve D for 600 ohms. Dimensions for the matching section can be obtained from Fig. 409.

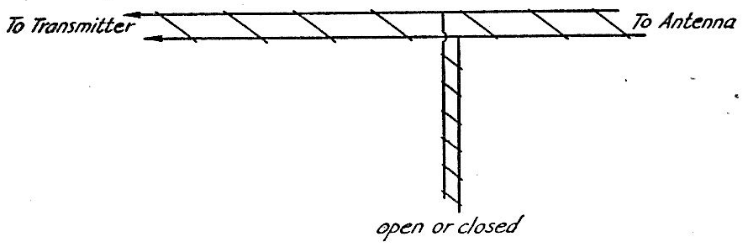


Fig. 421 — **The "corrective stub" is simply a section of transmission line hung on the line at the proper place. It is first necessary to determine the standing-wave ratio of the line; the position and length of the stub can then be found from Fig. 422.**

point of attachment and the antenna. However, in a case where a perfect match has not been obtained at the antenna and the line is long, it is possible to save some loss in the line due to standing waves by eliminating the standing waves between the point of attachment of the corrective stub and the transmitter.

The corrective stub system is shown in Fig. 421. In order to use it one must first determine the standing-wave ratio on the line (ratio of current node to current loop values) and the points where the loop and node occur. The chart in Fig. 422 gives the length and position of the corrective stub for various standing-wave ratios. An open stub is used near a current loop and a closed stub near a current node.

The stub performs much the same function as the quarter-wave matching section but can be inserted at any convenient point along the line, two positions being possible for every half wavelength of line. It should be placed as close to the antenna as is convenient, in order to make as much of the line as possible act as an untuned line.

Comparison of Tuned and Untuned Lines

Practically all of the various type of lines just described may be used with elaborate as well as simple antennas. Tuned lines are, in general, easier to adjust than the untuned types and have the advantage that they are adaptable to more than one band more readily than is the untuned line type of feed. However, the losses are somewhat higher in a tuned line than in an untuned line, and the tuned line should not be used where the length is more than about 3 or 4 wavelengths or where the tuned line is terminated in a low impedance. A comparison of the losses in a 600-ohm tuned line for various terminating impedances is shown in Fig. 423. It is apparent that if the line termination is about 40 ohms or less, as in the case of some of the close-spaced directive systems, the standing-wave ratio rises so high that serious losses ensue. In fact, the losses in the line can quite easily exceed the gain of the antenna system, resulting in a net loss instead of a gain.

Regardless of the type of line, the currents in the two wires should be kept as nearly equal as possible. An unbalance of current in the line can result in incomplete cancellation of radiation with resultant radiation losses from the line. The current in each wire of a two-wire line should be checked at some convenient point and, if the unbalance is greater than 10 per cent, a check of the line should be made. Line unbalance can be caused by unequal lengths of wire in the line, capacity unbalance to ground or, in the case of an unsymmetrical antenna system, incorrect length of antenna. For the latter reason, symmetrical antenna systems are always better from the standpoint of minimum feeder radiation. Capacity unbalance can be introduced at any place along the line where one side of the line has more capacity to ground (or a grounded object) than the other, or it can be introduced right at the coupling to the plate tank. Grounding the center of the coupling coil will sometimes help here, or a Faraday shield can be used.

Harmonic Radiation

From the standpoint of harmonic radiation, the untuned line systems usually result in lower harmonic radiation than do the tuned line ones, except in the case of a broad-band antenna such as the terminated rhombic. Harmonic transfer to the antenna system can usually be reduced by the use of a purely inductively-coupled system (such

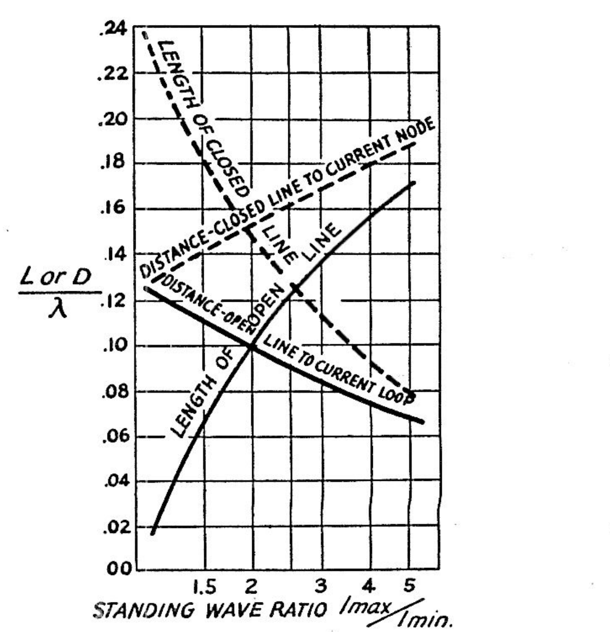


Fig. 422 — **Distances and length of the line or loop of the corrective stub are given in fractions of a wavelength, but this value can be easily converted, since one wavelength equals $\frac{980}{\text{Freq. (Mc.)}}$. All distances are measured from the current loop or node *towards* the transmitter.**

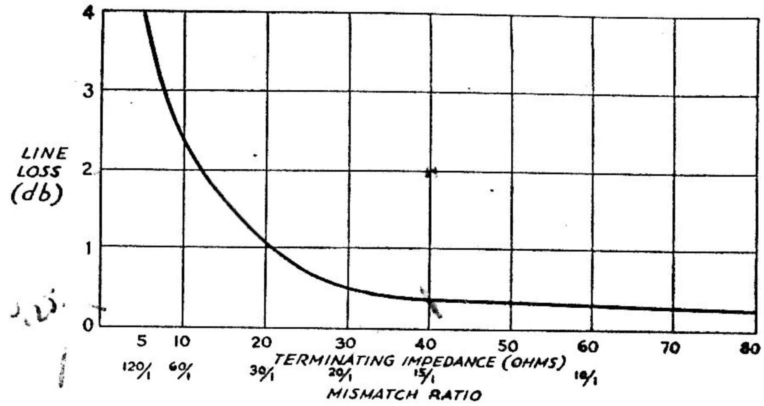


Fig. 423 — **An experimentally-determined chart of the losses in 1½-wavelengths of tuned line for various terminating impedances. The loss in 1½-wavelength of untuned line is about 0.2 db.**

as link coupling). The pi-section filter, unless tuned exactly as described, is notoriously bad for its harmonic-passing proclivities and should be avoided except for portable work, where its advantage of feeding practically any length of wire overshadows the disadvantage of harmonic radiation.

Since harmonics are usually transferred to the antenna by capacity coupling, it is desirable to reduce or eliminate the capacity coupling in every case. Link coupling is excellent in this respect, provided the link is kept at ground potential. This can be done by placing the link at the low-voltage points on the coils (at the part of the coil where it is by-passed to ground, or the center of a balanced circuit) or, in stubborn cases, by grounding the link. The link coil should be made up of turns wound close together, and they should never extend over an appreciable length of the tank coil.

In the case of untuned transmission lines, the center of the coupling coil can be grounded (this also affords good drainage for static charges), or a Faraday shield can be used. The Faraday shield, in its simplest form, consists of a comb of metal between the two coils to prevent capacity coupling. No closed loops of wire should be present in a Faraday shield, since induced currents would cause heating and losses. If the shield is used between two coils whose ends are coupled, the shield should be flat, and if it is used between two concentric coils it must be concentric between the two coils. In either case it can be made by winding wire spaced its own diameter on a flat or round form (depending on the use) on which has first been placed a sheet of celluloid or heavy paper. The wire can be anything from No. 22 to No. 14, and bare wire is the easiest to work with. The winding is painted with several coats of collodion or coil dope and, when dry, the wires at one end are soldered together. The wires are then cut and the resultant sheet of parallel wires, insulated from each other and fastened at one end, is grounded and used as a shield between the tank coil and the output coil. It prevents capacity coupling but has no effect on the magnetic coupling.

A single-wire feeder capacity-coupled to the tank circuit will have practically no discrimination to harmonics and, for this reason, the inductively-coupled system is preferable.

Line Velocity

The velocity of radio-frequency current along a line varies with the type of line, and this will modify the calculations for quarter-wave matching sections of various kinds, such as in the Q-match system. The length of a quarter-wave length of line can be caclulated from

$$L\ (\text{feet}) = \frac{246\ V}{\text{Freq. (Mc.)}}$$

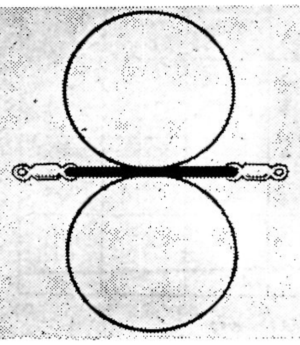
where *V* will depend upon the type of line used. The factors are as follows for the common types:

Parallel open wire line	$V = 0.975$
Parallel tubing	$V = 0.95$
Concentric tubes	$V = 0.85$
Twisted pair	$V = 0.56$–0.65

To obtain a half-wave or full-wave section, multiply *L* by 2 or 4, respectively.

Line Losses

As mentioned previously, the loss in an untuned 600-ohm open line is about 0.12–0.15 db. per wavelength of line and, if tuned, will vary depending upon the standing-wave ratio. The best rubber-covered low-impedance lines have a loss of about 1 db. per wavelength of line — ordinary rubber-covered lamp cord has a surge impedance of about 140 ohms and about 1.4 db. loss per wave-length when dry. It is practically worthless when wet, but can be used for many indoor applications. Two lengths may be paralleled to give a 70-ohm line, but the loss figure remains the same. The parallel moulded-rubber type of lamp cord has a surge impedance of about 120 ohms, and it will stand the weather much better.



5. HALF-WAVE ANTENNAS

CHARACTERISTICS — HORIZONTAL AND VERTICAL RADIATION PATTERNS — METHODS OF FEEDING

THE simple half-wave antenna is probably more widely used than any other type, since it is easy to install and adjust. It will, furthermore, give excellent results both in transmission and reception, and, when suitable feeding methods are used, is readily adaptable to use on more than one band.

The important characteristics of the half-wave antenna — radiation resistance, impedance variation along its length, current and voltage distribution, etc. — have already been discussed in Chapter 2. The free-space radiation pattern also was discussed in that chapter.

At the outset it is essential to keep thoroughly in mind that a single wire antenna having a total length of one-half wavelength at the operating frequency is always a half-wave antenna, no matter what special name may be given it. It has been the practice to label an antenna by the method of feeding it, and we find such terms as "Zepp," "single-wire-fed Hertz," "doublet," "center-fed doublet," "Y doublet," "J," and various others applied to what is essentially the identical antenna. The characteristics of a half-wave antenna are the same no matter what feed method is used. Of course, the results may vary somewhat with different feed methods, depending upon the efficiency of the feeder, length of the line, and the accuracy with which it is matched to the antenna. These variations are not chargeable to the antenna itself, however, since a given half-wave antenna in a given location will radiate a given amount of power fed to it in just the same way regardless of the means by which the power gets into the antenna.

Polarization

Half-wave antennas usually are suspended either horizontally or vertically, depending upon the type of polarization desired. As mentioned in Chapter 1, the kind of polarization is not of particular importance in the 3-30 Mc. range insofar as transmission through the ionosphere is concerned. The way in which the antenna is mounted does affect its directivity, however, and may also affect its efficiency when losses in nearby objects are considered.

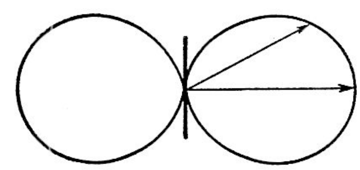


Fig. 501 — **Free-space radiation pattern of a half-wave antenna parallel to the ground. The pattern is in the plane of the wire, viewed from above.**

Referring to Fig. 501-A, imagine that the antenna is being looked down upon from a height, with the page representing the surface of the ground. The antenna is, therefore, horizontal. The directive diagram shows the relative intensity of radiation *along the surface of the ground* in various compass directions; maximum radiation is broadside to the antenna and minimum radiation is off the ends. If, however, we suspend the antenna vertically, the horizontal directive pattern will be simply a circle; in other words, the radiation is equally intense in all directions. A vertical antenna is non-directional in the horizontal plane, while a horizontal antenna shows marked directional effects in the same plane.

The losses in local objects tend to be somewhat lower with a horizontal antenna than with a vertical antenna. For a given height of pole or other supporting structure, a horizontal antenna usually will be farther away from the ground, trees, etc., since all of the wire is at the maximum height of the poles. When the antenna is vertical, however, its lower end is considerably nearer the ground, and if the pole height is the same only the top of the antenna will be at the same height as the horizontal antenna. The greater proximity of the ground and other energy-absorbing objects usually means that more of the energy in the radiated waves is absorbed before it gets well started on its way.

Effective Directive Diagrams

The purely horizontal directive diagram of an antenna does not always give a true indication of the directive performance of the antenna, since at high frequencies the waves which are useful for communication always depart or arrive at some angle above the horizontal. Thus when the half-wave antenna is horizontal, there may be considerable useful radiation off the ends *at some angle above the horizontal,* although the plane diagram of Fig. 501, which shows horizontal radiation from a horizontal antenna, indicates that in the direction of the wire axis there is none.

This can be made clear by examination of Fig. 502, which shows a horizontal half-wave antenna

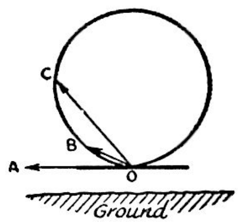


Fig. 502 — **The effective directive pattern of the antenna depends upon the angle of radiation considered. As shown by the arrows, the field strength in a given compass direction will be quite different at different vertical angles.**

with a section of its free-space radiation pattern, taken on a plane cutting vertically through the wire. The effect of the ground is neglected. The lines *OA*, *OB*, and *OC* all point in the same geographical direction, but make different angles in the vertical plane with the antenna, corresponding to different angles of radiation. So far as compass directions are concerned, all three waves are leaving the end of the antenna.

The purely horizontal wave *OA* has zero amplitude, but at a somewhat higher angle corresponding to the line *OB*, the field strength is appreciable. At a still higher angle corresponding to the line *OC* the field strength is still greater. The higher the angle considered, the greater the field strength in the same compass direction, for the figure shown. It should be obvious, therefore, that in plotting a directive diagram it is necessary to specify the angle of radiation for which the diagram applies. The shape of the diagram will be altered considerably at different radiation angles, when the antenna is horizontal.

Since the useful angles of radiation vary with frequency, as described in Chapter 1, the directivity of the antenna also will depend upon the frequency. In order to plot diagrams which represent the performance of the antenna under average conditions, it is necessary to choose radiation angles which are representative of transmission and reception on the frequency considered. Even on one frequency the most useful angle will depend upon the distance to be covered; for short distances, just beyond the limit of the first skip zone, the highest angles which will permit reflection from the ionosphere are most useful, while for extreme long distances low angles are most desirable since low angles give the smallest number of skips and hence the lowest attenuation. Thus the directivity of the antenna will also vary with the transmission distance and with ionosphere variations, which in turn depend upon the various factors described in Chapter 1.

It might seem from this discussion that it would be impossible to predict the directivity of the half-wave antenna without all sorts of qualifications, and in one sense that is true. However, it is possible to get a very good idea of the average directivity of the antenna for work over long distances ("long," that is, for the frequency considered) by choosing the angle which on the average represents about the center of the band of angles found to be useful for the purpose. Angles of 9, 15 and 30 degrees have been selected, representing the mid-band angles for 28, 14 and 7 Mc. respectively. The corresponding patterns are shown in Fig. 503. The diagrams should not be taken too literally, however, in view of the preceding discussion, but rather should be considered simply as an indication of the type of directivity to be expected for average work.

The Vertical Half-Wave

The directive pattern of a vertical half-wave antenna is a circle regardless of the angle of radiation considered. That is, for any given angle in the vertical plane the field strength is the same in any compass direction. The field strength will be different for each vertical angle, or angle of radiation, but the shape of a diagram will not change when the angle is changed.

This being the case, we can neglect the hori-

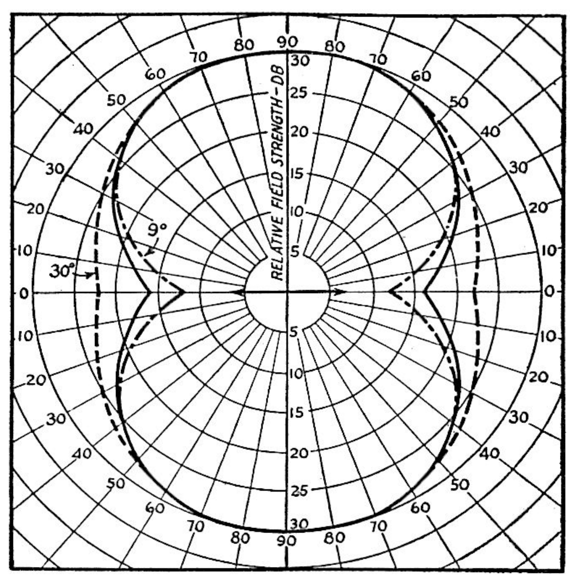


Fig. 503 — **Directive patterns of a horizontal half-wave antenna at three radiation angles, 9, 15 (solid line) and 30 degrees. The direction of the antenna itself is shown by the arrow. These patterns are plotted to a 30-db. scale, which is about proportional to signal strength as determined by ear. If 30 db. represents an S9 signal, 0 on the scale will be about S1. All three patterns are plotted to the same maximum, but the actual amplitudes at the various angles will depend upon the antenna height, as described in Chapter 3. The patterns shown here show only the *shape* of the directive diagram as the angle is varied.**

zontal directivity since there is none. The vertical directivity, or field strength at various angles of radiation, is the characteristic of interest. In a practical antenna system this will depend upon the height of the antenna above ground, as described in Chapter 3.

The relative intensity of radiation at various vertical angles will depend upon the free-space radiation pattern of the antenna alone and the modifications of that pattern brought about by reflection of the waves from the ground. The theoretical pattern is found by multiplying the field strength of the free-space pattern at each vertical angle by the ground reflection factor for that same angle. The ground reflection factors vary with the height of the antenna, as shown in Chapter 3. The effect of the ground on the pattern of a half-wave vertical antenna is shown in the charts of Figs. 504–507. These are theoretical patterns, based on the assumption of a perfectly-conducting ground. Except for the fact that the maximum radiation is not purely horizontal, because of ground losses, they are fairly representative of actual practice. The practical result of ground losses is to curve the lower end of the pattern inward, somewhat as shown by the dotted lines.

These charts illustrate the importance of height in relation to frequency. The height is, of course, in terms of fractions of a wavelength. The higher the antenna the sharper the directive characteristic in the vertical plane. If conditions permit, a height should be chosen which concentrates the radiation at the vertical angle most suitable for communication on the frequency used.

At 14 and 28 Mc. it is best to have the antenna as high as possible so that it will be well clear of energy-absorbing objects in the vicinity. The height used, however, should be such that a null will not appear in the region of the most useful angles of radiation. Usually, the actual height above the ground will not be exactly the same as the equivalent height for which the type of reflection indicated takes place. The equivalent reflecting surface is generally a few feet below the actual surface. It may pay to move the antenna up and down over a range of a few feet, continuing the test over a period of some days, to determine the best actual height.

When a ground screen is used, the screen acts as the conducting surface, and if its radius is of the order of a half wavelength or more the antenna height can be considered to be its actual height above the screen.

The Horizontal Half-Wave

The shape of the directive diagram of a horizontal antenna depends upon the radiation angle, as already described. The way in which it varies is shown in Fig. 503, for the three reference angles, 9, 15 and 30 degrees. At still higher angles the pattern approaches a circle, which means that a half-wave antenna working at high angles shows practically no directive effects. This is actually the case on 3.5 Mc., at least for moderate dis-

Vertical-Plane Radiation Patterns of Vertical Half-Wave Antennas Above Perfectly-Conducting Ground

The height is that of the center of the antenna. Dotted lines indicate approximate effect of attenuation of the very low-angle radiation because of ground losses.

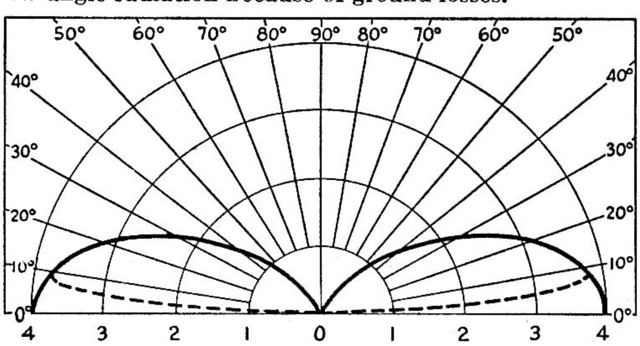


Fig. 504 — **Height ¼ wavelength.**

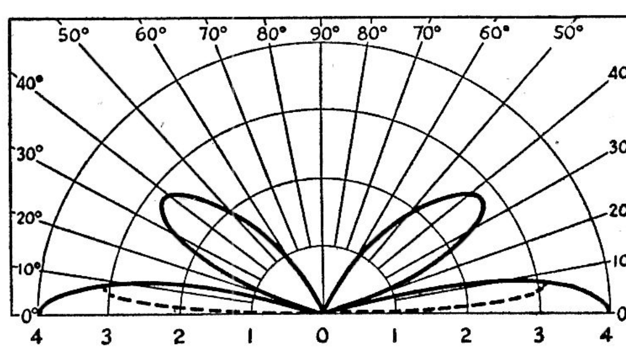


Fig. 506 — **Height ¾ wavelength.**

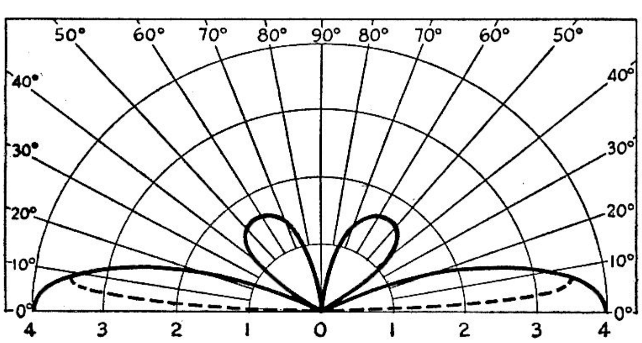


Fig. 505 — **Height ½ wavelength.**

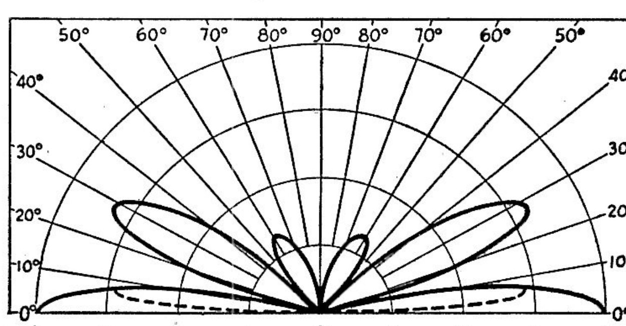


Fig. 507 — **Height 1 wavelength.**

tances, and often applies on 7 Mc. At long distances on either of these bands, where the lower angles are more useful, the "pulling in" effect at the ends of the antenna may be more pronounced.

The antenna should always be run in a direction which will give the greatest field strength in the most desired direction of communication. This means that the half-wave antenna should be broadside to the desired direction. For instance, if communication on an east-west line is most desired, the antenna should run from north to south. Proper orientation of the antenna is most important at the higher frequencies, where low-angle radiation is most useful, because it is at low angles that the antenna shows the most pronounced directivity.

Effect of Height

The height of the horizontal antenna does not affect the *shape* of the directive diagram at a given radiation angle, but simply changes the intensity of radiation. The effect of the ground is similar to the case of the vertical antenna, although as explained in Chapter 3 the angles at which the nulls and maxima occur are reversed.

The effect of height on the angle of radiation is shown in Figs. 508–519 for several heights. Since the free-space pattern of a horizontal antenna is not a circle, it would take an infinite number of diagrams of this type to give a complete picture of the vertical characteristic at all horizontal directions. In these charts, the shape of the vertical characteristic is shown for the direction

Vertical-Plane Radiation Patterns of Horizontal Half-Wave Antennas Above Perfectly-Conducting Ground

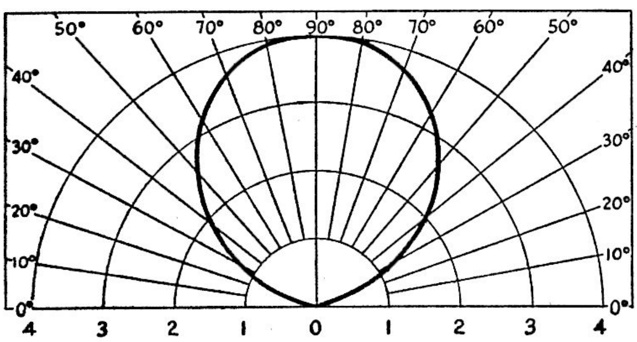


Fig. 508 — In direction of wire; height ¼ wavelength.

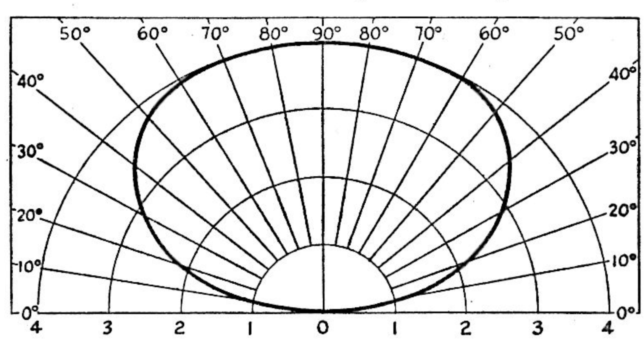


Fig. 509 — At right angles to wire; height ¼ wavelength.

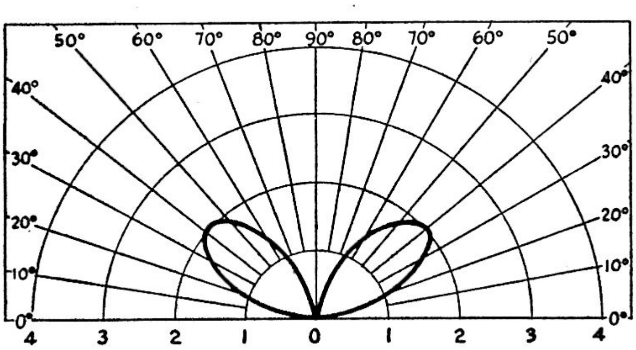


Fig. 510 — In direction of wire; height ½ wavelength.

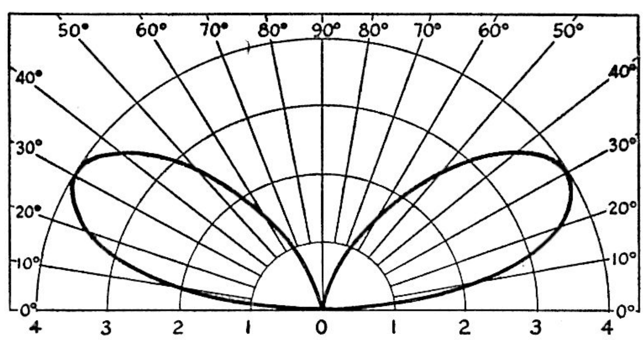


Fig. 511 — At right angles to wire; height ½ wavelength.

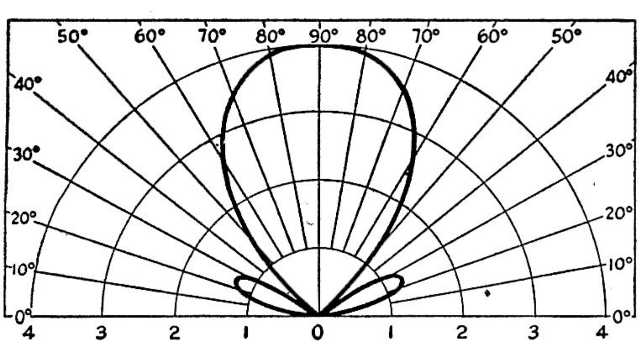


Fig. 512 — In direction of wire; height ¾ wavelength.

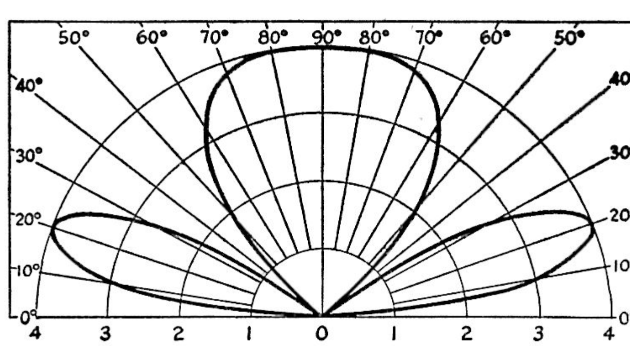


Fig. 513 — At right angles to wire; height ¾ wavelength.

in which the antenna runs (minimum radiation) and broadside to the antenna (maximum radiation). At intermediate directions the vertical characteristic will assume a shape which depends upon how close the direction considered is to one or the other of the two limiting directions shown.

A height of at least a half wavelength is necessary for appreciable radiation at angles of the order of 15 degrees, and greater heights are desirable. At the higher frequencies, where low-angle radiation is necessary, the heights needed are easier to attain, since the height is in terms of fractions of a wavelength. A height should be chosen which centers the radiation in the most useful group of angles for the frequency used, and heights which put nulls in these angles should be avoided. As in the case of the vertical antenna, the effective ground plane, for purposes of reflection, usually is a few feet below the actual surface of the ground, while a ground screen of suitable size tends to act as the actual reflecting plane.

These patterns are theoretical, and assume a perfectly conducting ground. Losses in the ground tend to reduce the maximum intensity of the lobes and to prevent the appearance of complete nulls. The positions of nulls and maxima may also be shifted slightly, but on the whole the charts are quite representative of actual performance.

Radiation Resistance

The theoretical value of about 73 ohms for the radiation resistance of a half-wave antenna in

Vertical-Plane Radiation Patterns of Horizontal Half-Wave Antennas Above Perfectly-Conducting Ground

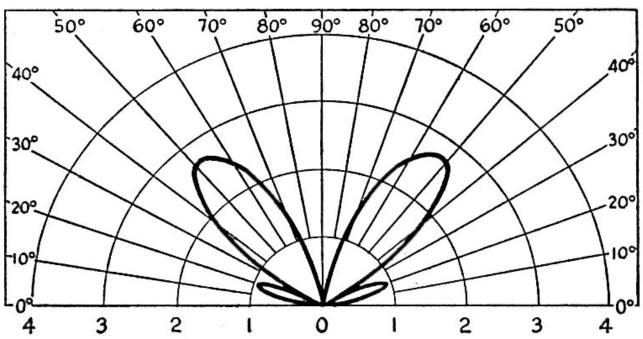


Fig. 514 **— In direction of wire; height 1 wavelength.**

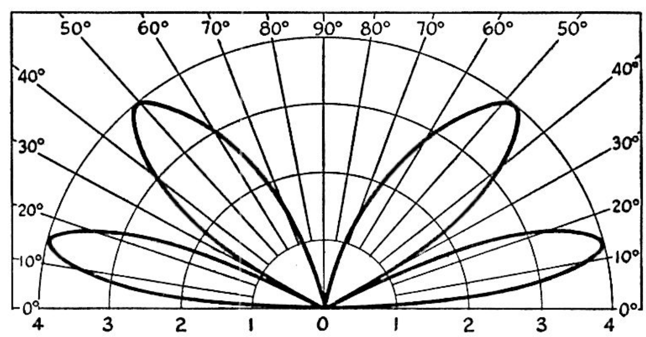


Fig. 515 **— At right angles to wire; height 1 wavelength.**

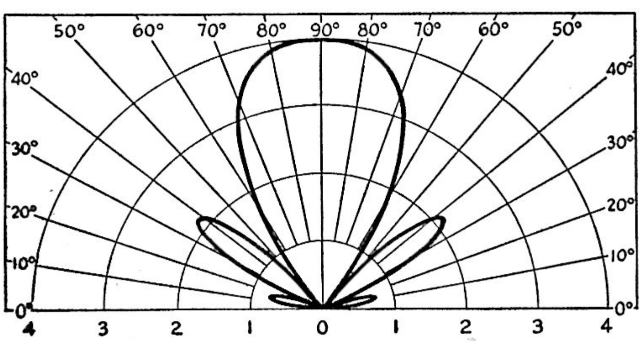


Fig. 516 **— In direction of wire; height 1¼ wavelength.**

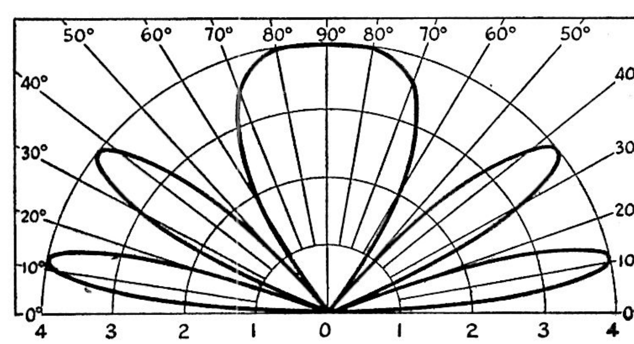


Fig. 517 **— At right angles to wire; height 1¼ wavelength.**

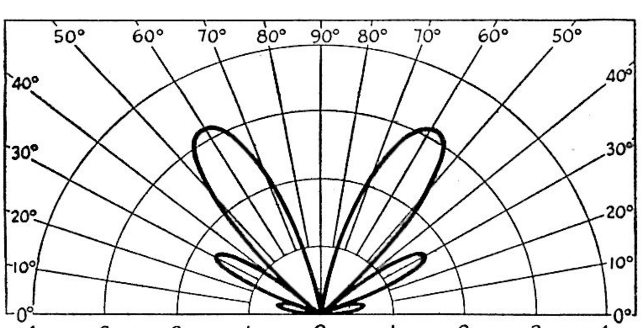


Fig. 518 **— In direction of wire; height 1½ wavelength.**

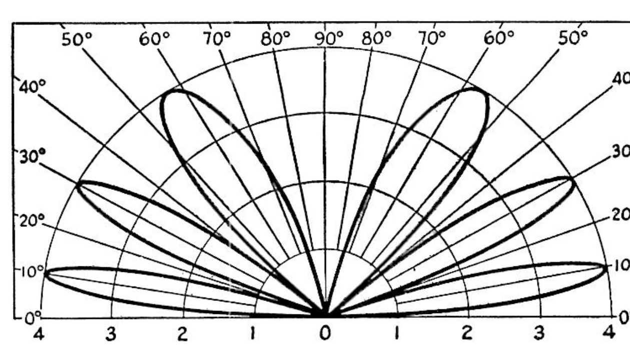


Fig. 519 **— At right angles to wire; height 1½ wavelength.**

free space is modified by the presence of the ground. For a horizontal half wave above perfectly conducting ground the actual value oscillates about the value of 73 ohms as shown in Fig. 322. The actual value of radiation resistance may be considerably above or below 73 ohms, particularly when the height is slightly less or slightly more than a half wavelength.

This variation in radiation resistance has little practical effect on the efficiency of a half-wave antenna because the loss or ohmic resistance is still quite low in comparison to the radiation resistance even at heights which give values of the order of 50 ohms. It is of interest chiefly because it may affect the termination of non-resonant feeder systems, particularly those types intended to match into the center of the antenna without in-the-field adjustment.

Length of a Half-Wave Antenna

It was pointed out in Chapter 2 that because of end effects the physical length of a half-wave antenna averages 5 per cent less than the length of a half wave in space. The factor varies somewhat with frequency, being 0.96 for frequencies below 3000 kc. and 0.94 for frequencies above 30 Mc. The factor of 0.95 applies throughout the frequency range of particular interest in this chapter, however, so that for frequencies from 3 to 30 Mc. the formula

$$\textbf{Length of half wave, feet} = \frac{468}{f\ (\text{Mc.})}$$

is sufficiently accurate. Antennas for amateur bands lying outside this range are treated in separate chapters.

In practice, the actual length of the antenna may be found to depart slightly from the figure given by the formula, principally because of height above ground and the proximity of such objects as poles, trees and buildings to the antenna. This variation may be neglected in most cases, except possibly insofar as it may affect feeder performance, a subject which will be discussed later. Aside from this, a few per cent variation in length will have no appreciable effect on the characteristics of the antenna itself.

A point of some concern to many constructors, particularly beginners, is that of determining the actual length of the antenna, since in practical construction it is necessary to run the wire through the supporting insulator and twist it back on itself to make a mechanically suitable connection. The best plan is to clean off all the insulation on the last 8 or 10 inches of wire, run it through the eye of the insulator, leaving a few inches of the bright wire over which the end can be twisted. The joint should be carefully soldered so that a closed loop is formed, both mechanically and electrically. The measurement can then be made to the insulator eye when the wire is stretched tight.

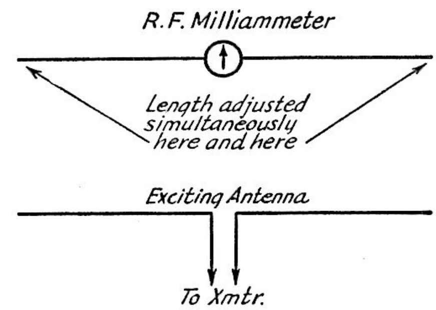


Fig. 520 — **Using a separate temporary antenna to excite a half-wave antenna whose length is to be adjusted.**

Determining Length

There are several methods by which the electrical length of the antenna may be adjusted quite accurately to a half wave at the desired frequency. All of them involve disconnecting the feeders from the antenna. Needless to say, the adjustment should be made with the antenna in its final position.

One such arrangement is shown in Fig. 520. An r.f. galvanometer is connected in the center of the antenna, either by inserting it in the wire or by connecting it across several inches of the wire. The full-scale range of the meter will depend upon the amount of power available and the coupling to the auxiliary antenna. The latter may be a temporary affair strung somewhere in the vicinity, preferably a half wavelength or more away from the antenna to be adjusted. It is connected to the transmitter by any convenient type of transmission line.

The conventional current-squared galvanometer, which has a full-scale range of 115 ma., will be satisfactory for powers up to 100 watts when connected directly in the center of the antenna. For larger powers it can be connected across a few inches of the antenna, the connections being made at equal distances from the center of the wire.

Starting out with the antenna known to be slightly long for the frequency, the power input to the transmitter is adjusted to give a suitable reading on the antenna meter. Then equal lengths of wire (a few inches) are clipped off *each* end of the antenna, so that the meter remains in the center, and the meter reading noted. The power input to the transmitter should be kept constant. This process should be repeated, with the meter readings recorded each time, until the current has passed through a maximum and begins to decrease. The length which gives the highest meter reading is the correct one for that frequency. A curve of antenna current against length may be plotted so that the exact maximum can be determined in case it falls between two arbitrarily-selected lengths in the experimental procedure.

Since the antenna length must be adjusted with the antenna in position, the determination of the correct length may be a somewhat tedious task because it will usually be necessary to lower the wire to change the length. Also, with this method it will often be necessary to use binoculars to read the ammeter, which is not altogether easy if there is a breeze.

An alternative method is to use a vacuum-tube oscillator loosely coupled to the antenna as shown in Fig. 521. A low-range (0–1 to 0–5) d.c. milliammeter is connected in series with the oscillator grid leak, and a small pick-up antenna connected to the oscillator grid. When the pick-up antenna is brought near the antenna to be checked, the oscillator is tuned to the point which gives maximum dip in grid current indicating that the antenna is taking energy, at its resonant frequency, from the oscillator. With the coupling loosened so that the pointer just flickers downward noticeably at resonance, the frequency of the oscillator should be checked by any convenient frequency-measuring means. If the frequency is too low, the antenna should be shortened a bit and checked once more; similarly, if the frequency is too high the antenna should be lengthened.

Since it will not usually be possible to bring the oscillator itself close to the antenna, a small doublet-type pick-up antenna may be connected to a twisted-pair line and the latter run to the oscillator, which may then be operated from the ground. The pick-up antenna may be temporarily fastened to one of the insulators supporting the antenna so that it will be near a high-voltage point. To avoid the possibility of resonance in the desired frequency range in the line, the grid current should first be checked with the pick-up antenna considerably removed from the regular antenna, to make sure that there is no dip within a reasonable range of the operating frequency.

Still a third method makes use of the fact that the addition of a half-wave section to a line does not disturb the line's operation when the additional section is exactly an electrical half wave. In this method the antenna is end-fed by a tuned line which can be disconnected from the antenna at will, as shown in Fig. 522. Either series or parallel tuning can be used at the transmitter end

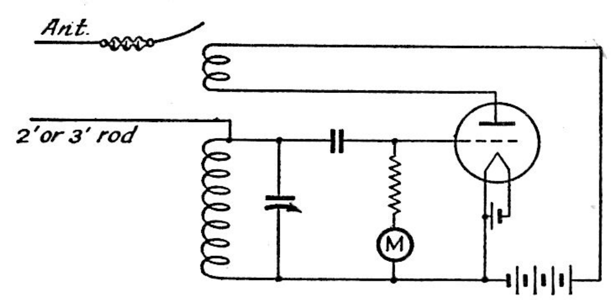


Fig. 521 — **The grid-dip method of checking the frequency of a half-wave antenna. The oscillator circuit may be of any type so long as it can be tuned to the frequency at which the antenna is resonant. With 45 to 90 volts on the plate, a 10,000-ohm grid leak will be satisfactory when a 0-5 d.c. milliammeter is used in series. The feedback should be adjusted to bring the pointer to about half scale.**

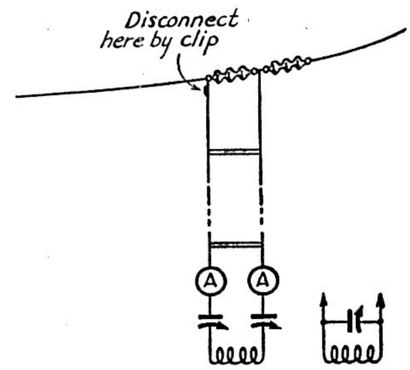


Fig. 522 — **Using a transmission line to determine the resonant frequency of the antenna. The method is described in the text.**

of the line, depending upon the line length. With the line disconnected from the antenna, the tuning is adjusted to give maximum feeder current, using the loosest coupling which will give a satisfactory reading. (Without the antenna connected, the meter readings will be quite high, so very loose coupling should be used at the start.) Then the feeder is clipped to the antenna and, *without changing the coupling*, the tuning is again adjusted for maximum feeder current. The current will be much lower, but this does not matter; it is the tuning adjustment giving resonance, or the maximum current, whatever that maximum value may be, which is wanted. If the condenser or condensers are found to be set at lower capacity than before, the antenna is too long; if at higher capacity, the antenna is too short. When the antenna is exactly the right length, the condenser settings will be the same either with or without the antenna connected.

Adjustment of the antenna length by one of the methods described is not necessary unless it is desired to get the most accurate feeder match at one frequency. This accuracy is not needed in the case of lines of ordinary length since, as described in Chapter 4, a mismatch ratio of 2 or 3 to 1 does not appreciably increase the losses in a line which is not more than a wavelength or so long. It is useful when the line is unusually long, so that feeder losses become appreciable when a mismatch occurs, but in most cases this is not a consideration. Furthermore, the length is correct for one frequency only, and for another frequency in the same band the antenna will no longer be exactly an electrical half wave.

Methods of Feed

In the following sections, the application of the various types of transmission lines to the half-wave antenna will be discussed. The information given here should be used in conjunction with the design and adjustment data given in Chapter 4 for the type of line under consideration. The discussions in Chapter 4 are perfectly general; only those conditions peculiar to the half-wave antenna are given attention in this chapter.

The feed methods apply equally well to antennas installed either vertically or horizontally, — or, for that matter, to those which slant. Although as a matter of convenience most of the diagrams show horizontal antennas, it should be kept in mind that the position of the antenna with respect to ground does not affect the feed method.

Voltage Feed

The simplest, although not the best, method of feeding power to the half-wave antenna is to connect one end through a low-capacity condenser to the final tank coil of the transmitter, as shown in Fig. 523-A. This is often called "end feed" or "voltage feed." The disadvantage of this system is that it necessitates bringing the end of the antenna into the station, which usually means that the height must be limited and that the dielectric losses in nearby objects will be comparatively high. It involves no feeder or tuning apparatus, however, and is useful on the lower frequencies where there may not be room enough for a regular antenna-feeder system.

The coupling condenser, *C*, is used simply for insulation in case the final tank is series-fed, to prevent plate voltage from appearing between the antenna and ground. Its capacity may be quite low; in fact, a condenser of the disc neutralizing type may be used. The condenser need not be variable, however, and may be constructed from two pieces of copper or aluminum sheet an inch or two square. A variable condenser will permit some adjustment of loading, but the same adjustment can be attained by tapping the antenna at the proper point on the tank coil. Whichever method is most convenient may be used. With the tap, the blocking or coupling condenser can be a mica unit of about 100-$\mu\mu$fd. capacity and a voltage rating higher than the maximum d.c. plate voltage (twice the d.c. plate voltage on a plate-modulated Class-C stage).

The method of adjustment is as follows: With the antenna disconnected from the tank, tune the tank to resonance (minimum plate current). Then tap the antenna on the coil at a point near zero r.f. potential. In the case of a single-ended tank circuit this will be near the end of the coil opposite that connected to the plate; with a balanced tank, near the center tap. Retune the tank to resonance, again indicated by minimum plate current. The new minimum will be higher than without the antenna connected, however. The setting of the plate tank condenser will change little, if at all, if the antenna is exactly a half wave at the operating frequency. An appreciable change in the condenser setting will indicate that the antenna length is incorrect; short, if more capacity must be used, and long if less capacity is necessary. Move the tap towards the plate end of the coil a turn at a time, returning the tank each time, until the amplifier is drawing full-load plate current. This will be the rated plate current for the tube or tubes if the amplifier is properly excited. A rough idea of the output can be obtained by touching a neon lamp to the end of the antenna; if the brightness of the glow passes through a maximum before the tap is moved up to the position which gives rated plate current, the point of maximum output has been passed, and the tap should be returned to the point which gives the brightest glow. If this happens, the amplifier probably is not being driven properly (insufficient excitation).

If a variable coupling condenser is available, the condenser may be connected directly to the end of the tank. The adjustment procedure is similar, but instead of moving the tap up on the coil the condenser capacity is increased from minimum in steps, with the final tank being retuned each time, until the maximum output or rated plate current is reached. The plate spacing of the coupling condenser must be at least that of the plate tank condenser, although only a small capacity is used.

Capacity coupling of the antenna is likely to lead to trouble with harmonic radiation, since the antenna also will be resonant to any harmonics which may be developed in the amplifier. Also, if the antenna is not just the right length a standing wave may develop on the transmitter. As a result the transmitter may assume an r.f. potential above ground, so that parts of the circuit which should be "dead" for r.f. turn out to be "hot."

Troubles of this sort can be largely avoided by using inductive coupling between the transmitter and antenna, as shown in Fig. 523-B. In this case the antenna is tapped on a separate tank, tuned to the same frequency as the transmitter, and coupled inductively to the transmitter tank coil. The coupling circuit should be grounded either at one end or at the center — it does not matter particularly which is used — through a short connection to a good ground separate from the transmitter ground. To adjust, couple L_1 and the tank coil loosely, and tune C_1 to resonance. There will be but a slight rise in plate current as C_1 passes through resonance, provided the coupling is very loose. Increase the coupling in small steps, re-

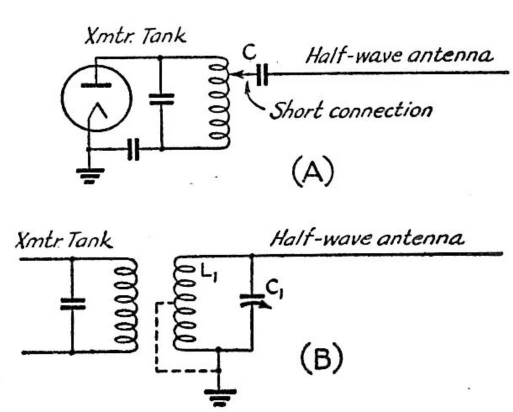


Fig. 523 — **Voltage feed to an antenna. With this method no feeders are used, but the end of the antenna must be brought into the station.**

tuning C_1 and the plate condenser to resonance each time, until the rated plate current is secured. The right coupling is that which will make the plate current drop off as C_1 is tuned to either side of resonance, and just rise to the full-load value (with the plate condenser tuned for minimum plate current) with C_1 at resonance. The coupling circuit should have about the same L/C ratio as the final tank circuit, although the values are not critical. The voltage rating of C_1 should be the same as that of the plate tank condenser.

Center Feed

Another method of putting power into the antenna without a feeder system is sometimes used. It is called center feed, and is shown in Fig. 524. The half-wave antenna is in two sections, with the

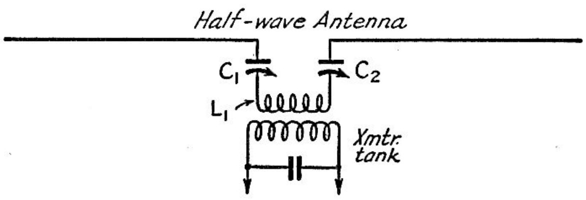


Fig. 524 — Current-fed antenna without feeders. The number of turns for L_1 is not critical; average values will be from 2 or 3 turns at 28 Mc. to 10 or 12 at 3.5 Mc., using the same type of winding as the plate tank coil. C_1 and C_2 should be identical; maximum capacity needed will vary from 250 to 350μμfd. at 3.5 Mc. to 100 μμfd. at 28 Mc. The larger size can of course be used for all bands.

center brought into the station. This scheme has the same disadvantages as to losses and lack of height as the end-feed method, although the losses may be somewhat lower because the part of the antenna entering the station is at low r.f. voltage.

The antenna is coupled to the final tank by means of a small coil, L_1, the reactance of which is tuned out by means of the two condensers, C_1 and C_2. The size of the coil is not critical; it need have only sufficient turns to give adequate coupling for power transfer between the final tank and antenna. Usually a few turns, varying from one or two at the higher-frequency bands to 10 or so at the low-frequency bands, of the same diameter as the tank coil, will be sufficient. The antenna condensers, C_1 and C_2, have to carry only a relatively small r.f. voltage, hence the plate spacing may be smaller than the spacing of the plate tank condenser. The maximum capacity needed depends upon the frequency and the size of L_1, as given under the diagram.

The tuning adjustment is carried out about as described under end feed. Starting with L_1 decoupled from the tank circuit, tune the tank to resonance. Then increase the coupling in small steps, tuning C_1 and C_2 simultaneously for maximum plate current and the tank condenser for minimum, until the minimum plate current is the rated current for the amplifier. Use the smallest value of coupling which will give this condition.

Ammeters may be inserted to read the antenna current, maximum current indicating maximum power in the antenna. One ammeter connected in either of the antenna leads will suffice to indicate the power in the system as a whole.

The center-feed arrangement tends to reduce radiation of even harmonics, and because of the inductive coupling seldom gives any trouble with r.f. at supposedly "dead" spots in the transmitter. Also, the antenna length need not be figured with extreme care, since the tuning apparatus inserted at its center permits varying the resonant frequency over quite a range on either side of the resonant frequency of the wire alone.

End Feed with Resonant Transmission Line (Zepp)

The use of a transmission line between the transmitter and antenna permits locating the latter in the most advantageous position available. One of the most popular types of feed for a half wave antenna is a resonant line with one wire connected to one end of the antenna. This arrangement, commonly known as a "Zepp" antenna, is shown in Fig. 525. The transmission line preferably should be some multiple of a quarter wave in length, or nearly so.

Since only one side of the transmission line is connected to the antenna, there is always a slight

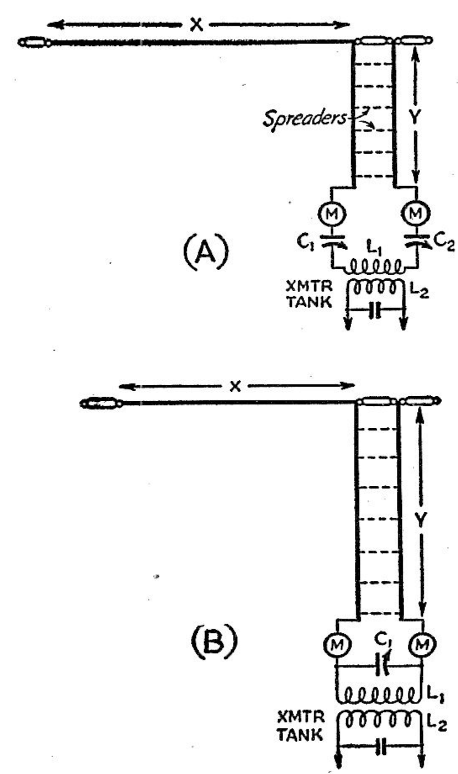


Fig. 525 — The Zepp antenna. The length of the half-wave antenna is given by the formula earlier in the chapter. When the feeder length, Y, is an odd multiple of a quarter-wave series tuning is required at the transmitter, as shown at (A). When the length Y is an even multiple of ¼-wave parallel tuning is needed (B). Method of coupling is described in Chapter 4.

unbalance in the line, even when the two currents are exactly out of phase all along the line. The two wires do not act independently, however, because of the coupling between them, and therefore the current at a loop in the "dead" or open feeder does not differ greatly from the current in the "live" feeder, or the side of the line connected to the antenna. Hence there is but little radiation from the line, provided the antenna length is correct.

The effect on feeder balance of incorrect length is shown in Fig. 526, which shows an antenna with quarter-wave feeders. Instantaneous current

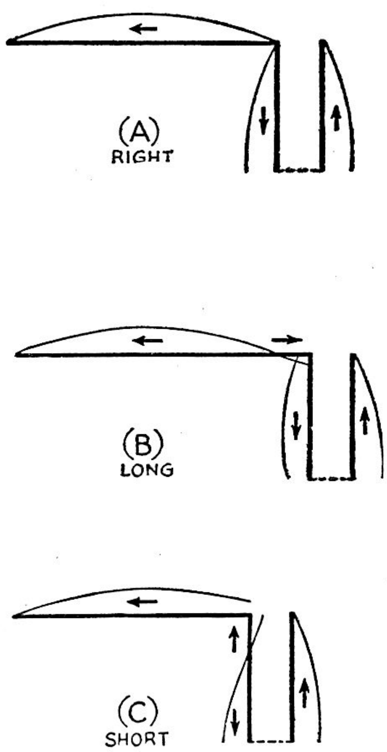


Fig. 526 — **Effect of antenna length on feeder-current balance with an end-fed antenna. (A), antenna length correct; (B) and (C), incorrect.**

directions also are shown. When the antenna length is correct, as at A, the feeder currents are opposite in phase all along their length, and of approximately the same amplitude in each feeder. If the antenna is too long, however, as at B, the current goes through a reversal on the antenna so that the standing wave on the live feeder is moved along as compared to that on the dead feeder. Thus the feeder currents are not exactly out of phase and there will be some radiation from the line. The effect of too short an antenna is shown in C, where the standing wave on the live feeder has been moved in the opposite direction. There must always be a current node at the end of the dead feeder, so that the current distribution on this feeder is not greatly affected by the antenna length.

The greater the departure of the antenna length from a true electrical half wave the greater the feeder unbalance, and hence the higher the radiation from the line. In most cases a small amount of line radiation does no particular harm, so it will usually suffice to cut the antenna for the most-used frequency and line radiation can be neglected for work over a range of a few per cent either side of the optimum frequency. This is particularly true for short lines. As the line becomes longer — a few wavelengths or more — the energy radiated becomes a greater percentage of the total fed to the system, and the frequency range over which operation can be carried out with negligible line losses becomes smaller.

For ease of coupling power into the system it is advisable to make the feeder length a multiple of a quarter wavelength. Some departure from this length can be tolerated, because the discrepancies can be made up to some extent in the tuning apparatus where the line is coupled to the transmitter. However, lengths which fall nearly midway between quarter wavelengths often give trouble, making it hard to find a tuning adjustment which will "take power" from the transmitter.

The most popular coupling system for the Zepp antenna consists of a coil and one or two condensers arranged either for series or parallel tuning, depending upon the feeder length; series tuning for feeders an odd multiple of a quarter wave in length, parallel tuning for even multiples. Recommended lengths are given in the table, with the type of tuning required.

RECOMMENDED LENGTHS OF TUNED FEEDERS, IN FEET, FOR VARIOUS FREQUENCY BANDS

Band	*Series Tuning, End Feed* / *Parallel Tuning, Center Feed*	*Parallel Tuning, End Feed* / *Series Tuning, Center Feed*
3.5 Mc.	**55–90**	**30–45**
	180–220	**110–150**
7 Mc.	**25–45**	**15–20**
	95–115	**60–90**
		125–150
14 Mc.	**15–22**	**28–38**
	48–55	**60–70**
	80–90	**125–135**
28 Mc.	**7–10**	**14–18**
	23–27	**30–35**
	39–44	**48–52**
	56–60	**65–70**

The feeders should be as nearly as possible a multiple of 1/4 wavelength, whenever circumstances will permit. A quarter wavelength is (average for each band) 65 feet at 3.5 Mc., 33½ feet at 7 Mc., 17 feet at 14 Mc., and 8¼ feet at 28 Mc.

Series tuning and parallel tuning correspond respectively to voltage feed and current feed as previously described. The same considerations apply to the coil and condenser constants and ratings, and the tuning procedure is that already described. The similarity of a quarter-wave feeder with series tuning to the current-fed half-wave antenna is readily appreciated, if the two halves of the antenna of Fig. 524 are imagined to be bent to form a parallel-wire transmission line. Likewise, parallel tuning with half-wave feeders is readily comparable to voltage feed to a half-wave antenna, Fig. 523, except that a second half-wave wire is connected to the other side of the coupling tank to eliminate radiation. A ground connection on the coupling coil is not necessary with the feeder system, but can be used if desired. It should be made to the center of the coupling coil, however, and not to one end.

Besides series and parallel tuning, other coupling arrangements suitable for use with resonant lines, as shown in Chapter 4, may be used with the Zepp antenna.

Center Feed with Resonant Feeders

Instead of feeding at the end, the resonant transmission line may be inserted in the center of the half-wave antenna as shown in Fig. 527. With this arrangement the feeder is connected to

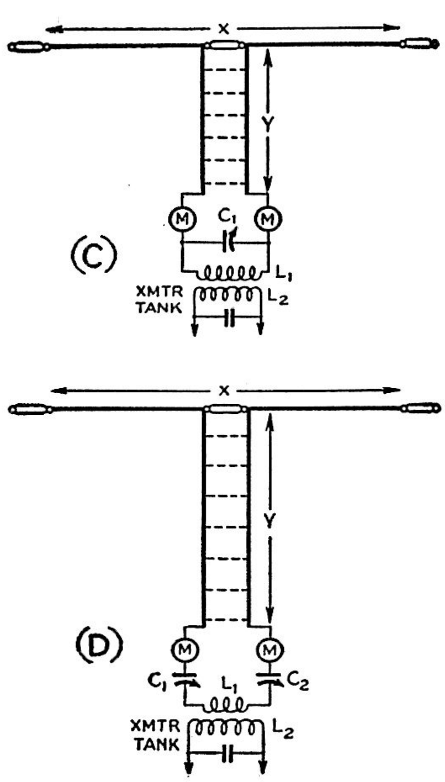


Fig. 527 — **Center-fed half-wave antenna with tuned feeders. The antenna length does not include the length of the center insulator. When the feeder length, Y, is an odd multiple of ¼ wavelength parallel tuning is required at the transmitter (A); when an even multiple, series tuning is used (B). See Chapter 4 for coupling and tuning data.**

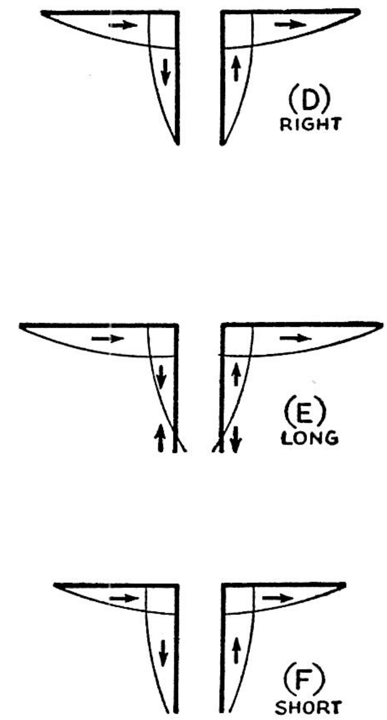


Fig. 528 — **Effect of antenna length with center feed. When the antenna length is incorrect the standing waves shift along the feeders, but the balance is not affected.**

a low-impedance point in the antenna, so that the impedance looking into the feeder at the transmitting end is just the opposite, for the same feeder length, to the case with the Zepp antenna. Thus a quarter-wave feeder shows high impedance at the transmitter, and parallel tuning is required, while a half-wave feeder shows low impedance and series tuning is necessary. The general rule is: Use series tuning with feeders an even multiple of a quarter wave in length, and parallel tuning with odd multiples.

With center feed incorrect antenna length does not unbalance the feeders, so long as both sides of the antenna are the same length. In other words, if the system is symmetrical, a situation such as that shown in Fig. 526 cannot occur. Rather, the standing waves on the feeders shift as indicated in Fig. 528. The nodes and loops move symmetrically along *both* feeders, so that a considerable departure from the resonant frequency will not cause feeder radiation. Such an antenna can be worked over a very wide frequency range with practically no loss of efficiency.

In addition, the inherent unbalance of the Zepp system is not present with the transmission line connected to the center of the antenna, since the two wires of the line are equally loaded. On the whole, therefore, this arrangement is preferable to the Zepp from the standpoint of feeder operation.

As in the case of the Zepp antenna, the preferred feeder lengths are those which are close to multiples of a quarter wavelength. Again, any type of coupling suitable for use with resonant lines (Chapter 4) can be employed.

Non-Resonant Lines

As explained in Chapter 4, a transmission line which is terminated in a resistance equal to its characteristic impedance will not have standing waves, and no special length is needed for proper operation. This feature is often advantageous, because it is sometimes inconvenient to make the length of a line one of the quarter-wave multiples desirable for satisfactory power transfer.

An important feature in the use of non-resonant or "flat" lines is the method by which the impedance at the antenna is matched to the line impedance. This distinguishes the various types of non-resonant feeder systems used with half-wave antennas.

Twisted Pair Feed

The simplest method of assuring a match between the antenna and the line is to make the line impedance equal to the antenna resistance. In the case of the half-wave antenna this resistance averages about 73 ohms at the center, so that a line of 73 ohms impedance is required.

It is not practicable to construct an open-wire line having this value of impedance, but one can be made by using rubber-insulated wire, which not only permits the two conductors to be quite closely spaced but also further raises the capacity per unit length by providing a higher dielectric constant in the medium between the wires. A line of this type is simply connected into the center of the half-wave antenna, as shown in Fig. 529. It may be made any convenient length. At the transmitter end it can be coupled to the final tank by means of a turn or two of wire, without any special tuning apparatus. However, a tuned coupling circuit can be used if desired, as shown in Chapter 4.

The accuracy of the match will naturally depend upon the exact value of line impedance — twisted pairs of different types have differing impedances, as listed in Chapter 4 — and in addition will depend upon the height and location of the antenna. The effect of height on the resistance has been already discussed in Chapter 3. It is possible to make the antenna impedance match the line impedance, if the latter is in the vicinity of 70 ohms, simply by adjusting the height of the antenna until standing waves are minimized. The antenna impedance will be affected somewhat by nearby trees and buildings, but it is impossible to forecast the magnitude of this effect. The best plan is to keep the antenna as much in the clear as possible.

For a good match, it is essential that the antenna be the right length; the correct length for the operating frequency can be determined by one of the methods already described. If the line impedance is somewhat lower than the antenna impedance a better match can be brought about by fanning the last few inches of the line, as shown in Fig. 529, to form a "V." The amount of fanning necessary will depend upon the relative antenna and line impedances, and usually will be between 6 and 18 inches. The match may be checked by inserting ammeters in each antenna leg at the junction of feeder and antenna, adjusting the "V" until the current is maximum.

It is not readily possible to measure directly the standing waves on a twisted-pair line. One method of checking is to measure the current into the line at the transmitter end, then temporarily insert a section about a quarter wave long (electrical length) between the regular line and the coupling coil, and read the current into the new section of line. If the current is within 10 per cent or so of its previous value, the line is quite well matched. A badly mismatched line will show "hot spots" along its length if operated for a period of time with a few hundred watts input, since the losses are higher at the voltage loops when standing waves of appreciable magnitude are present.

As shown in Chapter 4, the increased line loss for standing wave ratios of 2 or 3 as compared to a really "flat" line is not serious. If the line is properly matched to the antenna at one frequency, therefore, it will work quite efficiently over a fair range of frequencies on either side of the correct one. If the antenna is to be used over a whole band, the system should be carefully matched for a frequency near the center of the band.

Compared to air-insulated lines, losses in a twisted-pair feeder are high. Such lines therefore should be used only in short lengths (in terms of wavelength). The loss in a twisted-pair line increases markedly as moisture is absorbed in the insulation. It pays, therefore, to use high-quality lines and to take precautions against rain. Where the line connects to the antenna the "V" should be well covered with rubber tape, and care should be taken to keep the waterproof covering on the line intact. Ordinary lampcord is not recommended because of lack of weatherproofing.

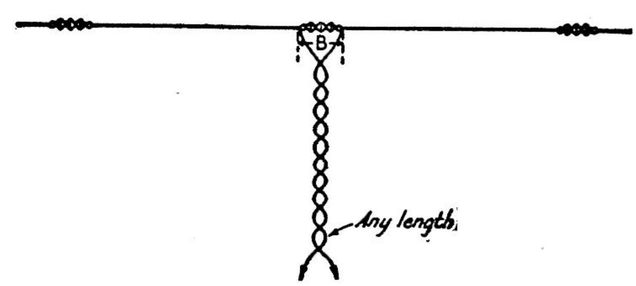


Fig. 529 **— Twisted-pair feed to a half-wave antenna. The antenna length does not include that of the center insulator. The distance B depends upon the relative impedance of the antenna and the line, as described in the text. As much as 18 inches may be beneficial.**

With twisted-pair feed, radiation of even harmonics of the transmitter frequency is quite low

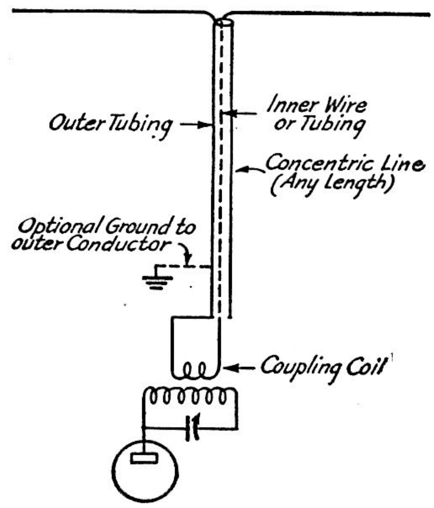


Fig. 530 — **Half-wave antenna fed by 70-ohm concentric line, either air- or rubber-insulated. See Chapter 4 for coupling details. The antenna length does not include the length of the center insulator.**

because the line is badly mismatched at even multiples of the fundamental frequency. Odd harmonics can readily be radiated, however. A coupling system which discriminates against harmonics is to be preferred.

Concentric-Line Feed

A 70-ohm concentric cable, either rubber- or air-insulated, can be used to replace the twisted pair feeder described in the preceding section. The arrangement is shown in Fig. 530. If a rubber-insulated cable is used, all of the remarks in the preceding section on adjustment, use and losses, apply with equal force.

With air-insulated lines — that is, lines in which the inner and outer conductors are held at fixed spacing by means of high-grade ceramic spacers, which form a relatively small part of the total dielectric — the losses are negligible, even in unusually long lines. The type consisting of a copper tube enclosing a concentric wire is especially good from the standpoint of being weatherproof, and there is practically no loss by radiation from such a line. Data for conductor sizes and spacing to make a 70-ohm line are given in Chapter 4. Also available are flexible concentric lines of the requisite impedance, consisting of a braided-wire outer sheath enclosing a stranded inner conductor, the two being separated by cup-shaped ceramic or polystyrene spacers. These are also low-loss, but less impervious to moisture than the solid type.

Matching and coupling adjustments are the same as for twisted-pair feeders. An antenna with this type of feed is equally capable of working over a reasonable frequency range without excessive loss because of standing waves.

Open-Wire Feed with Delta Match

When an open-wire line of conventional construction is to be operated non-resonant with a half-wave antenna, some form of special matching arrangement must be used at the antenna end, since the line impedance is of the order of 500 to 600 ohms while the antenna resistance is only 70 ohms. The delta matching transformer as applied to a half-wave antenna is shown in Fig. 531.

As in the case in all matched systems, the antenna length must be correct for the operating frequency if an exact match is to be secured. The length can be adjusted independently, as already described. For a 600-ohm line, the coupling length, E, and the feeder clearance, C, are given by the following formulas:

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

$$C \text{ (feet)} = \frac{118}{f \text{ (Mc.)}} \text{ (3 to 30 Mc.)}$$

$$C \text{ (feet)} = \frac{113}{f \text{ (Mc.)}} \text{ (Above 30 Mc.)}$$

where f is the frequency in megacycles.

The dimensions given are based on an antenna resistance of 73 ohms and therefore will be subject to some modification if the actual resistance differs from that figure because of the antenna height or other factors. The correct adjustment,

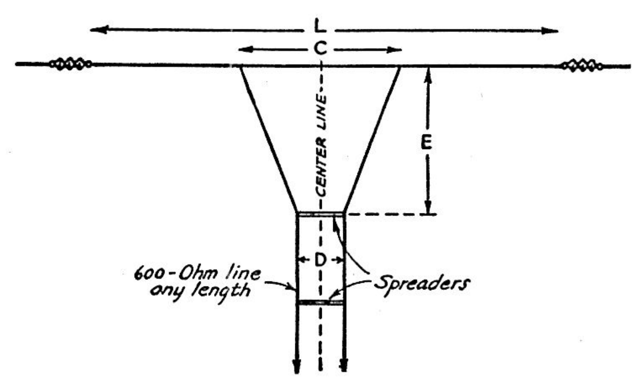


Fig. 531 — **Half-wave antenna with delta matching transformer. The antenna length L is calculated by the formula previously given in this chapter. Dimensions C, D and E are calculated as described in the text.**

in case the line is not flat, can be obtained by cut-and-try variations of the dimensions C and E until standing waves on the line are minimized.

When adjusted for the center of a band, this type of antenna system is capable of working at good efficiency over the whole band. Any of the coupling systems described in Chapter 4 suitable for working with a 600-ohm line may be used to transfer power from the transmitter to the line. One should be adopted which will help discriminate against harmonics, however, since this system will radiate harmonics, both even and odd, of the fundamental frequency fairly well as compared to other antenna-feeder arrangements.

Half-Wave Antennas with Matching Stubs

A non-resonant line of the order of 600 ohms can be readily matched to a half-wave antenna through the use of linear matching transformers of the type described in Chapter 4. Such a matching section or stub can be connected either to the center or the end of a half-wave antenna, where the antenna impedance is resistive, as shown in Fig. 532. If a quarter-wave stub is terminated at the center of the antenna where the resistance is low, the impedance looking into the other end of the stub is high; therefore an open-ended stub is required. On the other hand, if the stub is terminated at the end of the antenna, where the resistance is high, the impedance looking into the other end of the stub is low, hence a closed stub is called for. The closed stub is more convenient to adjust, so if the stub feeds into the center of the antenna it may be more convenient to make it a half wave long, which will permit using a shorting link on the far end.

Matching stubs resemble the quarter-wave or half-wave resonant feeders used with the Zepp and center-fed antennas both in electrical and mechanical properties. Ordinarily the stub has a surge impedance of 600 ohms, although other values may be used. Like these antenna systems, the center-fed arrangement is more symmetrical and can be more accurately adjusted, since both wires are connected to the antenna.

In the end-feed arrangement it is essential for accurate matching that the antenna length be an electrical half wave for the operating frequency. Departure from this length leads to the same sort of performance illustrated in Fig. 526. Although a reasonable frequency range can be covered without serious loss from mismatch and radiation from the stub, better performance in both respects will be secured when the stub connects to the center of the antenna. In this case, the antenna will work well over an entire band if its length is adjusted for the center of the band.

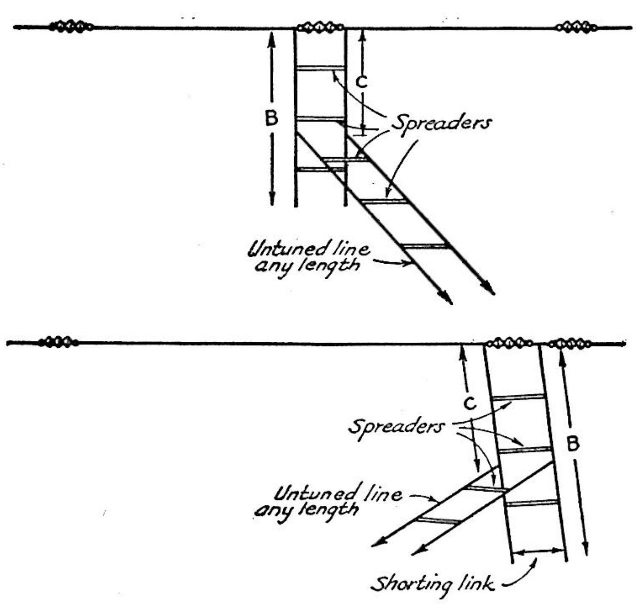


Fig. 532 — Use of quarter-wave stubs to match an open-wire line to a half-wave antenna. In the upper drawing, the antenna length does not include the length of the center insulator. Data on adjustment will be found in Chapter 4, together with additional information on the use of matching stubs.

The end-fed system shown in the lower drawing is often called a "J" antenna when the antenna and stub are vertical.

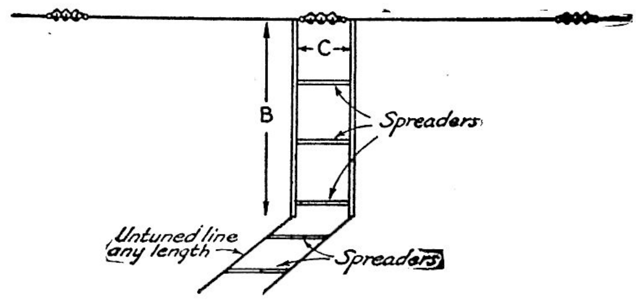


Fig. 533 — The "Q" antenna, using a quarter-wave matching section whose characteristic impedance is the geometric mean of the antenna and line impedances. The antenna length does not include the length of the center insulator. The length B and spacing C of the matching section can be found from the data given in Chapter 4.

With the end-fed system, the antenna length should first be adjusted independently to the operating frequency, with the stub disconnected. After this is done, the stub may be connected to the antenna (but not to the line) and, using the same method, the shorting link adjusted so that the whole system, antenna and stub, is resonant at the operating frequency. The line may then be tied to the stub and the matching carried out as described in Chapter 4.

With center feed, the antenna length is not critical, since discrepancies can be made up by adjustment of the stub. The antenna and stub may be resonated as a unit, independently of the line, again using the methods described earlier in this chapter. With a quarter-wave stub this will involve clipping the free ends until resonance is secured. It is best to start out with the stub intentionally long. Once the system is resonant the feeders may be attached and their position on the stub adjusted for minimum standing waves as described in Chapter 4. A further "touching up" of the stub length, as described in Chapter 4, may be necessary for an exact match.

These antenna systems will radiate harmonics to some extent, although the mismatch on harmonic frequencies is bad enough so that comparatively little harmonic energy reaches the antenna. However, it is advisable to use a coupling system which will help discriminate against harmonics. Chapter 4 should be consulted for suitable coupling arrangements for working into an open-wire line.

Q-Bar Matching

By using a quarter-wave line of suitable characteristic impedance an open-wire line can be matched to the center of a half-wave antenna without the necessity for tapping on the matching transformer. The linear transformer impedance must be the geometric mean of the antenna and line impedances, as described in Chapter 4. Data for the construction of such a transformer are also given in that chapter.

Thus the 73-ohm antenna resistance can be matched to a 600-ohm line by using a linear matching transformer having an impedance of 210 ohms, approximately, connected as shown in Fig. 533. The "Q" section must be constructed with large-diameter conductors to achieve this impedance. Conventionally, it is made of tubing of about half-inch diameter, usually aluminum, supported by insulating spacers which maintain the correct center-to-center spacing between the conductors. With half-inch tubing, this spacing will be 1.5 inches to match 73 ohms to 600. Spacings for other sizes of conductors can be found by consulting Chapter 4.

For an exact impedance match, the antenna length must be correct for the operating frequency. The correct length can be determined by one of the methods given earlier in this chapter. The length of the "Q" section also must be correct; it can be determined by the same methods if made slightly long to begin with, by disconnecting it from the antenna and using a movable shorting link on one end. The match will be affected by the height of the antenna, just as in the case of twisted-pair or concentric-cable-fed lines. If appreciable standing waves are present on the line when the antenna is installed, they can be minimized by varying the spacing of the "Q" bars, providing the antenna and "Q" section lengths are correct. "Q" antenna parts are purchasable in kit form, and a satisfactory match usually will be secured by following the instructions when such a kit is procured. In any event, the losses from standing waves will not be serious when operation is carried on in various parts of a band, providing the system is first correctly adjusted for the center of the band.

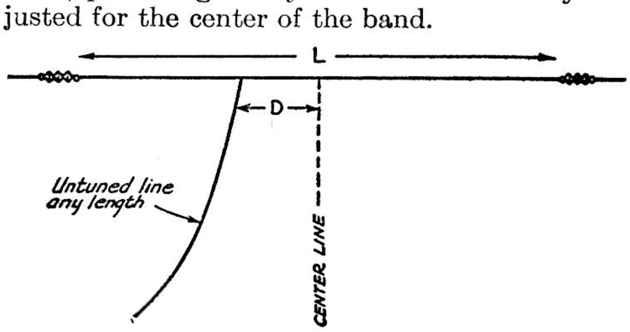


Fig. 534 — The single-wire-fed half-wave antenna. Length L is calculated as previously described, or may be taken from the charts, Figs. 535–539. The distance D also is given in the charts.

The "Q" matching system with a half-wave antenna discriminates against even harmonics of the transmitter frequency, just as in the case of other center-fed systems. Nevertheless, it is advisable, in the interests of low harmonic radiation, to use a tuned coupling circuit to provide further attenuation of the harmonics. Chapter 4 may be consulted for suitable circuits and operating data.

Single-Wire Feed

The single-wire non-resonant line can also be used to feed a half-wave antenna. Of all the various feeder systems available it is probably the least desirable, for three reasons. The line radiation tends to be higher because there is no second wire with out-of-phase current to cancel the radiation from the first. Hence there is always *some* radiation, which can be minimized only by as accurate matching as possible so that the line current will reach the lowest possible value. Second, a single-wire-fed antenna radiates rather well on harmonics (it is often used for that purpose) and particular precautions must be taken to prevent harmonics of the operating frequency from getting into the system. Third, the efficiency of the feeder is dependent upon the characteristics of the ground over which it is installed, since the return circuit is through the ground. Ground having good conductivity is essential to the performance of the feeder, and relatively poor results may be expected if the ground is very rocky, or dry and sandy, for any considerable depth.

For a good impedance match it is essential, as with other non-resonant lines, that the antenna length be correct for the operating frequency. The length may be adjusted independently as previously described in this chapter. The other critical dimension, shown in Fig. 534, is the distance *D* from the center of the antenna to the point where the feeder is attached. Antenna length and dimension *D* are both shown in the charts of Figs. 535 to 539, for a feeder of No. 14 wire. The distance *D* will depend upon the size of the feeder wire, since this determines the characteristic impedance of the feeder. *D* is equal to the length of the antenna multiplied by a factor which varies with the wire size. For No. 12 wire the factor is 0.133; for No. 14 wire, 0.139; and for No. 16 wire, 0.144.

Placing the feeder tap incorrectly does not change the resonant frequency of the antenna, but affects only the standing-wave *ratio* on the feeder. However, if the antenna is the wrong length standing waves on the feeder cannot be eliminated no matter what the position of the tap. The feeder should leave the antenna at right angles for a distance of at least a quarter wave, and sharp bends in the feeder should be avoided if possible.

The single-wire-feed system can be operated over a fair frequency range without serious losses. At frequencies other than that for which the antenna is resonant the standing wave of current on the antenna shows a discontinuity where the feeder joins the antenna, and of course standing waves show on the feeder. The antenna length can be checked by inserting an ammeter in the antenna on each side of the feeder, as close to the junction as possible; if the antenna length is correct, the ammeter readings will be equal. Standing waves on the feeder can be checked by the procedure outlined in Chapter 4.

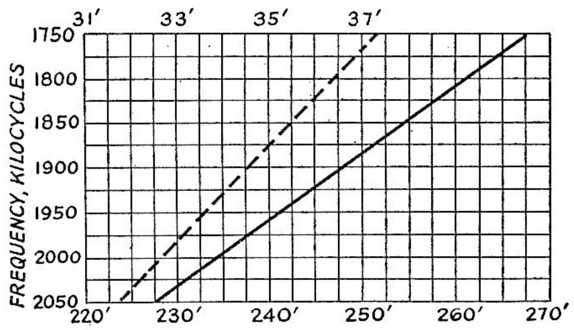


Fig. 535 — Length of half-wave antenna for the frequency range 1750–2050 kc.

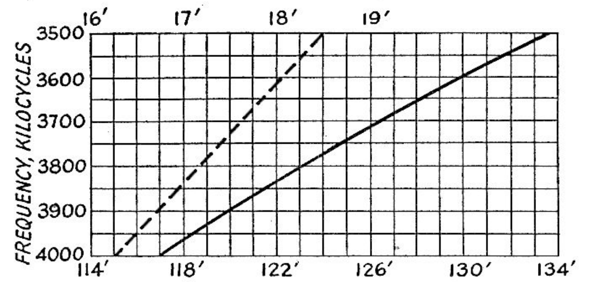


Fig. 536 — Length of half-wave antenna for the frequency range 3500–4000 kc.

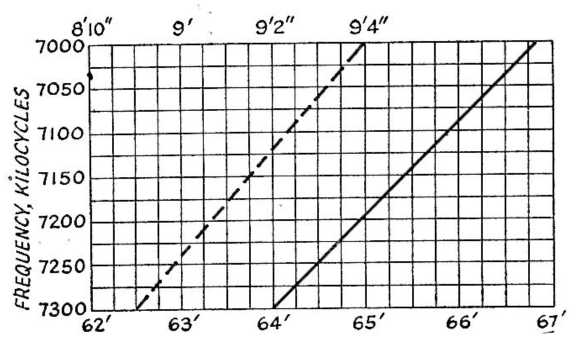


Fig. 537 — Length of half-wave antenna for the frequency range 7000–7300 kc.

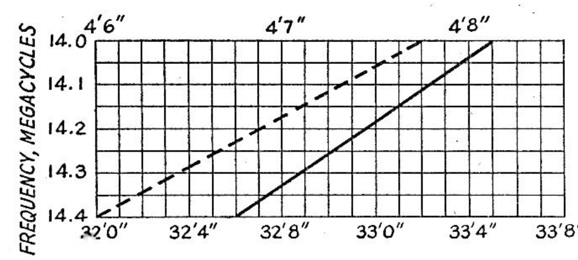


Fig. 538 — Length of half-wave antenna for the frequency range 14,000–14,400 kc.

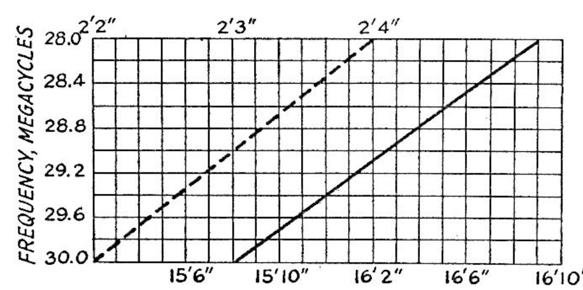
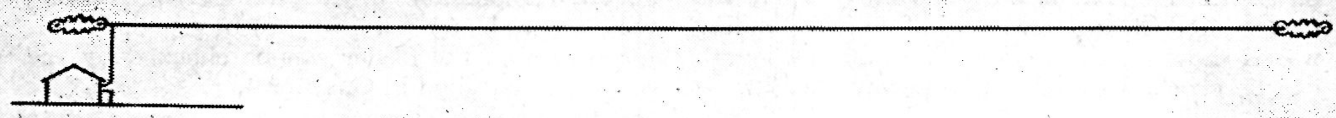


Fig. 539 — Length of half-wave antenna for the frequency range 28,000–30,000 kc.

Length of Half-Wave Antenna in Feet for the Various Amateur-Band Frequencies

The lengths shown by the solid curves apply to any half-wave antenna with any type of feed system, subject to slight modifications on account of location of the antenna as mentioned earlier in the chapter. The dotted curves show the distance D, Fig. 534, from the center of the antenna to the point where a No. 14 single-wire feeder is attached.



6. LONG SINGLE WIRES

THEIR DIRECTIONAL AND RESISTANCE CHARACTERISTICS

As pointed out in the previous chapter, the maximum radiation from a half-wave antenna is broadside to the wire, with some modification introduced by the height above ground. However, when the wire is a wavelength or more long the radiation tends to concentrate more and more off the ends, although some minor lobes appear and fill in the radiation in other directions. Further, the long-wire antenna radiates more power in its most favorable direction than does a half-wave antenna in its favorite direction. This power gain is obtained at the expense of radiation in other directions. By properly orienting a long-wire antenna it is possible to put out a stronger signal in the desired direction than would be possible with a half-wave antenna.

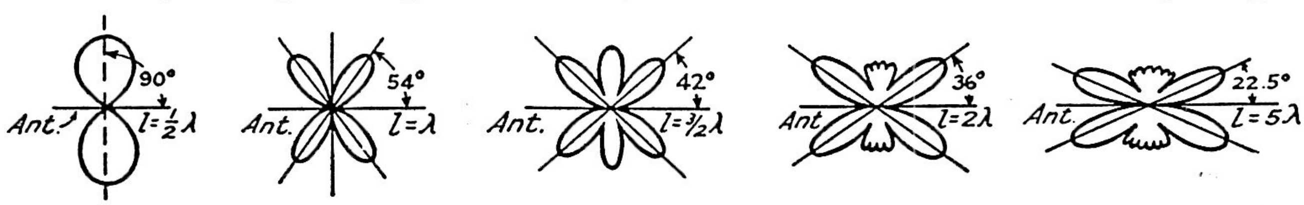


Fig. 602 — **Free-space diagrams of typical long-wire antennas.**

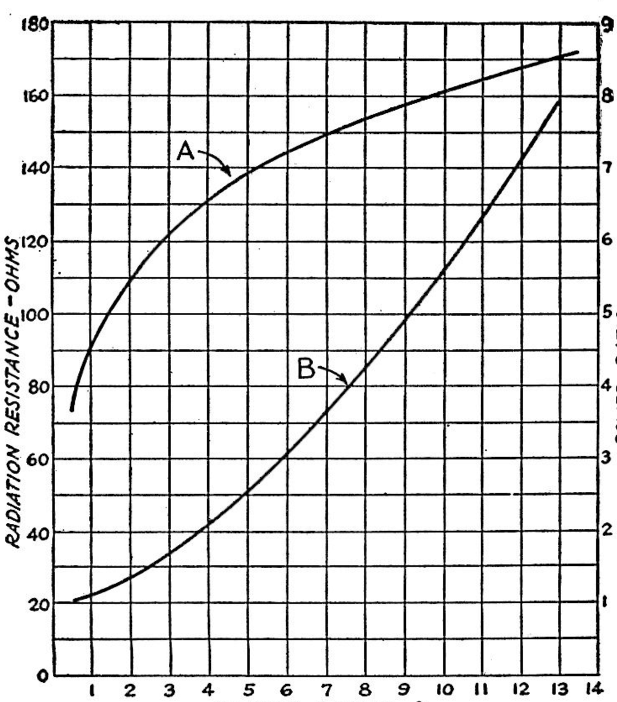


Fig. 601 — **The variation in radiation resistance and power in the major lobe of long-wire antennas. Curve A shows the change in radiation resistance with antenna length, while Curve B shows the power in the lobes of maximum radiation for long-wire antennas as a ratio to the maximum of a half-wave antenna.**

As in the case of the half-wave antenna, the long-wire antenna will normally be worked at resonance, so that maximum power can be introduced into it. The radiation resistance as measured at a current loop becomes larger as the antenna length is increased. Fig. 601 shows how the radiation resistance and power-gain of the major lobe increases as the length of the antenna is increased. The radiation resistance given is the free-space resistance and will be modified by the height above ground, similar to the case of the half-wave antenna.

Free-space patterns of a few long-wire antennas are given in Fig. 602. These are not the patterns obtained in actual practice, because of the ground modification and also because they only show what would be obtained along the horizontal plane, where no radiation is ever obtained in actual practice. However, they serve to show how the pattern is modified as the length of the radiator changes.

More practical patterns are shown in Figs. 603–608. These patterns show the radiation of various long-wire antennas for various vertical angles of radiation. The height above ground does not modify these patterns but it does have an effect on the gain of the antenna over a half-wave. Reference to Figs. 303–314 gives the factors that should be applied to the antenna pattern for various heights and, if possible, the antenna should be hung at a height that gives the maximum radiation at the desired vertical angle. In any event, a study of Figs. 603–608 will allow one to predict with a fair degree of accuracy the performance of a proposed long-wire antenna.

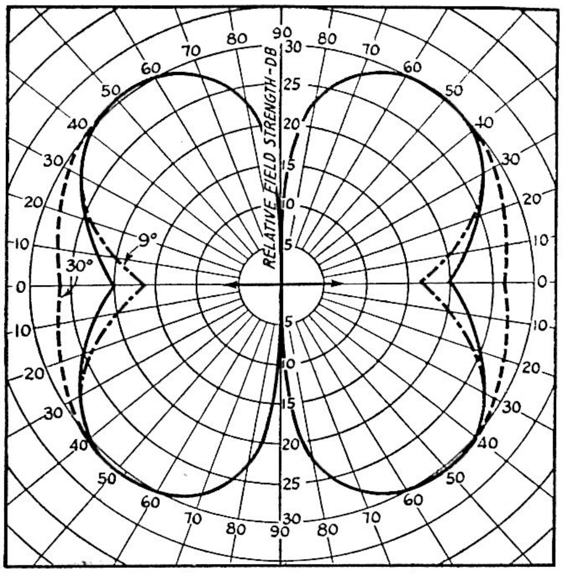


Fig. 603 **— The horizontal pattern for a one-wavelength antenna at vertical angles of 9, 15 and 30 degrees.**

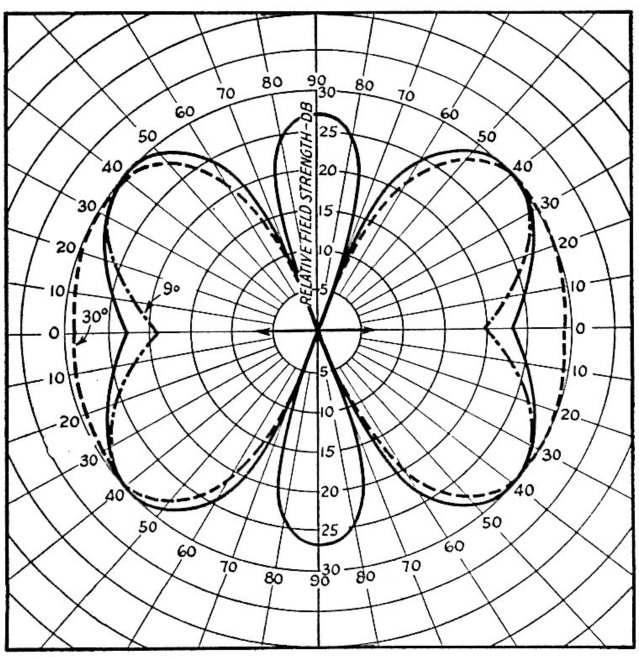


Fig. 604 **— The horizontal pattern for a 1½-wavelength antenna at vertical angles of 9, 15 and 30 degrees.**

For wires longer than five wavelengths, the chart shown in Fig. 609 shows the angles of the major and minor lobes and also the nulls of the free-space pattern.

The above patterns are for the wire at equal height above the ground throughout its length. If the wire is sloping on level ground, there will be a modification of the pattern, usually tending to result in greater radiation directly off the end of the wire in the direction the wire points downward. If the wire is parallel to sloping ground, there will be increased low-angle radiation in the downward direction of the slope and reduced radiation in the opposite direction.

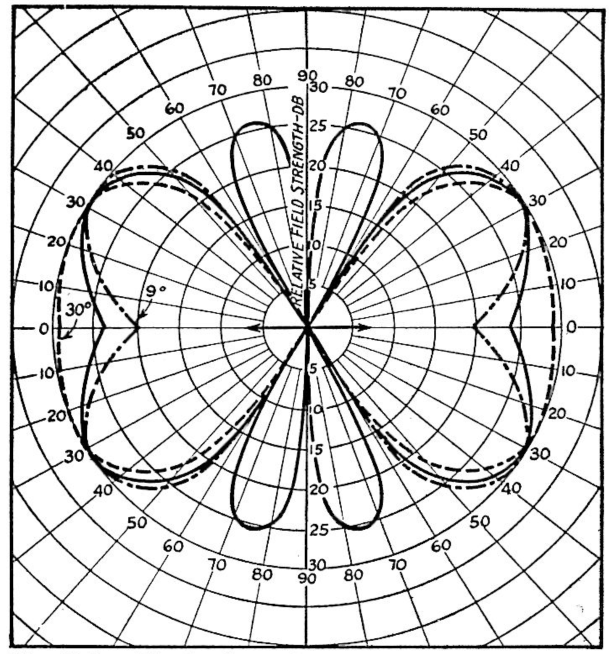


Fig. 605 **— The horizontal pattern for a 2-wavelength antenna at vertical angles of 9, 15 and 30 degrees.**

Length of a Long-Wire Antenna

The proper length of a long-wire antenna cannot be found by simply multiplying the length of a single half-wave antenna by an integer. As mentioned in the previous chapter, a half-wave antenna is shorter than a half wavelength in free space by about 5 per cent because of the "end

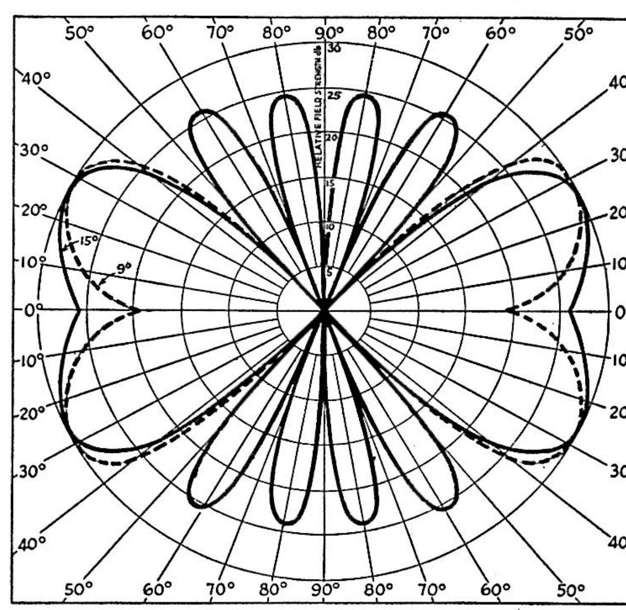


Fig. 606 **— The horizontal pattern for a 3-wavelength antenna at vertical angles of 9 and 15 degrees.**

effect" of the wire, but these effects operate only on the end sections of the antenna; in other parts of the wire these effects are absent and the wire length is approximately that of an equivalent portion of the wave in space.

The formula for the length of a long-wire antenna is

$$\textbf{Length (feet)} = \frac{492\ (N - 0.05)}{\textbf{Freq. (Mc.)}}$$

where N is the number of *half*-waves on the antenna. From this it is apparent that an antenna cut for any particular frequency will be slightly off resonance at exactly twice that frequency (on the second harmonic) or four times that frequency (on the fourth harmonic). This effect is not important except where tuned feeders are used at one end of the antenna, in which case there will be some unbalance of current in the feeders at the harmonic frequencies. A symmetrical system would of course be free from this slight disadvantage.

Feeding the Long-Wire Antenna

All that has been said about the feeding and adjustment of a half-wave antenna applies equally as well to the long-wire antenna except for one stipulation: since the currents in adjacent sections of a long-wire antenna must be out-of-phase, the feeder system must not upset this relationship. This requirement is met by feeding the long-wire antenna at one end or at a current loop. A two-wire feeder cannot be inserted at a current node (except at the end of the wire), since this invariably brings the currents in two adjacent half-wave sections in phase; if the phase in one section could be reversed then the currents in the feeders would be in phase and the feeder radiation would not be canceled out.

The above does not mean that the antenna would not work if the current in two adjacent half-waves were in phase; it simply means that the antenna would not be functioning as a long-wire antenna and the patterns given would not hold without modification.

TABLE I
LENGTHS OF LONG-WIRE ANTENNAS
(*Feet and inches*)

Mc.	λ	$\frac{3}{2}$λ	2λ	$\frac{5}{2}$λ	3λ	4λ	5λ	6λ	7λ	8λ
1.8	584	807	1080							
1.9	505	765	1024							
2.0	480	726	972							
3.5	275	415	555	696	836	1120				
3.6	267	403	540	677	813	1087				
3.7	260	393	525	660	791	1058				
3.8	253	382	512	642	770	1030				
3.9	246	372	498	625	751	1003				
4.0	240	363	486	609	732	978				
7.0	137′ 4″	207′ 6″	278	348	418	559	700	840	980	1120
7.1	135′ 4″	204′ 8″	274	343	412	551	690	828	967	1105
7.2	133′ 5″	202	270	338	407	543	680	817	954	1090
7.3	131′ 7″	199	266	334	402	536	671	807	940	1075
14.0	68′ 7″	103′ 11″	139	174	209′ 3″	280	350	420	490	561
14.1	68′ 1″	103′ 2″	138	172′ 8″	207′ 9″	278	347	417	487	557
14.2	67′ 7″	102′ 5″	137	171′ 6″	206′ 3″	276	345	414	483	553
14.3	67′ 2″	101′ 9″	136	170′ 4″	204′ 9″	274	342	411	480	549
14.4	66′ 8″	101	135	169′ 1″	203′ 3″	272	340	408	477	545
28.0	34′ 4″	51′ 9″	69′ 5″	87	104′ 6″	140	175	210	245	280
28.5	33′ 8″	51	68′ 2″	85′ 6″	102′ 9″	137′ 6″	172	206′ 6″	241	275
29.0	33′ 1″	50′ 2″	67	84	101	135	169	203	237	271
29.5	32′ 6″	49′ 4″	65′ 10″	82′ 6″	99′ 3″	132′ 9″	166	199′ 6″	233	266
30.0	32	48′ 5″	64′ 9″	81′ 3″	97′ 5″	130′ 6″	163	196	229	262
50.0	19′ 2″	29	38′ 11″	48′ 8″	58′ 7″	78′ 4″	98	117′10″	137′ 4″	157
51.0	18′ 10″	28′ 5″	38′ 1″	47′ 10″	57′ 5″	76′ 8″	96	115′ 6″	134′ 8″	154
52.0	18′ 6″	27′ 11″	37′ 4″	46′ 11″	56′ 4″	75′ 4″	94′ 1″	113	132	151
53.0	18′ 2″	27′ 5″	36′ 8″	46	55′ 2″	73′ 10″	92′ 4″	111	129′ 6″	148
54.0	17′ 10″	26′ 11″	36	45′ 1″	54′ 2″	72′ 6″	91′ 7″	109	127′ 2″	145′ 6″

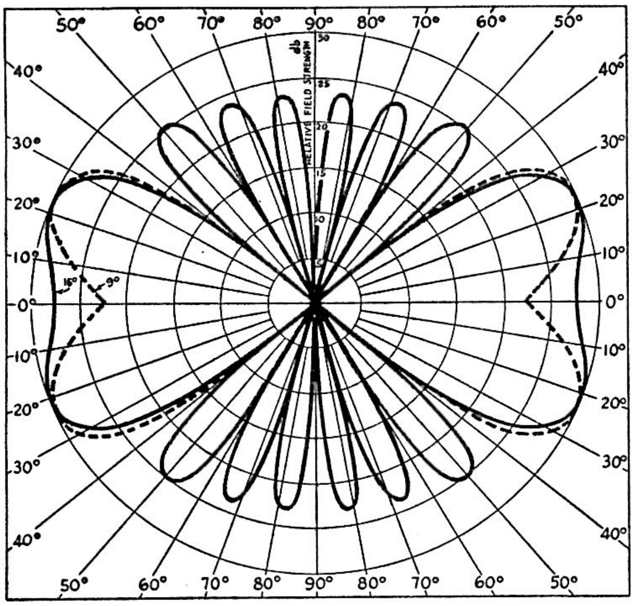


Fig. 607 — The horizontal pattern for a 4-wavelength antenna at vertical angles of 9 and 15 degrees.

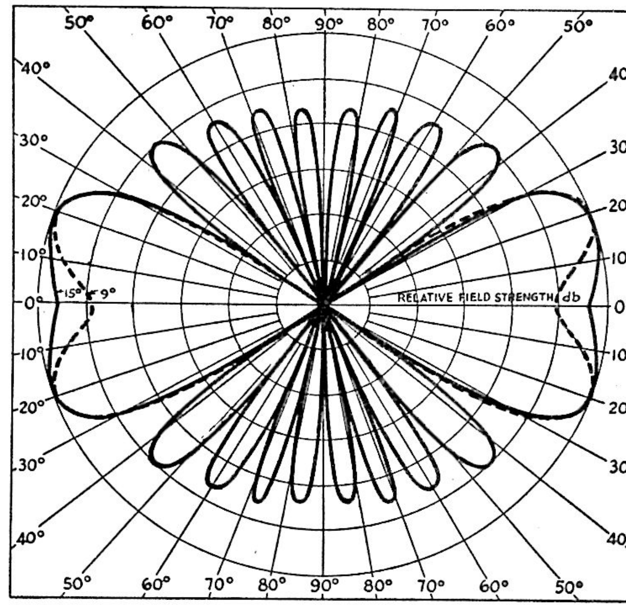


Fig. 608 — The horizontal pattern for a 5-wavelength antenna at vertical angles of 9 and 15 degrees.

End-Fed Long-Wire Antenna

The coupling, adjustment and tuning of an end-fed long-wire antenna is exactly the same as for a half-wave antenna and need not be mentioned in great detail, since it has already been covered in Chapter Five. However, it should be pointed out that, while it is possible to put power into almost any length of long wire, several experimenters have found that careful pruning of the length of the long end-fed antenna leads to greater ease of coupling and possibly better transfer efficiency. The exact length can be determined experimentally by the same means as outlined for the half-wave — the antenna should introduce no reactance to the tank circuit to which it is connected (have no effect on the tuning when connected). Since the wire can be made exactly resonant to only one frequency, some amateurs introduce an additional length of wire to the end-fed antenna when going from the high-frequency end to the low-frequency end of a band. Pruning of the antenna is a simple matter, since it terminates right at the transmitter, and it is only necessary to adjust the length until the antenna has no effect on the tuning when it is connected to the tank or antenna tuning coil.

Tuned Feeders for the Long Wire

Tuned feeders are probably the most practical for the long wire, since they permit multi-band operation with all of the antenna "in the clear." As mentioned previously, feeding the end of the long wire will allow it to operate as a long-wire antenna on all bands, but if it is fed at a current loop it only operates as a long-wire antenna on the band where it is fed at the current loop.

The tuned feeder lengths and tuning systems will be the same as for a half-wave antenna and need not be duplicated here. The same is true of the adjustment methods.

Matching Sections

Quarter-wave and "Q" match systems can be used with the long-wire antenna. However, the use of a quarter-wave matching section will limit the operation to one band, and the "Q" system must be used as tuned feeders for bands other than the one for which it is adjusted.

In designing quarter-wave matching sections and Q-match sections, it should be remembered that the radiation resistance for a long-wire antenna is higher than for a half-wave (see Fig. 601), and this must be taken into account in calculating the values of the matching section. However, because of the increased radiation resistance, the long-wire antenna tunes more broadly than one of lower resistance.

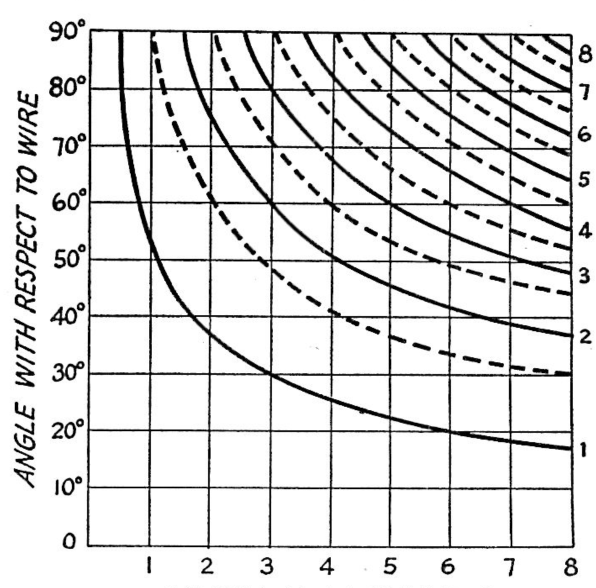


Fig. 609 — A chart of the angle the major and minor lobes (solid lines) make with the wire, for different length antennas. The dotted lines represent the nulls. No. 1 is the major lobe and has the gain given in Fig. 601.

7. MULTIBAND ANTENNAS

CONSIDERATIONS IN HARMONIC OPERATION

IT HAS already been explained how an antenna will not only be resonant at its fundamental frequency but also at frequencies very nearly equal to the harmonic frequencies. This immediately suggests that the same antenna can be used for operating on several bands, and that is exactly how the large majority of amateurs use their antennas. Space limitations often make it impossible to install more than one antenna system, and it is usually much better to have one well-designed antenna operating on several bands than to have two or three antennas packed closely together in one backyard. Although several antennas can be made to work individually even though they are close together, it is almost impossible to get clean directive effects from any one because of the mutual interaction of the various systems. And it is practically impossible to predict the performance of an antenna that is closely surrounded by several others.

Because the antenna will also respond to its harmonic frequencies, the problem of multi-band operation is not one of antenna but of feed system. In general, flat- or untuned-line systems work only on one band, and multi-band operation therefore predicates the use of a tuned line system. The only antennas that can be used on more than one band with non-resonant lines are terminated rhombics and a few special systems (see Chapter 14). Discussion in this chapter will be confined to the simpler types of antennas.

An antenna cut to be a half wavelength on one band will be a full wavelength long on the next band (second harmonic) and two wavelengths long on the next (fourth harmonic) amateur band after that. If this antenna is end-fed, as the Zepp or in Fig. 701, and thus fulfills the condition for a long-wire antenna (that adjacent half-wave sections be out-of-phase), the radiation characteristics on the various bands will be as shown in the previous chapters, Figs. 503, 603 and 605. If the antenna is center-fed, the patterns resemble those for half the antenna.

The table of feeder lengths and tuning arrangements given for half-wave antennas in Chapter 5 holds also for antennas worked on their harmonics. It is only necessary to know whether the feeder is connected to the antenna at a current or voltage loop. An examination of the current distribution of an antenna on its fundamental and harmonics will show that a feed line connected to a voltage loop on the fundamental is connected to a voltage loop on all of the harmonic frequencies that fall in the amateur bands (even-numbered harmonics), and a feed line connected to a current loop on the fundamental is connected to a voltage loop on all of the harmonic frequencies that fall in the amateur bands (even-numbered harmonics). The tuning procedure is identical to that with any tuned-line system.

As mentioned in Chapter 6, the harmonic resonant frequency of an antenna is not exactly equal to an integral multiple of the fundamental frequency. For example, a half-wave antenna resonant at 3500 kc. will not be resonant at 7000 and 14,000 kc. but at 7190 and 14,560 kc. This is

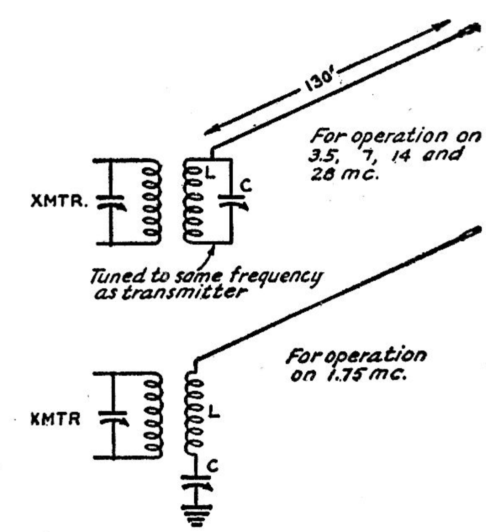


Fig. 701 — **A simple antenna system for five amateur bands. The antenna is voltage fed on 3.5, 7, 14 and 28 Mc., working on the fundamental, second, fourth and eighth harmonics, respectively. For 1.75 Mc. the system is a quarter-wave grounded antenna, in which case series tuning must be used. The antenna wire should be kept well in the clear and should be as high as possible.**

If the length of the antenna is approximately 260 feet, voltage feed can be used on all five bands.

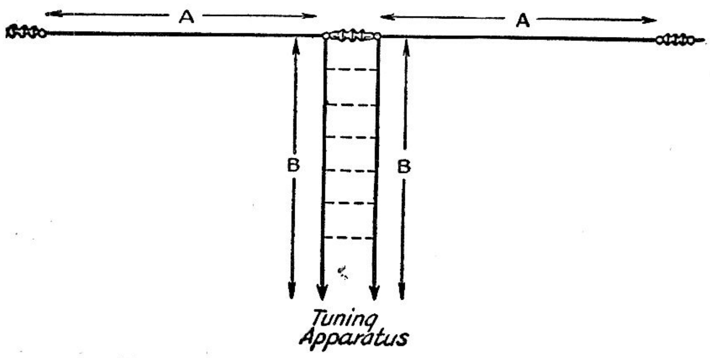


Fig. 702 — **Practical arrangement of a multi-band antenna. The total length A+B+B+A, should be a half-wavelength for the lowest-frequency band, usually 3.5 Mc. See Table II for lengths and tuning data.**

of no importance in an antenna system fed at the center because the currents in the feeder will be balanced at any frequency, the discrepancy in the length of the antenna proper being taken up symmetrically. As a matter of fact, any antenna that is center-fed with tuned feeders is not at all critical as to length, and it is only important that the system be as nearly symmetrical as possible. If both feeders read equal current it is a good indication that the system is balanced.

However, because a half-wave antenna is not resonant to the exact harmonics, a Zepp or other end-fed antenna should be cut for the band on which it is to be used most frequently. The proper length is obtained from

$$\textbf{Length (feet)} = \frac{492\ (N - 0.05)}{\textbf{Freq. (Mc.)}}$$

where N is the length of the antenna in *half* wavelengths. Table I in Chapter Six gives representative lengths.

Table I in this chapter shows the type of tuning system to be used on the various bands with several different lengths of antennas and feed lines.

The antenna with a tuned feed system is the most convenient for multi-band work, although some of the others can be used. A "Q"-fed system can be used on the higher frequencies by tuning the line. A system with a quarter- or half-wave matching section can be used by tuning the feeders, provided an open and not a closed matching section is used, although even a system with a closed section can be made to work in an emergency. An antenna fed by low-impedance line is practically worthless on the harmonic frequencies. The delta-match system can be used on the harmonic frequencies, although some standing waves will appear on the line. *Any* system can be used on the harmonic frequencies by tying the feeders together at the transmitter end and feeding the system as a single wire would be fed, by means of a tuned circuit coupled to the transmitter.

If single-wire feed is used on more than one band, a better match will be obtained if the point of connection of the feeder to the antenna is made exactly one-third the antenna length from one end. While this disagrees slightly with the figures given in Chapter Five for a half-wave antenna, it has been found to work better on the harmonic frequencies. The antenna length should be such that it resonates in the middle of the band on which it is used most, the length being determined from the formula previously given.

Compromise Multiband Antennas

Because of the inherent symmetry of a center-fed antenna system, it is readily possible to operate such an antenna on a frequency lower than that for which the flat-top is cut, provided the *total* length of wire in the system is great enough to be resonant at the lower frequency. Thus in Fig. 702 the radiating portion of the antenna consists of the two sections marked "A"; if, how-

TABLE I

MULTI-BAND RESONANT-LINE FED ANTENNAS

Antenna Length (ft.)	*Feeder Length (ft.)*	*Band*	*Type of Tuning*
With end feed:			
243	120	1.75-Mc. 'phone	series
		4-Mc. 'phone	parallel
		14 Mc.	parallel
		28 Mc.	parallel
136	67	3.5-Mc. c.w.	series
		7 Mc.	parallel
		14 Mc.	parallel
		28 Mc.	parallel
134	67	3.5-Mc. c.w.	series
		7 Mc.	parallel
67	33	7 Mc.	series
		14 Mc.	parallel
		28 Mc.	parallel
With center feed:			
272	135	1.75 Mc.	parallel
		3.5 Mc.	parallel
		7 Mc.	parallel
		14 Mc.	parallel
		28 Mc.	parallel
137	67	3.5 Mc.	parallel
		7 Mc.	parallel
		14 Mc.	parallel
		28 Mc.	parallel
67.5	34	7 Mc.	parallel
		14 Mc.	parallel
		28 Mc.	parallel

The antenna lengths given represent compromises for harmonic operation because of different end effects on different bands. The 136-foot end-fed antenna is slightly long for 3.5 Mc., but will work well in the region (3500–3600 kc.) which quadruples into the 14-Mc. band. Bands not shown are not recommended for the particular antenna. The center-fed systems are less critical as to length; the 272-foot antenna may, for instance, be used for both c.w. and 'phone on either 1.75 or 4 Mc. without loss of efficiency.

On harmonics, the end-fed and center-fed antennas will not have the same directional characteristics, as explained in the text.

TABLE II

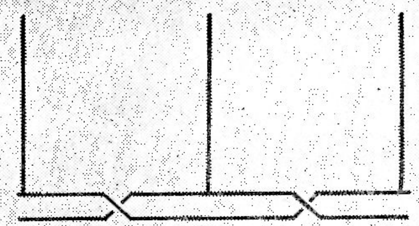
Antenna and Feeder Lengths for Short Multi-Band Antennas, Center-Fed

Antenna Length (ft.)	*Feeder Length (ft.)*	*Band*	*Type of Tuning*
137	68	1.75 Mc.	series
		3.5 Mc.	parallel
		7 Mc.	parallel
		14 Mc.	parallel
		28 Mc.	parallel
100	38	3.5 Mc.	parallel
		7 Mc.	series
		14 Mc.	series
		28 Mc.	series or parallel
67.5	34	3.5 Mc.	series
		7 Mc.	parallel
		14 Mc.	parallel
		28 Mc.	parallel
50	43	7 Mc.	parallel
		14 Mc.	parallel
		28 Mc.	parallel
33	51	7 Mc.	parallel
		14 Mc.	parallel
		28 Mc.	parallel
33	31	7 Mc.	parallel
		14 Mc.	series
		28 Mc.	parallel

ever, the feeders marked "B" each have the same length as one-half the antenna (A), the total length of wire obviously will resonate at just half the fundamental frequency of the antenna alone. For example, if A and B are each 33 feet, the antenna has a length of 66 feet and its fundamental frequency is therefore in the 7-Mc. band. The total feeder length is also 66 feet, which added to the 66 foot antenna gives a total length of 132 feet, a length which is resonant in the 3.5-Mc. band.

An antenna system operated with the feeders as part of the total resonant circuit will accept power readily, but is not so efficient a radiator as a full-length antenna, because only part of the system does the radiating. However, it will permit operation on bands for which space for a full-length antenna is not available, and even though the efficiency is reduced it is better to accept lower efficiency than not to be able to work on the band at all. Practically the only requirement of such a system is that the total length of wire must be great enough to permit tuning to the band. It is desirable, of course, to have as much of the length in the "flat-top" as the available ground space will permit. The proportion of length between flat-top and feeders can be anything that will fit the space, so long as the system is symmetrical.

Table II gives a number of representative combinations of this type for operation on various bands. The type of tuning required at the transmitter also is indicated.



8. DRIVEN ARRAYS

DIRECTIVITY — PHASED SYSTEMS — GAIN AND ADJUSTMENT

As has already been pointed out, no radiating system radiates equally well in all directions. Some antennas show directional effects in the vertical plane but none in the horizontal (simple vertical antennas) and most show directional effects in both the vertical and horizontal planes (horizontal antennas). These directional effects are not very marked in simple antennas, however, and it is only when more complicated systems are used that the term "directional" is normally applied.

Fundamentals

The merit of a directional antenna is usually measured in terms of its "gain," which can be defined as the ratio of the power that must be supplied to a standard comparison antenna to lay down a given signal at a distant point to the power that must be supplied to the directional system to give the same signal strength. For example, an antenna with a gain of "5" requires only one-fifth the power that the comparison antenna would to give the same signal or, in other words, using the directive antenna with the same power is equivalent to increasing your power five times. The comparison antenna is usually taken as a half-wave antenna in the same plane and at the same height above ground as the directional system. In the case of a "stacked" system (to be described later), the height of the comparison antenna is taken as the center of the directional system.

The *directivity* of an antenna relates to the sharpness or narrowness of the radiation pattern; the sharper the pattern, the greater the directivity. Directivity and gain normally go hand-in-hand, but some systems are capable of added directivity with little or no gain. In this case, the directivity is useful in reducing QRM in receiving, but no increase in signal strength is obtained. Antennas with sharp patterns in the horizontal plane are said to have good "horizontal directivity" and, likewise, antennas with sharp patterns in the vertical plane are said to have good "vertical directivity."

Incidentally, many amateurs wax enthusiastic about their new directional systems because they seem to be such a great improvement over their previous antennas, when actually all they have done is to take greater pains with the new installation and erect it a great deal higher and more favorably than the old one. This is not a fair comparison between the two antennas although, as far as the amateurs are concerned, the new antennas are world-beaters!

The gain realized in transmitting is also obtained in receiving and, if a directional system is available, it should be used for both transmitting *and* receiving, by means of an antenna change-over relay or switch. The old adage that "you can't work 'em if you can't hear 'em" is all too true.

All phased systems are derived from three essential types: the collinear, broadside and end-fire. Collinear elements are ones that lie on the same axis and are excited in phase. The maximum radiation is broadside to the axis and is modified by the ground in exactly the same way that the radiation from a single element is. Broadside elements are ones that are parallel to one another and are excited in phase. The maximum radiation is broadside to the plane of the elements. End-fire elements are parallel to each other but are excited out-of-phase, the exact phase difference being dependent on the separation and the desired pattern. The maximum radiation is in the plane

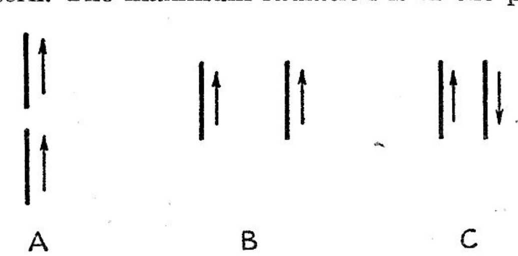


Fig. 801 — The fundamental elements of phased arrays. Collinear elements are shown at A. They are excited in phase, and the maximum radiation is broadside to the axis of the elements. Broadside elements are shown at B; they are excited in phase and their maximum radiation is broadside to the plane of the elements. C shows end-fire elements; excited out-of-phase, the maximum radiation is in the plane of the elements along a line perpendicular to the elements.

of the wires on a line through the centers of the elements. Radiation from collinear and broadside elements is always bi-directional, but it can be either bi- or uni-directional from the end-fire system, depending upon the separation and phase difference. Fig. 801 shows the various fundamental elements of phased systems.

The elements used in phased arrays are usually a half-wavelength long because they are then easiest to feed and phase, but some systems use elements that are ⅝-wavelength long and some employ shortened elements. However, unless otherwise specified, one should visualize half-wave elements in all of these discussions.

Horizontal collinear elements will give a sharpened broadside pattern in the horizontal plane but will have the same vertical pattern as a half-wave antenna at the same height. Vertical collinear elements will have a sharpened vertical pattern (lowered angle of radiation), but the horizontal pattern will be the same as that of a single vertical element.

Horizontal broadside elements will result in a sharpened pattern in the vertical plane (lowered angle of radiation) but no change in the horizontal plane over a single horizontal half-wave antenna. Vertical broadside elements give a sharpened horizontal pattern and the same pattern as a single vertical half-wave in the vertical plane.

End-fire elements give a sharpened pattern in both the horizontal and vertical planes.

Combinations of the various systems will combine their effects and result in a much sharper radiation pattern in both planes. There are no bargains in directional antennas. The end-fire system, which gives a sharpened pattern in both the horizontal and vertical planes, is often difficult to construct and feed. The other systems, although easier to feed, require more space.

Difficulty in feeding is brought about by the fact that as antenna elements are moved closer together, the radiation resistance is decreased (in some close-spaced systems it goes as low as 10 or 15 ohms). This lowered radiation resistance, the load that the feed line must tie into, results in a high standing-wave ratio on a tuned line, with consequent losses. If an untuned system is used, it is found that the antenna system tunes quite sharply (is said to have "high Q") and will not take power readily over an entire amateur band. In general, collinear and broadside arrays have a higher impedance (lower Q) than do the end-fire systems.

The plane of polarization of any directional system is the same as the plane of polarization of one of the elements. Vertical and horizontal elements in the same array do not result in very practical systems, since the radiation divides up into the two planes of polarization in proportion to the number of elements radiating in each plane. The resultant is a vector addition of the two components. In general, horizontal elements appear to be better than vertical ones because they make for quieter reception. There isn't much choice on transmitting, except that it is usually easier to put horizontal elements "in the clear."

TABLE I
THEORETICAL GAIN OF COLLINEAR HALF-WAVE ANTENNAS

Spacing Between Centers of Adjacent Half-Waves	*Number of Half-Waves in Array vs. Gain in DB.*				
	2	3	4	5	
½ wave........	1.8	3.3	4.5	5.3	6.2
¾ wave........	3.2	4.8	6.0	7.0	7.8

Collinear Arrays

The system shown in Fig. 802 is the fundamental type of collinear array. The gain for various numbers of elements is given in Table I and the free-space patterns are given in Figs. 803–805. The gain and sharpness of the patterns depend upon the number of elements and their spacing, center-to-center. Although ¾-wavelength spacing gives greater gain, it is difficult to construct a suitable phase-reversing system when the ends of the antenna elements are widely separated. For this reason the half-wave spacing is generally used. The length of the elements is not critical and if, in a system of three or four collinear half-wave elements, the elements are not exactly a half-wave long, no harm will be done as long as all of the radiating elements are the same length, so that the current in the phasing sections will be balanced and result in a minimum of radiation from these sections. For this reason, it is preferable to feed the system at the center, thus making it symmetrical and less prone to feeder unbalance and radiation.

The phasing sections of a collinear array of more than two elements can be adjusted by first balancing the two center elements. This is done by trimming them until the feeder currents are equal. Then a phasing section and additional element (that has been cut to the same length as the already-adjusted elements) is hung on to one

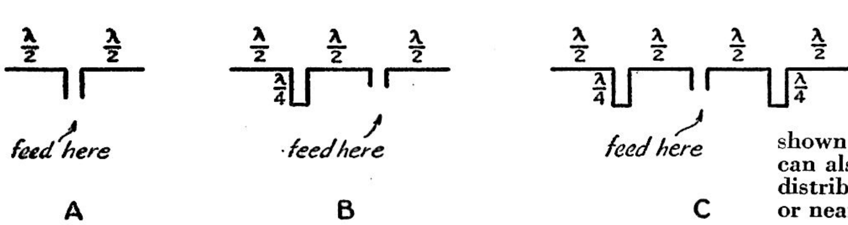


Fig. 802 — **The simplest form of collinear array is shown at A. The systems at B and C have greater gain but require the use of the quarter-wave phasing sections. All feed points shown are high-impedance. Collinear arrays can also be fed from one end, but the current distribution is not as good as with a balanced or nearly-balanced system.**

of the elements already in place and the phasing section (which was deliberately made slightly too long) is shortened until maximum current appears at the shorting bar, with constant input to the transmitter. The process is then repeated on the other side of the system. Adjusting the current to maximum at the shorting bar does not insure that the element length is exactly a half-wavelength (or whatever is counted on) but it does minimize radiation from the phasing section. The calculated length of the element will be close enough.

A collinear array with tuned feeders will work on more than one band but, unless it is only a two-element affair, the radiation will only be broadside on the band for which the array is cut. The two-element collinear array will give broadside radiation on the band for which it is designed and on the next lower-frequency band, although the gain and directivity will be less.

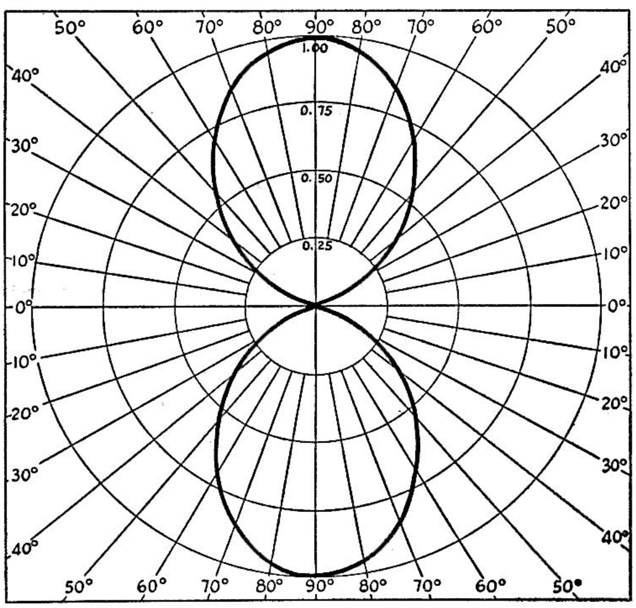


Fig. 803 **— Free-space diagram for a 2-element collinear array with half-wave elements. The scale is simply relative field strength.**

The Extended Double Zepp

If a two-element broadside array is contemplated, and some additional room is available, it is advisable to use the "extended double-Zepp." This is similar to the two collinear half-waves in phase except that 0.64-wavelength elements are used instead of 0.5-wavelength ones. With tuned feeders, it is an excellent two-band affair and has greater gain on two bands than if only half-wave elements were used. The length of the elements is not critical, since the gain increases as the elements are lengthened from 0.5-wavelength up to 0.64-wavelength, but they should not exceed the 0.64 figure because the gain falls off after that.

The extended double-Zepp principle can also be applied to more than two elements, and Fig. 806 shows the dimensions for several 14-Mc. variations. Fig. 807 shows the free-space pattern of a two-element extended double Zepp.

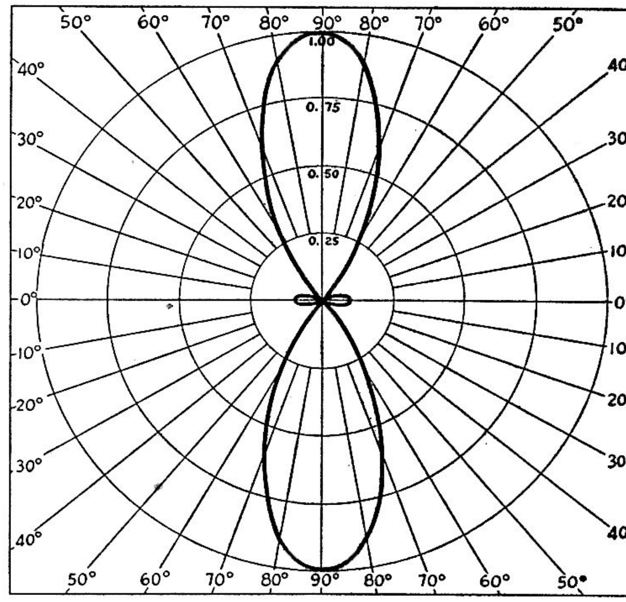


Fig. 804 **— Free-space diagram for a 3-element collinear array with half-wave elements.**

Broadside Arrays

The gain and directivity of broadside arrays also depends upon the number of elements and the spacing, the gain for different spacings being shown in Table II. Half-wave spacing is generally used, since it simplifies the feeding problem when the array has more than two elements.

Broadside arrays can be used with either vertical or horizontal elements. In the former case the horizontal pattern is quite sharp while the vertical pattern is the same as that of one element alone. If the elements are horizontal, the pattern is sharpened in the vertical plane, giving low-angle radiation, but the horizontal-plane pattern is the same as for a single element. The height re-

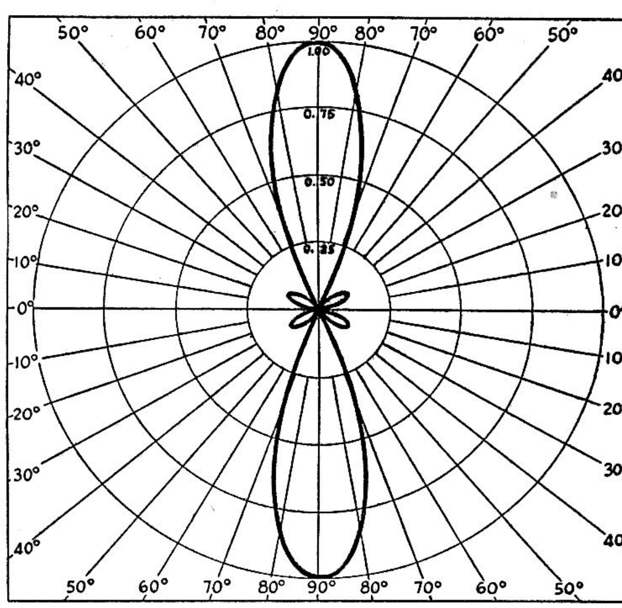


Fig. 805 **— Free-space diagram for a 4-element collinear array with half-wave elements.**

TABLE II
THEORETICAL GAIN OF BROADSIDE HALF-WAVE ELEMENTS AT DIFFERENT SPACINGS

Separation in Fractions of Wavelength	*Gain in DB.*
5/8	4.8
3/4	4.6
1/2	4.0
3/8	2.4
1/4	1.0
1/8	0.3

THEORETICAL GAIN VS. NUMBER OF BROADSIDE ELEMENTS WITH HALF-WAVE SPACING

No. of Elements	*Gain in DB.*
2	4
3	5.5
4	7
	8
6	9

quired limits the number of elements which can be suspended horizontally, so that more than two are seldom used. The lower element should preferably be a half-wavelength above ground, although the system is still effective if the lower element is only a quarter wavelength above ground.

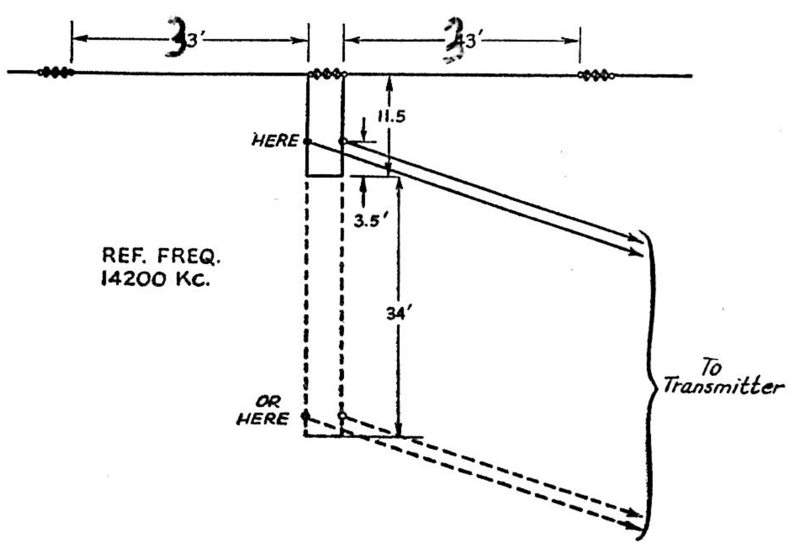
Broadside arrays can be fed by either tuned lines or matching sections and untuned lines. Fig. 808 shows typical examples.

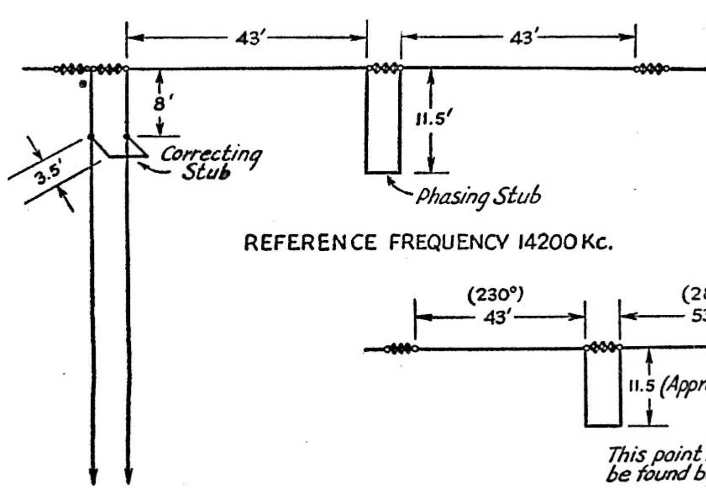
Whenever elements are mounted above each other, as in the case of a collinear system with vertical elements or a broadside array with horizontal elements, the elements are said to be "stacked." Stacked arrays have the advantage that they result in the low-angle radiation so necessary for DX work and that they minimize ground losses.

The "Lazy H"

A simple combination of two collinear elements stacked and phased for broadside radiation results in the so-called "lazy H" antenna that has been used quite effectively by a number of amateurs. It is shown in Fig. 809 and derives its name from its resemblance to a reclining "H." The elements can be either vertical or horizontal, but the horizontal elements are more popular because the system can then be fed from the bottom.

The "lazy H" can be fed by a tuned line or with an untuned line and matching section. If the elements have been cut with a fair degree of accuracy and the system is erected at least a half-wavelength from surrounding objects that might affect its tuning, the system can be tuned simply by the tuned line or the quarter-wave matching section. If exact adjustment is desired, the top elements can be connected and the system tuned (either





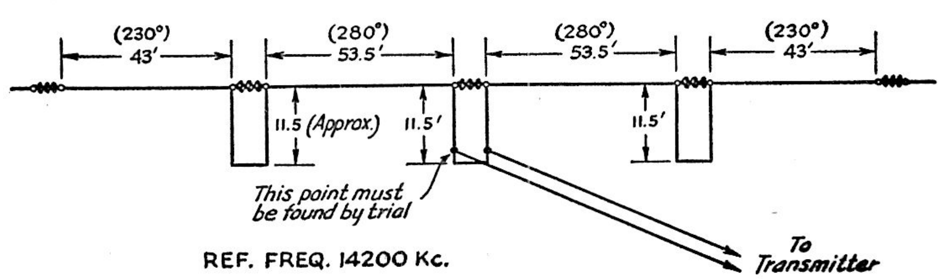


Fig. 806 — Application of the "extended double Zepp" principle to various collinear arrays. The dimensions shown are for 14.2 Mc. — they can be doubled for 7 Mc. and halved for 28 Mc. The top two arrangements are two-element arrays and have a gain of approximately 3 db. The bottom drawing shows a four-element array which has a gain of approximately 7 db. Although shown with matching sections, tuned feeders can be used.

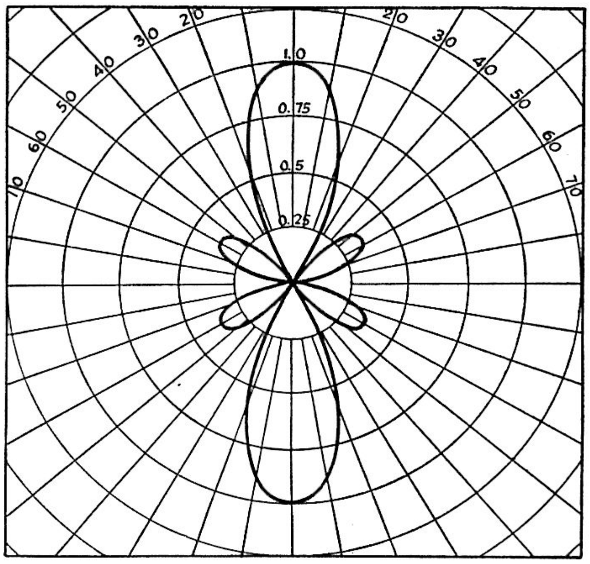


Fig. 807 — **The free-space pattern of a two-element extended double-Zepp.**

by tuned feeders or adjusting the shorting bar of the matching section), and then the lower elements can be clipped on experimentally and their length varied slightly until they show no effect on the *tuning* of the system. The bottom elements will affect the resistance of the system and if a matching section is being used the line will have to be tapped lower on the section, but the tuning should remain the same.

If it is not possible to have the lower section at least a quarter wavelength above ground, you can cheat a bit on the spacing between the top and bottom section by pulling the phasing section aside by means of an auxiliary rope. The spacing between top and bottom section can be reduced down to almost ⅜ wavelength without too much loss in gain. However, the phasing section must always be a half wavelength long electrically.

The Sterba Array

Another modification of stacked collinear elements is the horizontal Sterba array shown in Fig. 810. This system is very nearly the same as the "lazy H" except that it is a closed-circuit and consequently can be de-frosted or de-sleeted by running enough 60-cycle a.c., from a 5- or 10-volt transformer, to warm it up and melt the ice.

Two methods of feed are shown in the diagram, although the simpler point of feed is point "F," since the impedance at this point is fairly close to 600 ohms, and a line can be connected directly without serious standing waves.

Sterba arrays can be used with vertical elements, but the necessary height can only be obtained with elaborate structures or on the very-high frequencies.

The Bruce Array

Still another version of the broadside antenna is the Bruce array, shown in Fig. 811. Since the radiation from a wire is proportional to the current in it, only the center portion of each half-wave is used for radiation in the Bruce system. Although it results in vertical polarization and doesn't have the gain of the arrays with half-wave spacing, the Bruce can be quite effective for the

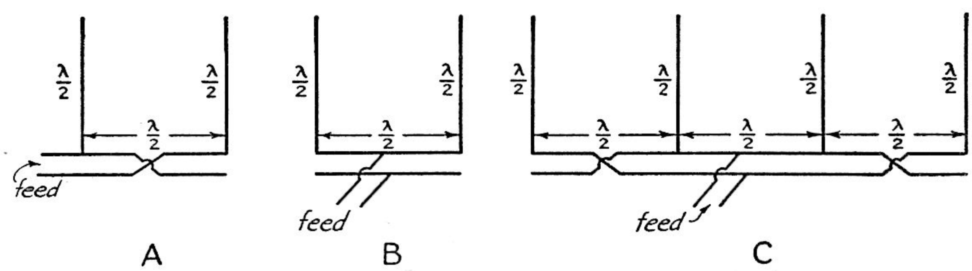


Fig. 808 — **Several combinations of broadside arrays. At A, the feed is at a high-impedance point, and it is low-impedance in B and C. Any number of elements can be used, but six is normally the practical limit.**

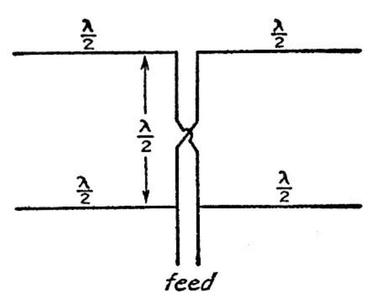


Fig. 809 — **The "lazy H" antenna uses two collinear elements stacked a half-wavelength above two more collinear elements, all excited in phase. The feed point shown is a high-impedance one.**

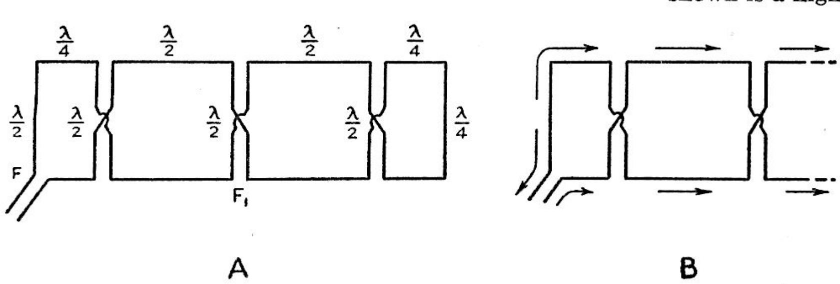


Fig. 810 — **A six-element Sterba array is shown at A. More or fewer sections can be used, for greater or less directivity and gain. The impedance at point "F" is such that it provides a fair match for a 600-ohm line, and no matching system is required. The antenna can also be fed at point "F1" (after closing F), and this point will be a high-impedance one. B shows the current distribution.**

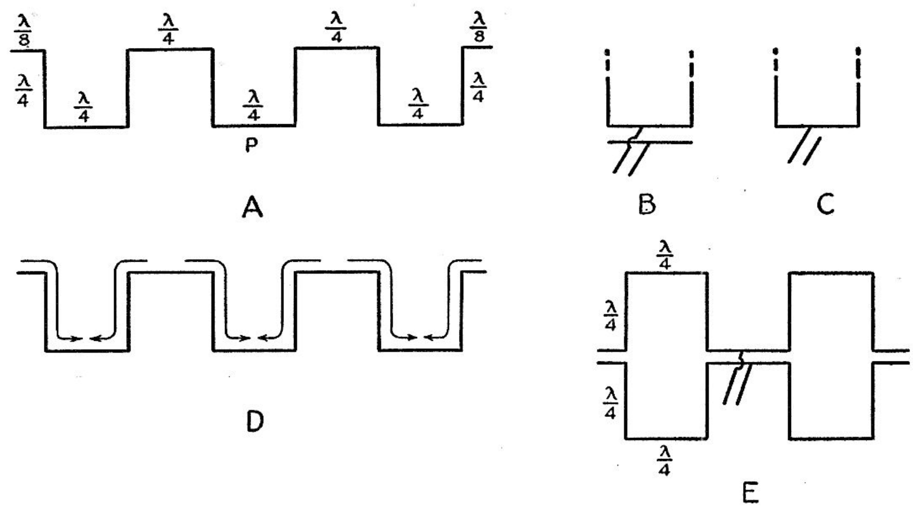


Fig. 811 — The Bruce array is shown at A. Any number of elements can be used, although the system should include at least three half-wavelengths of wire if any appreciable gain is to be obtained. The system can be fed at one end of the wire (a high-impedance point) or, preferably, at the center (point P) by either of the methods shown at B and C. This will be a medium-impedance point. The current distribution is shown at D. It is apparent that the currents in the vertical elements are all in phase, while the currents on the horizontal elements tend to cancel. Two Bruce arrays can be stacked, as at E, to improve the vertical directivity and make the feed truly symmetrical. The length of the elements can be found from the formulae:

$$\text{Quarter-wave elements Length (feet)} = \frac{246}{\text{Freq. (Mc.)}}$$

$$\text{Eighth-wave elements Length (feet)} = \frac{110}{\text{Freq. (Mc.)}}$$

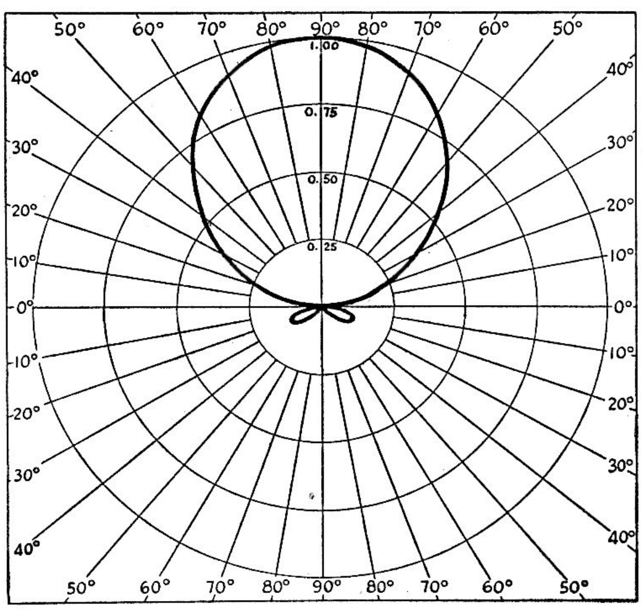


TABLE III
THEORETICAL GAIN OF TWO END-FIRE (180° PHASE DIFFERENCE) HALF-WAVE ELEMENTS WITH VARIOUS SPACINGS

Spacing in Fractions of Wavelength	*Gain in DB.*
1/8	4.3
1/20	4.1
1/4	3.8
3/8	3.0
1/2	2.2
5/8	1.7

Fig. 812 — Free-space pattern of two half-wave elements spaced a quarter wavelength and fed 90 degrees out-of-phase. The radiation is in the direction of the element with the lagging current.

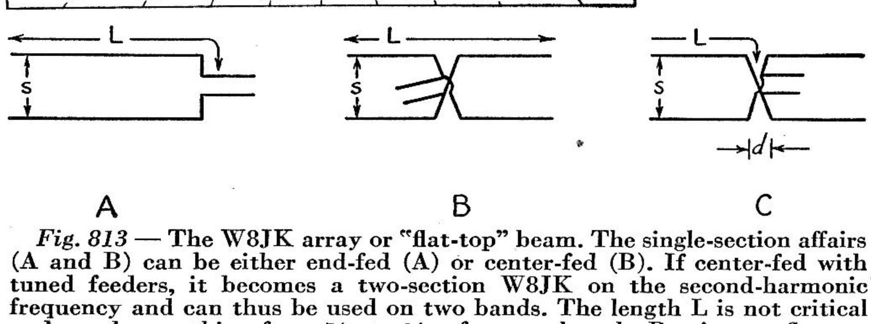


Fig. 813 — The W8JK array or "flat-top" beam. The single-section affairs (A and B) can be either end-fed (A) or center-fed (B). If center-fed with tuned feeders, it becomes a two-section W8JK on the second-harmonic frequency and can thus be used on two bands. The length L is not critical and can be anything from 7/16 to 6/10 of a wavelength. But in any flat-top beam, all lengths L should be exactly equal. The spacing should be between 1/6 and 1/8 of a wavelength, although the system will still show gain when the spacing is as high as a half-wavelength. The distance "d" in the two-section array (C) should be about two feet. The feed at A and C is high-impedance; that at B is low-impedance.

amateur with limited height. If two Bruce arrays are placed one above the other, as in Fig. 811E, vertical directivity will be improved.

End-Fire Arrays

End-fire arrays give the greatest gain and directivity for a given space and are widely used by amateurs. They have the disadvantage that their radiation resistance is low, which makes them more difficult to feed, and they tune more

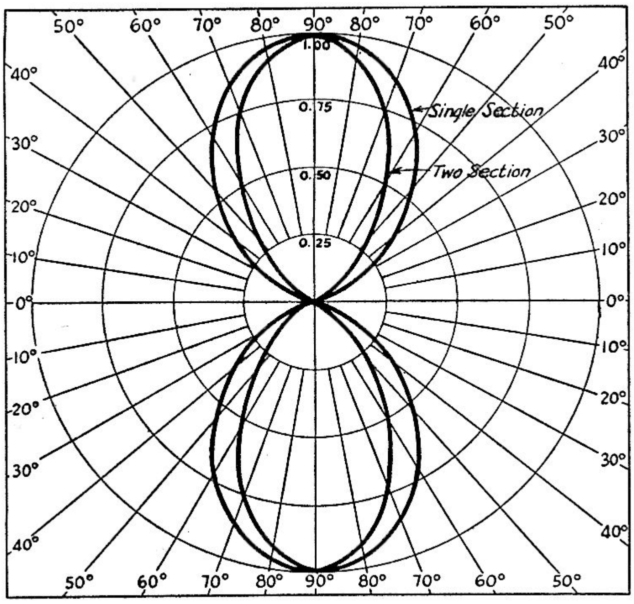


Fig. 814 — **Free-space patterns of single-section and two-section W8JK beams. The gain of the single-section W8JK is 4.3 db., the double-section yields a gain of about 6 db.**

sharply, which throws off the tuning in wet weather.

If two parallel half-waves are fed 180 degrees out-of-phase, their gain will increase as the spacing is decreased, as can be seen from Table III. The radiation resistance is lowered at the same time. Fed out-of-phase, they acquire a uni-directional characteristic at certain spacings and phasings, as can be seen in Fig. 812. Feeding other than 180 degrees out-of-phase is somewhat difficult and end-fire arrays are not normally used in this fashion, although methods will be mentioned later.

The W8JK or "Flat-Top" Array

The maximum gain for an end-fire array is obtained with eighth- to sixth-wave spacing, and the ordinary utilization of the principle is called the "W8JK array," after the amateur who first used it. Several versions are shown in Fig. 813. It can be fed by either a tuned or untuned line, at either the end or the center, although the center is preferable. A two-element affair is called a "single-section W8JK," one with four elements is called a "two-section W8JK," and so on. If a single-section W8JK is fed with a tuned line at the center, it becomes a two-section affair at the second harmonic (with quarter-wave spacing) and thus can be used for two-band operation. This makes a practical rotatable array for 14 and 28 Mc.

The array is adjusted by tuning the line or the quarter-wave matching section (if an untuned line is used). The length of the elements is not critical, and they can be anything from 7/16 to 6/10 of a wavelength. However, it is important that they all be exactly the same length. The longer elements will give a sharper beam in the horizontal plane.

End-fire arrays of this type have the advantage that, when used in the horizontal plane, they result in a lower effective angle of radiation than can be obtained by any other type of phased array of equivalent height.

Close-spaced end-fire arrays with vertical elements do not give a particularly sharp horizontal pattern (although the null is quite marked) but will result in a lower angle of radiation than would be obtained with a single vertical element.

Combinations of End-Fire with Other Systems

The end-fire principle can be combined with the broadside and collinear systems to give many different combinations, but most of them introduce structural difficulties and they are not normally used. The four-section W8JK is of course a combination of end-fire and collinear elements, and offers the most practical type of structure because it can be strung from two wooden spreaders.

If possible, it is particularly advantageous to combine the end-fire and other systems with quarter-wave spacing and 90 degrees phase difference, to obtain uni-directional characteristics. Fig. 815 shows how two "lazy H" antennas can be spaced a quarter wavelength and fed to give a choice of two uni-directional characteristics. Other adaptations will suggest themselves to the amateur. The phase difference can best be adjusted by listening or transmitting tests, adjusting the difference in line lengths until minimum back reception or radiation is obtained. Each antenna should have its matching section and line adjusted separately — the phasing adjustment is made only with the

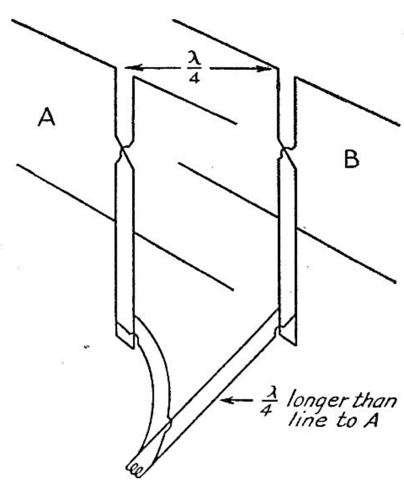


Fig. 815 — **Two antenna systems, arranged for end-fire radiation, can be controlled from the shack by running two separate feed lines to the transmitter and making one feed line a quarter wavelength longer than the other. If the lines are connected as shown in the diagram, the radiation will be unidirectional in the direction A through B. Reversing one feed line at the transmitter will make the system unidirectional in the opposite direction. Although shown here applied to two lazy H antennas, the principle can be used with any systems fed by flat lines and spaced an odd multiple of a quarter wavelength.**

length of one of the feed lines. As can be seen, transposing one set of feeders at the transmitter end will reverse the phase difference and the direction of maximum radiation.

Length of Elements in Phased Arrays

Since it is important in phased arrays to have all of the dimensions exact (except in the collinear and W8JK types), care should be taken that these dimensions are calculated properly. Although nearby objects can load the elements and modify their electrical length, an antenna "in the clear" can be calculated with a good deal of accuracy. The "end effect" that modifies the length of radiators is, for the most part, caused by the dielectric of the insulator, and elements that are supported at a current loop will not show this effect to such a degree. However, most antenna elements are supported at a voltage loop and consequently suffer the end effect. Half-wave phasing sections have to be made somewhat shorter than a half-wavelength in air because of the dielectric of the spacers. Self-supporting elements work out to be about the same length as wire ones because, being self-supporting, they have a greater diameter and more capacity.

The length of the half-wave elements used in the antenna this chapter should be computed from

$$\textbf{Length (feet)} = \frac{468}{\textbf{Freq. (Mc.)}}$$

The length of a half-wave phasing section should be computed from

$$\textbf{Length (feet)} = \frac{480}{\textbf{Freq. (Mc.)}}$$

Phasing

It is desirable to be able to trace out the relative phase of the currents in a multi-element antenna, in order to understand how a system operates or to check on the possibilities of a newly devised system. Many diagrams of multi-element antennas show arrows indicating the relative direction of currents throughout the system, but this is sometimes confusing to one who isn't used to it.

A somewhat simpler method of checking the phasing in an antenna system, that can be applied to any type of antenna, is shown in Fig. 816. It consists of starting at a known high-voltage point on a wire, arbitrarily marking that point "plus" and then following along that wire and alternately marking each half-wave point "minus" and "plus." For example, in the "lazy H" shown in Fig. 816-A, the point *E* on wire No. 1 is selected for the starting point and the marks are made along that wire. Where the lower right-hand element attaches, at *L*, both wires (the element and the feed line) are traced out. Then, knowing that the two-wire line connected at *L* must have currents out-of-phase on it, a mark of opposite polarity (minus) is made on the other leg of the line where it joins the antenna at *L*. The rest of the antenna is then traced.

An examination of the marks now shows that this is a workable system: the currents are in the same direction in all wires, as indicated by the relative positions of the plus and minus signs, and the phasing section is properly connected, since the currents are in opposition along it.

Fig. 816-B shows the result if the phasing section is not reversed. Obviously the system will not work as a broadside array because the upper and lower collinear sections are not in phase.

As a further example, a Sterba array is shown in Fig. 816-C. Here we use a point such as *F* as a starting point, since we know that if the phasing sections are to operate as phasing sections with no radiation, the current in the two wires must be out-of-phase. Further, it shows why the end wires, at points *G*, can be closed without affecting the performance, since connecting the wires does not affect the rest of the system. We see that this system can be fed at the ends of the phasing sections (high-voltage points) or a quarter wavelength from one of these points (high-current points).

Fig. 816-D shows still another example, in this case a Bruce array. However, in this case it is a little clearer to draw in the arrows to represent the current.

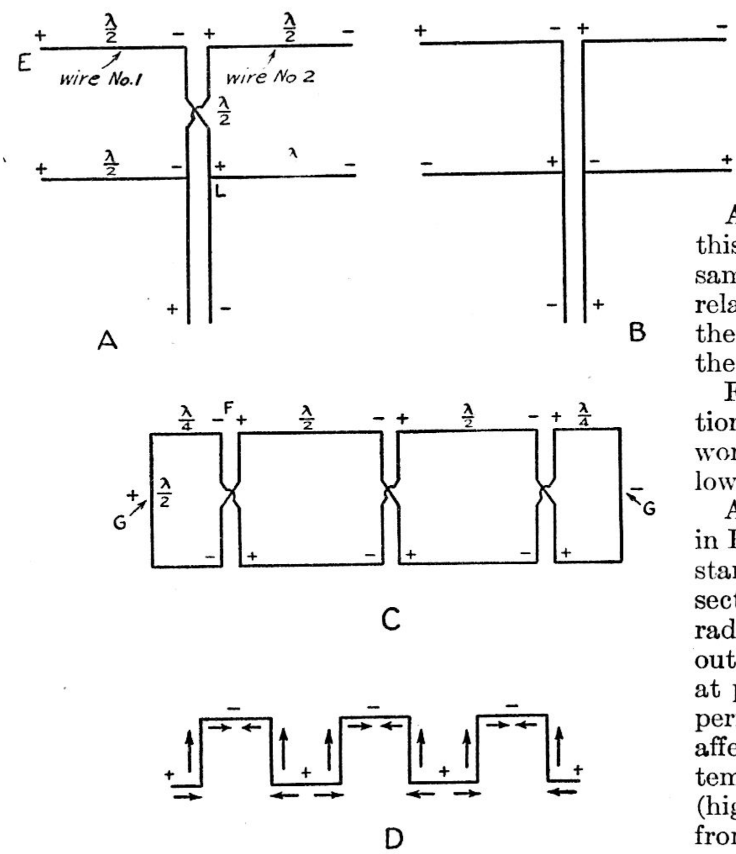
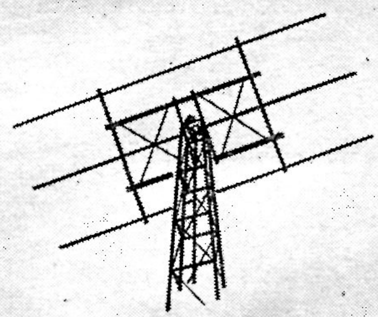


Fig. 816 — **Phasing can be traced out on any antenna system by starting at a voltage loop on the wire, arbitrarily marking that point "plus" and then marking the half-wave points alternately minus and plus. See text for further explanation.**



9. PARASITIC ARRAYS

REFLECTORS AND DIRECTORS — COMBINATION ARRAYS — FEED SYSTEMS — ADJUSTMENT

If a section of wire approximating a half wave in length is brought near a half-wave transmitting antenna, it will intercept some of the energy radiated by the antenna and will re-radiate it. The re-radiated energy will combine with that directly radiated by the antenna in such a way as to modify considerably the directional pattern of the antenna alone, depending upon the relative positions of the two wires, the magnitude of the currents flowing in them, and the relative phases of the currents. The "free" wire is said to be parasitically excited, and is called a parasitic element. Parasitic elements can be used to form, with a driven antenna, quite effective directive systems, and currently enjoy wide popularity because of their adaptability to rotatable installations.

It is characteristic of parasitic-element systems to show maximum radiation in one direction, as contrasted with the many wholly-driven systems which are bi-directional. This is a useful feature, especially for a rotatable system, because it helps reduce interference in receiving from directions other than that over which communication is being carried on, and also reduces the interference which the transmitter might otherwise cause in those same directions. The parasitic element, which is always parallel to the driven element (the driven element usually is called the "antenna," although the term really should be used to include the whole system), is called a *reflector* when it causes reinforcement of the radiation along the direction looking from the parasitic element to the antenna, and a *director* when maximum radiation is along a line looking from the antenna to the driven element. This is shown in Fig. 901.

The phase of the current in the parasitic element with respect to that in the antenna depends upon the spacing between the two elements and the tuning of the parasitic element. The tuning is usually adjusted by changing the length of the parasitic element, although regular tuning means may be employed instead. A reflector is usually tuned to a frequency somewhat lower than the operating frequency; that is, the reflector is slightly longer than the antenna. The converse is true of a director; it should be tuned to a frequency somewhat higher than the operating frequency, or its length should be slightly less than that of the antenna. It is possible, however, to tune either a reflector or director to the operating frequency directly, in which case it is called *self-resonant.* Whether the self-resonant parasitic element operates as a director or reflector is determined by the spacing between the antenna and the parasitic element.

Single Parasitic Elements ("Two-Element Beam")

The gain in field strength with a reflector or director as compared to the antenna alone will depend upon the spacing between the two ele-

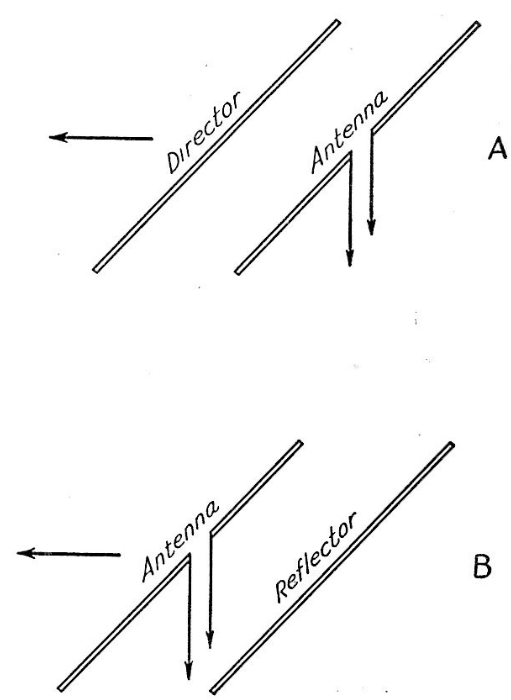


Fig. 901 — Antenna systems using a single parasitic element. In A the parasitic element acts as a director, in B as a reflector, the terms referring to the direction, with respect to the antenna, in which maximum radiation takes place.

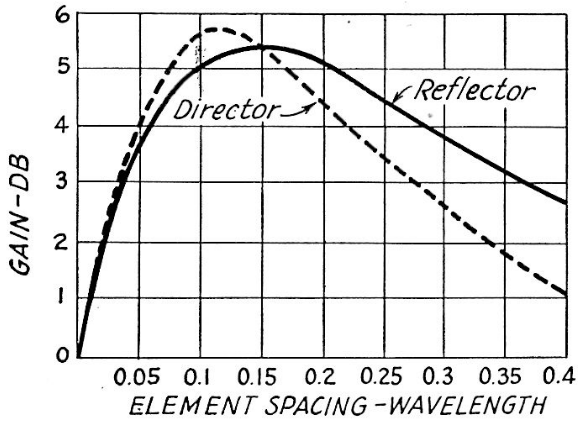


Fig. 902 — **The maximum possible gain obtainable with a parasitic element over a half-wave antenna alone. The parasitic element tuning is supposedly adjusted for greatest gain at each spacing. The effect of resistance loss in the elements is not included.**

ments and the tuning (or length) of the parasitic element. The maximum gain obtainable with a single parasitic element, as a function of the spacing, is shown in Fig. 902. The two curves show the greatest gain to be expected when the element is tuned for optimum performance either as a director or reflector. The shift from director to reflector, with the corresponding shift in direction as shown in Fig. 901, is accomplished simply by tuning the parasitic element — usually, in practice, by changing its length. In other words, the parasitic element may be either a director or reflector at any spacing.

With the parasitic element tuned to act as a director, maximum gain is secured when the spacing is approximately 0.1 wavelength. The peak is rather sharp, and the gain drops off rapidly at greater or smaller spacings. When the parasitic element is tuned to work as a reflector, the spacing which gives maximum gain is about 0.15 wavelength, with a fairly broad peak. The director will give slightly more gain than the reflector, but the difference is less than ½ db. and there is consequently little choice between the two types of operation on the basis of these theoretical curves. In practice, other considerations may influence the selection.

In only two cases are the gains shown in Fig. 902 secured when the parasitic element is self-resonant. These occur at 0.1- and 0.25-wavelength spacing, with the parasitic element acting as director and reflector, respectively. For reflector operation, it is necessary to tune the parasitic element to a lower frequency to secure maximum gain at all spacings less than 0.25 wavelength, while at greater spacings the reverse is true. The closer the spacing the greater the detuning required. On the other hand, the director must be detuned toward a higher frequency (that is, its length must be made less than the self-resonant length) at spacings greater than 0.1 wavelength in order to secure maximum gain. The amount of detuning necessary becomes greater as the spacing is increased. At less than 0.1 wavelength spacing the director must be tuned to a lower frequency to secure the maximum gains indicated by the curve.

Attenuation

Besides gain, another important consideration in the selection of the type of operation (director or reflector) for the parasitic element and its tuning is the amount by which the signal is reduced in the direction opposite to that in which maximum gain is secured. To get the best unidirectional effect it is obviously desirable to secure, along with high gain, maximum attenuation to the rear. In other words, the "front-to-back" ratio should be as high as possible.

Generally speaking, the conditions which give maximum gain forward do not give maximum signal reduction, or attenuation, to the rear. It is necessary to sacrifice some gain to get the highest front-to-back ratio. The reduction in backward response is brought about by adjustment of the tuning or length of the parasitic element. With a reflector, the length must be made slightly greater than that which gives maximum gain, at spacings up to 0.25 wavelength. The director must be shortened somewhat to achieve the same end, with spacings of 0.1 wavelength and more. The tuning condition, or length, which gives maximum attenuation to the rear is considerably more critical than that for maximum gain, so that a good front-to-back ratio can be secured without sacrificing more than a small part of the gain.

For the sake of good reception, general practice is to adjust for maximum front-to-back ratio rather than for maximum gain. Larger front-to-back ratios can be secured with the parasitic element operated as a director rather than as a reflector. With the optimum director spacing of 0.1 wavelength, the front-to-back ratio with the director tuning adjusted for maximum gain is

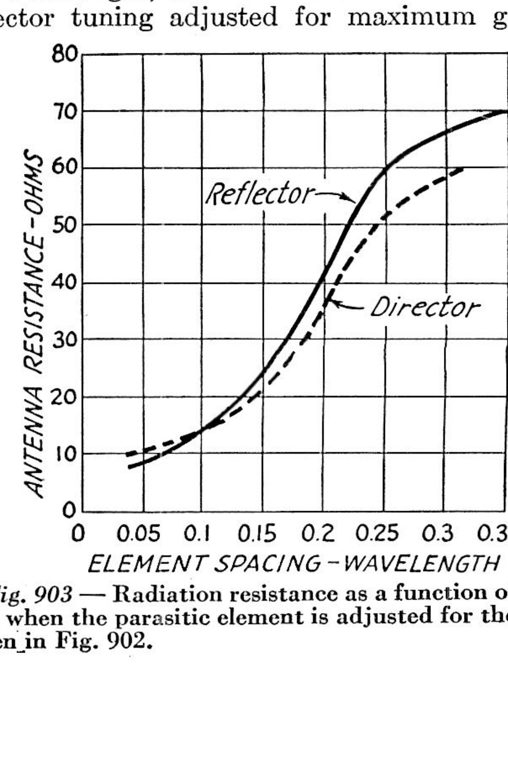


Fig. 903 — **Radiation resistance as a function of spacing, when the parasitic element is adjusted for the gains given in Fig. 902.**

only 5.5 db. (the back radiation is equal to that from the antenna alone). By proper director tuning, however, the ratio can be increased to 17 db.; the gain in the desired direction is in this case 4.5 db., or 1 db. less than the maximum obtainable.

Radiation Resistance

The radiation resistance as measured at the center of the antenna, or driven element, varies as shown in Fig. 903 for the spacings and tuning conditions which give the gains indicated by the curves of Fig. 902. These values, especially in the vicinity of 0.1-wavelength spacing, are quite low compared to the 73-ohm radiation resistance of the half-wave antenna alone. The reflector and director curves coincide at 0.1 wavelength, both showing a value of 14 ohms. At greater spacings the resistance increases, with the reflector showing somewhat higher values than the director.

The low radiation resistance at the spacings giving highest gain is important in three ways. First, the radiation efficiency goes down because, with a fixed loss resistance, more of the power supplied to the antenna is lost in heat and less is radiated, as the radiation resistance approaches the loss resistance in magnitude. Second, the selectivity of the antenna system becomes higher as the radiation resistance decreases. This means that optimum performance can be secured over only a narrow band of frequencies as compared with the frequency-performance characteristic of a higher-resistance antenna. Third, the number of suitable feeder systems becomes limited, and adjustment becomes more critical.

The loss resistance can be decreased by using low-resistance conductors for the antenna elements. This means, principally, large-diameter conductors, usually tubing of aluminum, copper,

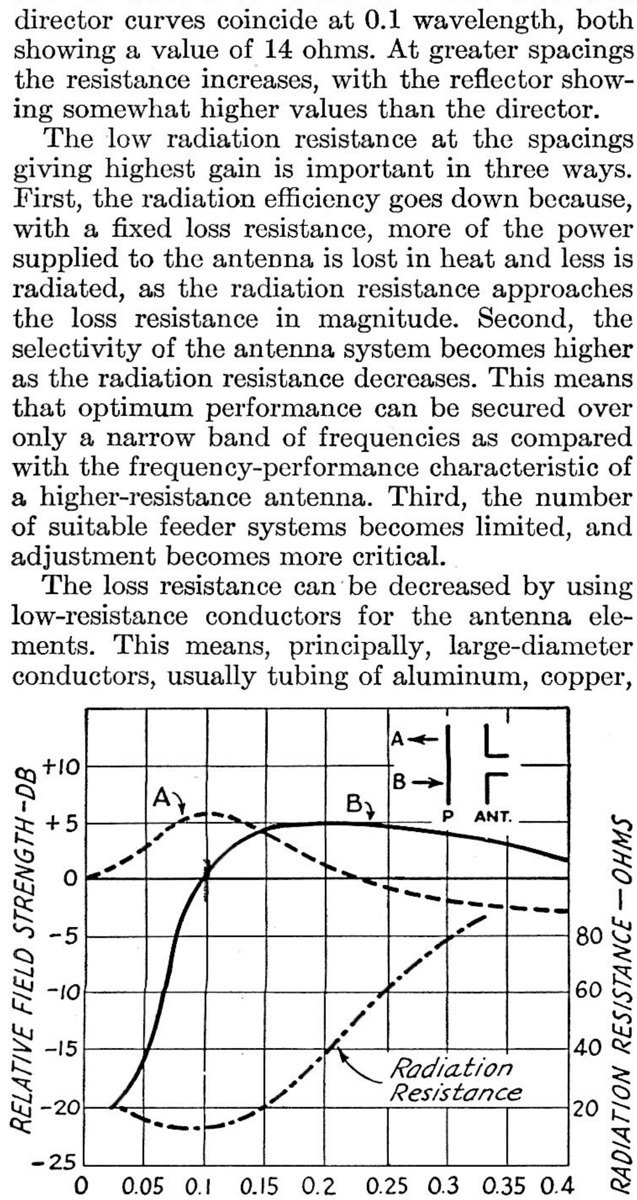


Fig. 904 — **The special case of a self-resonant parasitic element used in conjunction with a half-wave antenna. Zero db. is the field strength from a half-wave antenna alone. Greatest gain is in the direction A at spacings less than 0.14 wavelength; in direction B at greater spacings. Between 0.1 and 0.225 wavelength there is no attenuation in either direction.**

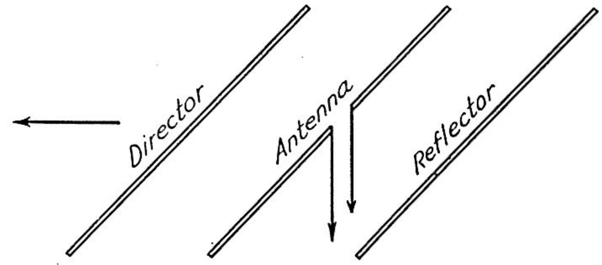


Fig. 905 — **Antenna system using two parasitic elements with a driven antenna, one as a reflector and one as a director.**

or copper-plated steel. Such conductors have mechanical advantages as well, in that it is relatively easy to provide adjustable sliding sections for changing length, while the fact that they can be largely self-supporting makes them well adapted for rotary antenna construction. With half-inch or larger tubing the loss resistance in any two-element antenna should be negligible.

With low radiation resistance the standing waves of both current and voltage on the antenna reach considerably higher maximum values than is the case with the antenna alone. For this reason losses in insulators at the ends of the elements become more serious. The use of tubing rather than wire helps reduce the end voltage, and furthermore the tubing does not require support at the ends, thus eliminating the insulators and one source of power loss.

Self-Resonant Parasitic Elements

The special case of the self-resonant parasitic element is of interest, since it gives a good idea of the performance as a whole of two-element systems, even though the results can be modified by detuning the parasitic element. Fig. 904 shows gain and radiation resistance as a function of the element spacing for this case. Relative field strength in the direction A of the small drawing is indicated by curve A; similarly for curve B. The front-to-back ratio at any spacing is the difference in the values at that spacing for curves A and B. Whether the parasitic element is functioning principally as a director or reflector is determined by whether curve A or curve B is on top; it can be seen that the principal function shifts at about 0.14 wavelength spacing. That is, at closer spacings the parasitic element is principally a director, while at greater spacings it is chiefly a reflector. At 0.14 wavelength the radiation is the same in both directions; in other words, the antenna is bi-directional with a gain of about 4 db.

The front-to-back ratios that can be secured with the parasitic element self-resonant are not very great except in the case of extremely close spacings. Spacings of the order of 0.025 wavelength are hardly practicable with outdoor construction, however, since it would be difficult, if not impossible, to make the elements sufficiently stable, mechanically. Better practice is to use spacings of at least 0.1 wavelength and detune the parasitic element for greatest attenuation in the backward direction.

The radiation resistance increases rapidly for spacings greater than 0.15 wavelength, while the gain, with the parasitic element acting as a reflector, decreases quite slowly. If front-to-back ratio is not an important consideration, a spacing as great as 0.25 wavelength can be used without much reduction in gain, while the radiation resistance approaches that of a half-wave antenna alone. Spacings of this order are particularly suited to antennas using wire elements, such as multi-element arrays consisting of combinations of collinear and broadside elements.

Two Parasitic Elements ("Three-Element Beam")

It is possible to use two parasitic elements in conjunction with a driven antenna to give a further increase in directivity and gain. In such a case it is best practice to use one parasitic element as a reflector and the other as a director, all three being in the same plane, as shown in Fig. 905. Experimental work indicates that the optimum spacings are the same as those for single elements; that is, director spacing of 0.1 wavelength and reflector spacing of 0.15 wavelength give maximum gain. Also, the previous remarks about tuning for gain and maximum front-to-back ratio continue to hold good. In some cases the reflector is spaced 0.1 wavelength rather than 0.15 from the antenna in order to secure mechanical symmetry; this reduces the possible gain somewhat, as is evident from Fig. 902, but the difference is small.

Loss resistance becomes more important when two parasitic elements are used because the radiation resistance as measured at the center of the driven antenna drops to a low value with close spacings. With the director spaced 0.1 wavelength, and the reflector 0.1 to 0.15 wavelength, radiation resistances of the order of 8 to 10 ohms are encountered. Good-sized tubing of good conductivity must be used for the elements if the gain possibilities of the system are to be realized. Further, the system becomes even more selective to frequency than the two-element antenna, so that peak performance can only be secured over a still smaller range of frequencies.

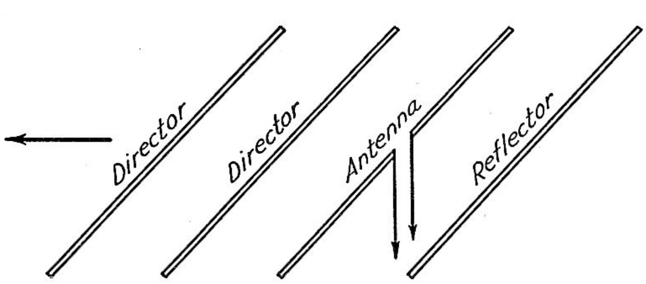


Fig. 906 — A "four-element" antenna system, using two directors and one reflector in conjunction with a driven antenna.

Three Parasitic Elements ("Four-Element Beam")

Additional parasitic elements may be added to any reasonable extent desired, and in an early form of this type of antenna (Yagi) several directors were used ahead of the driven element, with one reflector behind. With close spacing, two directors in addition to a single reflector represents about the practical limit insofar as usefulness is concerned, since the continually decreasing radiation resistance is being met by a rising loss resistance because of the greater number of elements. For the purpose of the rotatable antenna four elements represent a practical limit, in mechanical construction as well as in performance.

The four-element arrangement is shown in Fig. 906. Again the spacing and tuning considerations for single parasitic elements apply. Directors are spaced at intervals of 0.1 wavelength, while the reflector may be either 0.1 or 0.15 wavelength away from the driven element. The radiation resistance is 5 to 6 ohms, so that resistance losses in the system must be reduced as much as possible if appreciable improvement in gain over a 3-element array is to be secured. Large-diameter tubing should be used, and it should be mounted rigidly to ensure electrical stability.

The low radiation resistance gives a four-element system quite high selectivity, so that optimum performance can be secured over but a relatively small band of frequencies on either side of that for which the system is aligned.

Gain and Front-to-Back Ratio

The gain of arrays using parasitic elements is not readily calculated, nor is it easy to measure under conditions which hold in actual operation. It is impracticable to measure field strengths at the vertical angles useful for communication, while horizontal measurements do not necessarily give a true picture of the antenna's performance, particularly with respect to front-to-back ratios. There is no question, however, about the effectiveness of the systems.

On the basis of ground measurements and actual experience, average gains and front-to-back ratios realizable under normal conditions in practice are about as follows:

No. of Elements	*Gain over Half Wave*	*Front-to-Back Ratio*
2	4 to 5 db.	10 to 15 db.
3	6 to 7 db.	15 to 25 db.
4	7 to 9 db.	20 to 30 db.

A great deal depends upon the care with which the system is adjusted. Maximum front-to-back ratios, in particular, are obtained only at the frequency for which the system is tuned.

Methods of Feed

In antenna systems using close-spaced parasitic elements the low radiation resistance makes feeding the antenna a special problem. When the radiation resistance is below 30 ohms, an ordinary resonant line of the open-wire type should not be used if its length is more than a half wavelength, since the losses resulting from the drastic mismatch will reduce the overall gain of the system. Therefore some means should be used to provide at least an approximate match between the antenna and the line. The methods shown in Fig. 907 are most appropriate. Although in each case a 600-ohm line is indicated, other types may be substituted in A, B and C by suitable changes in the tap positions in A and B, or by choice of proper impedance in the quarter-wave matching section in C. For lines of appreciable length, however, the open-wire type is recommended because its losses are the lowest of any of those commonly used by amateurs. It does not pay to spend good money on a rotary antenna only to throw away the gain in the transmission line.

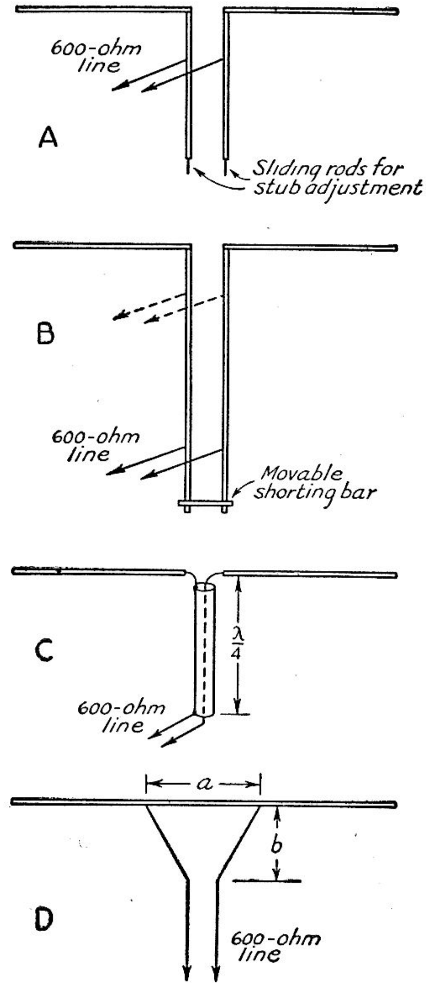


Fig. 907 — Recommended methods of feeding the driven antenna element in close-spaced parasitic arrays. The parasitic elements are not shown. A and B, open and closed stub matching transformers; C, quarter-wave matching section ("Q"); D, delta matching transformer.

The matching stub arrangements in A and B are of the type already described in Chapter 4 and are similarly adjusted. Because of the low terminating impedance it is desirable to use a fairly low-impedance stub, since the adjustment will be less critical. No special impedance value is necessary; simply construct the stub of tubing and use close spacing. Provision should be made for keeping the stub conductors rigidly spaced with respect to each other. The matching section of the familiar "Q" antenna makes a good stub for this purpose. The half-wave stub at B is somewhat more convenient to adjust than the open-ended arrangement at A, provided its length can be accommodated. See Chapter 4 for the adjustment procedure.

In C, a concentric line is used to bring about a match between the antenna and transmission line. The impedance of any practicable open two-conductor quarter-wave section is too high to be suitable for the purpose, hence the necessity for the concentric line. The matching section impedance is given by the equation

$$Z_0 = \sqrt{Z_1 Z_2}$$

where Z_0 is the required surge impedance of the matching section, Z_1 the antenna impedance and Z_2 the impedance of the transmission line. Assuming a 600-ohm transmission line, the required matching-section impedance varies from 95 ohms for a 15-ohm antenna to 55 ohms for a 5-ohm antenna. The ordinary 70-ohm line strikes a happy medium between these two values; it will give an exact match at about 8.5 ohms and the mismatch is less than 2:1 even at the extremes of 5 and 15 ohms. With this order of mismatch the line losses will not measurably increase over the perfectly-matched condition, even though the line is quite long. For all practical purposes, therefore, a 600-ohm line can be matched to any type of parasitic array — two, three or four elements — simply by connecting it to the center of the antenna through a quarter-wave section of 70-ohm line.

In the interests of minimum loss and to get a known impedance value, the air-insulated type of line is to be preferred. The length of the antenna and the length of the line should be independently adjusted to resonance, if possible, although the formulas given in Chapters 4 and 5 may be used without consequential error. The antenna may be resonated by one of the methods described in Chapter 5, and the line by the method given in Chapter 11.

Rubber-insulated twisted-pair or concentric lines also may be used for the purpose. The standing wave ratio on the matching section is quite high, so the losses will be higher than normal for this type of line, but since only a short length is required the actual loss is not high enough to be serious. The line length in this case will be considerably less than a quarter-wave-length in space; the approximate length can be found by reference to Chapter 4, but the line had best be adjusted to a quarter wavelength at the operating frequency before installation, using the oscillator method described in Chapter 11. The flexibility of the rubber insulated line may give it preference in some installations. Whatever the type of line used, it need not run in a straight line but can be coiled up or bent in any convenient fashion.

The delta matching section shown at Fig.

907-D is quite suitable for open wire lines. It has the advantage that cutting the antenna element in two to insert the line is not necessary. The sides of the delta should be kept as rigid as possible to avoid detuning in a wind. The dimensions *a* and *b* should be determined experimentally, since they will depend considerably upon the number of elements in the antenna, the spacing between them, their tuning conditions, and the size of the conductors used. Dimension *b* should be about 15 per cent greater than *a*, both being varied simultaneously, while a check is maintained on the standing-wave ratio on the line (see Chapter 4), until standing waves are minimized. It is not necessary to strive for a perfectly "flat" line, since the losses will not increase perceptibly with standing wave ratios of 3 or 4 to 1 on a 600-ohm line.

Frequency Characteristics

The selectivity of the various antenna systems becomes, as already mentioned, increasingly higher as the number of elements is increased. The system therefore should be adjusted for optimum performance on the frequency which is going to be used most. Changing the operating frequency is equivalent to shifting the tuning of the parasitic elements, and it is readily possible for an element to act as a director at one end of the band and a reflector at the other, when it has been cut to operate as one of the two at the center of the band.

Since the element length is not highly critical for good gain, but is highly so for attenuation to the rear, the chief effect of operating the antenna "off-frequency" is to reduce the front-to-back ratio without greatly affecting the forward gain. In some cases the gain may actually increase, at a frequency slightly different from that for which the system was adjusted, when the initial adjustment was made to secure maximum front-to-back ratio. For transmitting, therefore, the ordinary antenna will work quite satisfactorily over a band. It will also give good gain over the same band for receiving, but only near the right frequency will it give the attenuation to the rear for which it was designed.

There will usually be no trouble in getting the antenna to accept power when the frequency is shifted. A change in frequency usually brings with it a change in radiation resistance, but this is readily compensated for by adjustment of the coupling at the transmitter. The relatively small mismatch at the antenna will not materially increase the losses in an open-wire line.

Height Above Ground

Reflection from the ground takes place in the same way with parasitic element arrays as with any other type of antenna. The reflection factors shown in Chapter 3 apply with equal force, therefore. It is obviously desirable to choose a height which will aid in producing maximum radiation at the angles most useful for the type of communication to be carried on. Since this subject has already been covered in earlier chapters it need not be discussed further here.

Height above ground also plays an important part in determining the radiation resistance of the array, especially when the elements are horizontal. The radiation resistance figures so far discussed in this chapter are the free-space values, and they will be modified in much the same way as the radiation resistance of a horizontal half-wave antenna is modified in the presence of the ground. Since it is advantageous to keep the radiation resistance from dropping to too-low values, heights which cause a reduction in resistance should be avoided. Thus a height of the order of 0.6 wavelength (Fig. 322) is likely to give poorer performance than 0.5 wavelength, contrary to the customary impression that every bit of height gained is reflected in better performance. Since the effective ground plane usually is below the surface, the height cannot be determined very accurately without some type of measurement. One rather simple method is to "explore" with a horizontal half-wave antenna whose height can be readily adjusted. With an r.f. meter in its center, and keeping constant input to the transmitter, the height should be changed in small steps while readings are taken of the antenna current. A height which gives maximum antenna current of course represents a height at which the radiation resistance is low, and vice versa.

Adjusting Arrays

For proper adjustment of a parasitic array some means must be available for measuring field strength at a reasonable distance from the antenna. To obtain significant results, the measuring equipment should be set up at least several wave-lengths from the antenna. A receiver with an S-meter makes a satisfactory measuring set for comparative purposes. The coöperation of a local amateur can be secured for the tests; a receiving point a distance of even a mile or two from the transmitter will not be too far away providing there is a fairly clear path between the two locations.

The first step is to set up the antenna and couple it to the transmitter. The length of the parasitic element or elements should be set for self-resonance (the regular half-wave formula for length will be close enough). The line *should then* be matched to the antenna as closely as possible by whichever method is chosen, this adjustment being made with the parasitic elements in place at the spacings to be used.

With the preliminary work finished, the antenna should be directed so that the receiving point is directly to the rear. A field strength reading (S-meter reading) should be taken, then the director length should be decreased, readings being taken at each step, until the field strength at the measuring point is minimum. If there are two directors, the one nearest the antenna should be adjusted first, followed by a similar adjustment to the one farthest away. With the directors finished, the reflector should be lengthened to the point which gives a further reduction in field strength. It may be necessary to change the gain of the receiver occasionally to keep the reading at a suitable point on the meter scale; this change should preferably be made when the adjustment of one element is completed and before the next one is touched. Maximum backward attenuation should be secured with the director about 4 per cent shorter than a half-wave antenna and with the reflector about 5 per cent longer. That is, for the director

$$\textbf{Length, feet} = \frac{450}{f\ (\text{Mc.})}$$

and for the reflector

$$\textbf{Length, feet} = \frac{492}{f\ (\text{Mc.})}$$

These figures are approximate only, and the exact length can be found only by careful adjustment while measuring the signal strength. The antenna element length is not critical except insofar as it may affect the match to the transmission line. The regular half-wave formula is sufficiently accurate.

After the elements have all been adjusted as described it is advisable to make slight readjustments to each parasitic element again, in the same order as before, to compensate for interaction between elements when the tuning of one is changed. Going through the process a few times should bring out the best set of tuning conditions. Finally, the line may be rechecked for standing waves and, if necessary, rematched. The radiation resistance of the array will change as the elements are adjusted, but the shift will not be great enough to affect the line losses sufficiently to change the results.

The receiving antenna should have the same polarization as the transmitting antenna, and preferably should be far enough away from other antennas to be free from stray pickup. It should be connected to the receiver through a line, such as twisted pair, which will in itself have the least possible signal pickup. Likewise, the line between the transmitter and transmitting antenna should be checked for current balance. Radiation from the transmission line readily can confuse readings designed to bring out the set of adjustments which gives the minimum backward signal. This, and the possibility of direct pickup of signal by radiation from the transmitter itself, are additional reasons why the measuring point should be considerably removed from the transmitting point.

If the receiver S-meter is calibrated in db. the front-to-back ratio can be determined by swinging the antenna around to face the receiving point, keeping the receiver gain fixed. Since most receiver calibrations are approximate, too great reliance should not be placed on the reading so obtained, but it will at least indicate the order of front-to-back ratio secured.

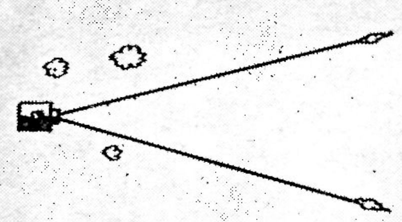
Gain measurements can be made only by comparing the field strength from the array with that from a half-wave antenna at the same height and position and fed the same amount of power. This is inconvenient, in most cases, since it involves taking down one antenna and putting up the other. The ordinary receiver is not capable of accurate enough measurement, and since day to day measurements with simple equipment of this type have been found to show variations of the same order as the gain to be expected, it is unsafe to compare a reading obtained on one occasion with another that may have been taken several days previously.

If the antenna is not rotatable, it will be necessary to install the receiver at some point directly behind the antenna. Alternatively, a portable transmitter may be similarly located and the array adjusted to give minimum response to its signal.

Multi-Element Arrays

Parasitic reflectors or directors may be used with any of the broadside or collinear arrays described in Chapter 8. The close spacing which gives greatest gains is not very suitable for this type of antenna, however, because it is practically impossible to get enough mechanical rigidity in wire elements to prevent bad detuning in a breeze.

It is more practical to use only one set of parasitic elements, one behind each driven element in the array, tuned to work as a reflector. Quarter-wave spacing between driven and parasitic elements is satisfactory mechanically, and does not involve much loss of gain. With proper tuning, — that is, with the reflector slightly longer than the condition which gives self-resonance — a theoretical gain of about 4 db. and a front-to-back ratio of about 10 db. can be secured. The correct length can be determined by measurement as described previously, using one pair of elements for the purpose. Then all the parasitic elements can be made the same length.



10. "V" ANTENNAS

SIMPLE AND COMBINATION FORMS OF LONG-WIRE DIRECTIVE SYSTEMS

As pointed out in Chapter 6, the lobe of maximum radiation from a single long wire makes a more acute angle with the wire, and the power in the lobe becomes greater, as the length of the wire (in wavelengths) is increased. There are several ways in which long harmonic wires can be combined to add the effects of the single wires and give greater gain.

The Echelon Antenna

If two long wires are made parallel to each other and excited out-of-phase, the radiation will cancel in the direction perpendicular to the plane of the wires. The radiation is then maximum in the plane of the wire and at angles equal to those of the lobes for a single wire of equal length. If the two wires are staggered, two of the four lobes will disappear, providing the stagger and spacing of the wires is correct for their length. This form of antenna is shown in Fig. 1001 and is called the "echelon" antenna. It is normally used with the wires in the horizontal plane, but it can be used with the wires in a vertical plane. However, when the wires are used in the vertical plane, they must be slanted to make the lobe come down to a reasonable angle with the horizontal and this necessitates supports that are too high for all practical purposes. The horizontal echelon antenna should be at least a wavelength above ground for best results.

The amount of stagger can be calculated from

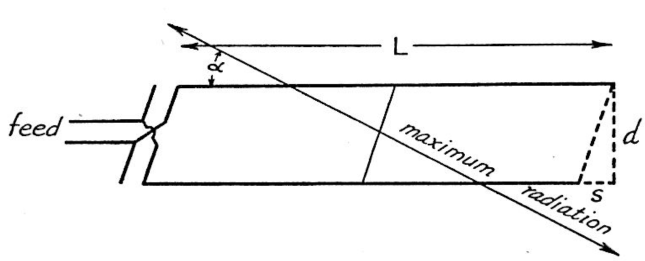


Fig. 1001 — The "echelon" antenna uses two long parallel wires excited out-of-phase. In its simplest form it is a bidirectional affair, although it can be made unidirectional by the addition of two more elements. See text for dimensions "s" and "d." The angle is the angle of the major lobe for the length L, and can be obtained from Fig. 609.

$$s \text{ (feet)} = \frac{492 \sin \alpha}{f \text{ (Mc.)} \sin 2\alpha}$$

and the distance between wires is given by

$$d \text{ (feet)} = \frac{492 \cos \alpha}{f \text{ (Mc.)} \sin 2\alpha}$$

where α = angle of maximum radiation from a single wire (obtained from Fig. 609).

As an example, an echelon antenna with 3-wavelength legs would be spaced a half wavelength and staggered 0.29 wavelength.

The echelon antenna can be made uni-directional by introducing another pair of wires at quarter-wave space and 90 degrees phase relation with the first pair, but this is a refinement used only in commercial installations.

The two wires of the echelon should be fed as shown in Fig. 1001 so that radiation from the feeders will be minimized and not tend to cancel the directivity.

The principal objection to the echelon antenna is the fact that the gain only becomes significant when wires of at least three wavelengths are used and when the height can be made at least a wavelength. These figures are not hard to attain at 28 Mc. and higher, however.

The "V" Antenna

Two wires combined to form a "V" at such an angle that the main lobes reinforce along the line bisecting the V make a very effective directional antenna. If the two sides of the V are excited 180 degrees out-of-phase, by connecting the two-wire feed line to the apex of the V, the lobes add up along the line of the bisector and tend to cancel in other directions, as shown in Fig. 1002. The V antenna is essentially a bi-directional system, and the gain depends upon the length (in wavelengths) of the wires. The V is a simple antenna to build and operate, providing the necessary room is available, and with tuned feeders it can be operated satisfactorily on several bands, although it is of course optimum for only one. Nevertheless, it will show considerable gain on several bands, the gain increasing as the frequency increases. The

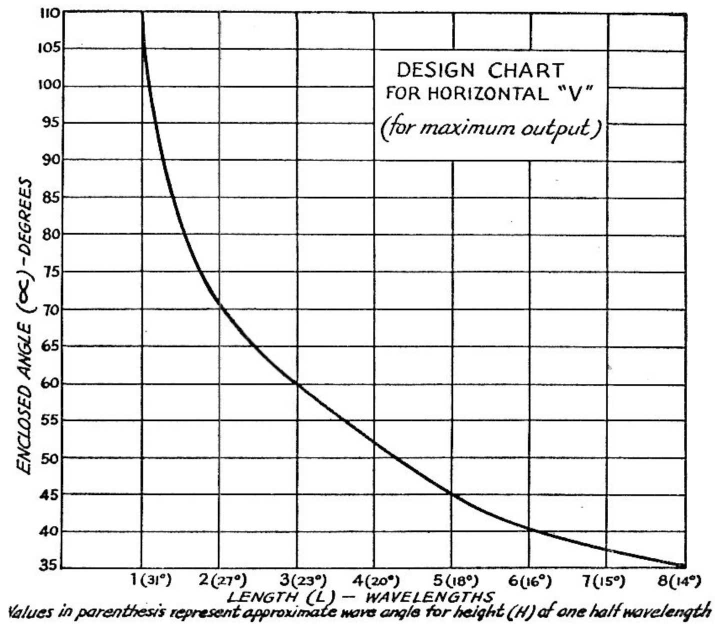


Fig. 1003 — Design chart for horizontal "V" antennas. The enclosed angle between sides is shown plotted against the length of the legs in wavelengths. The actual length of the legs in feet can be found from the table in Chapter 6.

longer the V the less will be the departure from optimum angle on several bands.

The chart in Fig. 1003 gives the dimensions that should be followed for an optimum design to obtain maximum power gain from a V beam. The wave angle referred to is the vertical angle of maximum radiation for a height of ½ wavelength, and this angle becomes less for any given length as the height above ground is increased. Tilting the whole horizontal plane of the V will tend to increase the low-angle radiation off the low end and decrease it off the high end. If the ground slopes, the antenna should be made parallel to the ground and preferably with the open end of the V down the slope.

The gain of the V beam can be increased by stacking two beams one above the other, a half-wavelength apart, and feeding them so that the legs on one side are in phase with each other and out-of-phase with the legs on the other side. This will result in a greatly lowered angle of radiation. The bottom V should be at least a quarter-wavelength above the ground and preferably a half-wavelength.

Two V beams can be broadsided to form a "W" and give greater gain. However, two feed lines are required and this fact, plus the five poles required to support the system, renders it normally impractical for the amateur. It is used by many commercial short-wave stations.

The V beam can be made unidirectional by using a reflector at least a quarter wavelength in back of the antenna. A better plan is to use another V placed an odd quarter-wavelength in back of the first and to excite the two with a phase difference of 90 degrees. The system will be unidirectional in the direction of the antenna with the lagging current for quarter-wave separation. However, the parasitic or driven reflector is not normally employed by amateurs because it restricts the use to one band, although it has proved to be quite effective in commercial work.

The V can be made unidirectional and aperiodic by terminating the open ends of the V to ground through resistors. These resistors must dissipate almost half the power fed to the antenna and the ground connection must be an excellent one. Because of the practical difficulties involved, terminated V's are not often used, although they present excellent possibilities.

Feeding the V

The V beam is most conveniently fed by tuned feeders, since they permit multi-band operation.

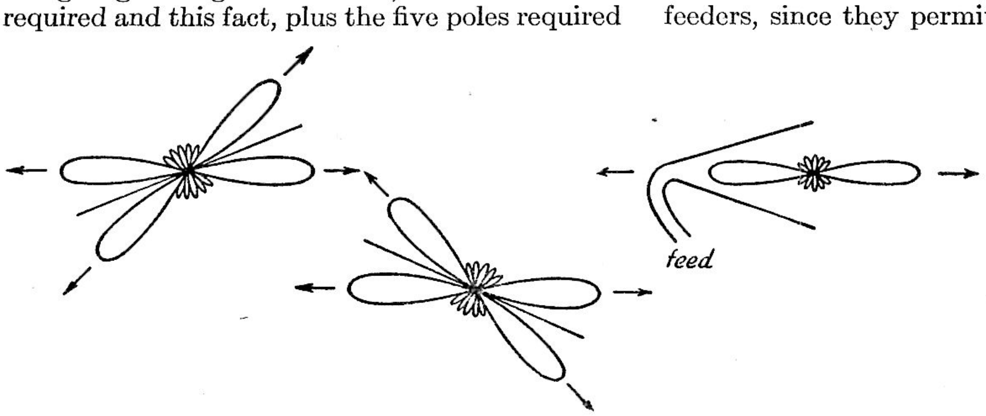


Fig. 1002 — Two long wires and their respective patterns are shown at the left. If these two wires are combined to form a "V" whose angle is twice that of the major lobes of the wires, and the wires are excited out-of-phase, the radiation along the bisector of the V adds and the radiation in the other directions tends to cancel.

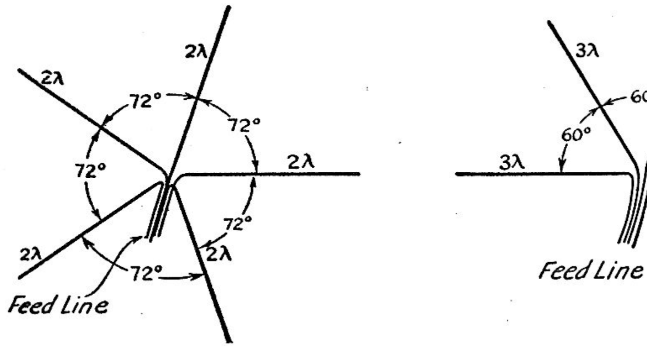


Fig. 1004 — Two suggestions for V-beam combinations. The two-wavelength affair at the left gives good general coverage, because it gives a choice of five directions. The system at the right gives more gain but a choice of only three directions. (Since the systems are bidirectional, "direction" means along a bidirectional line.) Other combinations could be: seven 4-wavelength elements arranged radially at 51½ degrees; five 5-wavelength elements arranged half-radially at 45 degrees; nine 6-wavelength elements arranged radially at 40 degrees.

If an untuned line is used, the quarter-wave matching section is as convenient as any, since it allows the entire system to be tuned before attaching the feeders, by simply adjusting the shorting bar on the matching section. The length of the wires in a V beam is not at all critical, but it is important that both wires be of the same electrical length. Balanced feeder currents (in a tuned line) give sufficient indication of balanced lengths in the antenna proper.

The terminated V is fed by a 600-ohm line, and a good match will be obtained with almost any combination. The terminating resistors should be adjusted for minimum standing waves on the feeders and the performance should be checked on several frequencies throughout a band.

V-Beam Combinations

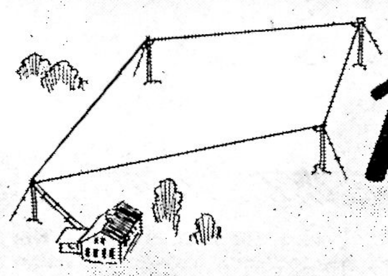
The V beam lends itself admirably to a general-coverage system by arranging several V beams radially and selecting the one in the desired direction by switching to the proper feeder combination. Antennas of this type have been used at several outstanding DX stations with excellent results. Fig. 1004 shows the general principle and gives the length and angle combinations that can be used.

The proper pair of wires can be selected by running all of the feeder wires into the shack (the feeder spacers will be hoops instead of bars) or the antennas can be switched at the pole by means of a remote relay. Fig. 1619 shows one practical scheme for supporting the multi-wire line from a V-beam combination. Other methods can be devised to fit different conditions.

In any V-beam combination, it is important that the flat-top lengths be so adjusted that going from one combination to the next will not affect the tuning at the transmitter end. This can be readily done by progressively pruning the antennas at the far ends until they all match up. Care must be taken, of course, that the wire in each feeder is exactly the same length if they are all brought into the station.

Obtuse-Angle Vs

It might be considered that an obtuse-angle V could be used, since if it were fed at one end and properly proportioned the lobes should reinforce along the perpendicular to the bisector. However, for the same amount of wire, the obtuse-angle V is definitely inferior to the acute-angle V. Two obtuse-angle Vs, side by side to form a diamond, are something else again, and require a chapter by themselves.



11. RHOMBIC ANTENNAS

TILTED-WIRE ANTENNAS — RHOMBIC DESIGN AND ADJUSTMENT — FREED METHODS — INSTALLATION

The family of antennas of which the rhombic, or diamond, antenna represents the highest development — and, in fact, the most practicable form — differs somewhat in principle from the antenna types already described. Previously discussed antennas operate with standing waves of current and voltage along the wires; in this chapter we are principally concerned with antenna systems in which the current is practically uniform in all parts of the antenna.

In its elementary form, such an antenna would consist of a single wire grounded at the far end through a resistor having a value equal to the characteristic impedance of the antenna, as shown in Fig. 1101. This termination, just as in the case of an ordinary transmission line, eliminates standing waves. The current therefore decreases uniformly along the wire as the terminated end is approached, the decrease being caused by loss of energy by radiation and by resistance loss in the wire. The energy remaining when the end of the antenna is reached is dissipated in the terminating resistor. For such an antenna to be a good radiator, its length must be fairly long, in terms of wavelength, because the current is relatively small. Hence greater wire length is necessary to radiate the same energy as that from a shorter antenna with the higher current which results with standing waves. Also, the wire must not be too close to ground so that the return path through the ground will cause cancellation of the radiation. If the wire is sufficiently long it will be practically non-resonant over a wide range of operating frequencies.

The directional characteristic of a non-resonant long-wire antenna differs from that of a resonant long wire of the same length in an important respect. The terminated wire is practically unidirectional, giving greatest response to incoming signals which arrive from the general direction in which the wire points, looking along the antenna toward the terminated end. The directional characteristic varies with the length of the wire, in a fashion somewhat similar to the shift in directional characteristic of resonant long-wire antennas, as shown in Fig. 1102, but in every case the radiation or response is considerably smaller in the backward direction than in the forward.

The free-space pattern of a non-resonant long wire antenna would have the usual solid form discussed earlier in this booklet, the drawings of Fig. 1102 representing cross-sections in planes containing the wire. The angle which the main lobe makes with the wire depends upon the antenna length, but because of the different type of current distribution these angles are not the same for resonant and non-resonant antennas of the same length. The difference is most marked for short wires (the main lobe makes an angle of about 45 degrees with the non-resonant antenna, and 54 degrees with the resonant antenna, when both are one wavelength long) but for lengths of two wavelengths and more the differences are so small as to be negligible. The energy which, in the case of a resonant wire, would be radiated in the backward direction, is absorbed by the terminating resistor in the case of the non-resonant antenna.

The elementary non-resonant antenna is not an especially good radiator in the single-wire form just described, but the general principle is utilized in the construction of highly-effective unidirectional antenna systems.

Tilted-Wire Antennas

The type of antenna shown in Fig. 1103 is the forerunner of the diamond or rhombic type, and is of interest for that reason, although now seldom used. The principle of operation resembles the combining of major lobes of radiation already described in Chapter 10, although in a somewhat

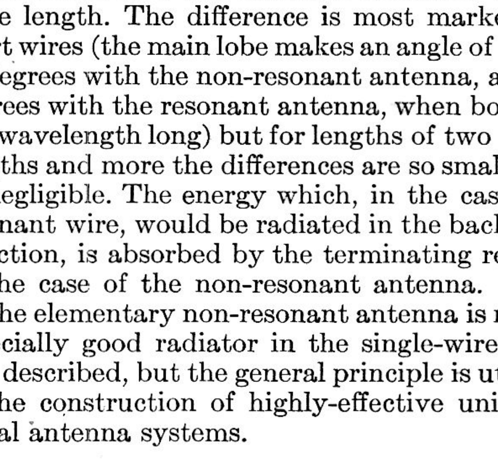


Fig. 1101 — **The terminated long-wire antenna which is the basis of non-resonant antenna design. The current falls off slowly from the transmitter end to the terminating resistor, but there are no standing waves.**

different fashion. For example, suppose that each of the sides, or legs, of the V is two wavelengths long, so that the major lobe of *each* wire makes an angle of 36 degrees with the wire. Then the tilt angle ϕ (half the total angle included between the wires) may be adjusted so that the major lobes of radiation from the two wires will add in the desired direction. The tilt angle then becomes the complement of the angle which the main lobe makes with each wire. This is shown in Fig. 1103, for horizontal transmission to the right in the figure. In directions other than to the right in the plane containing the antenna the radiation from the individual wires will tend to cancel more or less completely.

When the lobes of the two wires are aligned in this way, the currents induced in the antenna by a wave coming from the desired direction do not add exactly in phase at the receiver end. For this condition to be met a somewhat smaller tilt angle is required. This tilt angle, ϕ, is made such that the projection of one leg on a line joining the two ends of the antenna (in the figure, the ground forms such a line) is exactly one-half wavelength less than the length of the leg. The difference between the tilt angle for coincidence of the major lobes and that for optimum phasing is greatest with the shorter leg lengths; for example, with a leg one wavelength long, ϕ is about 45 degrees for alignment of the lobes, but 30 degrees for optimum phasing. With lengths greater than two wavelengths the difference is of the order of but a few degrees. In general, the optimum angle for best all-around performance lies between the two.

The terminating resistor at the far end absorbs the back radiation, just as in the case of the elementary form of terminated antenna, so that the antenna is essentially unidirectional.

The form of tilted wire antenna shown in Fig. 1103 is simple in construction, since only one pole is required. However, for all but quite high fre-

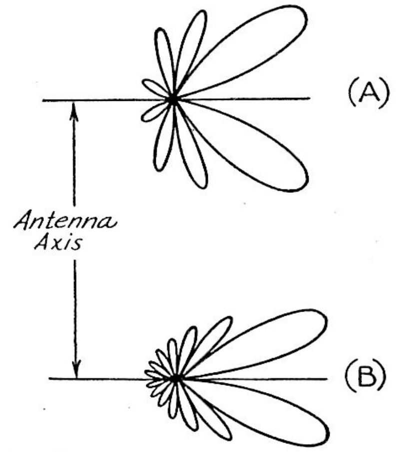


Fig. 1102 — **Typical radiation patterns (cross-section of solid figure) for terminated long wires. (A) length two wavelengths; (B) four wavelengths; both for an idealized case in which there is no decrease of current along the wire. In practice, the pattern is somewhat distorted by wire attenuation.**

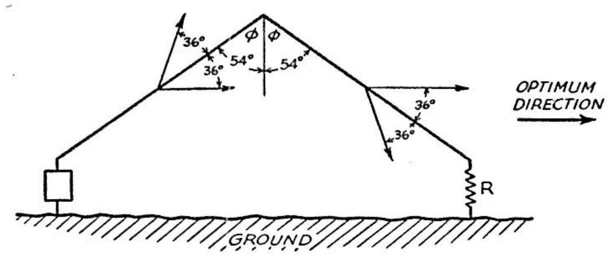


Fig. 1103 — **The tilted wire antenna, showing the directions of the main lobes for each wire for legs two wavelengths long, when the tilt angle ϕ is adjusted for alignment of the lobes.**

quencies — 28 Mc. and higher — the pole height needed to provide the proper tilt angle for a leg length great enough to provide appreciable gain is beyond the facilities available to most amateurs. Also, it is difficult to secure a satisfactory termination because of variation in ground resistance with weather conditions. This might be overcome by the use of a large ground screen under the antenna and extending a half wavelength or so beyond the wire in all directions, but the installation of such a screen probably would be impracticable in most locations. A form of transmission-line termination also may be used, with the far end of the antenna connected to the center of a half-wave wire running parallel to the ground and perpendicular to the line of the antenna. The impedance at the center of such a wire will be low, and currents induced by the incoming waves from the desired direction will balance out. However, such a termination is good only for the frequency for which the wire is cut, so that a wide frequency range is not possible. These difficulties are overcome by the use of the diamond-shaped, or rhombic, antenna.

The Rhombic Antenna

The rhombic antenna, shown schematically in Fig. 1104, consists of two tilted-wire antennas of the type shown in Fig. 1103 placed side by side. The terminating resistor is connected between the far ends of the two sides, and is made approximately equal to the characteristic impedance of the antenna as a unit. The rhombic may be constructed either horizontally or vertically, but practically always is made horizontal, since the pole height required is considerably less. Also, horizontal polarization is equally, if not more, satisfactory at the frequencies for which this antenna is suited.

The rhombic antenna is probably the *ideal* arrangement for the amateur who wants to obtain maximum gain in a given direction, and who has the ground space necessary for its construction. It will give excellent results over a frequency range of more than 2 to 1, and will also radiate well, although with reduced gain and directivity, at frequencies considerably lower than that for which it is designed. Along with the excellent frequency characteristic, it also gives higher gains than any other types of antennas except a very few which require much more elaborate construction. In addition, it is not critical as to adjustment or operation.

In the horizontal form the general principles for determining the tilt angle, ϕ, are the same as already described. However, the choice of the tilt angle is modified somewhat by the fact that the maximum radiation is not in the plane of the antenna, but is at some angle with respect to the ground. This is true of all horizontal antennas, and has already been discussed in the chapter on ground effects. In the design of a rhombic antenna, therefore, the angle of maximum radiation (often called the wave angle) above the ground must first be considered. It is desired, naturally,

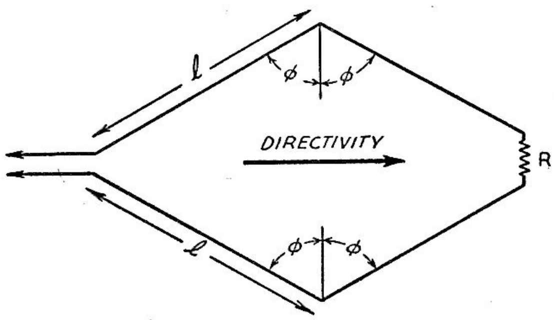


Fig. 1104 — **The rhombic or diamond antenna. The important elements are the leg length, *l*, the tilt angle, ϕ, the height (not shown) and the terminating resistor, *R*.**

to make the antenna radiate and receive best at the angles which normally are most effective for communication on the frequency to be used. Since rhombic antennas are chiefly used for 14- and 28-Mc. work, angles of the order of 5 to 20 degrees above the horizon are of most interest.

Several design methods are available. Once the desired wave angle is selected, there are three quantities to be determined; the tilt angle, ϕ, the antenna height, *H*, and the length of each leg, *l*. For a given wave angle there is one set of these dimensions which will give maximum radiation in the desired direction, or maximum response to signals coming from the desired direction. The design method which gives these optimum dimensions is called the "maximum output" method. Other design procedures, known as the "alignment" and "compromise" methods also are available to meet special conditions.

Maximum Output Design

For maximum output, the height, *H*, tilt angle, ϕ, and leg length, *l*, for a selected wave angle, Δ, can be determined from the following formulas:

$$H = \frac{\lambda}{4 \sin \Delta}$$

$$\sin \phi = \cos \Delta$$

$$l = \frac{\lambda}{2 \sin^2 \Delta}$$

These quantities may be determined directly by calculation, with the assistance of a table of trigonometric functions, or from the chart of Fig. 1105, which gives the solutions in curve form for wave angles from 10 to 30 degrees. For maximum output, use the length curve marked "max. output for ideal case." Following is an example of the use of the chart:

Given: Desired wave angle (Δ) = 18 degrees.
To find: H, L, Φ.
Method:

Draw vertical line thru point "a" (18 degrees wave angle-abscissa).

Read intersection of this line on each curve on its corresponding scale.

e = angle of tilt (Φ).
d = height (H).
c = length (L).

Result:

Φ = 72 degrees.
H = 0.81 wavelengths.
L = 5.25 wavelengths.

The chart also may be used to determine the other three quantities provided any one of the

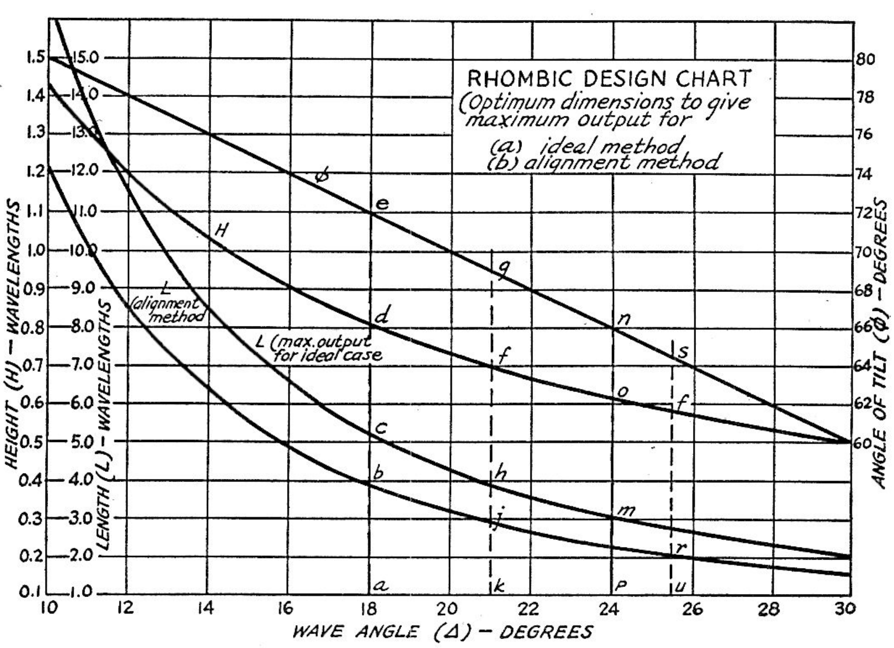


Fig. 1105 — **Rhombic antenna design chart for maximum-output and alignment design methods.**

four is given; usually, the height, H, and length, l, will be subject to limitations. In this case the curves will give the corresponding wave angle, Δ. It may readily occur, however, that the value of Δ so obtained will not be a desirable value for communication on the frequency under consideration; reduced height or length will raise the angle of radiation. The following examples illustrate the use of the chart in this way:

Given: Available and effective height (H) = 0.7 wavelengths.
To Find: L, Φ, Δ.
Method:
Draw vertical line thru point "f" (0.7 wavelengths on curve H).
Read intersection of this line on each curve on its corresponding scale.
g = angle of tilt (Φ).
h = length (L).
k = wave angle (Δ).
Result:
Φ = 69 degrees.
L = 3.9 wavelengths.
Δ = 21 degrees.

Given: Length for 1 side L = 3.0 wavelengths.
To Find: H, Φ, Δ.
Method:
Draw vertical line thru point "m" (3.0 wavelengths on curve L — ideal case).
Read intersection of this line on each curve on its corresponding scale.
n = angle of tilt (Φ).
o = height (H).
p = wave angle (Δ).
Result:
Φ = 66 degrees.
H = 0.618 wavelengths.
Δ = 24 degrees.

In all cases the linear dimensions are in terms of wavelength. This may be converted to feet by the relation

$$\textit{height (ft.)} = \frac{984}{f\ (Mc.)}$$

for the height, and

$$\textit{length (ft.)} = \frac{492\ (N-0.05)}{f\ (Mc.)}$$

(where n is the number of *half* waves) for the leg length. The latter includes end effects. In practice the length is not too critical, so end effects may be ignored and the leg length calculated on the basis of the length of a wave in space with negligible error.

Alignment Method

Although the maximum output method gives the greatest possible radiation or response at the desired wave angle, the maximum point on the vertical lobe taken on a plane cutting vertically through the antenna along the axis of the diamond always occurs at a somewhat lower angle. This is shown in Fig. 1106, where it is apparent that the radiation goes through a maximum below the desired wave angle, which is shown by the dashed line. Note that the amplitude of the lobe drops off rapidly *above* the desired wave angle, but

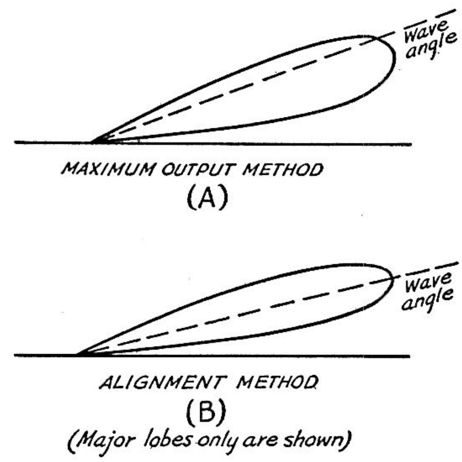


Fig. 1106 — Representative vertical characteristic of rhombic antennas along the line of maximum propagation as obtained by different design methods. Note that in the maximum output method the maximum radiation occurs at a lower angle than that for which the antenna is designed, although the maximum possible output at the desired angle has been secured. The alignment method makes the major lobe and desired wave angle coincide, but with less gain than the maximum output method.

that it is rather broad below. This is a favorable condition, in that it is usually advantageous to keep the radiation as low as possible; furthermore, it permits designing the antenna for a slightly higher angle (of the order of 5 degrees) than the optimum without a great deal of loss at the desired angle. This permits using smaller heights and leg lenths.

The major lobe in the vertical plane, along the desired direction of radiation, may be brought into alignment with the selected wave angle simply by changing the leg length. This procedure is advantageous in reducing the response to signals or static arriving at other angles than the desired, and thus may give a better effective signal-to-noise ratio in reception. There are no particular advantages to the alignment method of design for transmitting, however, as compared to the maximum output method. The alignment method results in a smaller antenna, but the gain also is less than with the maximum output design.

The formulas for height, H, tilt angle, ϕ, and leg length, l, in the alignment design method are as follows:

$$H = \frac{\lambda}{4 \sin \Delta}$$

$$\sin \phi = \cos \Delta$$

$$l = \frac{0.371\ \lambda}{\sin^2 \Delta}$$

It will be observed that the equations for height and tilt angle are identical with those given in the maximum output method; only the equation for length differs. The chart, Fig. 1105, may be used for determining the various quantities, in this case using the length curve marked "alignment method." Typical examples follow:

Given: Desired wave angle (Δ) = 18 degrees.
To Find: H, L, Φ.
Method:
Draw vertical line thru point "a" (18 degrees wave angle-abscissa).
Read intersection of this line on each curve on its corresponding scale.
e = angle of tilt (Φ).
d = height (H).
b = length (L).
Result:
Φ = 72 degrees.
H = 0.81 wavelengths.
L = 3.87 wavelengths.

Given: Available and effective height (H) = 0.7 wavelengths.
To Find: L, Φ, Δ.
Method:
Draw vertical line thru point "f" (0.7 wavelengths on curve H).
Read intersection of this line on each curve on its corresponding scale.
g = angle of tilt (Φ).
j = length (L).
k = wave angle (Δ).
Result:
Φ = 69 degrees.
L = 2.9 wavelengths.
Δ = 21 degrees.

Given: Length for 1 side L = 2.0 wavelengths.
To Find: H, Φ, Δ.
Method:
Draw vertical line thru point "r" (2.0 wavelengths on curve L — alignment case).
Read intersection of this line on each curve on its corresponding scale.
s = angle of tilt (Φ).
t = height (H).
u = wave angle (Δ).
Result:
Φ = 64.5 degrees.
H = 0.581 wavelengths.
Δ = 25.5 degrees.

Compromise Designs

In cases where the height or length, or both, of the antenna are limited, compromise design methods which will give greatest antenna output under the existing conditions are available. Antennas designed according to these compromise methods give smaller output than is obtained by either the alignment or maximum output methods, depending upon how far the antenna dimensions depart from the ideal case. A decrease in height can be compensated for by an increase in length without much loss in output, but if the length has to be reduced considerably below the ideal case a more serious loss in output is suffered.

Fig. 1107 is a compromise design chart applicable where the height is limited but the length can be adjusted to compensate. It is based on a height of one-half wavelength, which is rather easily obtainable at 14 Mc. For a given wave angle, the leg length and tilt angle are readily determined; or, if the leg length is given, the tilt angle and resultant optimum wave angle are easily found. The following example shows how the chart may be used:

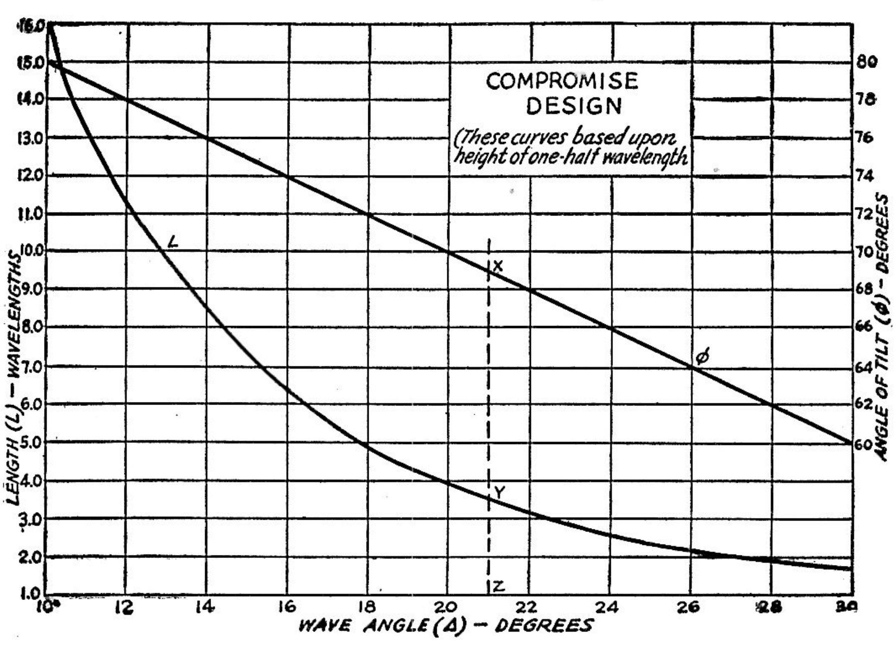


Fig. 1107 — Compromise design chart for rhombic antennas at a fixed height of one-half wavelength.

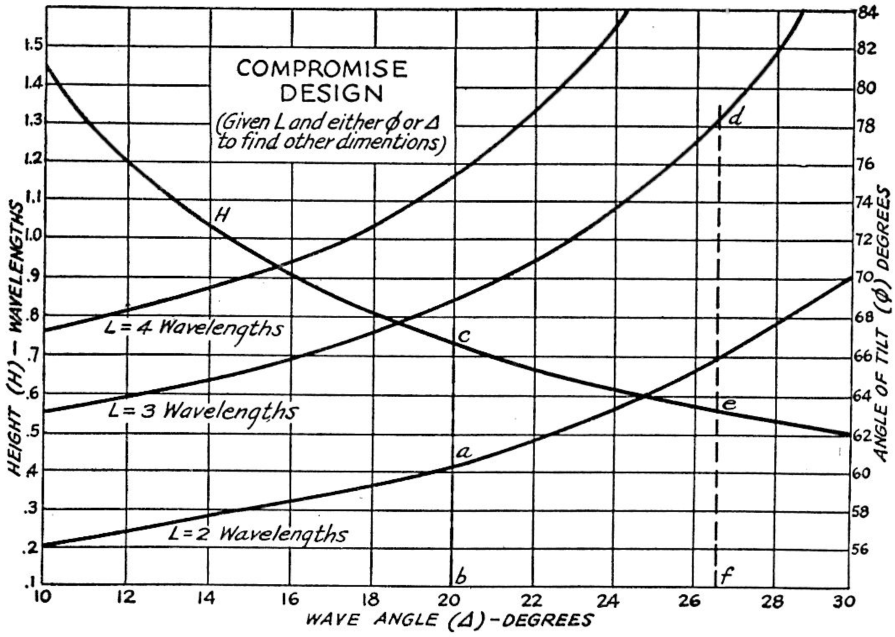


Fig. 1108 — Compromise design chart for various leg lengths.

Given: **Height = ½ wavelength. Available length of one leg = 3.5 wavelengths.**
To Find:
Angle of Tilt (Φ).
Wave Angle (Δ).
Method:
Place straight edge on curve "L" at 3.5 wavelengths (point y) and draw line XYZ. Read angle Φ from intersection at point X (right hand ordinate) and angle Δ at point Z (intersection of abscissa).
Result:

H = ½ wavelength **L = 3.5 wavelengths**	**given.**
Tilt angle Φ = 69 degrees **Wave angle Δ = 21 degrees**	**from curves.**

When the length and height are both subject to variation, with the length the determining factor, the chart of Fig. 1108 may be used. This chart gives the tilt angle and height in terms of the leg length and wave angle, but may also be used to determine the other two quantities when the leg length and height are known. The following examples give typical uses of the chart:

Given: **Length (L) = 2 wavelengths.**
Desired wave angle (Δ) = 20 degrees.
To Find: **H, Φ.**
Method:
Draw vertical line thru point "a" (L = 2 wavelengths) and point "b" on abscissa (Δ = 20 degrees). Read angle of tilt (Φ) for point "a" and height (H) from intersection of line ab at point "c" on curve H.
Result:
Φ = 60.5 degrees.
H = 0.73 wavelengths.

Given:
Length (L) = 3 wavelengths.
Height H = 0.56 wavelengths.
To Find: **Φ, Δ.**
Method:
Draw vertical line from point "e" on curve H at 0.56 wavelengths. Read intersection of this line on curve L = 3 wavelengths (point "d") for Φ and intersection at point "f" on the abscissa for Δ.
Result:
Φ = 78 degrees.
Δ = 26.6 degrees.

Leg lengths of 2, 3 and 4 wavelengths are indicated. For other lengths, a fair idea of the other three quantities can be secured by interpolating, or new curves for any desired leg length can be plotted from the following equation, substituting the desired value of l in terms of wavelength:

$$\sin \Phi = \frac{l - 0.371\,\lambda}{l \cos \Delta}$$

Solution of this equation for the various values of Δ given on the chart will give the corresponding tilt angles.

Terminating Resistance

The terminating resistance plays an important part in the operation of the rhombic antenna; upon it depends the undirectivity of the antenna and the lack of resonance effects. A properly terminated antenna will show practically constant impedance at its input end so that it can be operated over a wide frequency range without the necessity for changing the coupling adjustments at the transmitter. The reduction of back radiation is perhaps of lesser importance in transmission, since the energy which would be radiated backward without resistance termination is simply absorbed in the resistor when the antenna is terminated. For reception, however, the discrimination against signals coming from the rear may be of great importance. For instance, an antenna built for working DX in a direction opposite to that from which domestic interference comes will be vastly superior in reducing unwanted interference when properly terminated.

The characteristic impedance of a rhombic antenna, looking into the sending or input end, is of the order of 700 to 800 ohms when properly terminated in a resistance at the far end. The terminating resistance required to bring about the matching condition usually is slightly higher than the input impedance because of the loss of energy through radiation by the time the far end is reached. The correct value usually will be found to be of the order of 800 ohms, and should be determined experimentally if the "flattest" possible antenna is desired. For average work, however, a noninductive resistance of 800 ohms can be used with the assurance that the operation will not be far from optimum.

The terminating resistor must meet certain requirements if best results are to be secured. It should be practically a pure resistance at the operating frequencies; that is, its inductance and capacitance should be negligible. It must also be capable of dissipating about half the r.f. power supplied to the antenna by the transmitter. This power is "wasted" only in the sense that it is not being used for back radiation; even without any terminating resistor it would not contribute to the forward radiation.

Supplying a purely resistive load of great enough power-dissipating capability was until recently a considerable problem, but there are now available suitable non-inductive resistors from several manufacturers. These may be used either singly, when capable of dissipating the necessary power, or in combination so that several units of equivalent total power rating may be added to give the proper resistance. To lower capacity effects it is desirable to use several units, say three, in series even when one alone will safely dissipate the power. The two outer units should be identical and each should have one-fourth to one-third the total resistance, with the center unit making up the difference. The units should be installed in a weatherproof housing at the end of the antenna to protect them and to permit mounting without mechanical strain. The connecting leads should be short so that little extraneous inductance is introduced.

Alternatively, the terminating resistance may be placed at the end of an 800-ohm line connected to the end of the antenna. This will permit placing the resistors and their housing at a point convenient for adjustment rather than at the top of the pole. The line length is not critical, since it operates without standing waves and hence is non-resonant.

One type of termination sometimes employed is an 800-ohm transmission line, closed at the far end, constructed of resistance wire. The line must be long enough to provide a satisfactory value of resistance load, which usually makes the length quite cumbersome. The simple terminating resistor is preferable for amateur installations in view of the availability of satisfactory resistors.

Checking the Termination

The correctness of the termination may be checked by a simple means provided it is possible to get at the input end of the antenna conveniently. A small balanced (push-pull) oscillator, used in conjunction with a receiver, may be used for the purpose. The oscillator should be capable of tuning over the frequency range for which the antenna is to be used, and its coil should be arranged to permit tapping on the antenna terminals symmetrically about the center tap. Suitable tap points may be predetermined by using an 800-ohm carbon resistor as a load, the taps being adjusted so that the oscillator is not too heavily loaded.

The checking procedure is as follows: With the antenna disconnected, set the oscillator to some frequency within the desired range and tune to zero beat on the receiver. Then connect the antenna and, without touching the oscillator tuning condenser, retune the receiver to zero beat. If the frequency changes appreciably the input impedance of the antenna has a reactive component, showing that the terminating resistor is not of the correct value. If the change is small, a second check should be made at a different oscillator frequency to make sure that the first test did not happen to be made on a frequency at which the antenna, even though improperly terminated, was resonant. Should both checks show an appreciable frequency change the terminating resistance should be changed about 10 per cent and the procedure repeated. A few back-and-forth trials will determine the value of terminating resistance which gives the least frequency change, and hence makes the antenna input impedance as nearly resistive as possible. An oscillator having a fairly high L/C ratio in its tuned circuit will be most sensitive.

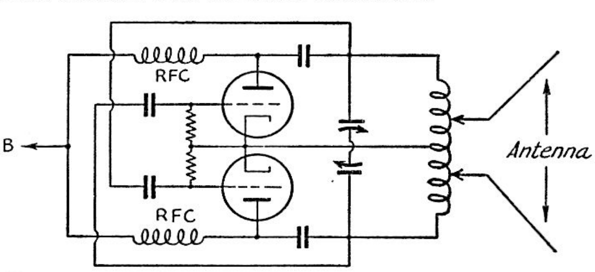


Fig. 1109 — A push-pull oscillator may be used for checking the effectiveness of the resistor termination on the antenna. A Hartley circuit is shown, but any balanced circuit capable of working over about a 3:1 frequency range will be satisfactory. It should be battery operated.

If it is not convenient to work directly at the antenna terminals the method may be modified to connect the antenna to the oscillator through a half-wave transmission line, which will reproduce at the oscillator the conditions existing at the antenna. An ordinary 600-ohm line is convenient; the impedance is not particularly important since the line is resonant. The line should be cut for some convenient frequency and then its exact resonant frequency determined by connecting it to the oscillator but not to the antenna, although it should be in the position in which it will be used. The oscillator frequency should then be adjusted to a value which does not change when the line is disconnected from the oscillator. Once this frequency is found the oscillator is left alone and the line connected between oscillator and antenna, when the procedure becomes the same as that already described. Checks on other frequencies may be made by using other lines of different lengths.

Because the separation of the antenna wires is continually changing, the impedance is not uniform along the length of the antenna. This effect can be overcome by using two wires, one above the other, for each side of the antenna, starting with no separation at the ends and gradually increasing the separation to a maximum at the apex of the side angle. This construction is often used in commercial work, but the complication in construction is hardly justified for amateur purposes.

Adjusting for Maximum Front-to-Back Ratio

It is theoretically possible to obtain an infinite front-to-back ratio with a terminated rhombic antenna, and in practice very large values can actually be secured. However, when the antenna is terminated in its characteristic impedance the infinite front-to-back ratio can be secured only at frequencies for which the leg length is an odd multiple of a quarter wavelength. At other frequencies the front-to-back ratio decreases, and is smallest at frequencies for which the leg length is a multiple of a half wavelength. The greatest reduction in front-to-back ratio occurs for short antennas; the greater the number of half waves on a leg the higher the front-to-back ratio at frequencies for which the leg length is a multiple of a half wave.

When the leg length is not an odd multiple of a quarter wave at the frequency under consideration, the front-to-back ratio can be made infinite by slightly decreasing the value of terminating resistance. This permits a small reflection from the far end of the antenna which cancels out, at the input end, the residual response. With large antennas the front-to-back ratio may be made very large over the whole frequency range by experimental adjustment of the terminating resistance. When this is done the antenna will show slight resonance effects, but these are small enough to be neglected since the resistance is changed only a few per cent from the optimum value for eliminating standing waves.

Modification of the terminating resistance also permits "steering" the back null over a small horizontal range so that signals coming from a particular spot not exactly to the rear of the antenna may be minimized. This refinement is seldom necessary in amateur work, although it is well to keep it in mind should an occasion for its use arise.

Methods of Feed

If the broad frequency characteristic of the rhombic antenna is to be fully utilized the feeder system used with it must be similarly broad. This practically dictates the use of a transmission line of the same characteristic impedance as that shown at the antenna input terminals, or approximately 750 to 800 ohms. Data for the construction of such lines will be found in Chapter 4. It will be found, however, that the spacing required is rather awkward, and also that rather small wire must be used. Both these considerations are disadvantageous mechanically, and the radiation from the line also tends to be comparatively high at 28 Mc. because of the wide spacing.

While the usual matching stub can be used to provide an impedance transformation to more satisfactory line impedances, this limits the operation of the antenna to a comparatively narrow range of frequencies centering about that for which the stub is adjusted. On the whole, the best plan is to connect a 600-ohm line directly to the antenna and accept the small mismatch which results. The operation of the antenna will not be adversely affected, and since the standing-wave ratio is quite low (1.33 to 1) the additional loss over the perfectly matched condition will be unappreciable even for rather long lines. The chief disadvantage is that at some frequencies a slight readjustment of the coupling to the transmitter may be necessary to maintain constant input.

Any of the coupling systems suitable for working into a 600-ohm line, as described in Chapter 4, will be suitable.

General Considerations

To realize the performance indicated by the design data previously given, particularly with respect to the wave angle to be obtained, it is desirable that the rhombic be installed over practically level ground. The various designs are all based on lining up the free-space radiation of the antenna with the reflected waves from flat ground. If the ground slopes uniformly, it may be expected that the computed wave angle will be obtained if the antenna is constructed parallel to the slope. However, the angle in this case is that made with the ground over which the antenna is erected, provided the slope extends considerably beyond the limits of the antenna, and this should be taken into account in determining the actual angle which the wave will make with the horizon.

The design data likewise are based on perfectly-reflecting ground, which of course is not found in practice. However, it has been established that the results are not greatly changed by the normal type of ground, at least for wave angles of the order of those under consideration. The kind of soil, therefore, is not of great consequence.

Experience with rhombic antennas has shown that excellent results can be obtained even though the existing conditions are far from ideal. "Haywire" antennas which perforce ran over uneven ground, through trees, and even were not at a uniform height above ground have given surprisingly good results. Nevertheless, it will pay to do the best possible job of meeting the design data indicated by the charts. The point is that the antenna will give good results even in unlikely locations, provided reasonable care is used in construction and it is made as large as the circumstances will permit.

Generally speaking, the gain of the rhombic antenna will depend principally on its length. Height as well as length plays an important part in the determination of the optimum wave angle, but height has a much smaller effect on the gain than length. Antennas designed by the maximum output method will give average gains of the order of 14 to 16 db. over a half-wave antenna, depending upon the wave angle which happens to be most effective at the time. The alignment and compromise designs give smaller gains, averaging in the neighborhood of 10 to 12 db. if the leg length is not too greatly reduced. If the leg lengths indicated by the maximum output design method are not permissible, then base the design on the greatest leg length which can be accommodated in the available space.

Unterminated Rhombics

The rhombic antenna may be used without the resistor termination, although two of the desirable features of the antenna are sacrificed by unterminated operation. The antenna becomes bidirectional instead of unidirectional, and it is no longer possible to use the feeder as a non-resonant line. This means that, in reception, the signal-to-noise and signal-to-interference ratios are poorer, and the feeder system must be retuned for each change in operating frequency. Since standing waves appear on both antenna and feeder, series or parallel tuning must be used at the transmitter according to the number of quarter waves which happen to exist on the system at the particular operating frequency.

When the rhombic antenna is non-terminated, the difference in the current distribution (no standing waves, terminated, as against standing waves, non-terminated) changes somewhat the angle which the lobe of maximum radiation makes with each leg of the antenna. This effect already has been mentioned earlier in this chapter. The shift in the lobe is negligible, however, if each leg is two or more wavelengths long and, as a result, the same design methods previously discussed may be used.

The gain in the forward direction is nearly the same whether or not the antenna is terminated in a resistor. A small decrease may be expected because, in the terminated rhombic, the power dissipated in the resistor is not quite half the total power supplied to the antenna, while with the unterminated antenna the radiated power divides about equally in both directions. That is, with the terminated antenna slightly more than half the power is radiated in the forward direction, while without the termination the division between front and back is about 50–50.

The unterminated rhombic antenna can be looked upon as two V-type antennas placed end-to-end, or as two "obtuse angle" Vs placed side by side. Comparison between the unterminated rhombic and the V antenna is difficult because of lack of data on forms of most interest to amateurs. Experience indicates, however, that for the same *over-all* length the rhombic gives greater gain than the single V.

Secondary Lobes

Since the radiation patterns of the individual legs of which long-wire antennas, including the rhombic, are composed are multi-lobed, it is to be expected that the antenna will radiate, or respond to incoming signals, in directions other than that of the main lobe. With some lengths, heights and tilt angles certain secondary lobes may exhibit considerable strength, although their effects are confined to only a few degrees in the horizontal plane. Likewise there may be a large number of null points, or near nulls, in the directive diagram.

It is important, particularly in reception, to recognize the existence of secondary lobes, because, despite the marked gain in the direction for which the antenna is laid out, casual listening often gives the impression that signals can be heard almost equally well in all directions. The nulls usually are quite sharp, so that their presence often is difficult to detect. Of course, if the rhombic is properly terminated the reduction in back response will be very apparent.

It is a fact that some of the secondary lobes often give considerable gain over a half-wave antenna, while others are at least comparable in effect to radiation in the same direction from a half wave. In one sense this is an advantage, because in practice one finds that, along with high gain in the desired direction, the secondary lobes permit communication practically "around the horizon" with results at least as good as would

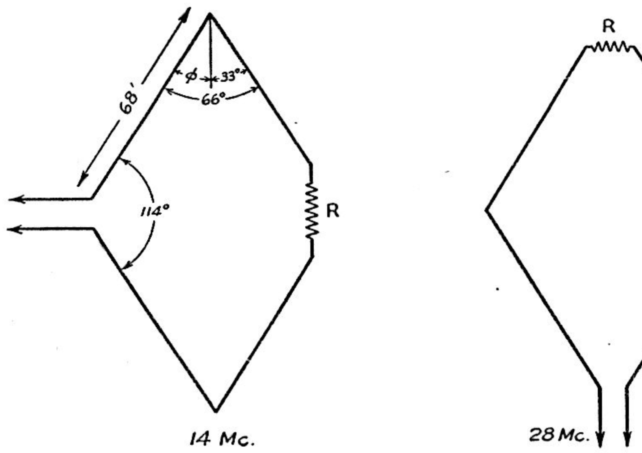


Fig. 1110 — Suggested dimensions for a small rhombic for 14 and 28 Mc. For best results, provision must be made for switching the resistor and feeder as shown when the band is changed. The directivity shifts 90 degrees when the change is made.

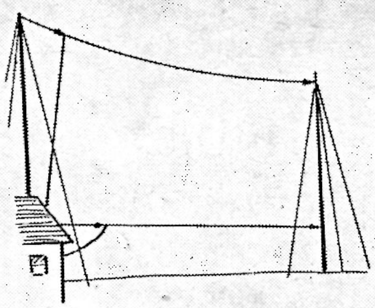
be obtained with a half-wave antenna. It is not especially a sign that the antenna is not working properly if this is the case.

Small Rhombics

The outstanding results which have been secured with rhombic antennas of ample size often tempt the builder whose space is restricted to try his luck with a small antenna and hope for the best. It should be realized, however, that long-wire antennas do not really begin to perform unless they are actually "long" — in the case of the rhombic, at the very least two, and preferably three wavelengths on a leg. The gain decreases rapidly when the wire length is decreased, and the ability of the antenna to work well over a wide frequency range also is impaired. Where space is restricted, considerably more gain can be obtained by the use of phased half-wave elements, as described in Chapters 8 and 9.

The small rhombic has at least one advantage, however, over the phased arrays. It will accept power on any frequency for which the sides will be resonant, and will radiate it in some fashion, at least. It will not exhibit the expected directive effects, however, except on the band for which it is designed. If one simply wants a small amount of gain and directivity on one band, say 14 Mc., plus the ability to use the same antenna on other bands without being too greatly concerned about maximum effectiveness, a small rhombic might be worth a try.

In the extreme case of a rhombic one wavelength on a side for 14 Mc., the dimensions would be about as shown in Fig. 1110. It happens that the tilt angle can be selected so that for 28-Mc. work the antenna will work as a two-wavelength-per-leg antenna for transmission and reception at right angles to the optimum direction on 14 Mc. This requires shifting the feed point from one apex to another, as shown, together with closing one apex and opening another. If the antenna is fed primarily for 14-Mc. and operated without change on 28 Mc. the lobes of the various legs will not be aligned and the directional characteristic will be poor. Likewise, the gain will be negligible. A similar condition will occur on 14 Mc. if the antenna is fed on the basis of 28-Mc. operation



12. ANTENNAS FOR 160 METERS

GENERAL CONSIDERATIONS — BENT ANTENNAS — FOLDED-TOP ANTENNAS — TOP LOADING — GROUNDS AND COUNTERPOISES

With respect to sky-wave transmission, the requirements which the antenna system must meet on 1750–2050 kc. do not differ materially from those which hold on the high-frequency bands. Of course, waves entering the ionosphere even vertically are reflected back to earth so that there is no such phenomenon as skip distance on these frequencies. However, it is still true that to cover the greatest possible distance the waves must enter the ionosphere at low angles. Although a given distance may be covered by multiple hops when the radiation angle is high, there will be less absorption, and hence the signal strength will be greater, at the same point when the wave reaches it by only one hop.

On the "160-meter" band the ground wave assumes considerable importance for transmission over short distances. The useful range of the ground wave will depend upon the transmitter power, the background noise at the receiver, and the type of soil over which the wave must travel. If the antenna system radiates most of the transmitter power at relatively low angles, particularly along the ground, the ground wave will give reliable communication over distances from 50 to considerably over 100 miles, the latter distances applying where conditions are particularly favorable, as when the path is mostly over sea water.

Polarization

It was mentioned in Chapter 1 that a ground wave must be vertically polarized, so that the radiation from an antenna which is to produce a good ground wave likewise must be vertically polarized. This dictates the use of an antenna system the radiating part of which is mostly vertical. A horizontally polarized antenna will produce practically no ground wave, and it is to be expected that such an antenna will be ineffective for daytime communication. This is because absorption in the ionosphere in the daytime is so high at these frequencies that the reflected wave is too weak to be useful. At night a horizontal antenna will give better results since night-time ionosphere conditions permit the reflected wave to return to earth without excessive attenuation. The difference between day- and night-time conditions is similar to that existing on the broadcast band, where distant stations can be heard well at night but not at all in the day.

There is still another reason why a vertical antenna is better than the horizontal for 160-meter work. Comparison of the ground reflection factors in Figs. 303 and 304, Chap. 3, for horizontal antennas at heights of ¼ and ⅛ wave will show that at the lower height the ground is less effective in reinforcing radiation. At 160 meters even a height of ⅛ wave, about 65 feet, is not easy for all amateurs to attain, while a height of ¼ wave is out of the question for nearly everyone. Any reasonable height is small in terms of wavelength, so that a horizontal antenna on 160 meters is a poor

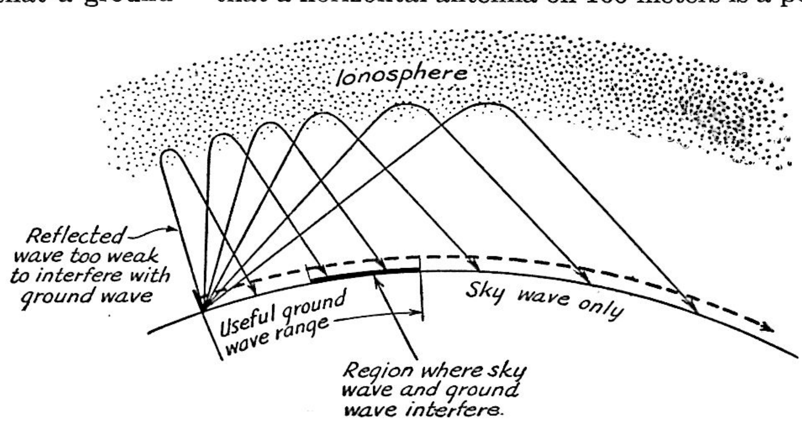


Fig. 1201 — **How sky waves interfere with the ground wave to cause a bad fading area. This is typical of night conditions, when sky waves are refracted without much attenuation in the ionosphere.**

radiator at angles useful for long distances ("long," that is, for this band). Its chief field of usefulness is for communication over relatively short distances at night.

The chief disadvantage of vertical polarization is the fact that the stronger ground wave is more likely to cause interference with nearby broadcast receivers.

Vertical Antenna Design Considerations

For good night coverage at distances toward the limit of the ground wave it is desirable to use an antenna which will give comparatively little radiation at angles above about 45 degrees. This is because the high-angle radiation returns to earth within the useful range of the ground wave, and in the outer part of this range may have intensity comparable to that of the ground wave itself. The sky waves arrive at the ground in random phase with respect to the ground wave, giving rise to severe fading in this area. See Fig. 1201. The antenna should, therefore, confine its radiation to angles sufficiently low so that the nearest point to the transmitter at which sky waves return to earth is just beyond the limits of the ground wave.

The various conditions can be met by the use of an antenna a half-wave high, but this is impractical since a height of over 250 feet would be required. Fortunately it is possible to approach the effect of a half-wave antenna by suitable treatment of a much lower structure.

A vertical antenna will be most effective when it can be erected in a fairly clear spot so that the ground wave is not absorbed in nearby buildings. Frame buildings are not likely to cause much trouble, but it is best to keep clear of steel structures by at least a wavelength or two.

Grounded Antennas

It was explained in Chapter 2 that the smallest self-resonant antenna is an electrical half-wave in length. A mechanical analogy to such an antenna is a flat strip of spring metal firmly supported at its center, with both ends free to vibrate, Fig. 1202. Experience tells us that if half the spring is cut off, leaving the remaining half supported at one end, the free end of the remaining half will still vibrate at the original rate when set into oscillation. A similar condition exists if we cut a half-wave antenna in two, making its length a quarter wave, and then ground one end. The grounded quarter-wave antenna will resonate at the same frequency as an ungrounded half-wave antenna. We can consider that the missing half of the antenna is supplied by the "image" of the antenna in the ground. The directional characteristic of a grounded quarter-wave antenna will be the same as that of a half-wave antenna in free space, because of reflection from the ground. Thus a vertical grounded quarter-wave antenna will have a circular radiation pattern in the horizontal plane. In the vertical plane, however, the radiation will decrease from maximum along the ground to zero at the perpendicular.

The grounded antenna may be much smaller than a quarter wave and still be made resonant by "loading" it with inductance at the base, as in Fig. 1203. By adjusting the inductance of the loading coil even very short wires can be tuned to resonance. However, the efficiency of the wire as a radiator is decreased considerably by decreasing its length. This is because the current at the top of a simple vertical wire such as is indicated in the figures is necessarily zero, so that as the length is reduced less and less of the wire is carrying the high current which produces the greatest radiation.

Current and Voltage Distribution

The current along a grounded quarter-wave vertical wire varies practically sinusoidally, as is the case with a half-wave wire, and is highest at the ground connection. The r.f. voltage, however, is highest at the open end and minimum at the ground. The current and voltage distribution are shown in Fig. 1203-A. When the antenna is shorter than a quarter wave but is loaded to resonance, the current and voltage distribution are part sine waves along the antenna wire. If the loading coil is substantially free from distributed capacity, the voltage across it will increase uniformly from minimum at the ground, as shown at B and C, while the current will be the same throughout.

The radiation resistance of a grounded quarter-wave vertical antenna is approximately 36 ohms. With shorter antennas the radiation resistance decreases. The radiation resistance is particularly important in the case of a grounded antenna not only in connection with methods of feeding but also because the ratio of the radiation resistance to the resistance of the ground contact system determines the portion of power supplied to the

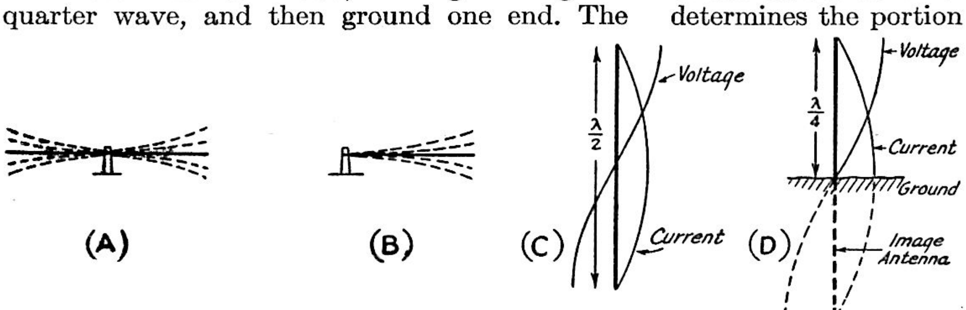


Fig. 1202 — **Mechanical analogy of steel spring to half- and quarter-wave antennas.**

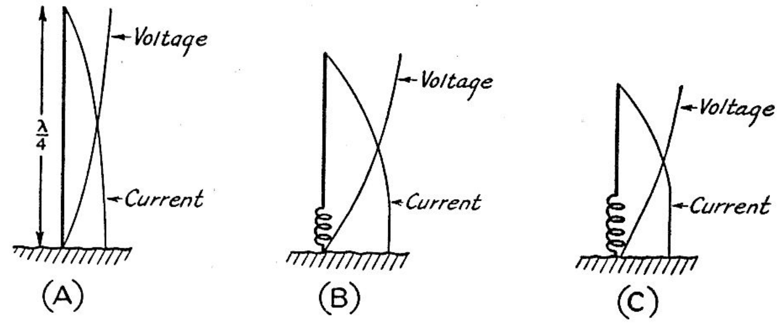


Fig. 1203 — **Current and voltage distribution on a grounded quarter-wave antenna (A) and on successively shorter antennas loaded to resonate at the same frequency.**

antenna which is actually radiated. The total power dissipated in the antenna is equal to

$$I^2(R_o + R_g)$$

where I is the current at the base of the antenna, R_o the radiation resistance, and R_g the resistance of the ground connection. Since only I^2R_o produces useful radiation, while I^2R_g is pure loss, it is important to keep the ground resistance as low as possible. If, for instance, the two resistances are equal only half the power supplied to the antenna will be radiated; the other half simply represents a loss in the ground connection.

If the grounding resistance is fixed, the ratio of radiated power to power lost in the ground connection can be increased by increasing the radiation resistance of the antenna. The radiation resistance as measured at the base of the antenna can be increased by making the antenna longer than a quarter wave, when the current distribution becomes as shown in Fig. 1204. The highest value is secured when the length becomes a half wave, since this length brings a current node at the ground connection.

Note that as the length increases beyond a quarter wave the maximum current point on the antenna is no longer at the base, but has moved up on the wire. When the antenna height is a half wave the current is maximum half way up, or one-quarter wavelength above the ground. The upward shift in the current loop is beneficial in two respects; a greater length of wire is carrying high current, thus giving greater effective radiation, and the high-angle radiation is decreased.

Since the heights required for realization of these desirable characteristics are impracticable

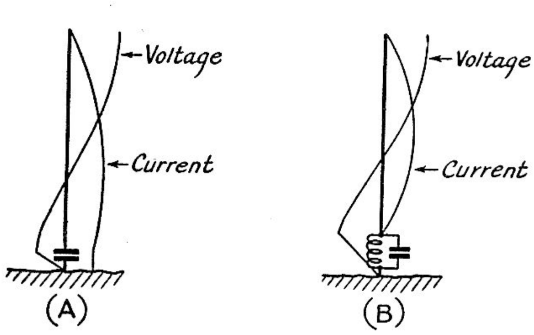


Fig. 1204 — **Current and voltage distribution on grounded antennas longer than ¼ wavelength. (A), between ¼ and ⅜ wave, approximately; (B) half wave.**

for amateur work, the object of design of vertical grounded antennas which are necessarily of heights less than ¼ wavelength is to make the current loop come near the top of the antenna, and to keep the current as large as possible throughout the length of the vertical wire. A number of methods can be employed for this purpose.

Bent Antennas

Perhaps the simplest method of meeting the fundamental requirement of keeping the current

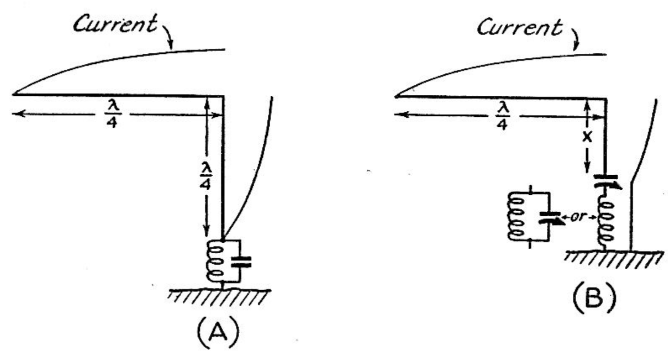


Fig. 1205 — **Bent antennas using a quarter-wave horizontal section to bring a current loop at the top of the vertical wire. A quarter-wave vertical section is shown at (A); at (B) the height X is made as great as the circumstances permit. Series tuning may be used for lengths of X up to about ⅛ wavelength; parallel tuning for greater lengths of X.**

loop high is to use a bent antenna such as is shown in Fig. 1205-A, with part of the antenna vertical and part horizontal. The horizontal part should be one-quarter wave in length so that the current loop will appear at the top of the vertical portion. The current distribution will be as shown in the drawing, assuming that the vertical portion is ¼ wave high. If smaller heights are used, the horizontal portion should still be ¼ wave in length. Since the most useful radiation is from the vertical part, it is of course desirable to make the antenna as high as possible.

The length of the horizontal top portion can be calculated from the formula

$$\textbf{Length of } 1/4 \textbf{ wave (ft.)} = \frac{234{,}000}{f(\text{kc.})}.$$

There is no need for excessive accuracy in determining this length, since a discrepancy of even several feet will make comparatively little difference in the performance of the antenna.

The lower end of the antenna is grounded through a loading circuit which tunes the system to resonance and also provides a means for coupling power from the transmitter into the antenna. The constants of the loading circuit will depend upon the total length of the antenna system, and therefore depend upon the antenna

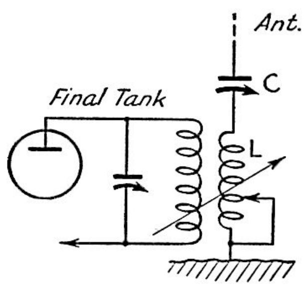


Fig. 1206 — The practical loading and coupling circuit for antennas of the type shown in Fig. 1205-B when the height X is ⅛ wavelength or less (up to 65 feet approximately). The series tuning condenser C should be 250 to 500 μμfd.; receiving-type condensers will suffice for moderate powers. Coil L may consist of 20 turns of No. 12 wire space-wound (6 turns per inch) to a diameter of 3 inches, arranged so that it can be tapped conveniently at least every few turns. Tuning procedure is that for series tuning as described in Chapter 4. An r.f. ammeter may be connected in series with the antenna where it joins C. A 2.5-ampere instrument will suffice for powers up to a few hundred watts.

height. For heights between 40 and 70 feet a circuit of the type shown in Fig. 1206 will be suitable, provided the leads between the bottom of the antenna and the coupling circuit, and between the loading circuit and the effective ground, are negligible in length. These leads are part of the effective length of the antenna, and must be added to the antenna length in determining the actual constants required in the loading circuit.

For maximum effectiveness, the vertical part of the antenna should actually be vertical, and not simply run off at some convenient angle from the operating room to the top of the pole. The wire may come down the pole on stand-off insulators, or may be pulled down vertically from the horizontal strain insulator after the fashion shown in Fig. 1207. Wire guys on the pole should be broken up at intervals of 25 feet or so with egg-type insulators to prevent pick-up of r.f. energy from the antenna.

Antennas of this type offer an opportunity for use of a rather simple feeder system which permits installing the antenna at some distance from the transmitter. If the antenna height is ⅛ wave, for example, the total length is ⅜ wave including the horizontal part. An additional ⅛ wave wire may be added to the antenna as shown in Fig. 1208 to make the total length ½ wave. This extra section is connected to the bottom of the vertical wire and is used as a feeder. It should run parallel to and fairly close to the ground for as much of its length as possible (a height of 6 or 7 feet is permissible so that it will not be a hazard to walkers) and terminate at the transmitter in a parallel-tuned circuit the other end of which is grounded. (The length of the ground lead should be included in the "feeder" length.) At this point the impedance looking into the feeder and antenna has its highest value so that losses in the ground connection are relatively low. There will be very little current in the ground lead under these conditions, but an ammeter inserted at the base of the vertical portion will read about 70 per cent of the current at the top.

Such a "feeder" does comparatively little radiating because it is parallel to and close to the ground and because it represents the section of the antenna which carries the least current. In cases where the antenna height is not an eighth wavelength the "feeder" length, including the ground lead, should be ½ wavelength less the actual length of the antenna from the base to the far end of the horizontal portion. The length of a half wave is given closely enough by the formula

$$\text{Length of } \tfrac{1}{2} \text{ wave (ft.)} = \frac{468}{f(\text{Mc.})}.$$

The feeder may be made longer or shorter than the exact length necessary to make the whole

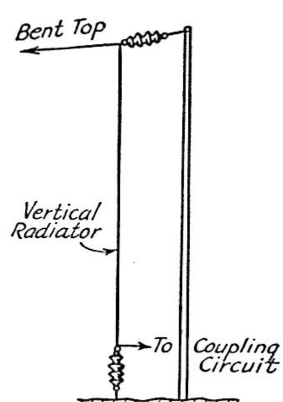


Fig. 1207 — An arrangement for keeping the main radiating portion of the antenna vertical.

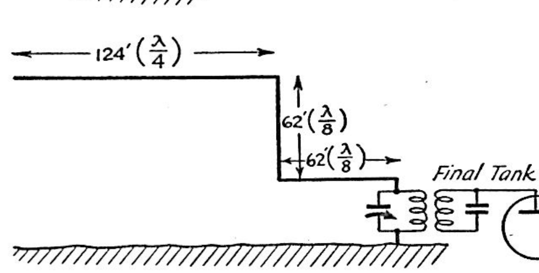


Fig. 1208 — Bent antenna ⅛ wave high, with a "feeder" section making the total length ½ wavelength. The length figures are for 1900 kc., approximately, and the same antenna may be used over the whole band. The parallel-tuned coupling circuit should be capable of being tuned independently to the operating frequency, and the inductance of the coil preferably should be variable by means of taps so that the optimum L/C ratio can be secured.

system a half-wave long, if more convenient, provided the whole system is brought to resonance by means of the coupling system. However, excessive length in a feeder of this type is not desirable. Also, it is preferable to have the length to the ground connection a half-wave so that the current in the ground lead will be minimum, which means lowest loss in the ground connection.

Folded-Top Antennas

The horizontal part of an antenna of the type shown in Figs. 1205 and 1208 naturally radiates part of the total power supply by the transmitter. This horizontally-polarized radiation does not contribute to the ground wave, and is practically all at high angles. Both these features are undesirable for the reasons previously outlined.

Radiation from the horizontal portion can be minimized by folding the wire so that the field about one section cancels, at least partially, the field from the adjacent section. The folds can be made in a variety of ways, several of which are shown in Fig. 1209. The desirable condition is to have adjacent wires carrying currents of the same order of magnitude so that the cancellation will be as great as possible. Reduction of radiation from the top section means an increase in the power available for the vertical portion where it is most usefully radiated.

An incidental advantage of folding the top section is that less ground space is needed for the installation of the system. Also, with some arrangements it is possible to drop the vertical portion from the center of the horizontal part, if a more convenient installation results from so doing. The folded wires should be a foot or two apart, and may be fastened to small wooden spreaders as shown in Fig. 1210. The folds may be worked out to be accommodated in almost any reasonable ground space.

With the folded-top antenna the desirable condition is still that which brings the current loop to the top of the vertical portion. Therefore the total length of the folded horizontal wire should be equal to ¼ wavelength at the operating frequency.

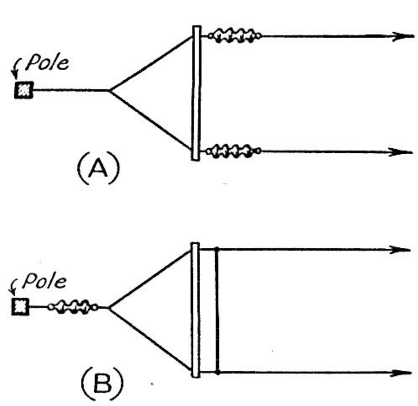


Fig. 1210 — How spreaders may be used (A) for open ends and (B) for closed ends. The spreaders may be made of light wood.

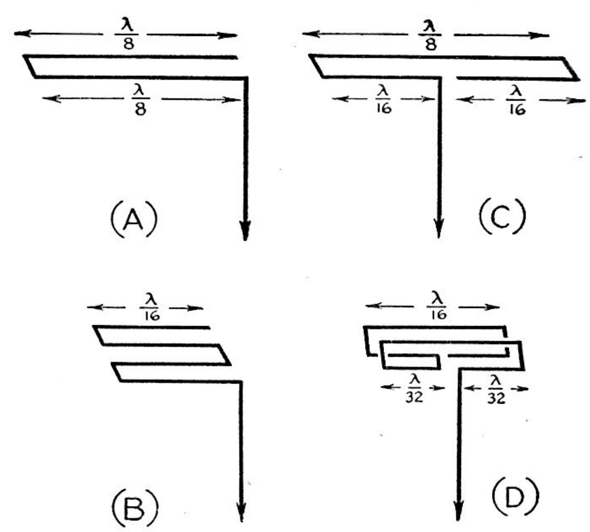


Fig. 1209 — Several ways in which the top quarter-wave section may be folded to reduce radiation. Spacing between folded wires is not critical; from 1 to 4 feet is satisfactory provided some means is provided to keep close-spaced wires from swinging in relation to each other. The lengths of the connecting pieces at the folds should be counted in the total length of the quarter-wave top section. ⅛ wave is approximately 60 feet, 1⁄16 wave 30 feet, and so on.

Both this and the plain bent antenna may be designed for a particular frequency in the center of the band — say 1900 kc. for the 1800–2000-kc. 'phone section — and will work equally well over the whole band by returning the loading-coupling circuit when the frequency is changed.

The feeding methods already described for the bent antenna may be used equally well with the folded-top arrangement.

A somewhat different top-folded arrangement, used by the British Marconi Company, is shown in Fig. 1211. The top section is made practically completely non-radiating by branching the currents through parallel wire sections. Thus the current flowing into the top at the junction with the vertical section branches in opposite directions as shown. At the ends, the current again divides between the two outer wires. A current node occurs at the midpoints of the outside wires, and the relative phases are such that a continuous wire section may be used. The whole flat top is a quarter-wave long, which requires more ground space (about 150 feet between poles, including room for supporting wires for the spreaders) than is needed for the folded-top systems already described. The branching arrangement makes the currents in the two halves of each horizontal wire flow in opposite directions, thus minimizing radiation perpendicular to the top wires, and there is additional field cancellation because of the folding.

As previously stated, for minimum ground connection loss it is desirable to make the antenna system a half-wave long so that there will be a current node at the grounding point. With vertical sections less than a quarter-wave high the average current over the vertical portion is not as large, under these conditions, as when the length is adjusted to bring a current loop at its top. Thus one design gives somewhat lower current but lower

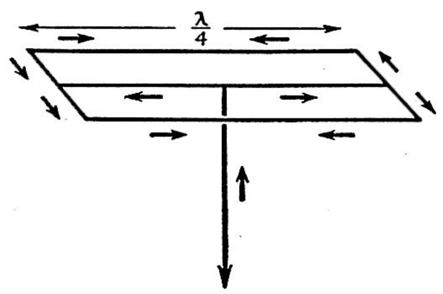


Fig. 1211 — **Folded-top antennas with branched wires to provide practically complete cancellation of radiation from the top section. The top shown here is equivalent to a simple quarter-wave horizontal section. The vertical portion may be any length up to a quarter wave, the greater heights being more effective as in the case of the bent and top-folded antennas of Figs. 1205, 1208 and 1209.**

ground loss, the other higher current but higher ground loss. Usually a compromise between the two will give the most effective radiation. For average grounds, however, it will be found that the field strengths will differ in but a small degree for either type of operation, provided the vertical section of the antenna is between about 50 and 70 feet in height.

For the minimum ground loss condition the *total* length of the wire is simply made equal to ½ wavelength. The length of the folded part then becomes the figure found by the formula previously given less the length of the vertical portion. As before, maximum effectiveness of the folds will be obtained when adjacent wires are carrying nearly equal currents.

Top-Loaded Antennas

Instead of bending or folding up the antenna length required for resonance, it is possible to use a simple vertical wire with concentrated capacity and/or inductance at its top to simulate the effect of the missing length. This system is more critical as to frequency — that is, it is not quite as tolerant with respect to working over a band of frequencies — but is structurally advantageous since only one pole is required.

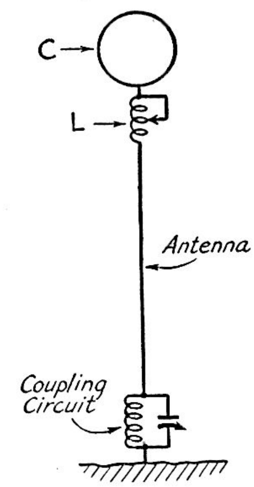


Fig. 1212 — **Top-loaded antenna. A parallel-tuned circuit, independently resonant at the operating frequency, is required for coupling to the transmitter when the top loading is adjusted to bring a current minimum at the lower end of the antenna.**

The top-loading apparatus may consist simply of a capacity or, better, a capacity and inductance suitably proportioned. The capacity used is not the usual type of condenser, which would be ineffective since the connection is one-sided, but consists of a metallic structure which exhibits the necessary capacity to space. Practically any

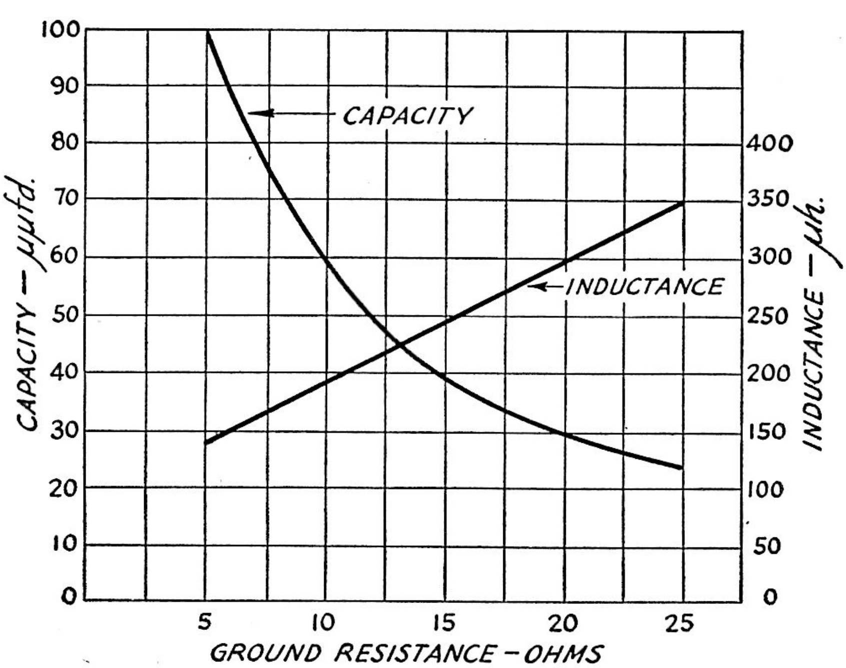


Fig. 1213 — **Capacity and inductance required at the top of a vertical antenna as a function of ground resistance, for a frequency of 1875 kc. These values are sufficiently close for the entire band, when the adjustment procedure described in the text is followed.**

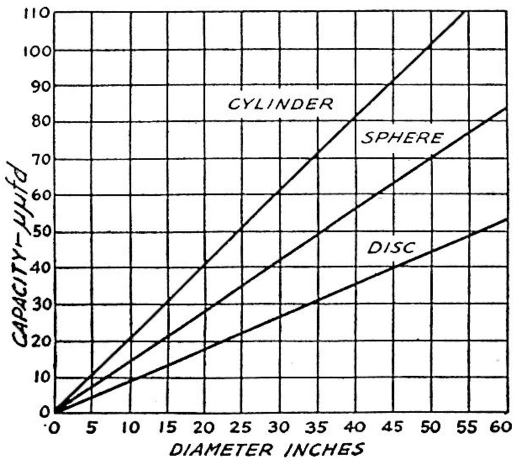


Fig. 1214 **— Capacitance of sphere, disc and cylinder as a function of their diameters. The cylinder length is assumed equal to its diameter.**

sufficiently-large metallic structure can be used for the purpose, but simple geometric forms such as the sphere, cylinder and disc are preferred because of the relative ease with which their capacity can be calculated. The inductance may be the usual type of r.f. coil, with suitable protection from the weather.

The ratio of inductance to capacity depends, for a given frequency, principally upon the ground resistance. Fig. 1213 is a set of curves giving the values for 1875 kc., which is representative of the 1750- to 2050-kc. band. These curves are based on obtaining 75 per cent of the maximum possible increase in field strength over an antenna of the same height without top loading. An inductance coil of reasonably low-loss construction is assumed. The general rule is to use as large a capacity as the circumstances will permit, since an increase in capacity will cause an improvement in the field strength. It is particularly important to do this when, as is usually the case, the ground resistance is not known and cannot be measured.

The capacity of three geometric forms is shown by the curves of Fig. 1214 as a function of their size. For the cylinder, the length is specified equal to the diameter. The sphere, disc and cylinder can be constructed from sheet metal, if such construction is feasible, but the capacity will be practically the same in each case if a "skeleton" type of construction, using screening or wire networks, is used. The disc is probably the easiest to make, and has less wind resistance than either of the other two shapes. A disc of the openwork type is shown in Fig. 1216.

The bottom of the antenna is fed through a parallel-tuned circuit with one side grounded, as in Fig. 1212. The adjustment procedure is as follows: Starting with all of L shorted out, adjust the tuning to give a satisfactory transmitter input, using the method for parallel-tuned circuits described earlier in this booklet. Measure the field strength by means of a simple field-strength meter (vacuum-tube voltmeter and antenna), or by using a receiver, equipped with an S-meter, some distance away. Comparative readings only are needed. Next, move the tap on L to include a few turns, readjust the coupling and parallel-circuit tuning to maintain the same transmitter input, and note the new field strength. Continue this process until all of L is in the circuit. Plot a curve of relative field strength against turns in L; the curve should rise at first as the turns are increased until a critical point is reached where there is a sudden drop in field strength. Finally, set L a turn or two just below the maximum point.

Grounds

One of the chief problems of obtaining optimum performance on 1750–2050 kc. is that of getting a good low-resistance ground. The old standby

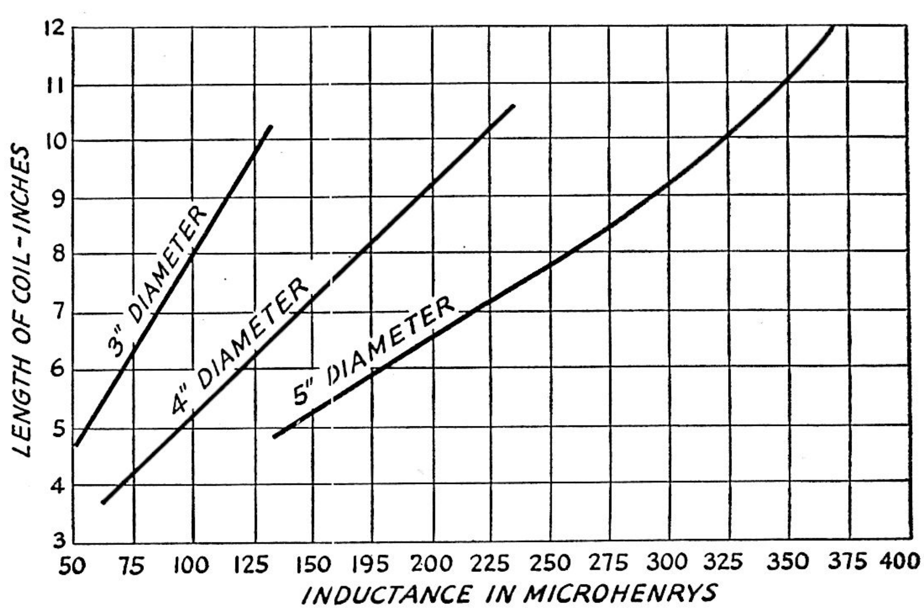


Fig. 1215 **— Inductance of coils of various diameters wound with No. 14 wire, 8 turns per inch.**

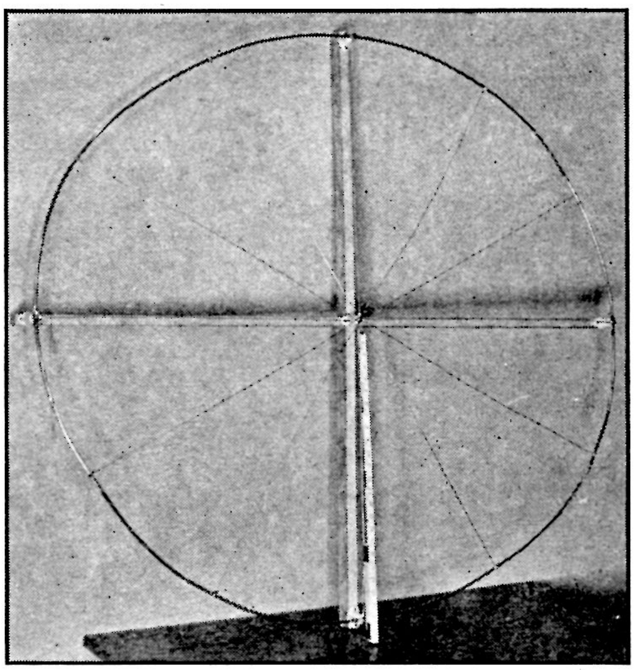


Fig. 1216 — **A skeleton disc for top loading, suitable for 160-meter operation. This disc, constructed with a 4-foot diameter outer rim of quarter-inch copper tubing and wire "spokes," has a capacity of approximately 40 μμfd. Connection should be made to its center.**

connection to a water pipe may serve in a pinch, but seldom results in the best possible antenna performance.

If circumstances make it necessary to use a water pipe for a ground connection, always select a cold-water pipe since it usually goes more directly to ground than the hot-water variety. Gas pipes never should be used because insulated joints are sometimes included in the piping. Wherever possible, the connection to the cold water piping should be made directly at the point where the pipe enters the ground; that is, on the street side of the water meter. The length of the ground lead necessarily must be taken into account in computing the total length of the antenna.

To make the connection, carefully clean the pipe by scraping and sand-papering. Fit on a clean ground clamp, make it good and tight, and make sure that the ground wire makes a good electrical connection to the strap. Solder it if necessary. The assembly may be rubber-taped to prevent oxidation if there is considerable dampness.

If it is impossible to reach the pipe at the point where it enters the ground, a connection of the type described above may be made to any convenient cold-water pipe as a secondary resort. In such cases, estimation of the effective length of the ground lead is difficult, since piping systems sometimes are rather extensive and hence have considerable capacity to ground. The effective length usually will be appreciably less than the actual length of the shortest path which might be traced back to ground along the piping, and in the case of a ground to a heating system may be quite small because of the large masses of metal at the radiators. In such cases the amount of loading for bringing the system to resonance must be determined experimentally.

A simple outdoor ground may be made by driving a length of 1-inch pipe (6 feet or more) into the soil. If possible, pick a spot where there is considerable natural moisture; the resistance will be less under such conditions. Four pipes arranged at the corners of a 10-foot square, all connected together at the top, will be considerably better than one.

A quite good low-resistance ground connection can be made as shown in Fig. 1217, if the space is available and some digging is permissible. The chemicals increase the conductivity of the ground in the vicinity of the grounding pipes or rods and thus reduce the losses from current flow.

Radial Grounds

The ideal form of ground is a series of conductors buried a foot or two beneath the surface, radiating like the spokes of a wheel from under the vertical part of the antenna, as shown in Fig. 1218. Its construction is beyond most amateurs, but it is mentioned here for the benefit of those who may have the space and a plow to cut the furrows which contain the ground conductors. Such a ground system not only reduces I^2R losses at the ground connection but provided it is made extensive enough also reduces losses in the ground in the immediate vicinity of the antenna.

Better results can be expected as the length of

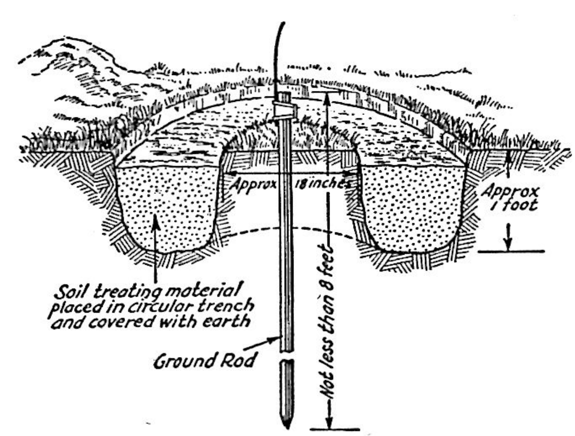


Fig. 1217 — **Ground system treated to increase conductivity. The circular trench is filled with rock salt, magnesium sulphate, or copper sulphate, put in dry and then flooded with water. After treatment, the trench is covered with earth. Fifty pounds of treating material so disposed will have a life of two or three years.**

the radial wires is increased. There is no necessity for a length greater than ½ wavelength, however, and even 1/10 wavelength will give satisfactory performance. This calls for a length of about 50 feet per radial, or a total diameter of about 100 feet for the ground system. As many radials as possible should be used.

The Counterpoise

The counterpoise is a form of capacity ground which is quite effective. Its use is particularly beneficial when an extensive buried system is not practicable, or when an ordinary pipe ground cannot be made to have sufficiently low resistance, as in rocky or sandy soils.

To work properly, a counterpoise must be large enough to have considerable capacity to ground, which means that it should cover as much ground area as the location will permit. No specific dimensions are necessary, nor is the number of wires particularly critical. A good form is an approximately circular arrangement using radial wires with cross-connectors joining them at intervals, as in Fig. 1219-A. There is no particular necessity for extending the radius of a circular counterpoise beyond a half wavelength, nor is it desirable that the lengths of the individual wires bear any particular relation to the wavelength. Rather, the intention is to have the counterpoise act as a pure capacity instead of exhibiting resonance effects. The capacity of the counterpoise will be approximately equal to that of a condenser consisting of two plates each of the same area as that of the counterpoise, with spacing equal to the height of the counterpoise above the ground.

The shape of the counterpoise may be made anything convenient; square or oblong arrangements are usually relatively easy to construct and will work satisfactorily. There should not be too few wires, but on the other hand separations between wires up to 10 or 15 feet will do no harm on fairly large counterpoises, and 5 to 10 feet on smaller ones. It is a good plan to join adjacent wires with jumpers at intervals about equal to the wire separation so that resonance effects will be minimized.

The height of the counterpoise is not particularly critical. It is best to construct it high enough to be out of the way, which ordinarily means from 6 to 10 feet above the ground. Remember that the height of the antenna is reduced by the amount of counterpoise height.

Satisfactory results have been secured with counterpoises simply lying on the ground, or with large screens of chicken wire similarly laid under the antenna. However, the best performance will be secured, as a general rule, when the counterpoise is insulated from ground. When in contact with the ground surface, the losses are likely to be higher because the counterpoise tends to act either as a poorly-conducting direct ground or as a leaky-dielectric condenser.

Antennas for Small Space or Height

The antennas discussed thus far have been designed to take advantage of the transmission characteristics of the 1715–2000-kc. band. A certain amount of height and ground space is essential for this purpose. Many amateurs, however, do not have the facilities available for the construction of even these simple forms and — particularly the city "cliff dwellers" — must simply string up a wire where some space available.

A vertical antenna must be quite clear of surrounding buildings, particularly those of steel

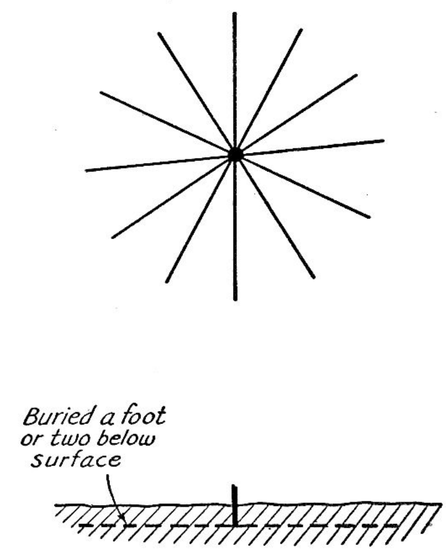


Fig. 1218 — **The best ground is a radial system of buried copper strip or heavy bare copper wire.**

construction, if good results are to be secured. If the height required for this purpose is not obtainable, then a horizontal wire must suffice. No useful purpose is served in erecting a vertical antenna between buildings which are going to absorb most of the radiated energy, or which perhaps re-radiate some of the energy to make the horizontal directional pattern of the antenna poor in the most desired directions of communication.

The fundamental requirement for an antenna which cannot be "designed" for 160-meter work is that it must be resonant at the operating frequency. That is, it must accept as much power as possible from the transmitter, even though the radiation of the power must be left more or less to chance. It is desirable to get the high-current portion of the antenna well away from buildings, if this is possible. The antenna may be bent, if necessary, to fit the available space, but the bends should be made with a view to their effect on the performance of the antenna as a radiator.

To make tuning easy, it is desirable that the antenna length be a multiple of a quarter wavelength, within reasonable limits. The ground lead

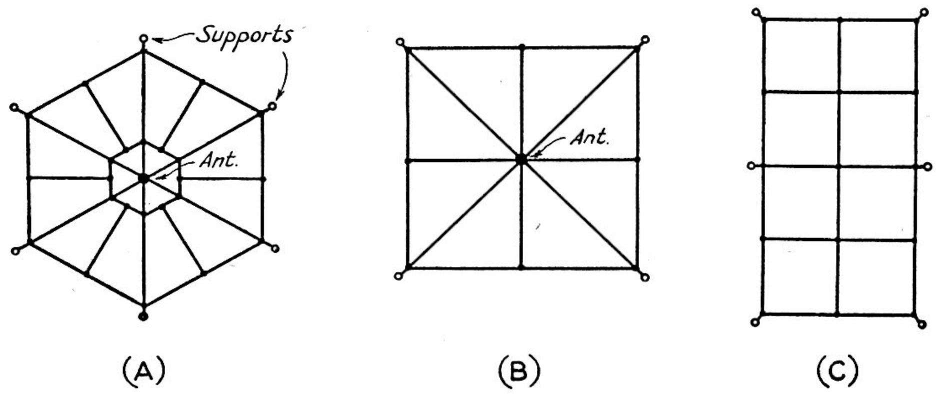


Fig. 1219 — Some suggested forms of counterpoise. Perfect symmetry is not essential, but it is desirable to extend the counterpoise as nearly as possible for the same distance in each direction from the antenna.

should be short, although as already explained the "length" of this lead may depend upon the grounding system. An antenna length of about 125 feet is the smallest recommended for working over the band, although shorter lengths can be loaded to the proper electrical length with a series inductance as shown in Fig. 1220-B. Provided the effective length of the ground lead is not too great (up to perhaps 35 or 40 feet) the system may readily be tuned to resonance with an adjustable coil and series condenser.

If no space sufficient to allow the antenna to be installed in a straight line is available, it may be bent to fit. The far end may be bent down, as shown in Fig. 1220-C, or even back on the antenna as in Fig. 1220-D. In the latter case at least ⅛ wavelength of the near end (the high-current part) should be unparalleled by the bent wire, since there is partial cancellation of the radiation from the folded-back part. Bends in horizontal directions may be made at several points along the wire, in cases where this is necessary, provided the angle between the bent portions is as large as possible. Try not to have less than a right angle bend, especially in the high-current portion of the antenna.

A disadvantage of the quarter-wave "random" antenna is the fact that the high-current end, which does the most radiating, is the end brought into the station. If there is at least one quite long straight stretch available for erecting the antenna, it is a better plan to make the antenna length such that the maximum current point comes at the middle of the straight section. This means that the wire should be a quarter-wave long (125 feet will be satisfactory) from the middle of the span to the far end, the necessary bends or folds to make up any excess length being made at the far end. The distance from the middle of the span to the transmitter can form the antenna length on that side or, alternatively, the wire length here may also be made a quarter wavelength, with bends or folds, to make a half-wave antenna and thus bring a voltage loop at the coupling point. The total length of the wire would be 250 feet in that case, and parallel-tuning would be called for at the transmitter.

Antennas of this type will work quite well, especially for moderate distances at night, even though they are not capable of the type of performance to be expected from a good vertical antenna. The chief points to be remembered are these: it is easiest to make the antenna take power if its length is near a multiple of a quarter wavelength, and that bends will not do a great deal of harm provided they are made in parts of the antenna where the current is small. The aim

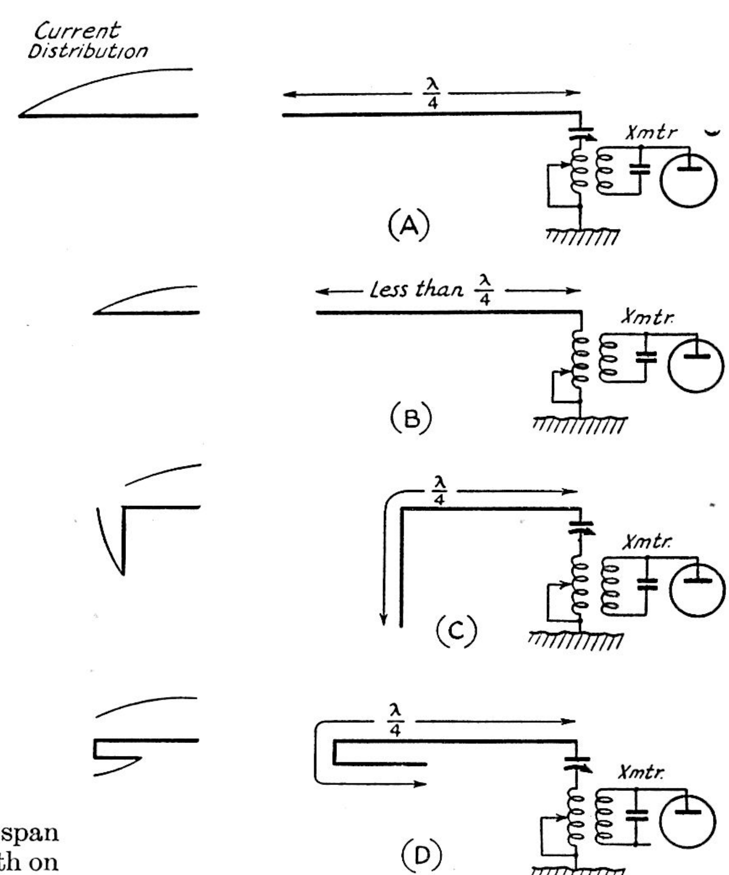


Fig. 1220 — Typical arrangements of a quarter-wave horizontal antenna, for installation where height or space are limited. Current distribution is shown for each case. A length of about 125 feet will be satisfactory.

should be to obtain the longest possible straight stretch for the high-current part of the antenna.

Alternative Coupling Methods

Other types of coupling systems may be substituted for those shown in this chapter, and Chapter 4 should be consulted for design and adjustment information on this subject. In the case of vertical antennas, particularly, where the base of the antenna may be some distance from the transmitter, it may be desirable to use a link line to a coupling circuit installed in a weatherproof box at the antenna. The feeder already described usually will be more convenient for this purpose, however, if its length fits in with the station and antenna layout.

The pi-section filter type of coupler is especially convenient with antennas shorter than a quarter wavelength, but should be tuned carefully as described in Chapter 4 to prevent harmonic radiation. A quarter-wave grounded antenna inherently discriminates against even harmonics, but this is not true of several of the systems described in this chapter since some of them approach or equal a half wavelength in total wire length.

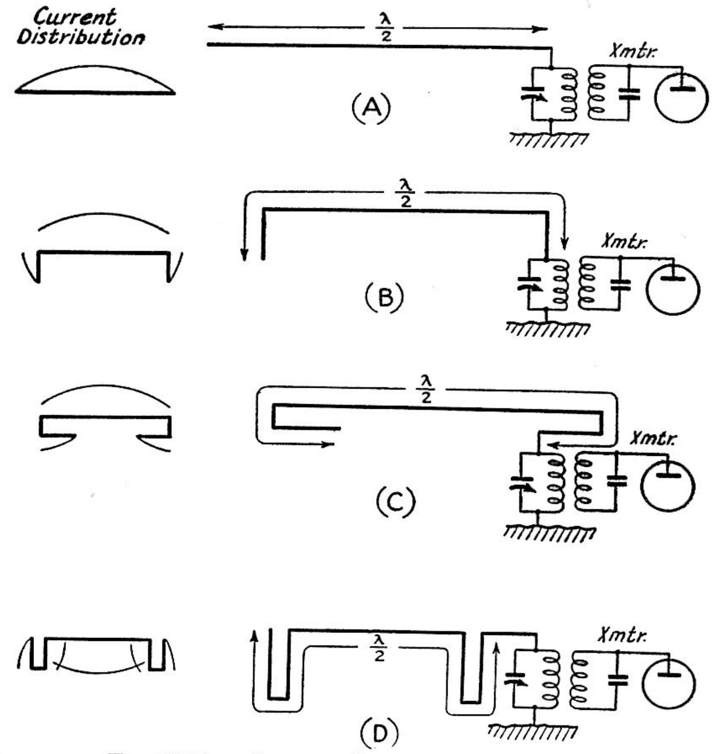
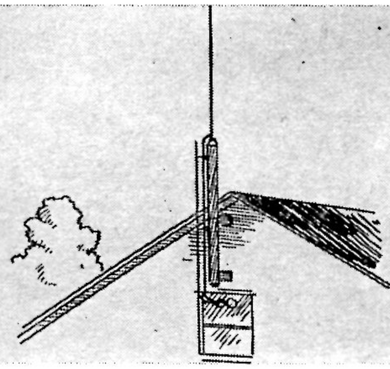


Fig. 1221 — Suggested methods of bending half-wave antennas for installation where space is limited. The points to watch out for in making bends are discussed in the text. The total wire length is about 250 feet for an antenna which can be used over the 1715–2000-kc. band.

When the antenna proper is located at some distance from the transmitter the two may be connected by means of a transmission line, either tuned or untuned, of one of the types described in Chapter 4. The principles of design and operation are exactly as set forth in that chapter. Probably in the majority of cases, however, the distance does not justify the use of such a line.



13. V.H.F. ANTENNAS

RADIATING SYSTEMS FOR 50 MC. AND HIGHER FREQUENCIES

VERY-HIGH FREQUENCY transmission and reception differs from lower-frequency work in that it is normally carried out by means of semi-optical transmission paths, and not by means of a sky wave. However, this does not mean that communication cannot be carried on over greater-than-sight ranges, and it is not uncommon for a well-equipped 50-Mc. station to have a consistent range of 40 to 50 miles and sometimes up to 100 miles. Contacts over distances greater than 50 miles are most frequent at night during the summer. The range on 144 Mc. is not as well established, but it is well beyond the optical range.

On the very-high frequencies, space-wave signals sent from a vertical antenna (vertically polarized) can only be received well on a vertical antenna, and signals from a horizontal antenna (horizontally polarized) are only received well on a horizontal antenna. Vertical antennas have been more common than horizontal ones on the very highs, although there is some evidence that the horizontally polarized waves provide better signals over long indirect paths.

It has been found that directive antenna systems will extend the operating range on 50-Mc. to such a degree that suitable communication can be carried on with a directive system where no signal could be put through with a simple antenna. Because of the small physical dimensions of antennas on the very-high frequencies, there is practically no reason why the v.h.f. antenna should not be a directive affair, except possibly in the case of mobile or portable work. Further, since the only radiation effective at these frequencies is at quite a low angle with respect to the ground, every effort should be made to concentrate the radiation as near to the horizontal as possible.

It is desirable to keep the Q of the v.h.f. antenna as low as possible, because the bands are proportionately wide and a high-Q system could not be made to take power except over a small portion of the band. "Q" relates simply to the sharpness of resonance of the antenna — a high-Q antenna is one of low radiation resistance and consequently has a sharp resonance characteristic. Close-spaced arrays with either driven or parasitic elements are to be avoided because of

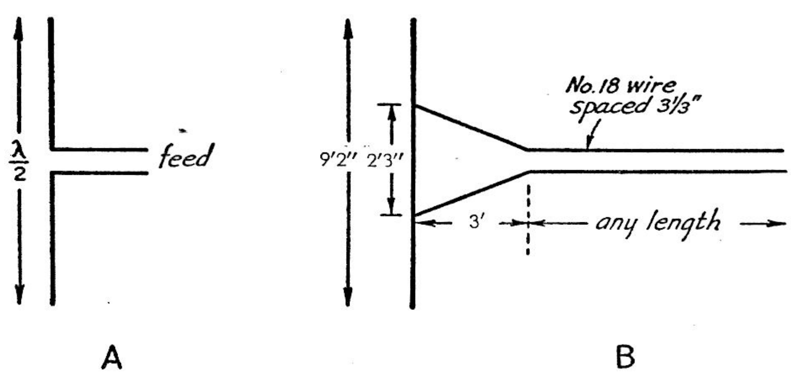


Fig. 1301 — Two methods of feeding a simple vertical radiator. That shown at A is with a tuned line, while B shows a 50-Mc. antenna with delta match. The dimensions are approximate and may be subject to some slight modification if it is found that coupling the feeders to the tank coil changes the tuning considerably. The 2-foot dimension may have to be changed slightly, to affect a better match, by tapping the line at slightly different points than shown in the sketch.

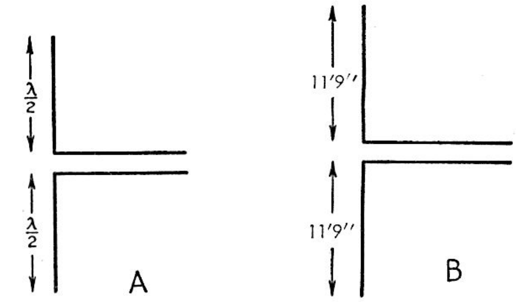


Fig. 1302 — Two types of collinear array. Either can be fed by a matching section and untuned line or with a tuned line.

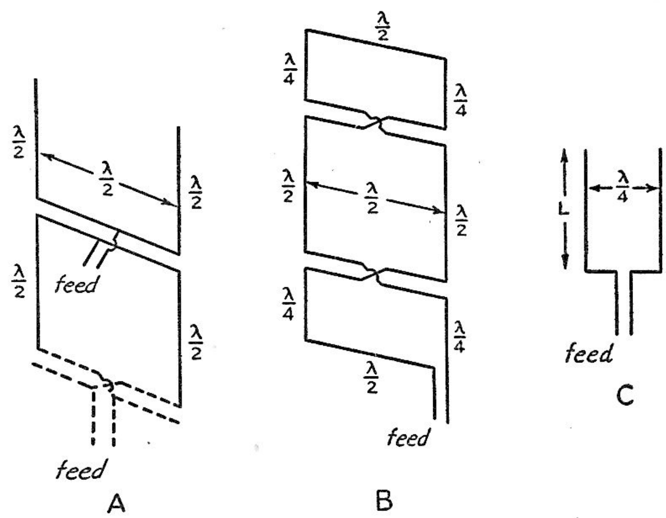


Fig. 1303 — The system shown at A is a vertical lazy H and can be fed at either of the points shown. B is a vertical Sterba. Both of these systems are bi-directional in the broadside direction.

The antenna shown at C is a simple end-fire system — L can be anything from a half-wave to 0.64-wavelength, with greater gain being obtained with the longer elements.

their high *Q*, and arrays with quarter-wave (or greater) spacing should be used if the array is to be effective over a wide frequency range.

The *Q* of a v.h.f. antenna can be lowered by using heavy wire or even metal tubing for the elements. Tubing of ½-inch or even 1-inch diameter is not too unwieldy for the elements of a 50- or 144-Mc. array, and it has the further advantage that the elements will be self-supporting, thus avoiding any possible loss due to poor insulation at the voltage loops.

It is particularly important that the v.h.f. antenna be placed in the clear and as high as possible. The field strength at a distance is dependent on the height of the antenna, and adding height is like getting more watts output from the transmitter.

Tuned lines can be used to feed the v.h.f. antennas, but untuned ones are recommended, used with suitable matching systems. If an open-wire line is used, either tuned or untuned, it should be carefully balanced as to length, and the spacing should not exceed 4 inches. Coaxial line is excellent for feeding v.h.f. antennas. Feed lines should be carefully balanced and made with small spacing to reduce the radiation from the line, since radiation can become quite serious at these frequencies.

Half-Wave Antennas

Even though directive systems are undoubtedly the most effective, good results can be obtained with simple half-wave antennas. They are normally used vertically, so that the radiation will be vertically polarized. Although it is more convenient to end-feed a vertical antenna, center-feed is preferable so that the feed line can be more readily balanced and remain balanced over the whole band. Tuned feeders can be run to the center of the radiator, or a delta match can be used with an untuned transmission line. Fig. 1301 shows suggested methods of feeding a half-wave radiator for the very-high frequencies.

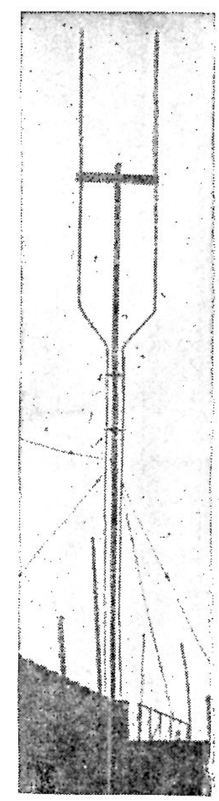


Fig. 1305 — A practical application of the principle of Fig. 1303-C. The two copper-tubing elements are curved-in and run down the pole to form part of the feed line. (W2JCR).

Simple Collinear Antennas

By placing a second vertical element above the first, a collinear antenna results which will give increased low-angle radiation and consequently greater signal strength. Fig. 1302 shows two collinear arrays, one with half-wave elements and one with the "extended double Zepp" (Chapter 8) elements. The latter, which gives some-

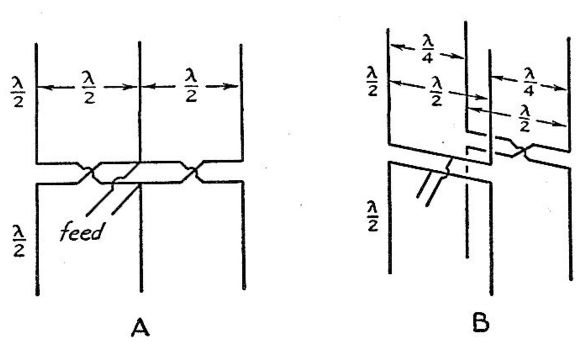


Fig. 1304 — The v.h.f. antenna at A is an extension of the lazy H that will give greater horizontal directivity. The system at B is a lazy H with parasitic reflectors spaced a quarter wavelength from the antenna, to give uni-directional radiation. The length of the parasitic elements should be adjusted for minimum back radiation (see Chapter 9).

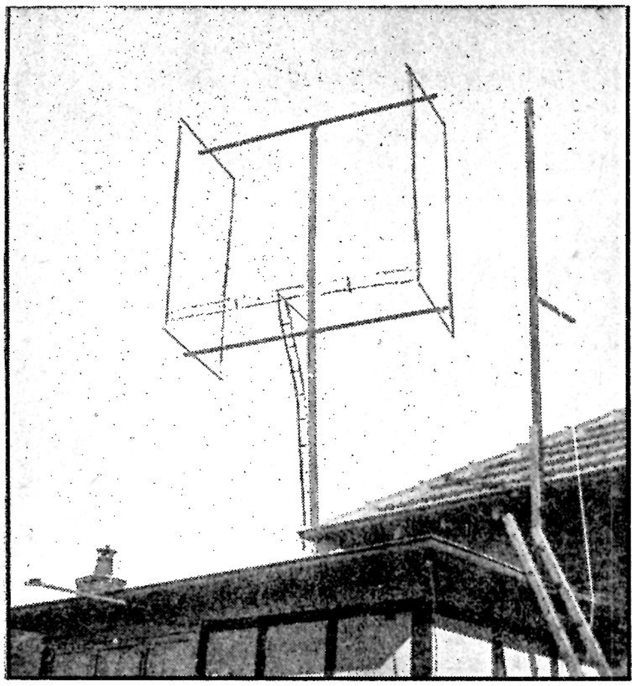


Fig. 1306 — **The simple rotatable 50-Mc. beam at VK2NO. Two half-wave broadside elements with two parasitic reflectors a quarter wavelength behind them.**

what more gain, has had considerable popularity on the very-high frequencies.

The elements can be made of copper tubing and supported on the side of a pole by stand-off insulators, or the antenna can be of wire suspended from a suitable support. Either tuned feeders or a matching section can be used, as explained in Chapter 8.

Length of Elements

The formula given for the length of a half-wave antenna on the lower frequencies must be modified somewhat for 50 Mc. and higher because of the greater "end effect" at these frequencies. The length of a half-wave element can be found from

$$\text{Length (inches)} = \frac{5540}{\text{Freq. (Mc.)}}$$

The length of a half-wave section of open-wire line is still

$$\text{Length (inches)} = \frac{5760}{\text{Freq. (Mc.)}}$$

For ready reference, typical lengths are tabulated in Table I for the 50- and 144-Mc. bands.

A quarter-wave radiator or open line will be half the length of the half-wave value.

A reflector element should be spaced a quarter wavelength back of the radiator and its length made the same as a half wavelength of open line for the same frequency.

TABLE I

Freq. (Mc.)	*Half-Wave Radiator*	*Half-Wave Open Line*
50.0	9′ 3″	9′ 7″
51.0	9′ ½″	9′ 5″
52.0	8′ 10½″	9′ 3″
53.0	8′ 8½″	9′ 1″
54.0	8′ 6½″	8′ 11″
144	3′ 2½″	3′ 4″
146	3′ 2″	3′ 3½″
148	3′ 1½″	3′ 3″

Phased Arrays

Several types of phased arrays particularly suited to v.h.f. work are shown in Figs. 1303 and 1304. Tubing elements can be used with a simple wooden framework to support them at their centers, or wire elements can be used, strung in a box-like wooden framework or simply hung from a rope. The various arrays can be adjusted, if it is found to be necessary, by the methods outlined in Chapter 8.

The end-fire antenna of Fig. 1303-C is par-

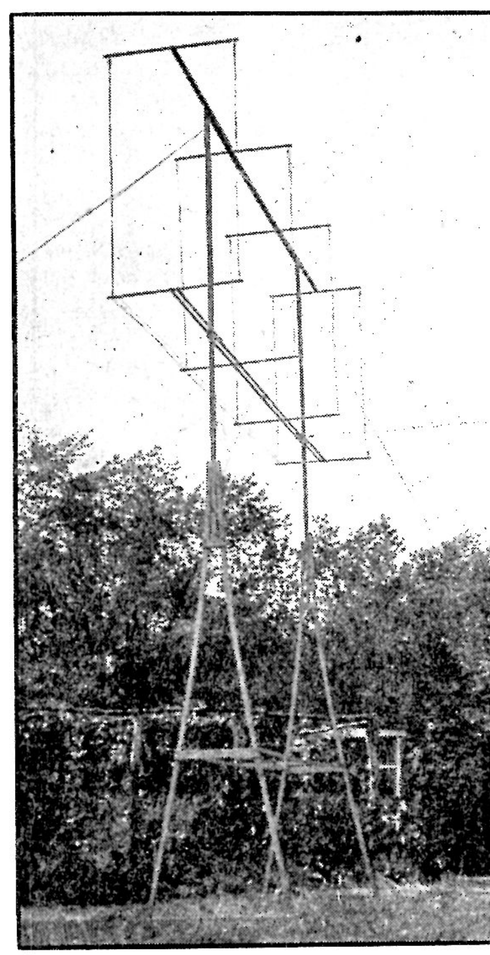


Fig. 1307 — **An elaboration of the antenna shown in Fig. 1306. This installation, which cannot be rotated, uses 4 half-wave elements in a broadside array with four parasitic reflectors a quarter wavelength away. (W1HRX).**

ticularly simple to construct by supporting the two vertical elements of copper tubing from the top of a single vertical pole and running the feed line down the pole, as shown in Fig. 1305. If the pole can be made to rotate 90 degrees, full advantage can be taken of the directivity of this simple system. While this type of antenna will not show as sharp a lobe as the broadside type of array, it will show a very definite null which is useful in reducing QRM in congested areas. Its pattern is similar to a figure "8," with the nulls broadside to the plane of the elements.

When the antennas are constructed as shown in the drawings the polarization will be vertical. For horizontal polarization the elements should be mounted horizontally. In all cases except Fig. 1303-C this simply means that the drawings should be rotated 90 degrees; the antenna of Fig. 1303-C should be mounted so that the plane containing the two elements is parallel to the ground.

Parasitic Arrays

Directive arrays with parasitic elements are frequently used at very-high frequencies, particularly in the 50-Mc. band. As stated before, the spacing between elements should not be too close, otherwise the antenna will be useful only over a small portion of the band. A horizontally polarized antenna of this type is readily rotatable by using construction and rotating means as described in Chapter 17. Half- to one-inch tubing should be used for the elements, for mechanical reasons as well as to lower the losses and *Q*.

A popular antenna of this type is the three-element beam, with quarter-wave spacing between elements. In other respects it is similar to the three-element beam described in Chapter 9, and the elements may be cut to size using the same formulas. The feed system shown in Fig. 907-B is recommended. Final adjustment of element lengths by means of field-strength measurements may be carried out as described in Chapter 9.

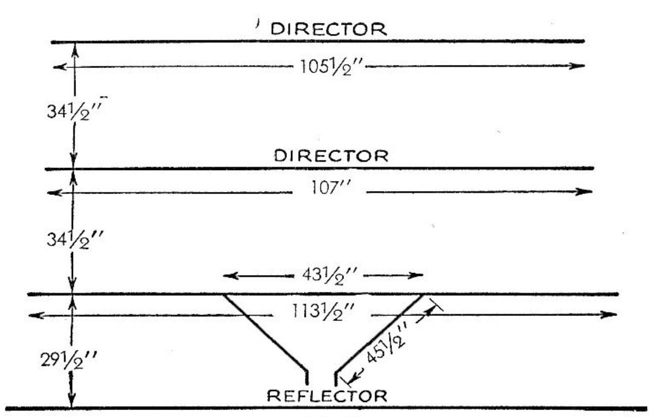


Fig. 1309 — W6QLZ's 4-element 50-Mc. array. Delta shown is for 4-inch spaced line. For 2-inch line use 33 inches with 36-inch sides. Dimensions are for 50 Mc.

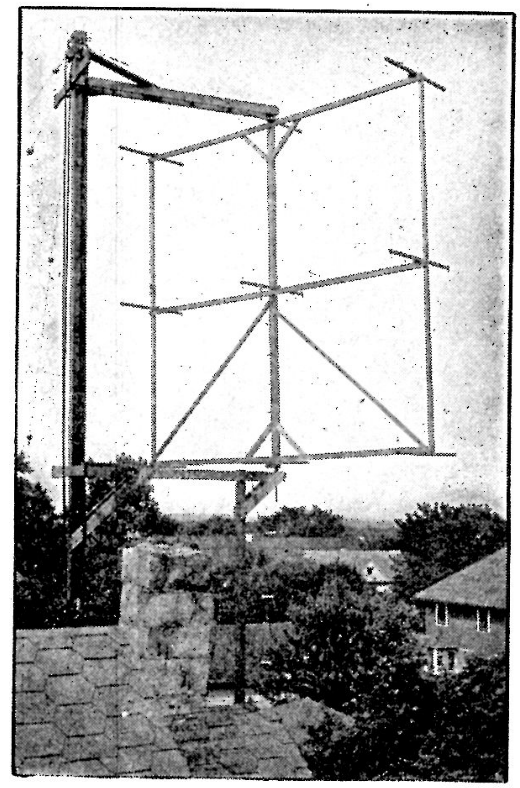


Fig. 1308 — The 144-Mc. array at W2CUZ uses two collinear sets of three broadside driven elements, backed by parasitic reflectors. This type of construction allows rotation of the system.

A very successful four-element antenna using element spacing of less than one-quarter wavelength is shown in Fig. 1309. The larger number of elements and relatively close spacing make this system more selective than the other directive antennas described. For other frequencies than that indicated (50 Mc.) the element lengths and spacings should be in inverse proportion.

The Coaxial Vertical Radiator

If only a single vertical radiator can be used, and it is necessary to run the line for 30 feet or more, serious thought should be given to the use of coaxial-line feed. It is doubtless the best method of feeding a simple antenna, as testified to by the many police and other v.h.f. installations where no horizontal directivity is desirable but where a maximum of efficiency is required. Although it is possible to run the coaxial line directly to the center of the antenna with no modifications, it is much better to use the method shown in Fig. 1310. This amounts to feeding the antenna at the center with coaxial line but short-circuits the possibility that the whole coaxial line may act as a vertical radiator, resulting in high-angle radiation and loss of signal strength. The wire extends a quarter wavelength above the juncture of the line and the outer sheath. Because there is no field in the inside of the sheath, the coaxial line can run up through it with no harmful effects. This antenna is used in many amateur and commercial installations and always results in increased signal strength over that obtained with a single half-wave antenna and any other type of feed.

The coaxial line should have an impedance of around 70 ohms (see Chapter 4), although this is not critical and value up to 120 ohms can be used without serious mismatch.

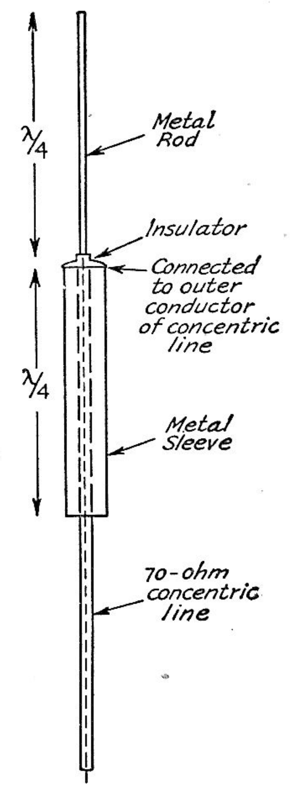


Fig. 1310 — **The coaxial vertical radiator is one of the most efficient methods for feeding a vertical half-wave antenna. The wire above the sheath is a quarter-wave-length long, and the sheath is also a quarter-wavelength long. The sheath and wire combine to form a half-wave radiator, and the concentric line feeding the system works to best advantage because of the way it is introduced. If desired, a horizontal ground screen or radial-wire counterpoise can be installed just below the bottom of the sheath (but not connected to it) to increase low-angle radiation. The entire system should be mounted as high as possible.**

An open-wire line may be kept out of the immediate field of a vertical center-fed dipole by a similar method in which the section of line within the shielding portion of the antenna is designed to form a matching section between the line and the antenna. In the concentric antenna shown in Fig. 1312, the section is designed to have a surge impedance of 160 ohms, which will provide a match to a 400-ohms line consisting of No. 12 wire spaced 1¼ inches.

The "J" Antenna

The "J" antenna, so called because it resembles the shape of the letter "J," is a half-wave vertical element end-fed by a quarter-wave matching stub, as shown in Fig. 1313. It is intended for use with two-conductor open-wire transmission lines, a suitable value of line impedance being 600 ohms. Since the lower end of the matching stub is at zero potential with respect to earth a direct ground may be made to this point, using a connecting wire of any convenient length, without disturbing the operation of the antenna. Such a ground furnishes a convenient method for obtaining continuous lightning protection.

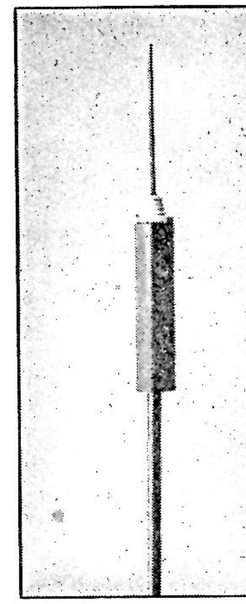


Fig. 1311 — **A practical coaxial vertical radiator, used at W6-GPY on 325 Mc.**

Adjustment of the system, together with the method of finding the proper point along the matching stub at which to attach the line, is as described in Chapter 4. This type of antenna, like the center-fed systems described earlier, is used when a non-directional pattern is desired.

Folded Dipole

An arrangement which combines the radiation characteristics of a half-wave antenna with the impedance-transforming properties of a quarter-wave line is shown in Fig. 1314. Essentially, it consists of a center-fed half-wave antenna with another half-wave element connected directly between its ends. The spacing between the two sections should be quite close — not more

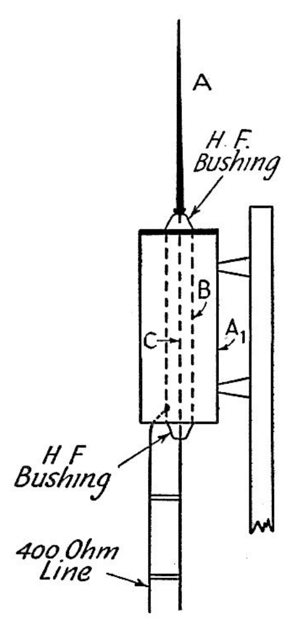


Fig. 1312 — **Coaxial antenna with matching section for 400-ohm line. *A* is a ¼-wave rod or wire and *A1* a ¼-wave section of 3-inch rain spouting. The matching section is made up of *B*, a 2-ft. section of 1-inch thin-wall conduit, and *C*, a piece of No. 12 wire. — W8SR.**

♦

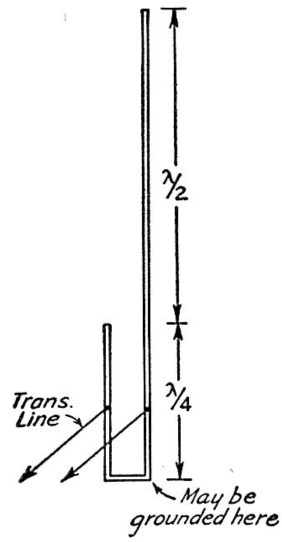


Fig. 1313 — **The "J" antenna. It is usually constructed of metal tubing; frequently with the ¾-wave vertical section shown and extension of a grounded metal mast. The stub may be adjusted by a sliding shorting bar.**

than a small percentage of the wavelength. As used at very-high frequencies, the spacing is of the order of an inch or two with elements constructed of metal tubing.

The impedance at the terminals of the antenna is four times that of a half-wave antenna, or nearly 300 ohms, when the antenna conductors are all the same diameter. A 300-ohm line will therefore be non-resonant when the antenna is connected to its output end. The standing-wave ratio with a 600-ohm line will be only of the order of 2 to 1.

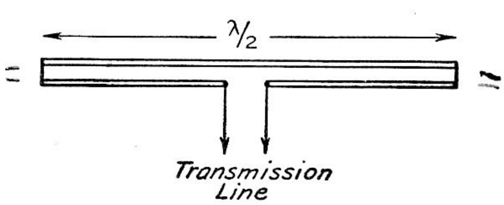


Fig. 1314 — **Folded dipole for increasing the value of impedance at the feed point.**

The total length around the loop formed by the antenna may be calculated by the following equation:

$$\text{Length (feet)} = \frac{955}{\text{Freq. (Mc.)}}$$

or,

$$\text{Length (inches)} = \frac{11{,}450}{\text{Freq. (Mc.)}}$$

An almost exact match between the antenna and a 600-ohm line may be obtained by adding a third wire to the doublet, as shown in Fig. 1315.

Corner Reflector Antenna

A type of antenna system particularly well-suited to the v.h.f. ranges about 50 Mc., is the "corner" reflector shown in Fig. 1316. It consists of two plane surfaces set at an angle of 90 degrees, with the antenna set on a line bisecting this angle.

TABLE II

Frequency Band	*Length of Side*	*Length of Reflector Elements*	*Number of Reflector Elements*	*Spacing of Reflector Elements*	*Spacing of Driven Dipole to Vertex*
235–240 Mc. (1¼ meters)	47¾″	29½″	20	4¾″	24¾″
144–148 Mc. (2 meters)	6′ 6″	4′	20	8″	3′ 4½″
144–148 Mc. (2 meters)	5′ 10″	4′	16	8″	2′ 8½″
50–54 Mc. (6 meters)	18′ 8″	11′ 8″	20	1′ 10½″	9′ 8″
50–54 Mc. (6 meters)	15′	11′ 8″	16	1′ 10½″	7′ 9″

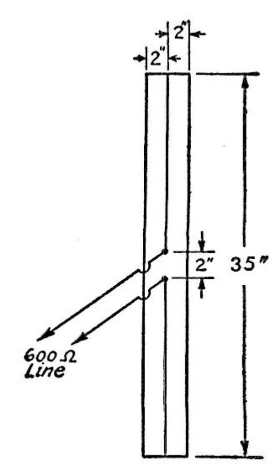
Table II. — **Dimensions of square-corner reflector for the 235-, 144-, and 50-Mc. bands. Alternative designs are listed for the 144- and 50-Mc. bands. These designs, marked (*), have fewer reflector elements and shorter sides, but the effectiveness is only slightly reduced. There is no reflector element at the vertex in any of the designs.**

The distance of the antenna from the vertex should be 0.5 wavelength, but some compromise designs can be built with closer spacings (see Table II). The plane surfaces do not need to be solid, and can most easily be made of wire or metal rod elements spaced about 0.1 wavelength apart. The elements do not have to be connected together electrically.

The resistance of the antenna is raised when a corner reflector is used. The transmission line should be run out at the rear of the reflector to keep the system as symmetrical as possible and thus avoid any unbalance. Two simple antennas which can be used with the corner reflector are shown in Fig. 1317.

The corner reflector can be used with the antenna either horizontal or vertical, and the plane of polarization will be the plane of the antenna. The relative positions of the antenna and reflector must remain the same, however, which means that a support for both horizontal

Fig. 1315 — **Three-wire folded doublet antenna for matching a 600-ohm line. The three conductors are connected together at the ends as indicated. They may be of wire, rod or tubing, and can be mounted on stand-off insulators on a wooden support.**



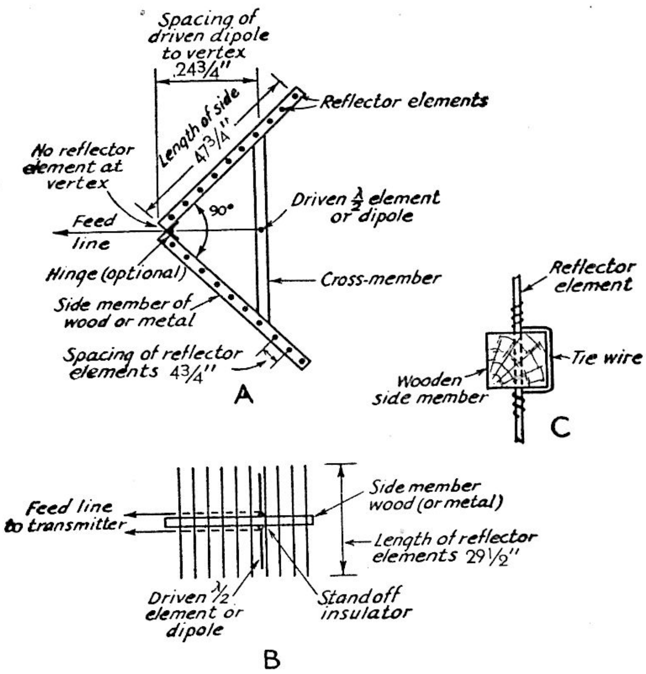


Fig. 1316 — **A corner reflector antenna system with grid-type reflector. The reflector elements are stiff wire or tubing. The dimensions shown are for 235 Mc. See Table V for dimensions for 144 Mc. The gain of the system is close to 10 db.**

and vertical polarization would require a means for rotating the reflector about its horizontal axis.

The corner reflector antenna will give a gain of nearly 10 db. over a simple half-wave antenna. It has excellent front-to-back and front-to-side ratios, these being of the order of 35 and 25 db., respectively, in a typical case. It is also quite free from secondary lobes of appreciable amplitude.

Feeding the V.H.F. Antenna

As mentioned before, close spacing and balance are important factors in v.h.f. feeder operation so that the radiation from the line will be minimized. For this reason, the coaxial line is doubtless the best type of feed for the v.h.f. antenna, but the open-wire line is quite effective if care is taken in its construction. Low-impedance twisted pair lines, and solid rubber insulated concentric lines are not to be recommended, although they will not be bad for short distances of less than a wavelength. The desirable type of coaxial line is one using ceramic beads or some other good material for insulation.

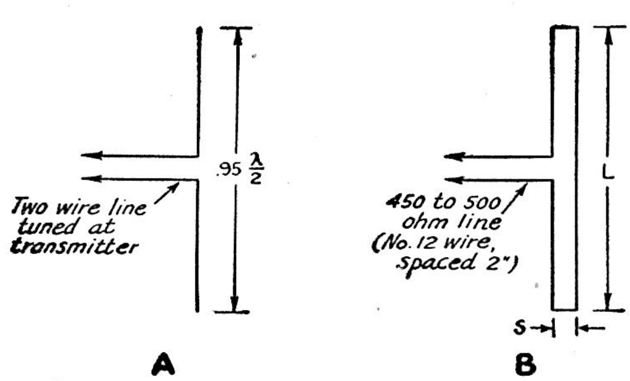


Fig. 1317 — **Dipoles suitable for use with the corner reflector antenna system. The length *L* is 24 inches for 235 Mc., *s* = 0.95 inch for the same band.**

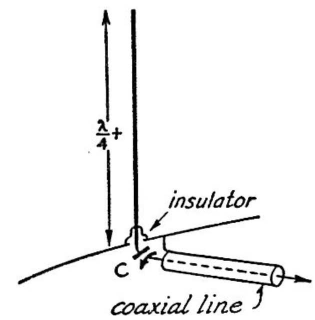


Fig. 1318 — **Matching the concentric line to a vertical quarter-wave radiator is expedited by using a condenser C in series with the inner conductor. The radiator is made slightly longer than a quarter wavelength and the condenser tunes out the reactance. C can be a 50-μμfd. midget variable.**

If a matching section is used, it should be symmetrical and loaded on both sides, to maintain current balance in the matching section. If, for example, a single vertical antenna is fed at the bottom by a quarter-wavelength matching section, any radiation from the matching section (due to current unbalance) will combine with the radiation from the antenna to result in raising the vertical angle of radiation. This is less likely to occur if the vertical half-wave antenna is fed at the center. Less trouble with feeder radiation will be experienced with any symmetrical system, which simply means a system with equal amounts of wire each side of the end of the feeder.

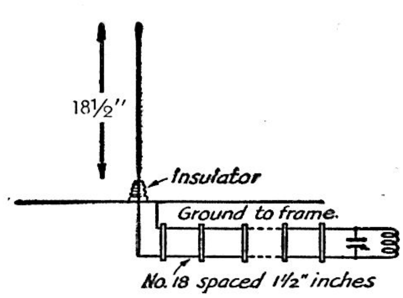


Fig. 1319 — **Quarter-wave antenna system for 144 Mc. mobile work.**

Antennas for Mobile Work

A common type of antenna used with 50-Mc. mobile installations is a quarter-wave grounded vertical fed by a concentric line. The antenna should be so placed on the car that it is as high and as much in the clear as possible.

It is difficult to examine the concentric line for standing waves and other means of adjusting the length of the antenna must be used. Further, the impedance of a quarter-wavelength antenna is around 40 ohms, a value which cannot be matched by most concentric lines. However, the concentric line can readily be made to have a value of 70 to 100 ohms, and it can be used to feed a quarter-wavelength antenna as follows: A series condenser is used between the inner conductor of the concentric line and the bottom of the quarter-wave radiator, as shown in Fig. 1316. The antenna is made longer in small steps and the condenser adjusted until the concentric line introduces a minimum of reactance at the transmitter (shows the least detuning effect on the tank circuit). The method is simply to vary the length of the radiator until it shows an impedance near that of the line and then to cancel the reactance by the series condenser. Some mismatch can of course be tolerated, but the system just described will give a closer match.

When the transmitter is installed close to the antenna, a tuned feeder, either a quarter or half wavelength long, can be used to good advantage. With a quarter-wave rod antenna, one feed wire should connect to the bottom of the rod and the other to the car frame near the antenna insulator, as shown in Fig. 1319. The feeder should be approximately a half wave long in such case. With a half-wave antenna regular Zepp feed can be used, one wire being connected to the bottom of the antenna and the other being left free. With the latter type of feed the line should be approximately a quarter wave long.

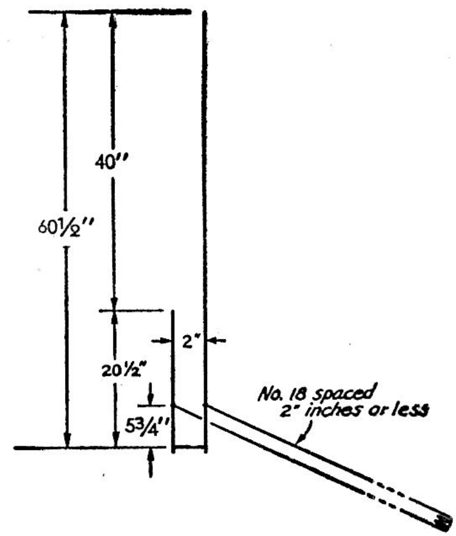


Fig. 1321 — **The dimensions of the window "J" antenna shown in Fig. 1320.**

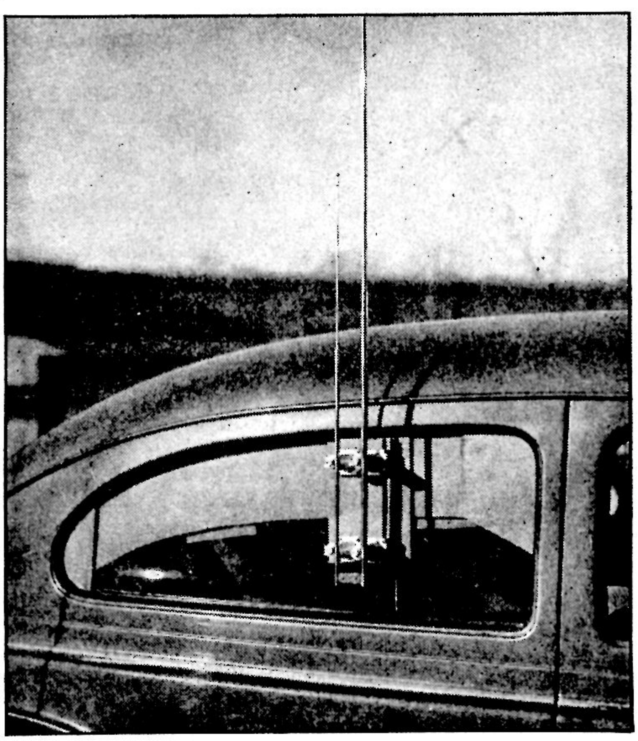
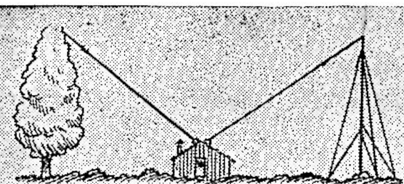


Fig. 1320 — **An antenna for 144 Mc. mobile operation can be mounted easily in the window of a car, allowing the radiator proper to be placed above the roof of the car. This installation is a J-type antenna — the dimensions are given in Fig. 1319.**

The method of mounting the antenna rod on an insulator is the one generally used. The rod may be the adjustable "buggy whip" type used for car broadcast receivers; the flexibility is distinctly advantageous if the antenna is likely to strike any obstructions while the car is moving. If other considerations permit, the best place to mount the antenna is in the middle of the car roof, when the car has a metal top. The top forms a "ground" of good conductivity and improves the performance of the antenna. In any event the radiating portion of the antenna should project above the top, even if the antenna is mounted on the baggage compartment or bumper. It is usually found that an antenna mounted alongside the car body, but projecting above the metal top, will transmit best in the direction over the top of the car.

A convenient method of mounting which does not involve drilling holes in the metalwork of the car is shown in Fig. 1320. The antenna, a "J" type, constructed as shown in Fig. 1321 (the dimensions given are for 144-Mc. operation), is mounted on a piece of plywood which fits in the rear window frame. It is held in place by turning the window up against it tightly. Wooden pieces nailed to the sides of the plywood form a sort of groove which fits around the ends of the window and prevents the assembly from falling out.



14. SPECIAL ANTENNA SYSTEMS

FLAT LINES FOR TWO BANDS—THREE-FEEDER ANTENNAS—TRANSMITTING LOOPS—DUMMY ANTENNAS

Two-Band Antenna With Non-Resonant Feed

An antenna system in which the 600-ohm transmission line is quite accurately matched on both fundamental frequency and second harmonic, devised by W5FDQ, is shown in Fig. 1401. The antenna operates as a center-fed half-wave on the fundamental, and as two half waves in phase on the second harmonic. The line is matched to the antenna through an open-ended stub. Fig. 1402 shows the voltage distribution on stub and antenna on both bands. The stub is a quarter wave long at the fundamental frequency, or a half wave at the second harmonic.

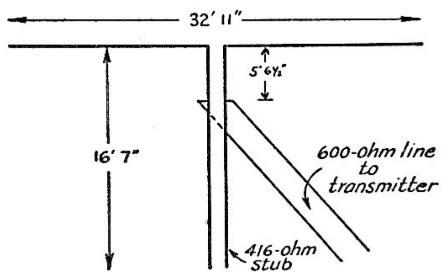


Fig. 1401 — **A two-band antenna system using a 600-ohm non-resonant line. The line is correctly matched on both bands, without readjustment when going from one band to the other.**

In Fig. 1402-A, point D is ⅙ wavelength from the voltage loop B, and D is also ⅙ wavelength from voltage loop A in Fig. 1402-B. Thus this one point represents corresponding conditions, electrically, on both bands. Furthermore, the impedance relations are such that the impedance looking into the stub will be 600 ohms on both bands when the stub impedance is made the geometric mean of the antenna impedances at point A on the two bands. With approximate impedances of 72 ohms for the center of the half-wave antenna and 2400 ohms for the two half waves in phase, the required stub impedance becomes 416 ohms. A line having this impedance can be constructed with No. 10 conductors spaced 1.65 inches. Special spreaders to give this spacing may be constructed from insulating material such as bakelite, cellulose acetate, or celluloid.

The antenna may be constructed quite simply by following the dimensions given in Fig. 1401. The line is attached to the stub at a point one-third the length of the stub from the antenna. No in-the-field adjustments should be needed. For use on 7 and 14 Mc., all dimensions should be doubled. The system will work satisfactorily over an entire amateur band, the dimensions given being for the center of the 14-Mc. band.

The "Q" Beam

The "Q" beam is an end-fire array, using quarter-wave matching sections to couple into a 600-ohm line, and capable of working on two adjacent bands without necessity for rematching the feeders when the band is changed. It is shown in Fig. 1403. Using center-fed half-wave elements spaced 0.2 wavelength apart, the impedance at the center of each element is 21 ohms, approximately. Since the two "Q" sections are in parallel at the line end, each one is made to have a characteristic impedance which will match 21 ohms to twice the line impedance, 1200 ohms. The required matching section impedance, as found by the formula in Chapter 4, is 158 ohms. A line of this impedance may be constructed by using half-inch diameter conductors with 1-inch center-to-center spacing. The connections at the top must be made as shown for correct element phasing.

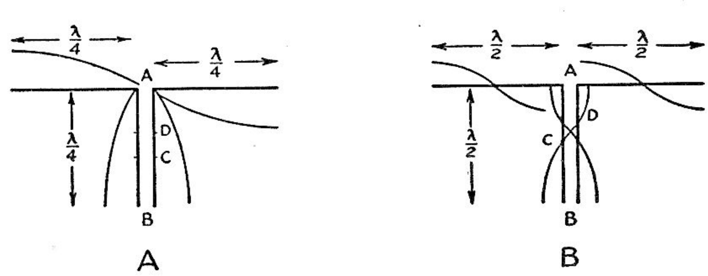


Fig. 1402 — **Voltage distribution on the antenna and matching stub, using the antenna system of Fig. 1401, on two bands.**

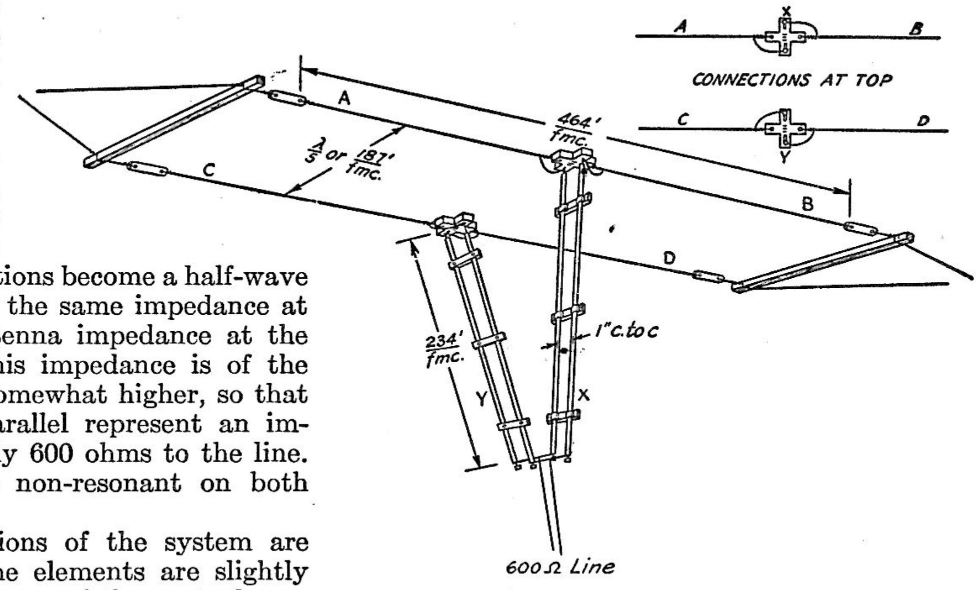


Fig. 1403 **— The "Q" beam antenna, an end-fire array which can be used on two bands with the line non-resonant on both.**

On twice the fundamental frequency each element represents two collinear half-waves in phase. The matching sections become a half-wave long, so that they show the same impedance at the line end as the antenna impedance at the point of connection. This impedance is of the order of 1200 ohms or somewhat higher, so that the two elements in parallel represent an impedance of approximately 600 ohms to the line. Thus the line operates non-resonant on both bands.

The essential dimensions of the system are shown in Fig. 1403. The elements are slightly shorter than normal because of the mutual coupling, but the difference is small. At the point where the matching sections join the line the connections should be quite short. Providing the dimensions are carefully followed it should not be necessary to make any adjustments except, if desired, to check the current in the line for standing waves. If these occur, it may pay to adjust the height of the antenna to bring the radiation resistance to the right value.

The gain of the antenna is approximately 4 db. on the fundamental and 6 db. on the second harmonic.

Three-Feeder Systems

By the rather simple stunt of using an extra feeder wire it becomes possible to shift the directivity of certain types of antennas. For instance, the center-fed system of Fig. 1404 (two half-waves in phase) shows maximum radiation broadside to the wires, as given in Fig. 803, Chapter 8. The same length of *continuous* wire becomes a full-wave antenna at the same frequency, giving the pattern of Fig. 603, Chapter 6. The feeder can be moved to the center of such an antenna, as shown at C, without changing the operating conditions materially; the feed point is still a voltage loop, so the feeders are still of the "Zepp" type, although the two halves of the antenna are fed in parallel. However, the phasing is such as to give full-wave operation.

In practice, the change over from one type of operation to the other can be made by using three feeder wires, the connections being made as shown at D and E. Tuned feeders are necessary. The same type of tuning at the transmitter end — series or parallel, depending upon the feeder length — will be used in both cases, since with either method of connection there is a voltage loop at the antenna end of the line. Since the terminating impedances are different, however, the feeder currents will not be quite the same in either case. The antenna can be used on three bands or more, the connections at D being used for the band on which the total length of the antenna is a half-wave, and either connection being used on higher-frequency bands. A simple switching arrangement can be used to shift from one to the other. One advantage of the system as shown is that the null which occurs broadside to a full-wave antenna is changed to a maximum when the feeder connections are shifted, an effect which immediately becomes apparent when the antenna is used for reception as well as transmission.

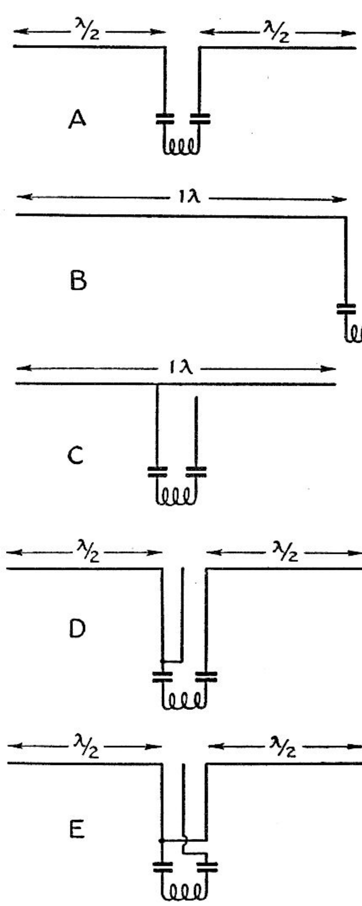


Fig. 1404 **— Center-fed antenna with three feeder wires for shifting directivity.**

Another three-feeder system is shown in Figs. 1405 and 1406. In this case two separate half-wave antennas are used at right-angles to each other, with three feeders brought down so that either can be used alone or both can be used together. The three directions of maximum radiation shown in Fig. 1405 thus become possible. "North" in the drawings is simply a convention, of course; the antennas may run in any direction so long as they are approximately at right angles to each other. In this system it is desirable to space the feeder wires triangular fashion so that energy pick-up by the unused feeder will be minimized. The same system also can be used with the antenna of Fig. 1404, although the necessity for it does not exist because all three wires are used in all cases. The third feeder can be fastened to the center of the conventional six-inch spacer, between the other two wires, and held in place by tightly-twisted lengths of wire about the feeder and spacer. Or other methods of spacing readily can be devised.

Long Antenna Without Nulls

A horizontal antenna a wavelength or more long shows nulls at one or more points in its directive pattern, as described in Chapter 6. Although the end null is effective only at zero horizontal angle, so that in practice it can be considered to be simply a depression in the pattern rather than a null, those at the sides are real at any vertical angle considered. These nulls are sharp and sometimes masked by local effects and slight changes in wave direction, but in general represent "hard-to-work" directions.

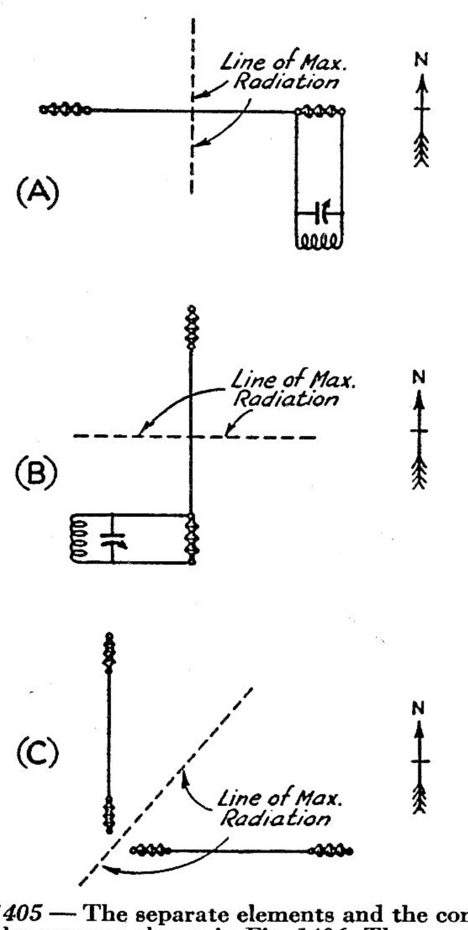


Fig. 1405 — **The separate elements and the combination of the antenna shown in Fig. 1406. Three optimum directions may be secured.**

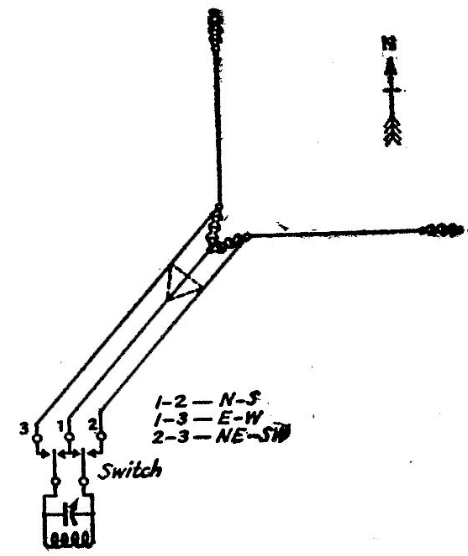


Fig. 1406 — **The three-feeder double antenna system. Either half-wave antenna may be used alone, or both may be used together.**

The several benefits of using a long wire (slight gain, operation on several bands) can be secured by using the principle illustrated in Fig. 1407. The one-wavelength wire has a broadside null, which is overcome by the broadside radiation from the half-wave wire attached to the other side of the feeder. The approximate pattern of such a system is as shown in Fig. 1408, for a wave angle of 15 degrees. In its optimum direction, the system shows a small gain of the order of 3 db., over a single half-wave. Off the ends of the wire it is about equivalent to a full-wave antenna alone.

A system of this type can be made more useful by using three feeder wires so that several an-

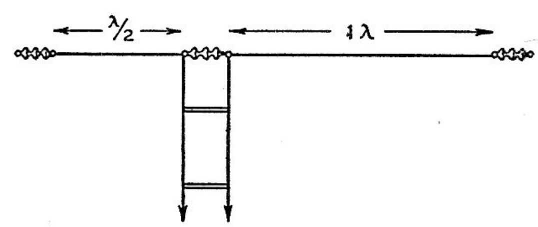


Fig. 1407 — **In this antenna, the half-wave section fills in the broadside null of the full-wave section.**

tenna combinations are available. Thus, as shown in Fig. 1409, either wire can be used alone, or the two can be combined to form either a 3/2-wavelength antenna or the system just described. If the antenna is designed for 14 Mc., the right-hand wire alone can be used as a half-wave on 7 Mc. On 28 Mc. any of the four combinations can be used to give various directive effects. The same system can also be used on 3.5 Mc. even though it is slightly short. Tuned feeders are necessary in all cases.

Directive Antennas With Bent Elements

The possibility of bending antennas which are too long to fit the available space has been men-

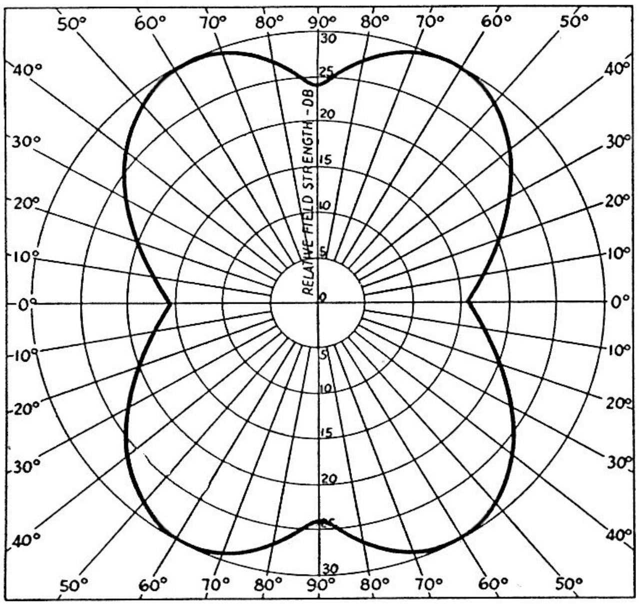


Fig. 1408 — **Directive pattern of the antenna of Fig. 1407.**

tioned in Chapter 12. The same principle can be applied to the simpler directive systems, provided the proper spacing between elements can be maintained. The field strength will be somewhat less than from a system using full-length elements, but not greatly so.

Driven end-fire arrays such as the "W8JK" using two elements, and parasitic arrays with two or three elements are most readily adapted to this

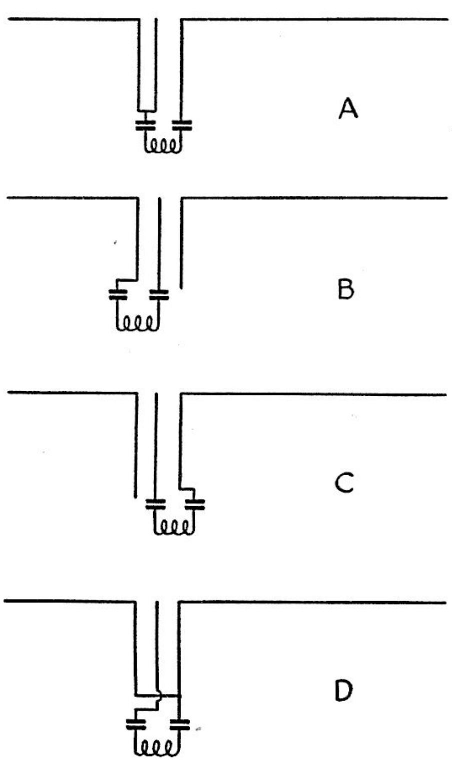


Fig. 1409 — **Three feeders may be used with the antenna of Fig. 1407 to obtain various directive effects and multi-band operation.**

type of treatment. Some typical arrangements are shown in Fig. 1410. If possible, the ends should be bent in a direction at right angles to the plane of polarization of the antenna so that the antenna's directivity will be least affected. If the ends must be horizontal, it will be better, if the construction is feasible, to bend the ends in the form of a transmission line so that radiation from the end sections will be cancelled to the fullest possible extent.

At least half the antenna should be left for primary radiation purposes, so that the bent ends

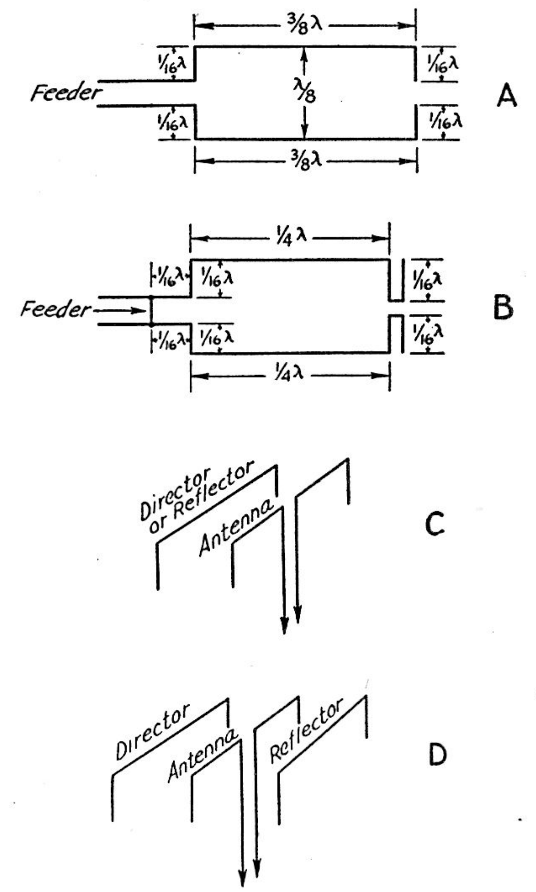


Fig. 1410 — **Several types of simple directive systems using bent antenna elements to conserve space.**

should be not more than 1/8 wavelength long. By this means a 14-Mc. rotary can be constructed to occupy little more space than a 28-Mc. job of ordinary construction. The antenna elements should be made of tubing to keep them rigid, particularly with close spacing and in systems with the ends folded back on themselves. In the latter case there is a further reduction in radiation resistance beyond that normally to be expected with close-spaced elements, so that particular attention should be paid to reducing standing waves on the transmission line. The methods described in Chapters 4 and 9 should be employed.

In directive systems where the gain is principally a function of the spacing of antenna elements, such as the broadside and collinear arrays, no particular advantage is secured by bending the ends of the elements. This is particularly the case with collinear arrays, since the gain is a function of the actual length of the antenna rather than the number of elements.

Half-Wave Loop Antennas

The arrangements of half-wave wires into circular or square loops shown in Fig. 1411 are due to W1QP. An antenna of this type has two advantages: less space is required than for a normal straight-away half-wave, and the directive effects are more marked than with the simple half-wave. In the optimum direction the antenna also shows a slight gain over a conventional half-wave, of the order of 18 per cent in field strength. Maximum radiation is in the direction indicated in the drawings. The antenna may be mounted either horizontally or vertically, depending upon the type of polarization wanted. With vertical polarization, it is important to feed the system half-way up one side, as shown, to keep the radiation angle low.

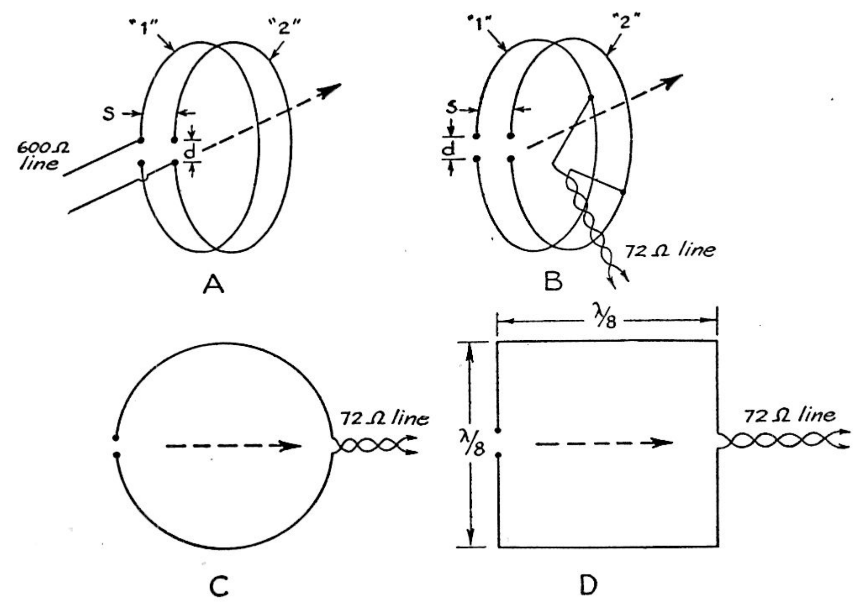


Fig. 1411 — Double-circle, single-circle and square half-wave loops with different feeder connections. Dimensions are discussed in the text.

The preferred form of the loop is the double circle, as shown at A and B. Aside from using half-wave elements, whose length may be calculated from the formula in Chapter 5, the dimensions are not highly critical. The recommended spacing at the ends, *d*, is 0.2 inch per meter of wavelength; i.e. for 14 Mc. (20 meters, approximately) the opening *d* would be 4 inches. In the double loop the spacing between elements, S, should be about 1 inch per meter of wavelength; that is, 20 inches for 20 meters, and so on.

The optimum direction of the loop is along a line pointing from the open end through the side carrying the maximum current point. The arrows indicate this in Fig. 1411. The front-to-back ratio is from 4 to 6 db. Either open-wire or twisted-pair feeders may be used; the former should be tuned, or the usual form of matching stub can be employed to couple the antenna to a non-resonant line. In the double loop a twisted-pair line may be coupled as shown at B in Fig. 1411, one wire going to one antenna element and the other to the second. The wires should be attached symmetrically about the center of the system, the positions being adjusted to minimize standing waves on the feeder. In practice, this will correspond to the settings which, with fixed coupling between transmitter and line, make the system take greatest load, or which show least reaction on the final tank tuning when the feeder is disconnected from the coupling coil. In the single-element system, a twisted-pair line can be connected in at a current loop with sufficiently good match to avoid undue losses in lines a wavelength or less long.

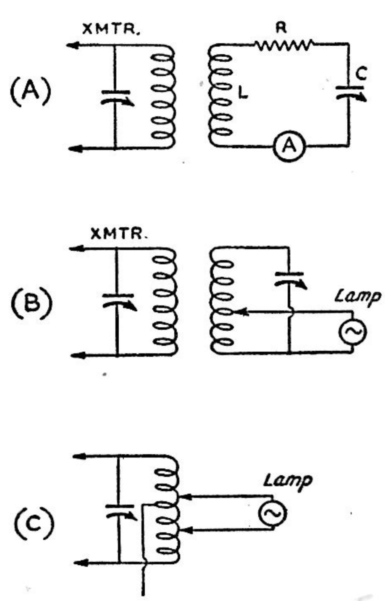


Fig. 1412 — Three types of circuits for using dummy antennas. Alternatively, the dummy antenna may be substituted for the feeders, using the regular coupling apparatus, or even installed in place of the antenna at the end of the transmission line.

Dummy Antennas

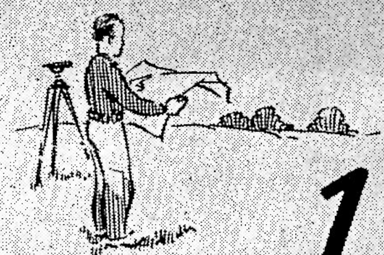
A dummy antenna is simply a resistance capable of dissipating power from the transmitter. It is a useful adjunct to transmitter tuning, in that it can be made to indicate the order of r.f. power output being secured, and also avoids radiating a signal during the tuning-up period. By selection of proper constants it is possible to make the dummy antenna simulate the actual feeder system to which the transmitter is to be connected so that tuning can be predetermined.

Some typical connections for dummy antennas are shown in Fig. 1412. In A, the resistor R should be non-inductive and should have a low value, of the order of 25 ohms or less. In B and C either a resistor or electric lamp can be used, these connections being suitable for resistances up to a few thousand ohms. The coupling can be varied by means of the taps on the coils, or (in A and B) by changing the coupling between the coils themselves.

An ordinary 115-volt lamp is about the handiest form of dummy antenna, and can be used for the measurement of power at frequencies up to 56 Mc. It is best to choose a size of lamp which is rated at about the expected power output of the transmitter. With the transmitter tuned and the coupling to the dummy adjusted to give maximum lamp brilliance, the amount of illumination can be judged by eye as compared to that from a similar lamp in a 115-volt socket, to determine whether the transmitter output is higher or lower than the lamp rating. For more accurate measurement some sort of photometer is necessary. A photographic exposure meter of the photoelectric type is well suited to this purpose. It should be set up at some convenient distance which gives a satisfactory reading, then the lamp dummy is disconnected from the transmitter and connected to the 115-volt line through a resistor or variac control which can be adjusted so that the meter gives the same reading as before. The power input to the lamp, which will be the same as the r.f. power output of the transmitter, can be measured by a wattmeter or by taking readings of voltage and current at the lamp. The small universal test instruments are quite suitable for the purpose. Care should be taken in making these measurements to prevent extraneous light from acting on the exposure meter and introducing error. The apparatus may be mounted in a box to keep out light, if necessary.

When non-inductive resistors are used instead of lamps the power may be determined by measuring the r.f. current through the resistor with an r.f. ammeter of suitable range. $P = I^2R$. The instrument range necessary can be found by substituting the resistance and the probable power into the formula. Resistors capable of handling moderate amounts of power have recently been made available, and have low enough distributed capacity and inductance to be substantially purely resistive at frequencies up to and including 14 Mc. Skin effect raises the effective resistance of the lower values using fairly large wire, so that low-resistance units may actually have more resistance than the label shows at the higher frequencies. Skin effect may be neglected with types using filamentary wire, and with carbon types.

Carbon resistors of the 1-watt size are practically non-inductive and non-capacitive in values up to several thousand ohms, for frequencies up to 60 Mc. In the higher ranges, however, the shunting capacity of leads and end caps causes the apparent resistance to decrease. Values below 5000 ohms or so are excellent for r.f. work, their only disadvantage being the limited power-handling capability. For measurement work, where only a small amount of power need be dissipated, they are very useful since the r.f. and d.c. resistances are practically identical.



15. FINDING DIRECTIONS

USING A GLOBE — AZIMUTHAL MAPS — METHODS FOR DETERMINING TRUE NORTH

The ability to determine the bearing of distant points with fair accuracy is a matter of interest to almost every amateur. Anyone laying out a fixed directive array does so in order to put his signal into certain parts of the world; in such cases, it is essential to be able to determine the bearings of the desired points. Too, the amateur with the rotatable directive array likes to know where to aim if he is trying to pick up certain countries. And even the amateur with the single wire is interested in the directive pattern of the lobes when the wire is operated harmonically at the higher frequencies, and often is able to vary the direction of the wire to take advantage of the lobe pattern.

Finding Direction

It is probably no news to most people nowadays that true direction from one place to another is not what it appears to be on the old Mercator school map. On such a map, if one starts "east" from central Kansas, he winds up in the neighborhood of Lisbon, Portugal. Actually, as a minute's experiment with a strip of paper on a small globe will show, a signal starting due east from Kansas never hits Europe at all but goes into the southern part of Portuguese West Africa.

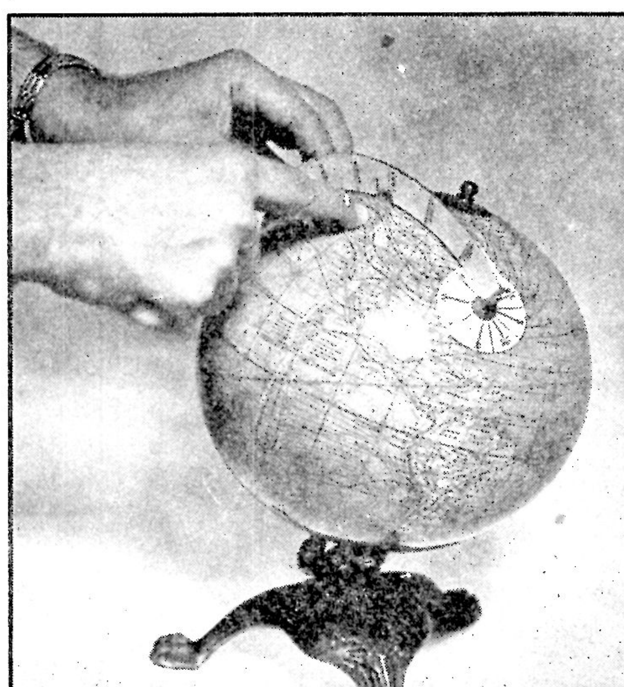
If, therefore, we want to determine the direction of some distant point from our own location, the ordinary Mercator projection is utterly useless.

True bearing, however, may be found in several ways: The first, by mathematics, will not be treated here since it involves a working knowledge of spherical trigonometry or instruction in the use of specialized navigation tables; the second is the method of working direct from a globe; and the third involves the use of a special type of world map which *does* show true direction from a specific location to other parts of the world.

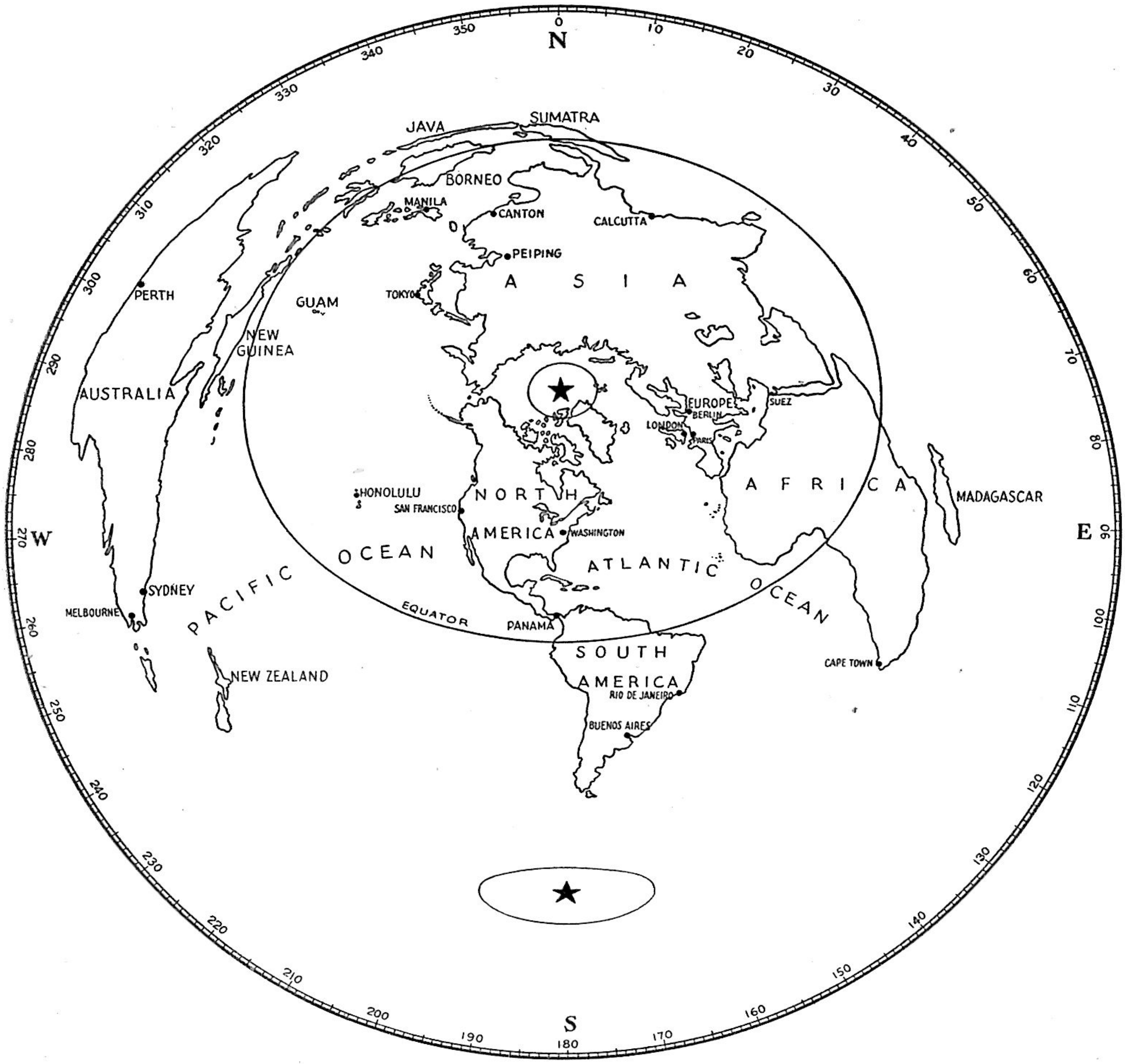
Working from a Globe

Entirely satisfactory bearings for beam purposes can be taken from an ordinary globe with nothing more complicated than a small school protractor of the type available in any school-supply or stationery store. For best results, however, the globe should be at least eight inches in diameter.

From a piece of thin paper, cut out a small circle — something like a three-inch circle for use with an eight-inch globe. Put a pin through the center and draw a straight line from the center to any point on the circumference. Now, put the paper circle on the globe, sticking the centerpin into your location. Using the edge of a sheet of plain paper as a straight-edge, line up the straight line on your paper circle so that it points North; this is done by laying the straight-edge against the centerpin and running it up to the North Pole at



A direction indicator made from a semicircle of thin metal can be fitted easily to a small globe. Pins at the ends permit fastening one end to the home location, the other to the antipodes. The paper scale is marked in miles to show approximate distances (12,000 miles to the semicircle).



Azimuthal Map Centered on Washington, D. C.

the top of the globe, then turning the paper circle until the straight line on it coincides with the straight-edge. When you have done this, stick another pin through the paper circle into the globe to hold it in position with this line pointing North.

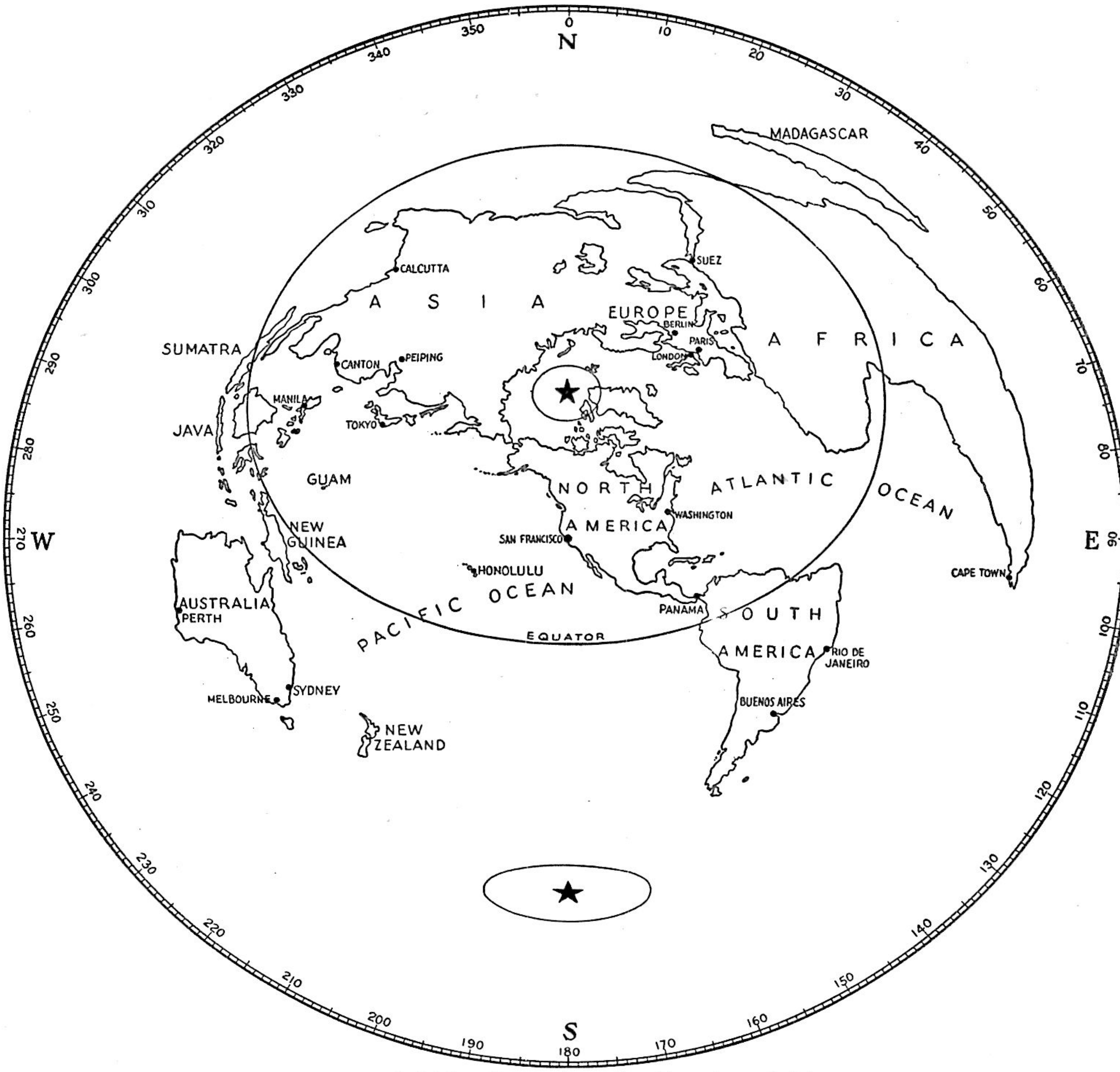
Now all you have to do is to use your paper straight-edge from the centerpin to such points as you wish, drawing short lines on your paper circle and labeling them as required. These lines may be extended later to the periphery of the circle.

With your protractor it is now a simple matter to determine the bearing, in degrees from North, of any of the points.

If your problem is to lay out a long wire to best advantage, make a diagram from the data in Chapter 6, showing the angular direction of the lobes, and superimpose this on your direction chart, adjusting it until the theoretical power lobes seem to take in the points in which you are interested. The direction of the wire can then be determined with the protractor.

Azimuthal Maps

While the Mercator projection does not show true directions, it is possible to make up a map which will show true bearings for all parts of the world from any single point. We reproduce three such maps in this handbook. One shows directions from Washington, D. C., another gives directions from San Francisco and the third (a simplified version of the A.R.R.L. 30″ x 40″ amateur radio map of the world) gives directions from the approximate center of the United States — Wichita, Kansas.



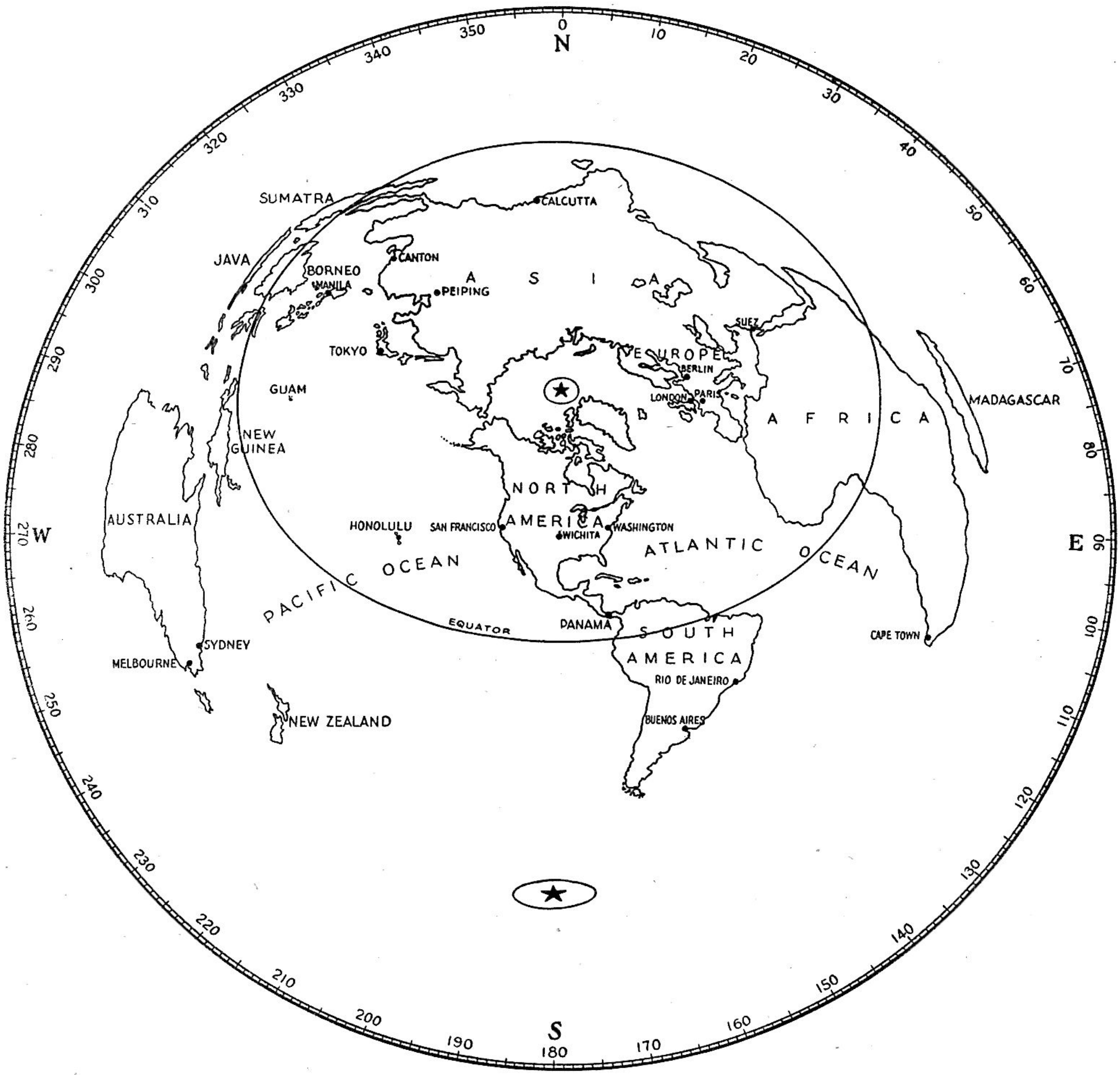
Azimuthal Map Centered on San Francisco, Calif.

For anyone living in the immediate vicinity (within 150 miles) of any of these three reference points, the directions as taken from the maps will have a high degree of accuracy. However, one or the other of the three maps will suffice for any location in the United States for all except the most accurate work; simply pick the map whose reference point is nearest you. Greatest errors will arise when your location is to one side or the other of a line between the reference point and the destination point; if your location is near or on the resulting line, there will be little or no error.

By tracing the directional pattern of the antenna system on a sheet of tissue paper, then placing the paper over the azimuthal map with the origin of the pattern at one's location, the "coverage" of the antenna will be readily evident. This is a particularly useful stunt when a multi-lobed antenna, such as any of the long single-wire systems, is to be laid out so that the main lobes cover as many desirable directions as possible. Often a set of such patterns will be of considerable assistance in determining what length antenna to put up, as well as the direction in which it should run.

Determining True North

Determining the direction of distant points is of little use to the amateur erecting a directive array unless he can put up the array itself in the desired direction. This, in turn, demands a knowledge of the direction of *true* North (as against magnetic North), since all our directions from globe or map are worked in terms of true North.



Azimuthal Map Centered on Wichita, Kansas

A number of ways may be available to the amateur for determining true North from his location. Frequently, the streets of a city or town are laid out, quite accurately, in north-south and east-west directions. A visit to the office of your city engineer will enable you to determine whether or not this is the case for the street in front of or paralleling your own lot. Or from such a visit it is often possible to locate some landmark, such as factory chimney or church spire, which lies true North with respect to your house.

If you cannot get true North by such means, three other methods are available: Compass, Pole Star and Sun.

By Compass: Get as large a compass as you can; it is difficult, though not impossible, to get satisfactory results with the "pocket" type. In any event, the compass *must* have degree graduations (not more than two degrees per division) for satisfactory results.

It must be remembered that the compass points to *magnetic* North, not true North. The amount by which magnetic North differs from true North in a particular location is known as *variation.* Your local weather bureau or city engineer's office can tell you the magnetic variation for your locality. When correcting your "compass North," do so *opposite* to the direction of the variation. For instance, if the variation for your locality is 12 degrees West (meaning that the compass points 12 degrees west of North) then true North is found by counting 12 degrees *East* of North as shown on the compass.

When taking the bearing, make sure that the compass is located well away from ironwork, fencing, pipes, etc. Place the instrument on a wooden tripod or support of some sort, at a convenient height as near eye level as possible. Make yourself a sighting stick from a flat stick about two feet long with a nail driven upright in each end (for use as "sights") and then, after the needle of the compass has settled down, carefully lay this stick across the face of the compass — with the necessary allowance for variation — to line it up on true North. *Be sure you apply the variation correctly.*

This same sighting-stick and compass rig can also be used in laying out directions for supporting poles for antennas in other directions — provided, of course, that the compass dial is graduated in degrees.

By the Pole Star: Many amateurs use the Pole Star in determining the direction of true North. An advantage is that the Pole Star bears true North, so that no corrections are necessary. Disadvantages are that some people have difficulty identifying the Pole Star, which is none too bright at best, and that because of its comparatively high angle above the horizon it is not always easy to "sight" on it accurately.

In any event, it is a handy check on the direction secured by other means.

By the Sun: With some slight preparation, the sun can easily be used for determination of true North. One of the most satisfactory methods is described below. The method is based on the fact that exactly at noon, local time, the sun bears due South, so that at that time the shadow of a vertical stick or rod will bear North. The resulting direction incidentally is *true* North.

Two corrections to your standard time must be made to determine the exact moment of true local noon.

The first is a longitude correction. Standard Time is time at some particular meridian of longitude: EST is based on the 75th meridian; CST on the 90th meridian; MST on the 105th meridian; and PST on the 120th meridian. From an atlas, determine the difference between your own longitude and the longitude of your time meridian. Getting this to the nearest 15 minutes of longitude is close enough. Example: West Hartford, which runs on 75th meridian time (EST) is

TABLE I

Apply to Clock Time as indicated by the sign, to get time of true noon

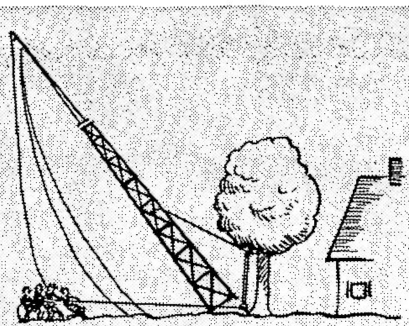
January	1	+ 4 mins.	July	10	+ 5 mins.
	10	+ 8 "		20	+ 6 "
	20	+ 11 "		30	+ 6 "
	30	+ 13 "			
February	10	+ 14 "	August	10	+ 5 "
	20	+ 14 "		20	+ 3 "
	28	+ 13 "		30	0 "
March	10	+ 10 "	September	10	− 3 "
	20	+ 7 "		20	− 6 "
	30	+ 4 "		30	− 10 "
April	10	+ 1 "	October	10	− 13 "
	20	− 1 "		20	− 15 "
	30	− 3 "		30	− 16 "
May	10	− 4 "	November	10	− 16 "
	20	− 3 "		20	− 14 "
	30	− 2 "		30	− 11 "
June	10	− 1 "	December	10	− 7 "
	20	+ 1 "		20	− 2 "
	30	+ 3 "		30	+ 2 "

at 72° 45′ longitude, or a difference of 2° 15′. Now, for each 15′ of longitude, figure 1 minute of time; thus 2° 15′ is equivalent to 9 minutes of time (there are 60 "angle" minutes to a degree, so that each degree of longitude equals 4 minutes of time). SUBTRACT this correction from noon if you are *east* of your time meridian; ADD it if you are *west.*

To the resulting time, apply a further correction for the date, from Table I. The resulting time is the time, by Standard Time, when it will be true noon at your location. Put up your vertical stick (use a plumb bob to make sure it is actually vertical), check your watch with Standard Time, and at the time indicated from your calculations, mark the position of the shadow. That is true North.

(In the case of West Hartford, if we wanted correct time for true noon on October 20th: First, subtracting the longitude correction — because we are east of the time meridian — we get 11:51 A.M.; then, applying the further correction of − 15 minutes, we get 11:36 A.M., as the time of true noon at West Hartford on October 20th.)

— A. L. Budlong



16. SUPPORTS AND CONSTRUCTION

MASTS AND ANCHORS — OPEN-WIRE AND CONCENTRIC FEEDERS — LEAD-INS ANTENNA KINKS

The problem of supporting the antenna at the requisite height above ground can be solved in a variety of ways, depending upon local conditions. Quite frequently at least one end of the antenna can be hooked to a convenient building or tree, thereby obviating the expense and trouble of erecting a pole or tower.

Anchoring one end of the wire to a building presents no particular problems. Some precautions must be taken, however, when the support is a tree, particularly if the antenna is fastened near its top. Trees sway considerably in a wind, so that some means must be taken to prevent the antenna wire from snapping in two, and at the same time to get rid of too much slack in calm weather. If the tree can be climbed to the point where the antenna is to be supported, a wire can be looped around the trunk or limb to hold a pulley as firmly as possible. The antenna rope, which should run freely through the pulley, should not be tied at its free end but should be fastened to a counterweight heavy enough to keep the antenna taut.

A somewhat similar scheme can be used when it is necessary to throw a rope over a limb because the tree cannot be climbed to the height desired. In this case the pulley can be fastened to the end of the rope which goes through the tree, while the antenna rope goes through the pulley, somewhat as shown in Fig. 1601. The tree rope is securely fastened at the bottom.

In using either of these systems it is essential, to prevent the rope from jamming in the pulley, to use a rope heavy enough so that it will not jump out of the pulley wheel and get caught between the wheel and frame. Some tension should be kept on the pulley, especially while the antenna is being raised, to keep it from twisting.

Telephone Poles

Probably the most satisfactory type of pole is the kind used by utility companies to carry power and telephone wires. These poles are heavy enough to support most amateur antennas without being guyed, and can be provided with steps so that they can be climbed without difficulty. Their chief drawback is the fact that they are comparatively expensive.

Costs vary in different parts of the country, depending upon the distance to the source of the poles. In lengths of 30 to 60 feet, however, an average cost for a creosoted pole, installed, is around a dollar per foot. In ordinary soil about one-tenth of the length is set in the ground, so that the pole height is about 90 per cent of its length.

Poles of this type usually can be purchased from the local electric light or telephone company and installed by their crews. In some localities the companies let out this work to local contractors, in which case the contractor can be approached directly. Use caution in picking up "bargains" in

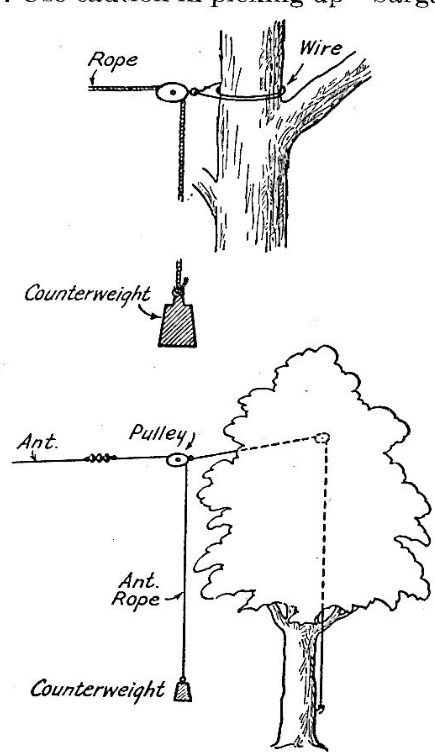


Fig. 1601 — Fastening the antenna to a tree. The counterweight prevents the antenna wire from being snapped off when the tree sways in a wind.

the pole line; a pole with an unsound center is not a good investment nor is it a safe thing to climb.

Small Masts

Where the height required is of the order of 20 feet or less (particularly when the mast is to be installed on the roof of a house or garage) a single piece of 2 × 3 lumber will make a good pole. A vertical antenna for 10 and 5 meters, for instance, can be constructed on a 20-foot 2 × 3 as shown in Fig. 1602. Three guys spaced 120 degrees around the pole and fastened about half-way up will suffice to keep the pole erect. If the roof is flat, the bottom of the pole need not be fastened down since it will have no tendency to move once the guys are tightened. A small flat board may be placed under it to prevent damage to the roof. On peaked roofs, a small wooden inverted "V" can easily be nailed to the bottom of the pole to keep it from slipping.

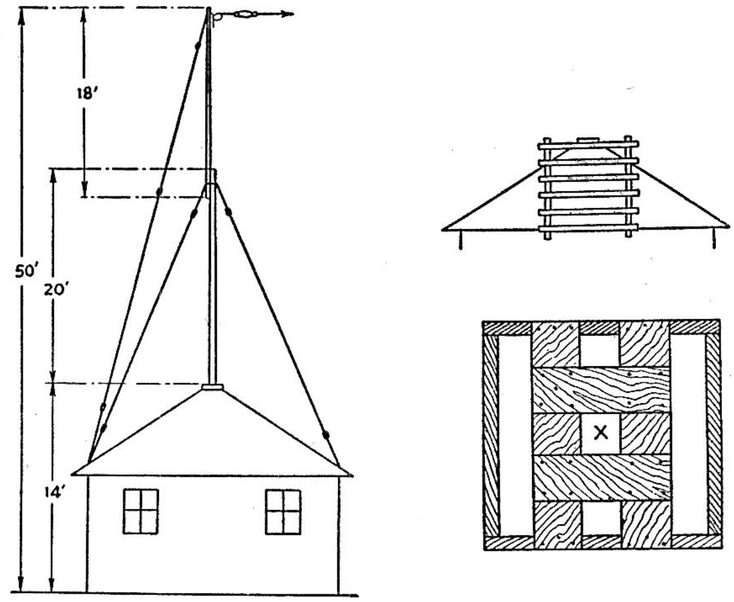


Fig. 1603 — **A socket for installing a mast on the garage roof. Bolted timbers make a satisfactory mast; 2 × 4 or 3 × 4 at the bottom, 2 × 3 at the top.**

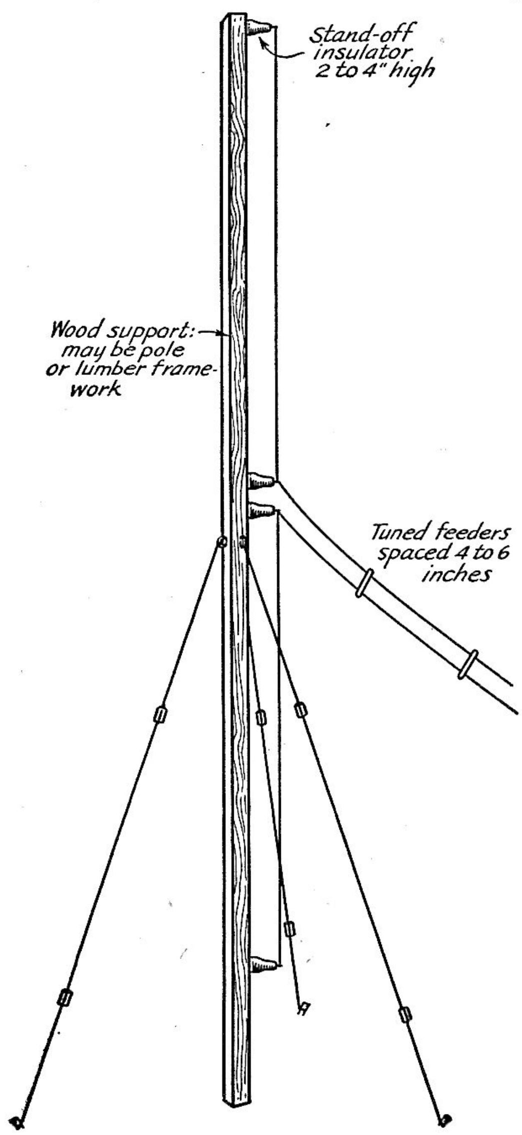


Fig. 1602 — **A single 2 × 3 will serve as a mast for heights up to about 20 feet. This drawing shows how a 28-Mc. vertical can be installed on such a pole. For horizontal antennas, the guys should go to the top.**

To support a horizontal antenna, the guys should run to the top of the mast. Actually, only the two which pull away from the antenna need go to the top; the antenna itself provides the pull in the opposite direction. The third guy, in the direction of the antenna, is used only to keep the pole from falling over when the antenna is lowered, and may be fastened about half-way up where it will not interfere with the antenna pulley and rope.

Fig. 1603 shows how a socket can be constructed to fit over the pointed roof of a typical two-car garage to seat a mast, which in this case consists of two pieces bolted together. A satisfactory method of guying also is shown. From the joint between the two sections of the pole four guys go to the corners of the garage, but only two at the back are used at the top of the mast. The pull of the antenna is ample to keep the upper section vertical. The lower section of a bolted mast of this type preferably should be 2 × 4, with the upper section 2 × 3.

Fig. 1603 also shows a sketch of a "cattle walk" which is lashed in place on the roof to permit walking the mast up without danger of slipping. Such a gadget can be used on any sloping roof; even a ladder will suffice in many cases when its upper end is roped to a solid anchorage so that it cannot slide.

The "A-Frame" Mast

A type of light and inexpensive mast which has been very popular is shown in Fig. 1604. In lengths up to 40 feet it is very easy to erect and

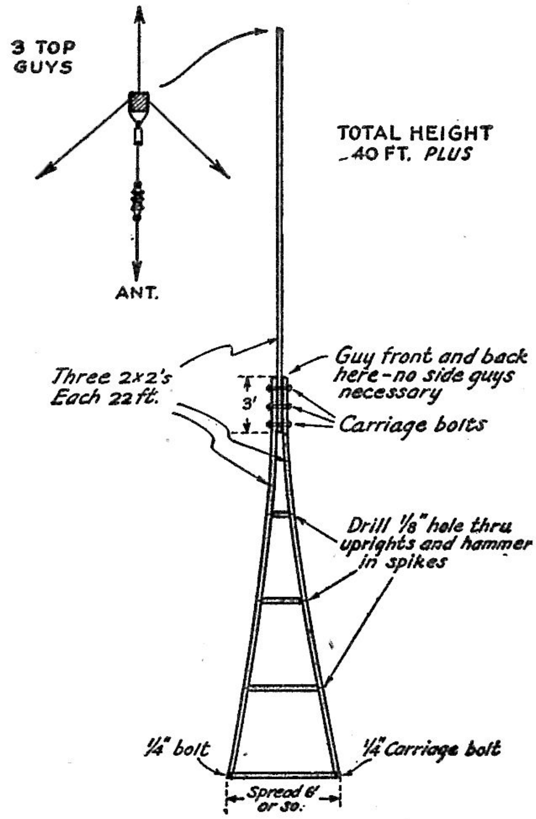


Fig. 1604 — The A-frame mast, light weight and easily constructed and erected.

will stand without difficulty the pull of ordinary antenna systems. The lumber used is 2 × 2 straight-grained pine (which many lumber yards know as hemlock) or even fir stock. The uprights can be each as long as 22 feet (for a mast slightly over 40 feet high) and the cross pieces are cut to fit. Four pieces of 2 × 2, 22 feet long, will provide enough and to spare. The only other materials required are five ¼-inch carriage bolts 5½ inches long, a few spikes, about 300 feet of No. 12 galvanized iron wire for the guys or stays, enough No. 500 ("egg") glazed porcelain strain insulators to break up the guys into sections, and the usual pulley and halyard rope. If the strain insulators are put in every 5 feet approximately 30 of them will be enough.

After selecting and purchasing the lumber — which should be straight-grained and knot-free — three sawhorses or boxes should be set up and the mast assembled in the manner indicated in Fig. 1605. At this stage it is a good plan to give the mast two coats of "outside white" house paint.

After the second coat of paint is dry, attach the guys and rig the pulley for the antenna halyard. The pulley anchorage should be at the point where the top stays are attached so that the back stay will assume the greater part of the load tension. It is better to use wire wrapping around the stick, with a small through-bolt to prevent sliding down, than to use eye bolts.

If the mast is to stand on the ground, a couple of stakes should be driven to keep the bottom from slipping. At this point the mast may be "walked up" by a pair of helpers. If it is to go on a roof, first stand it up against the side of the building and then hoist it, from the roof,

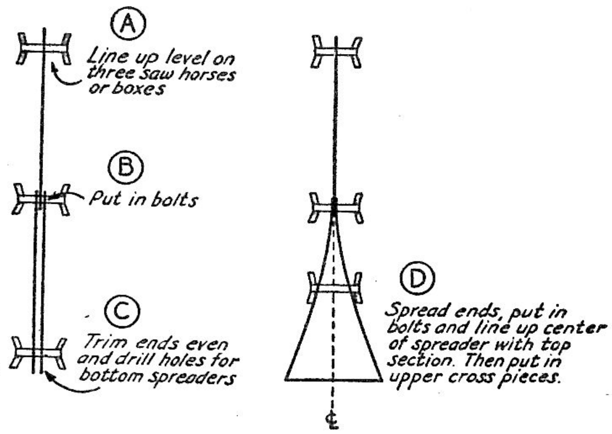


Fig. 1605 — Method of assembling the A-frame mast.

keeping it vertical. The whole assembly is light enough for two men to perform the complete operation — lifting the mast, carrying it to its permanent berth and fastening the guys — with the mast vertical all the while. It is therefore entirely practicable to put up this kind of mast on a small flat area of roof that would prohibit the erection of one that had to be raised vertical in its final location.

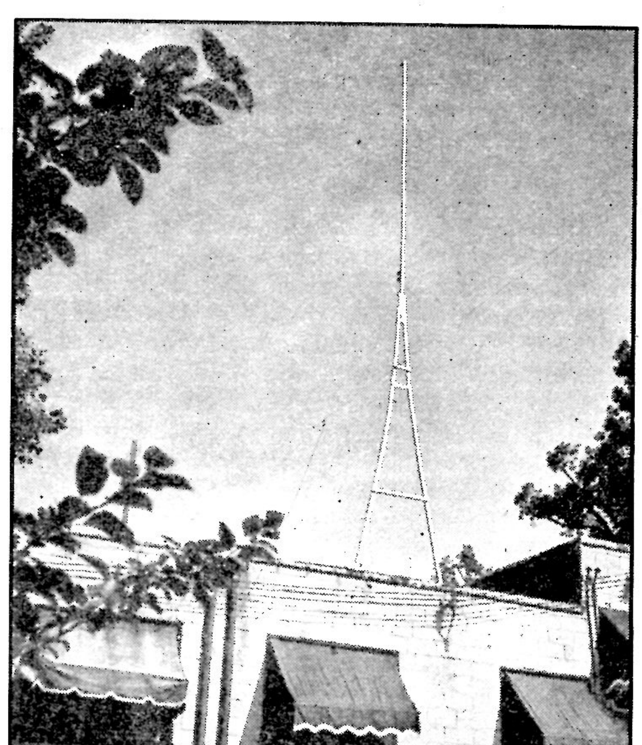


Fig. 1606 — This A-frame mast is doing duty on W3QY's roof.

Another Simple Mast

The mast shown in Fig. 1607 is relatively strong, easy to construct, and costs very little. Like the "A frame," it is suitable for heights of the order of 40 feet. It is also easily dismantled in case it has to be moved.

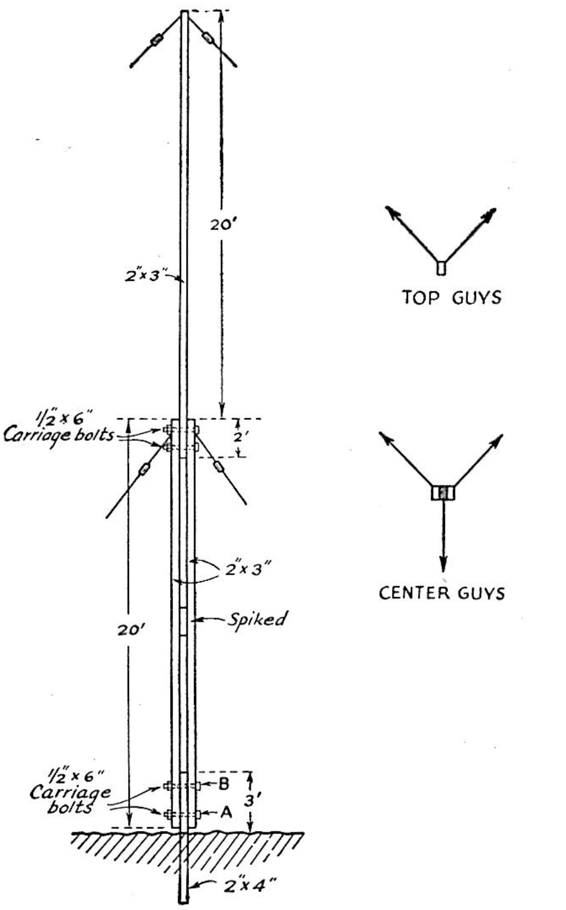


Fig. 1607 — **A simple and sturdy mast for heights in the vicinity of 40 feet, pivoted at the base for easy erection. The height can be extended to 50 feet or more by using 2 × 4s instead of 2 × 3s.**

The top section is a single 2 × 3, bolted at the bottom between a pair of 2 × 3s with an overlap of about 2 feet. The lower section thus has two legs spaced the width of the narrow side of a 2 × 3. At the ground, the two pieces are bolted to a 2 × 4 which is set in the ground. A short length of 2 × 3 is set between the two legs about half way up the bottom section to maintain the spacing. Four ½ × 6 carriage bolts are needed, along with washers; this length is sufficient since the "2 × 3s" actually are about 1¾ × 2½ inches. All pieces of lumber are set so that the long axis faces the antenna direction.

It will be sufficient to guy the mast as shown in the drawing. The two back guys at the top pull against the antenna, while the three lower guys prevent any buckling at the center of the pole. The two sets of back guys may be anchored at the same point. For a height of about 40 feet, the guys should be anchored about 15 feet or more from the bottom of the pole.

The mast can easily be raised by two people; in fact, one man can manage the job without too much difficulty. The length of 2 × 4 which is set in the ground should be placed so that it faces the proper direction, and should be made vertical by lining it up with a plumb bob. The holes for the bolts should be drilled beforehand. The lower section is then laid on the ground so that bolt A can be slipped in place through the three pieces of wood and tightened just enough so that the section can turn freely on the bolt. Then the top section is bolted in place and the mast pushed up, using a ladder or another 20-foot 2 × 3 for the job. As the mast goes up the slack in the guys can be taken up so that the whole structure is in some measure continually supported. When the mast is vertical bolt *B* is slipped in place and both *A* and *B* tightened. The lower guys can next be given a final tightening, leaving those at the top a little slack until the antenna is pulled up when they can be adjusted to pull the top section into line with the bottom.

The 2 × 4 should extend at least 3 feet into the ground, and should set solidly. Concrete is not necessary, but it will help to pack rocks in the hole to provide some bracing. The pole will stand without guying when the two bottom

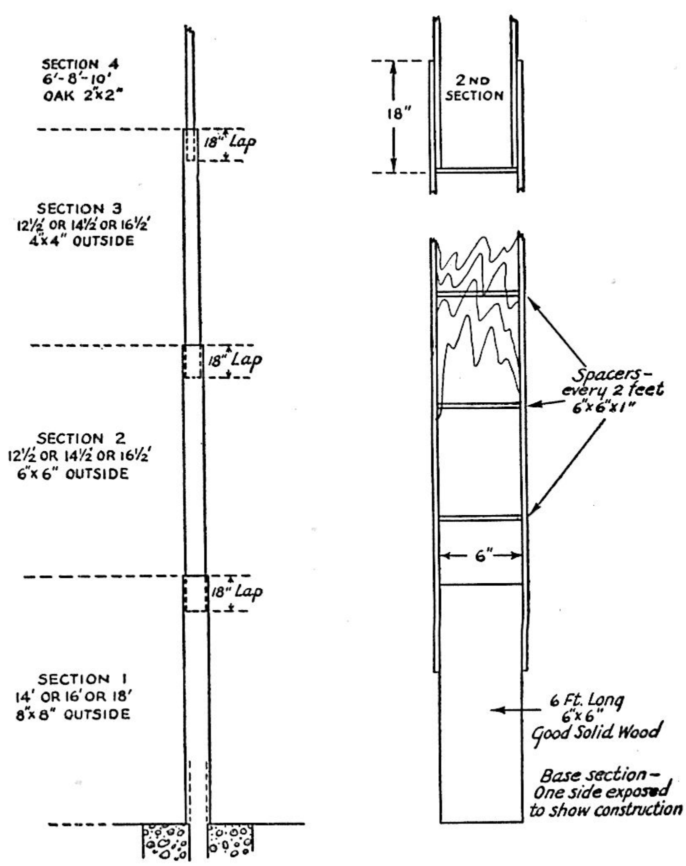


Fig. 1608 — **A hollow mast, light weight but strong, constructed of 1-inch boards.**

bolts are in, which does away with the necessity for having a helper on each guy, but of course will not stand much strain under those conditions.

A Hollow Mast

A different type of mast construction, suitable for heights of the order of 50 to 60 feet, is shown in Fig. 1608. Although comparatively light in weight, it is practically as strong as a solid pole of the same cross-section.

It is a square hollow pole, held together in the fashion of bamboo growth; that is, with a bracing and strengthening section spaced about every 2 feet.

The foundation is a 6 × 6 timber about 6 feet long. The next section is about 14 to 18 feet long, depending upon the availability of the lumber, which should be good, smooth finish, hard pine, cypress or spruce. Three pieces (assuming that 18-foot stock is available) are laid out. There will be two sides 6″ wide by 18′ long of ¾″ or ⅞″ stock, and the third will overlap on the edges so that it will be 8″ wide by 18′ by ¾″ or ⅞″. Insert the 6 × 6 about 2′ into the U formed by the three pieces and after lining up so that all edges are flush, commence to fasten together with nails, or preferably iron screws with flat heads, not forgetting to paint thoroughly every edge with a thick mixture of white lead and linseed oil. The next operation is to put in the braces every 2 feet. These are 6 × 6 × 1-inch thick, and should be put in with white lead between wood surfaces and thoroughly fastened with screws or finishing nails. At the open end of the "U" leave 18″ for the insertion of the next section of the mast which telescopes into the base section. Give the inside a thorough coat of white lead and linseed oil about the consistency of glue and let dry for a week or so. The cover for this section of the "U" is another 8-in. × 18-ft. × ¾-in. piece which is screwed down after the second coat of white lead and linseed oil is dry. Any irregularities in the lumber and joints should be smoothed down with a plane.

The second and third sections of the mast are constructed in a fashion similar to that of the base, except that they are progressively smaller. The second section should have outside dimensions of 6 × 6-inch to telescope inside the base section. The third section will be 4 × 4-inch to telescope into the second and the top section is a solid 2 × 2.

The complete list of material required is given below:

1st Section

1 — 6″ × 6″ × 6′
2 — 6″ × 18′ × ⅞″
2 — 8″ × 18′ × ⅞″
7 — Spacers 6″ × 6″ × 1″

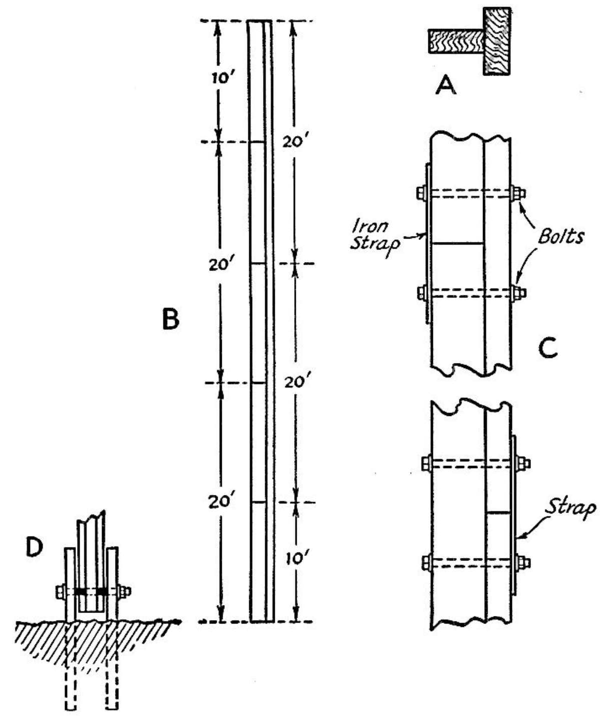


Fig. 1609 — T-section mast made from overlapping 2 × 4s or 2 × 6s.

2nd Section

2 — 4″ × 18′ × ⅞″
2 — 6″ × 18′ × ⅞″
8 — Spacers 4″ × 4″ × 1″

3rd Section

2 — 2″ × 18″ × ⅞″
2 — 4″ × 18″ × ⅞″
8 — Spacers 2″ × 2″ × 1″

Top Section

1 — 2″ × 2″ × 20′ — oak
1 — Pulley (brass or bronze)
1 — (Necessary length) manila rope
4 — Guys (necessary length) No. 8 iron galvanized wire
Strain insulators

Masts with Butted Timbers

A type of mast construction suitable for heights up to about 80 feet is shown in Fig. 1609. The mast is built up by butting 2 × 4 or 2 × 6 timbers edgewise against a second 2 × 4, as shown at A, with alternating joints in the edgewise and flatwise sections as shown at *B*. The construction can be carried out to greater lengths than shown simply by continuing the 20-foot sections. It will be noted that one or both ends must end with a 10-foot section on either the edgewise or flat timbers. Longer or shorter sections may be used if more convenient.

The method of making the joints is shown at *C*. Quarter-inch or $^3\!/_{16}$-inch iron, 1½ to 2 inches wide, is recommended for the straps, with half-inch bolts to hold the pieces together. In addition, a bolt should be run through the pieces midway between joints to provide additional rigidity.

Although there are many ways in which such a mast can be secured at the base, the "cradle" illustrated at *D* has many advantages. Heavy timbers set firmly in the ground, just far enough apart so that the base of the mast will pass through them, hold a large carriage bolt or steel bar which serves as a bearing. This passes through a hole in the mast so that the latter is pivoted at the bottom. As the mast swings upward in an arc while being raised the bottom is free to pivot on the bearing.

The job of raising the mast can be simplified, when a bottom bearing of this nature is used, because half of the guys can be put in place and tightened up before the mast leaves the ground. Four sets of guys should be used, one in front, one directly in the rear, and two on each side at right angles to the direction in which the mast will face. Since the base position is fixed by the bearing, all the side guys can be put in place, anchored and tightened while the mast is lying on the ground. Thus there is no danger of side-sway or bending while the mast is going up, and a smaller crew can do the job. A set of guys should be used at each of the joints in the edgewise sections, the guy wires being wrapped around the pole rather than fastened to bolts or passed through holes in the pole, as either of the latter two methods tend to weaken the joint.

For heights up to 50 feet, 2 × 4s may be used throughout. For greater heights it is advisable to use 2 × 6s for the edgewise sections, although 2 × 4s will be satisfactory for the flat sections.

Raising the Mast

Specific instructions have been given for raising the masts already described, in most cases. There are, however, a few kinks which will help in the erection of almost any kind of mast.

The "scissors" arrangement shown in Fig. 1610, constructed of two 2 × 3s or 2 × 4s about 20 feet long, will be of considerable assistance in getting the mast off the ground. Starting out near the end, the mast is pushed up a little at a time and the scissors moved in each time to keep it from dropping back. With small masts (40 feet or so) it is the only auxiliary necessary, since by the time its length is too small to be of further service it should be possible to pull the mast up the rest of the way by the guy wires. A 20-foot ladder can be substituted for the scissors if one is available, but it does not possess the stability of the scissors arrangement and therefore cannot as readily prevent side-sway. In either case a short pole or ladder can be used to push up the mast while the scissors or ladder is being moved into a new position.

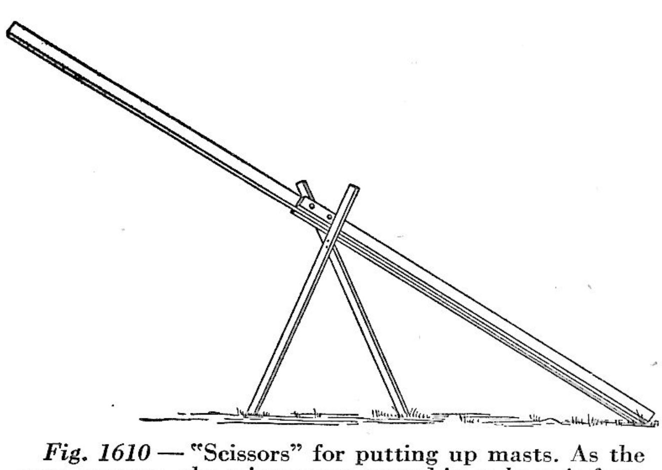


Fig. 1610 — "Scissors" for putting up masts. As the mast goes up, the scissors are moved in to keep it from falling and to prevent side-sway.

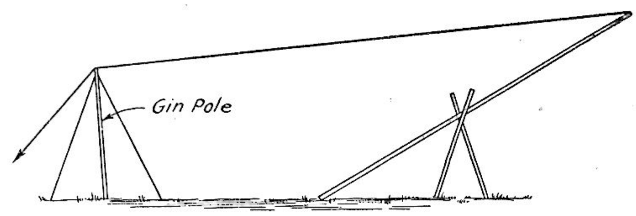


Fig. 1611 — A gin pole is a useful accessory when a tall mast is to be raised, providing additional leverage when the mast is near the ground.

When the mast is 50 feet or more high, it will be easier to pull it up if an auxiliary mast or "gin pole" is used as shown in Fig. 1611. The gin pole should be ⅓ to ½ the height of the mast, and should be erected fairly close to the base of the mast so that the maximum possible leverage can be secured. The erection of a small auxiliary mast of this type should present no special problems. Provision should be made for keeping the guy wires of the main mast from slipping off the top of the gin pole as they are pulled back. All the back guys should pass over the gin pole and should be kept taut so that there will be no bending of the main mast as it goes up.

As the mast is pulled up, the guys should be allowed just enough slack to permit the mast to move without the necessity for "pulling against the guys." With tall masts of the usual construction a too-slack guy may allow the pole to bend enough to get out of control and perhaps snap. It is advisable to take the pulling-up process slowly on that account.

Guys and Guy Anchors

For poles up to about 50 feet, No. 12 iron wire makes a satisfactory guy (No. 12 in this wire is considerably heavier than in copper). A heavier size, or stranded cable, can be used for taller poles or poles installed in locations where the wind velocity is high.

Guy wires should be broken up by strain insulators to avoid the possibility of their becoming resonant at the transmitting frequency. Common practice is to insert an insulator near the top of each guy within a few feet of the pole and then make each section of guy wire, between insulators, a length which will not be resonant in any amateur band to be used, either on its fundamental or harmonics. An insulator every 25 feet will be satisfactory for all bands up to

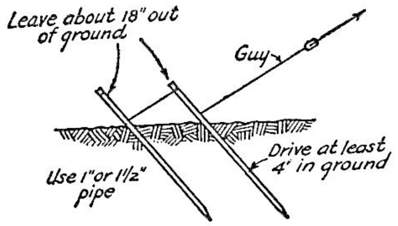


Fig. 1612 — **Pipe guy anchors. One will be sufficient for small masts, but the two installed as shown will provide additional strength for larger poles.**

and including the 28-Mc. band. The insulators should be of the "egg" type, with the insulating material under compression so that if the insulator breaks the guy will not come down. The No. 500 size is suitable for ordinary guy-wire sizes.

Guy wires may be anchored in a variety of ways. Simplest of all is to anchor the wires to a tree or building, when they happen to be in convenient spots. For small poles a 6-foot length of pipe (about 1-inch diameter) driven into the ground at an angle, with the bottom of the pipe pointing to the base of the pole, will suffice. Additional bracing can be provided by using two pipes as shown in Fig. 1612.

One form of "dead man" guy anchor is shown in Fig. 1613. The "dead man" is a heavy plank (two 2 × 6s nailed together, for example) 5 or 6 feet long and buried about 3 or 4 feet in the ground. A fair amount of surface is necessary to give maximum resistance to the pull of the guys. The wires are brought out at the proper angle to the pole so that they are, in effect, a continuation of the regular guy wires.

For heavy jobs, regular guy anchors can be secured through firms dealing in line materials, or through the local utility company.

Fig. 1614 shows a method of connecting several guy wires to a single dead man, using an open thimble (obtainable from marine supply stores) to prevent sharp bends and possible breakage of the wires.

With large guy wires, it is difficult to make tight joints at the insulators even with pliers. A simple tool can be made for the purpose from a piece of heavy iron or steel with a single hole drilled about a half-inch from one end. The wire is passed through the insulator, given a single

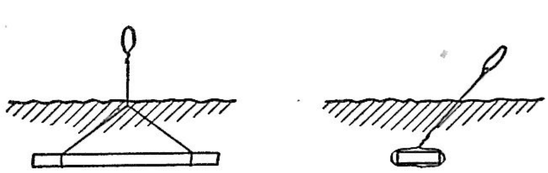


Fig. 1613 — The "dead man" guy anchor.

Fig. 1614 — **An open thimble provides a method for hooking several guys to a "dead man" anchorage, and avoids sharp bends in the guys at the junction. This installation is at W2DC**

turn by hand, and then held with a pair of pliers at the point shown in Fig. 1615. By passing the wire through the hole in the iron and rotating the iron as shown, the wire can be twisted quickly and neatly.

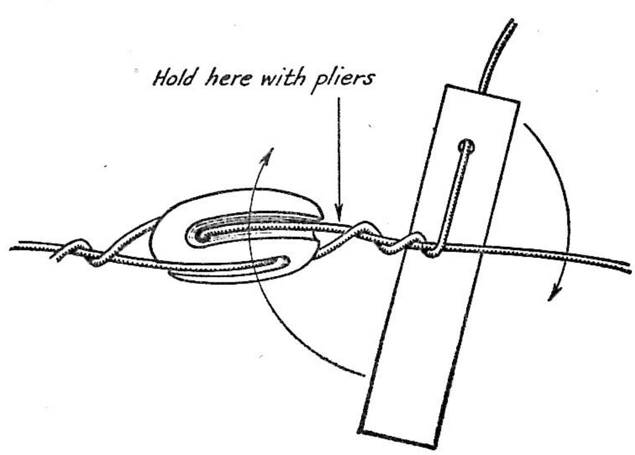


Fig. 1615 — **Simple lever for twisting guy wires.**

With high poles it may be advisable to use turnbuckles in the guy wires so that they can be tightened satisfactorily. With small poles this is usually an unnecessary refinement, since the wires can be pulled tight enough by hand.

Halyards and Pulleys

A free-running pulley and a long-lived halyard are definite assets to an antenna system. Common clothesline rope will be strong enough for small antennas, but does not stand the weather too well and should be renewed fairly frequently. Sashcord is a bit better, but still not weather resistant. A satisfactory halyard is ⅜- or ½-inch waterproofed manila rope, the larger size being needed only to hold long stretches of wire.

Ordinary rope or cord can be waterproofed by soaking it a day or two in automobile top-dressing.

It will pay to purchase good-quality pulleys. A good grade of galvanized iron pulley will be satisfactory in locations where the atmosphere is free from salt, but at seashore locations a pulley intended for marine use should be used. One of the best types is a hardwood block with bronze roller-bearing shaft, which will stand up well and resist corrosion under adverse conditions.

Feeder Construction

Two-wire open transmission lines are readily constructed from materials available from all amateur suppliers. Rod-type spacers or spreaders are universally used to keep the separation between the wires constant, the usual size of spacer being 6 inches long. Six-inch separation is quite satisfactory at frequencies up to about 30 Mc., but smaller spacing is desirable on the very-high frequencies to reduce line radiation. Four- and 2-inch spacers are available for the purpose.

If the line is to hang free, a 6-inch line should have a spacer every six feet or so to reduce swinging of the wires with respect to each other in a wind. Correspondingly smaller separation between spreaders should be used with lines having closer spacing. Even though the wires do not swing enough to touch, the movement will vary the characteristic impedance of the line and thereby cause variable loading on the transmitter.

Manufactured spreaders, generally made of ceramic material, are inexpensive and stand up well in the weather, so that it is not usually worth while to make spreaders at home. However, there may be cases where home construction is desirable, as when special sizes are needed. Fig. 1616 shows two methods of construction. Spreaders may be made from bakelite, hard rubber, cellulose acetate, or similar materials, or even hard wood thoroughly impregnated with paraffin. None of these materials stands up as well outdoors as the ceramics, however.

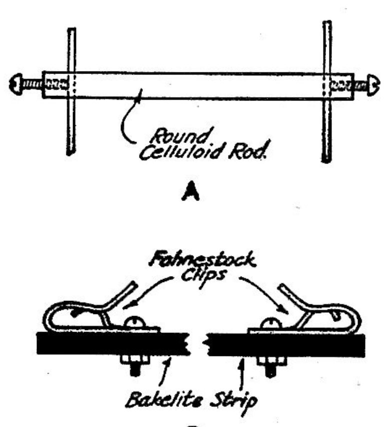


Fig. 1616 — Easily-made feeder spacers.

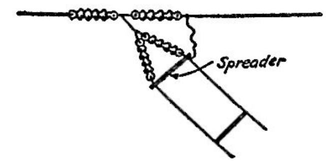


Fig. 1617 — Method of pulling off Zepp feeders to keep the wires taut.

To keep feeders taut it is necessary to have the same tension on each wire. With an end-fed antenna this may be difficult to accomplish unless an arrangement similar to that shown in Fig. 1617 is used. The single-point support permits pulling off the feeders at any convenient angle to the antenna. Where a feeder must be run a considerable distance so that simply letting it hang is impracticable, a support of the type shown in Fig. 1618 may be used. A similar mechanical terminating arrangement at each end of the line will keep the spacing constant and the line shipshape. Fig. 1619 shows how one amateur uses counterweights on feeders in a multiple-antenna installation to keep feeders tight.

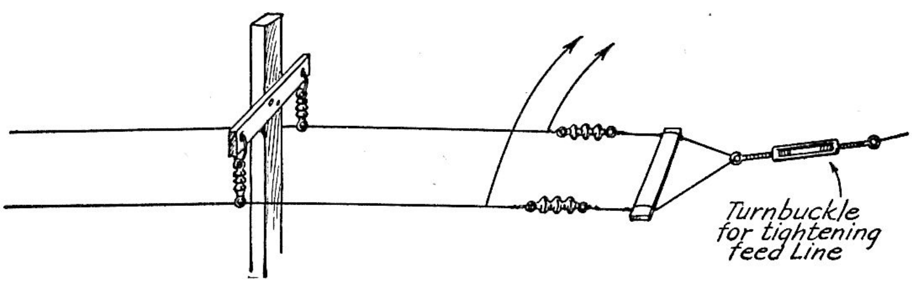


Fig. 1618 — Method of supporting long feed lines. The wires are run through the insulators and tightened at the ends of the line. The wire is allowed to slip freely through the insulators.

Concentric Lines

The construction of concentric or coaxial lines is not too difficult, although some care must be exercised. Isolantite "beads," or spacers designed to pass a given size of wire (the center conductor) through a center hole, and having an inside diameter slightly less than the inside diameter of standard sizes of metal tubing, are available from several manufacturers. The process of constructing a concentric line is simply that of stringing the beads on the wire, fastening them at suitable intervals, and then drawing the assembly through the tubing. It is essential to have tubing which is clean on the inside, which may or may not be the case with ordinary copper tubing. Brass tubing usually is better in this respect.

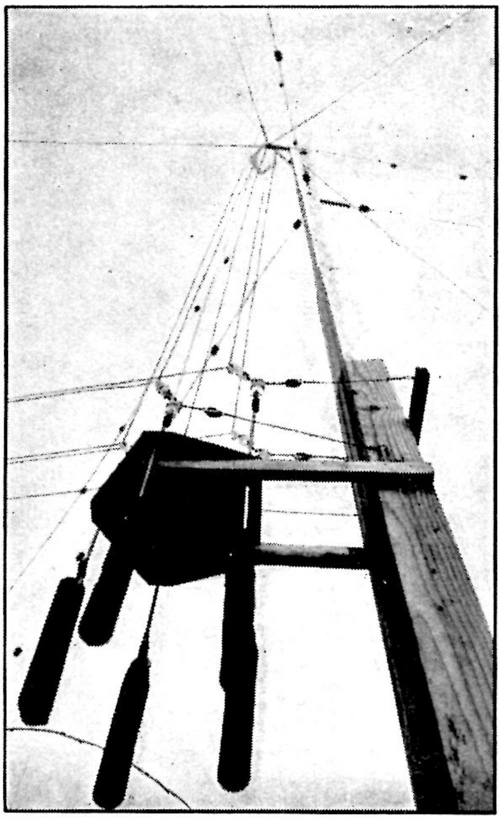


Fig. 1619 — Counterweights keep the feeders tight in this installation at W9TJ.

To fasten the beads in place the wire should be given a slight "crimp" on each side of the bead. A tool for this purpose can be made out of a pair of cheap cutting pliers. File the cutting edges to the point where the pliers will no longer cut wire, leaving a space of about 1/100 inch between the edges. Then, using a thin file, file two square notches opposite each other in the two edges. Make the width of the notches slightly less than the diameter of the wire to be used, and deep enough so

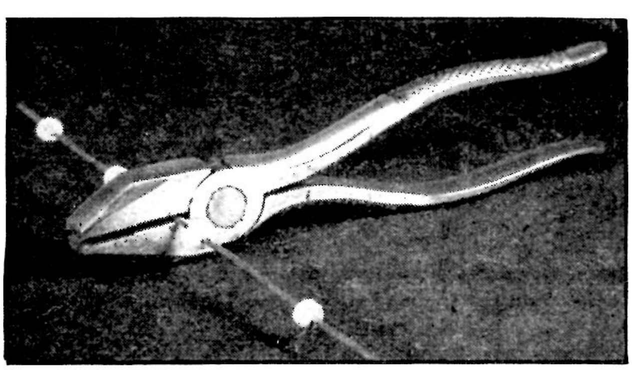


Fig. 1620 — **Crimping tool for concentric lines.**

that when the wire is squeezed it will bulge out into the 1/100th-inch tap between the edges. The bulges will prevent the bead from slipping. A bead every 2 inches along the wire will be about right.

Straight joints in the line can be made with fittings of the type used for automobile gas lines

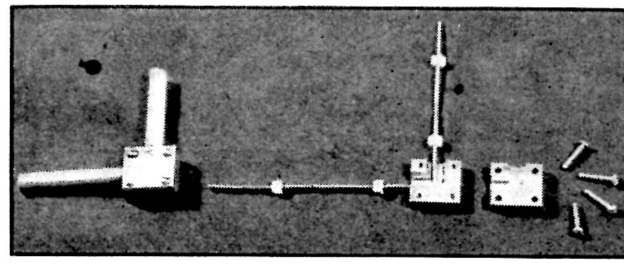


Fig. 1621 — **Right-angle joint for coaxial lines and its components.**

and refrigeration units. It is inadvisable to solder a joint because of the danger that solder will run into the line and cause trouble. Where bends are to be made it is important to maintain the conductor spacing, which can be done by making fittings of the type shown in Fig. 1621. These are made of brass stock $\frac{5}{16}$ inch thick by one inch square. Two pieces, one drilled to pass the assembly screws and the other tapped to take the screws (6-32), as shown in the photograph,

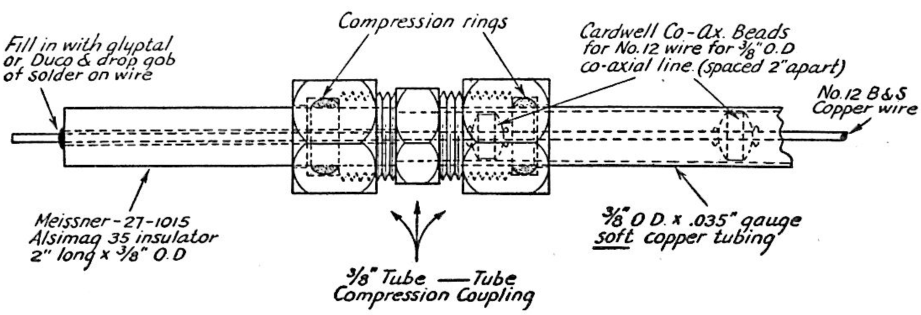


Fig. 1622 — **End seal for concentric lines.**

are placed in a vise and drilled from two adjacent edges to the center, as shown, with a drill which will make a hole just large enough to give a snug fit to the outer tubing. The inner faces of the two pieces should be perfectly flat, and before final assembly should be coated with Duco cement, so that moisture cannot get into the joint. The inner wire should be bent carefully so it will pass through the center of the channel without danger of touching. The ends of the outer conductor may extend into the square fittings about $\frac{1}{4}$ inch.

It is important to keep the line moisture-free, and to this end all joints should be air-tight. At the ends of the line, moisture-proof seals should be used. A simple end seal can be made as shown in Fig. 1622. It uses a compression connecter to join a $\frac{3}{8}$-inch (o.d.) line to an isolantite insulator also having an outside diameter of $\frac{3}{8}$ inch. The wire conductor passes through the center of the insulator as shown, with the space being filled around the wire with glyptal or Duco cement to keep out moisture. A spot of solder at the end anchors the wire.

Bringing the Antenna or Transmission Line into the Station

In bringing the antenna or transmission line into the station, the line should first be anchored to the outside wall of the building, as shown in Fig. 1623, to remove strain from lead-in insulators. When permissible, holes cut directly through the walls of the building and fitted with feed-through insulators of suitable size are undoubtedly the best means of bringing the feeders into the station, for the job can be done with little difficulty and can provide greater mechanical permanence than other schemes. It involves no interference to screening or storm windows. The holes should have plenty of air clearance about the conducting rod, especially when tuned lines, which develop high voltages, are employed. Probably the best place to go through the walls, from the standpoint of appearance, is the trimming board at the top or bottom of a window frame which provides flat surfaces for tightening lead-in insulators. Cement or rubber gaskets may be used to water-proof the exposed joints.

Where such a procedure is not permissible, the window itself usually offers the best opportunity. One satisfactory method is to drill holes in the glass near the top of the upper sash. If the glass which is to be drilled is replaced by plate glass, a stronger job will result. Plate glass may be obtained reasonably from automobile junk yards and may be drilled before placing in the frame. The glass itself provides the necessary insulation and the transmission line may be fastened to bolts fitting the holes. Rubber gaskets cut from inner tube will render the holes water-proof. The lower sash should be provided with stops at a suitable height to prevent damage when it is raised.

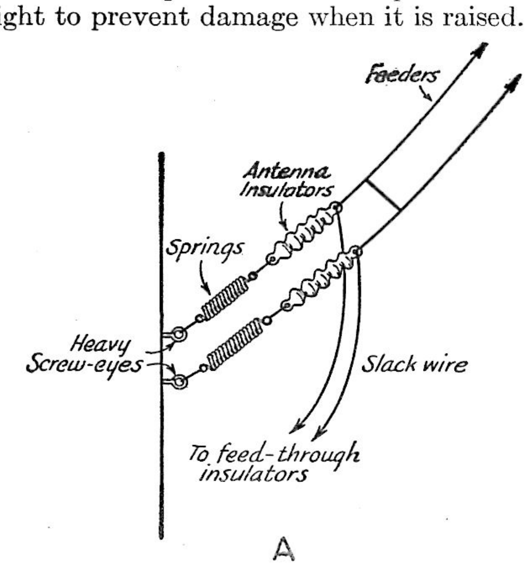


Fig. 1623 — Feeders anchored to take the strain from feed-through insulators or window glass.

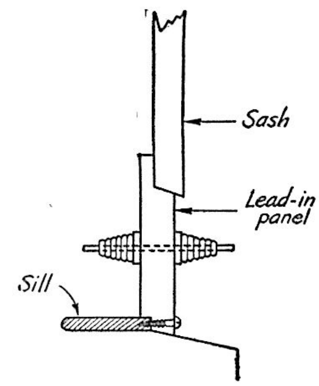


Fig. 1624 — Antenna lead-in panel. It may be placed over the top sash or under the lower sash of window. The overlapping joint makes it weather-proof. The single thick board may be replaced by two thinner boards fastened together.

In a less permanent method, the window is raised from the bottom or lowered from the top to permit the insertion of a board three or four inches wide which carries the feed-through insulators. This arrangement may be made weather-proof by making an overlapping joint between the board and window sash, as shown in Fig. 1624, and covering the opening between upper and lower sashes with a sheet of soft rubber cut from an inner tube.

Fig. 1625 shows a method for keeping rain from running down the feeders and into the lead-in insulators. The short lengths of wire are pinched on the feeders far enough out to clear the building so that the water does not drip on the sill. These "drip wires" also help prevent ice formation around the lead-in insulators in winter.

Drilling Glass or Ceramics

Glass and ceramic materials may be drilled by several methods, one of which involves the use of a special drill of the type shown in Fig. 1626, ground from a piece of 3/8-inch drill rod. To drill a hole, place the drill in a hand brace, engine lathe or slow speed drill press. If the material to be drilled is flat, such as plate glass, make sure that the supporting surface is flat. Apply turpentine to the point of the drill and press firmly against the work in the desired location. Then turn the drill slowly and apply sufficient turpentine to keep the drill wet at all times. Use care when breaking the point through the work to avoid chipping. After the point has broken through, turn the work over and drill from the opposite side, repeating this operation as often as is necessary to keep the edges of the hole nearly parallel.

Lightning Protection

Some form of protection from heavy induced charges on the antenna from lightning discharges in the vicinity always should be provided. The conductors in an ordinary antenna system are not heavy enough to handle a direct stroke, but fortunately these are rare.

One method satisfactory to the fire underwriters is the use of a special "lightning switch," somewhat larger than the ordinary porcelain-base knife switch, by means of which the feeders are grounded when the station is not in use. The ground wire should run directly to a good ground connection preferably, although not necessarily, outside the building. Alternatively, a similar ground wire with a clip which can be fastened on the feeders may be substituted for the switch.

Automatic protection can be secured by installing spark gaps between the feeders and a good ground. A good method of making such a gap is shown in Fig. 1627. The gap electrodes are made of pieces of heavy wire. Rubber cones cut from an old inner tube, slipped over the upper electrodes, protect the gap from short-circuit by snow or rain.

It is a good plan to get in touch with a fire insurance agent or the city inspection department to ascertain local requirements with respect to antenna lightning protection. The booklet *Safety Rules for Radio Installations,* Handbook of the Bureau of Standards No. 9, also will provide useful information. It is available from the Superintendent of Documents, Government Printing Office, Washington, D. C., for ten cents.

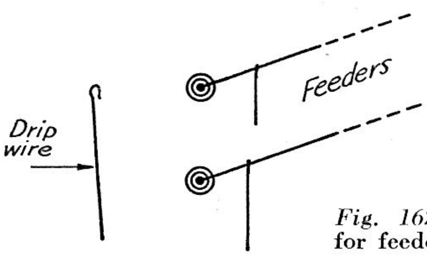


Fig. 1625 — Drip wires for feeders.

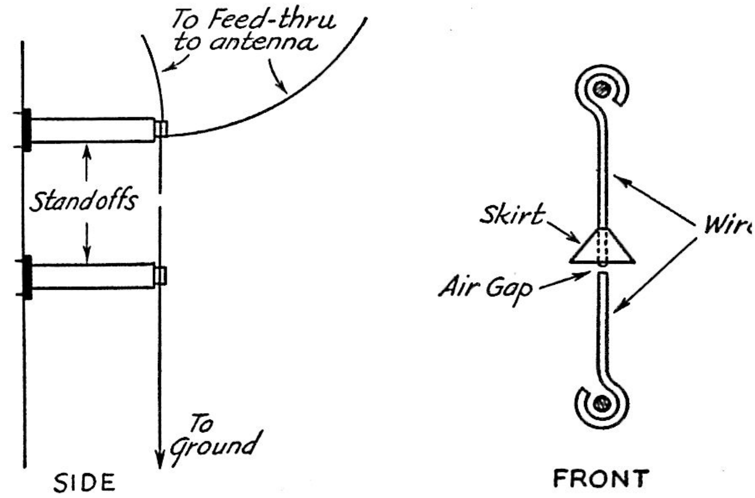


Fig. 1627 — Spark gap for static discharges.

Replacing Broken Antenna Halyards

In the event that the antenna rope breaks, getting a new rope through the pulley may involve taking down the mast if the latter cannot be climbed. There are several ways in which a new pulley and rope can be installed at the top, however.

Some schemes make use of the top guy wires in coaxing a new pulley, fitted with a new halyard, to the top of the mast. If you have a second mast or can make use of a tree or housetop or temporarily erected support, the method shown in Fig. 1628-A is probably one of the easiest to execute. One of the top guys is set free. The new pulley with halyard is fitted with a heavy metal ring or a loop of several turns of heavy wire and the loose end of the guy wire is passed through this loop. The loop should be large enough to pass easily over the guy-wire insulators. A light cord is tied to the loop and the free end of the guy wire is tied to the halyard from the second support, hoisted up and pulled tight. It should then be possible to make the loop slide along the guy wire towards the top of the mast by shaking the new halyard and pulling on the assister cord from a distance. In some cases, it may be possible to coax the loop up over the top of the mast if one has sufficient patience and the top guys are not fastened too far from the top of the mast, although this is not necessary. When the loop has been worked up close to the mast, it may be held there by the assister cord while the guy wire is lowered. While holding the free end of the guy wire, several turns about the mast should be made by walking around the mast outside all other guys. This will bind the loop securely to the mast. A sharp yank will break the assister cord after the job is finished.

Another scheme which may be tried is shown in Fig. 1628-B. A loop of wire, as previously described, is passed around the rear top guy wire. If the loop is covered with tape or a section of old bicycle tire or garden hose, it may slide more

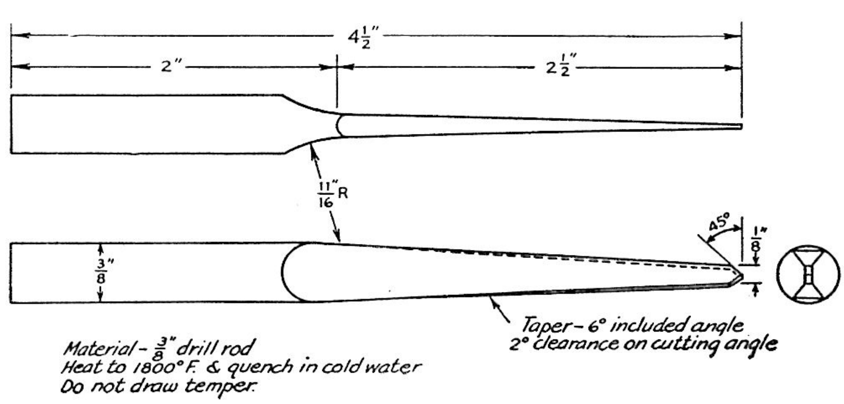


Fig. 1626 — Drill for cutting glass.

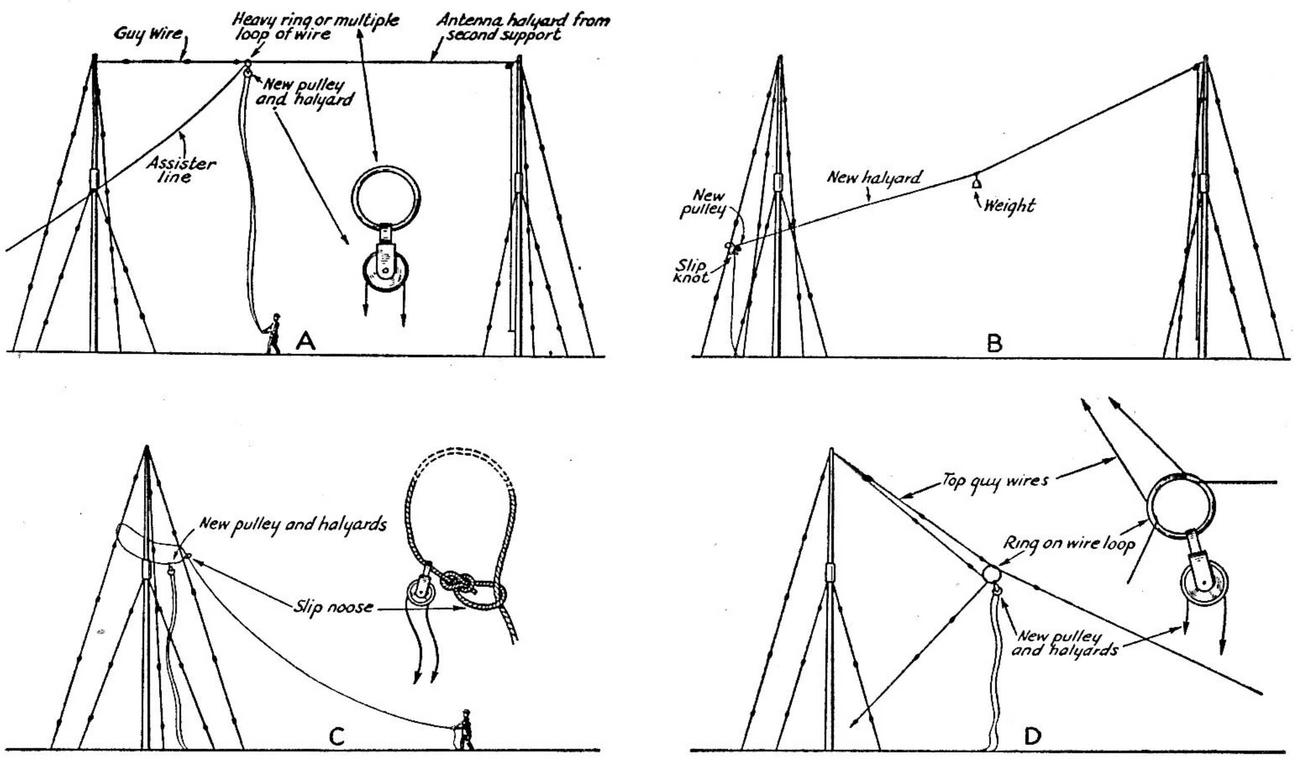
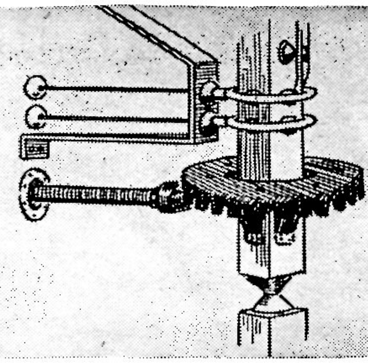


Fig. 1628 — Schemes for replacing broken antenna halyards.

readily on the guy wire. The new halyard and the halyard from the second support are tied together and a large slip-knot is tied in the other side of the new halyward to prevent the new halyard from running through the pulley when it is pulled up the guy. Alternatively, the two ends of the new halyard may be tied together and then tied to the halyard from the second support. An assister cord tied to the wire loop might be helpful in getting the loop over insulators; shaking the guy wire should also help. When the pulley reaches the top of the mast, the guy wire is wrapped around the top of the mast as previously described. A sharp yank on the free end of the new halyard will take the slip-knot out. It might be a good idea to tie a weight between the two halyards to make sure that they will fall to the ground when released.

If no second support is available there are other ways, one of which is shown in Fig. 1628-C. Pass a heavy rope around the outside of all top guy wires. Then pass the rope through the eye of the new pulley fitted with the new halyard and form a slip noose. By shaking and pulling the rope, it should be possible to work the loop up the guy wires to the top. Best results will be obtained by working the rope at a fairly good distance. If the loop becomes caught on an insulator, a friend can assist by sliding the pulley along the loop to a point near the insulator and whipping the halyard. When the noose reaches the top of the mast, its rope should be made fast to the pole.



17. ROTATING MECHANISMS

TYPES OF SUPPORTS — METHODS OF ROTATION — DRIVE MECHANISMS — DIRECTION INDICATORS

THE deserved popularity of rotary beam antennas has stimulated interest in the purely mechanical problems of the construction of suitable supporting structures and their rotation. The schemes devised to rotate antennas vary from very simple and inexpensive ones to elaborate and costly arrangements. The methods shown in this chapter are presented chiefly to indicate general principles and not necessarily to give full descriptions suitable for exact duplication. In other words, the accent is on ideas and only secondarily on details. All of them have been in everyday use at various amateur stations, however, and are thoroughly practical.

Naturally the size of the structure will depend upon the frequency, and for this reason the use of rotating antennas is confined to 14 Mc. and the higher-frequency bands. Some of the structures shown here are for 14-Mc. and others for 28-Mc. antennas. Most of them readily can be adapted to different electrical systems which may be selected after consultation of Chapter 9.

Vertical antennas present the fewest constructional problems, undoubtedly. On the other hand, most amateurs want horizontal polarization on 14 and 28 Mc. to reduce response to man-made static in reception. However, if the location is fairly free from this type of interference the vertically-polarized antenna can be expected to be equally effective as its horizontal counterpart. While with many systems ordinary wire can be used for antenna elements in vertical structures, the horizontal rotary usually requires more rigid conductors made of metal tubing to give the necessary stiffness for self-support.

Some Vertical Rotary Systems

Fig. 1701 shows an extremely simple antenna

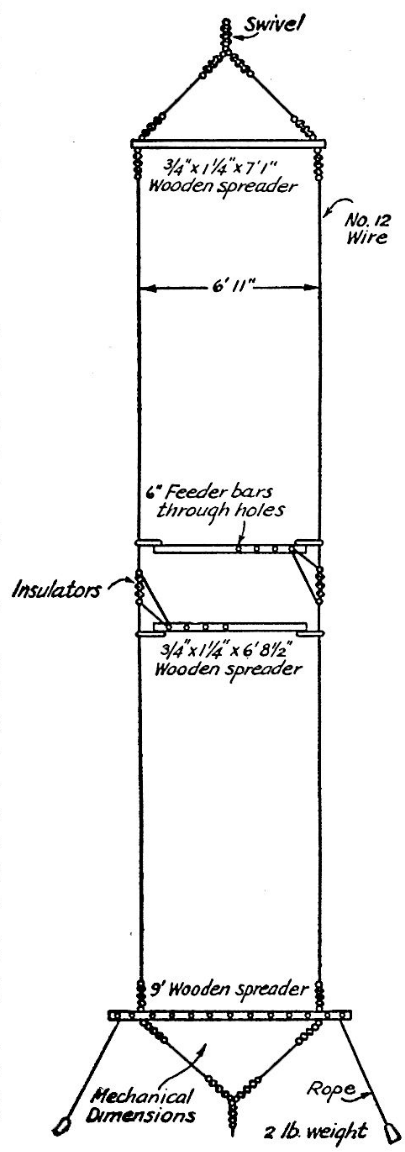


Fig. 1701 **— A simple form of rotatable antenna which can be suspended from any convenient support, such as a horizontal antenna. Rotated by hand, it costs little more than the price of the wire and insulators.**

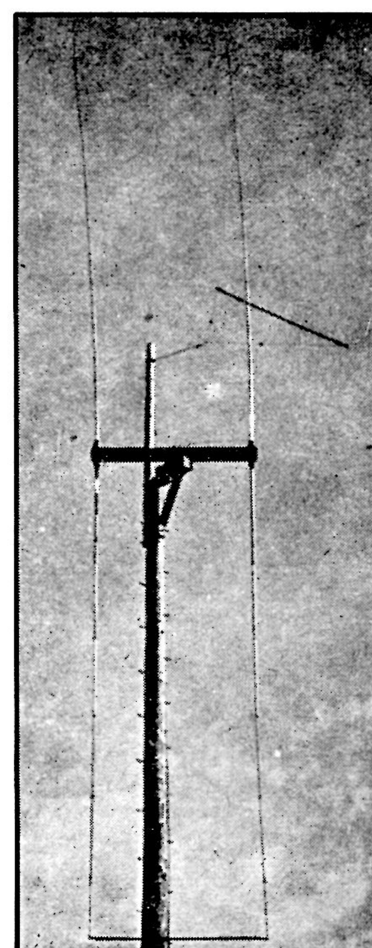


Photo by W. E. Diehl, ex-2CY

Fig. 1702 **— A vertical rotary antenna using tubing elements. It is motor-driven, and is mounted on an arm extending from the top of a telephone pole.**

arrangement used by W6AM. The dimensions given are for a 28-Mc. extended double-Zepp with reflector, but the general idea of the use of spreaders and a single-point suspension readily can be

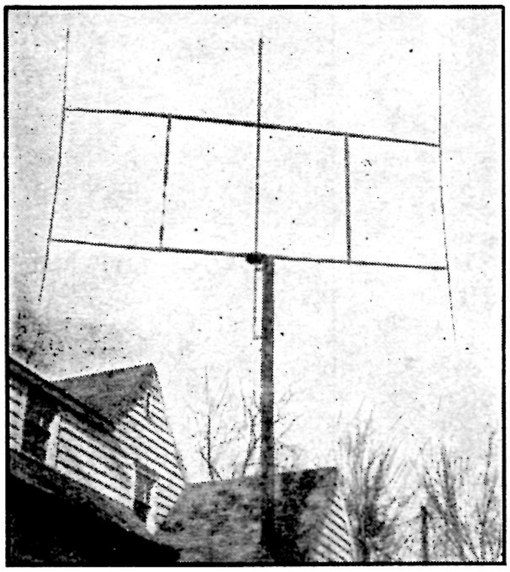


Fig. 1703 — **In this vertically polarized system the antenna or driven element is fixed, while the parasitic elements rotate around it. Construction details are given in Fig. 1704.**

adapted to other antenna systems. The swivel at the top can be attached to any convenient support which is high enough and will permit the antenna to hang free. An arm of suitable length from the top of a pole or even a horizontal wire such as an antenna will do the job. The weights at the bottom keep the antenna from swinging when set to the desired direction.

This type of system is best operated by hand and is not readily adapted to motorized or remote-control rotation because of its flexibility. Although it would be possible to connect a motor shaft to the bottom spreader, it is probable that the upper part of the antenna would tend to "stay put" without some shaking at the bottom to maneuver it into the right position.

Fig. 1702 shows how a vertically polarized beam using tubing elements can be installed on an arm at the top of a pole. The particular antenna shown, a bi-directional "W8JK," is at W2AZ. The driving motor is in the housing at the center of the cross-arm on which the antenna elements are mounted. Only 180-degree rotation is necessary. Obviously the same idea could be applied to continuous rotation if the cross arm is set on the top of an unguyed pole.

Vertical beam systems have a distinct advantage over horizontal antennas in that when

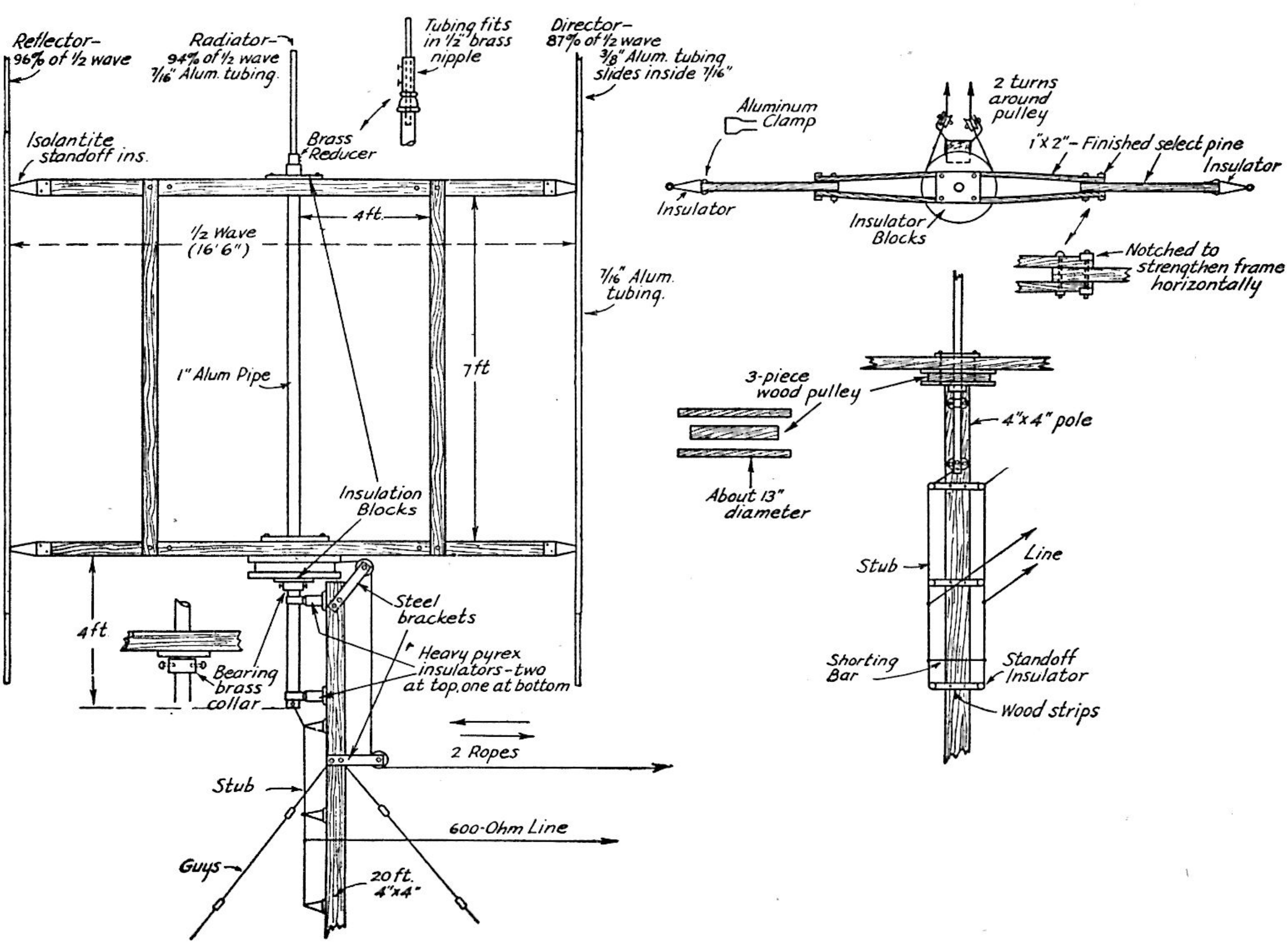


Fig. 1704 — **Essentials of the rotary beam shown in Fig. 1703.**

parasitic director or reflector elements are used the antenna element itself need not rotate. It is only necessary to rotate the director or reflector *around the antenna*. There is, therefore, no necessity for special feeder contacts; the feeders may be installed and connected just as though the antenna were not a rotary.

Fig. 1703 shows a photograph of a rotary beam using this principle, a 28-Mc. antenna used at W2BSF. The mast on which it is installed is a 20-foot 4 × 4. As shown in Fig. 1704, the detailed drawing of the antenna, the antenna element is a section of pipe fitted with bearings on which the rotating assembly turns. The director and reflector are at the extremities of the wooden framework. The whole beam is rotated by means of ropes and pulleys which run to the station. For electric rotation it would be relatively easy to arrange a belt drive to replace the ropes, mounting the motor in a housing at the top of the pole.

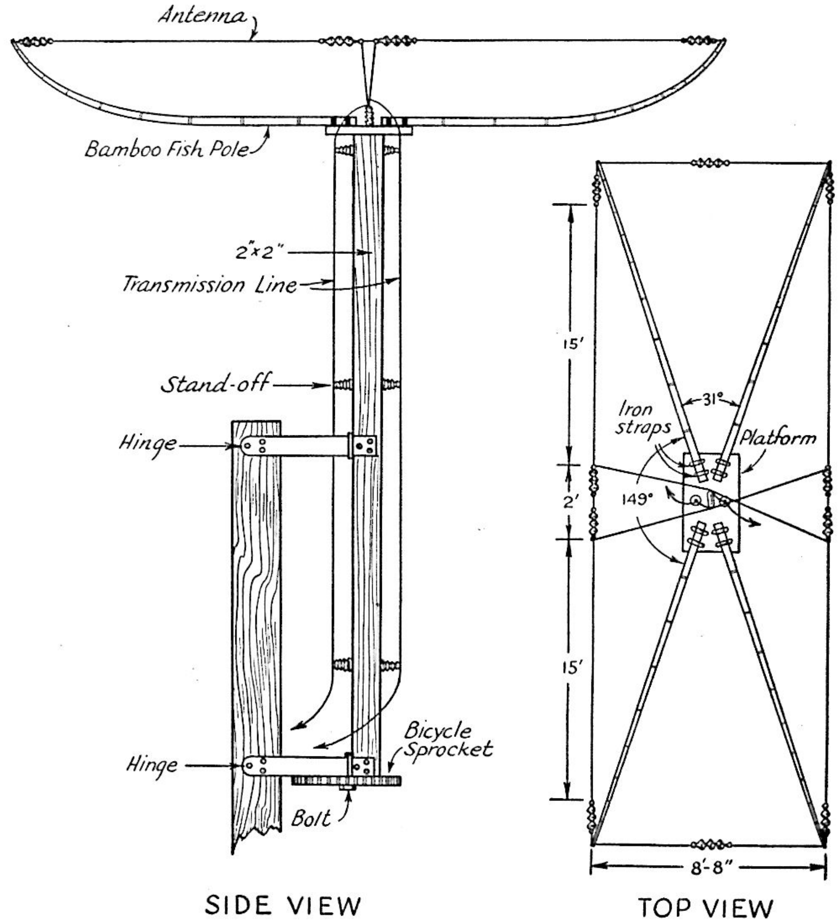


Fig. 1705 — **An inexpensive form of horizontal rotary antenna using bamboo poles for supports. An unusual method of rotation is also incorporated in the antenna.**

Horizontal Antennas

An extremely simple and inexpensive method of making a horizontal rotary beam, suitable for bi-directional antenna systems, is shown in Fig. 1705. As used by W5EOW, the antenna, a two-element end-fire with close spacing ("W8JK") is of ordinary wire construction, held in a horizontal position by bamboo spreaders under tension. Besides being inexpensive and easy to build, this type of structure offers very little wind resistance.

Fig. 1705 also shows a simple and cheap method of rotating the antenna. The antenna and feeders are mounted solidly on a short section of 2 × 2 which is hinged to the main pole. Full 180-degree rotation is possible. The bicycle sprocket at the bottom, centered on the axis of the bottom hinge, is driven by a chain from the operating position. Alternatively, the short pole could be fixed on bearings so that it could be rotated through 360 degrees, if a uni-directional antenna system is used. The dimensions given are for 14-Mc. operation; they can easily be altered for different electrical systems or for 28 Mc.

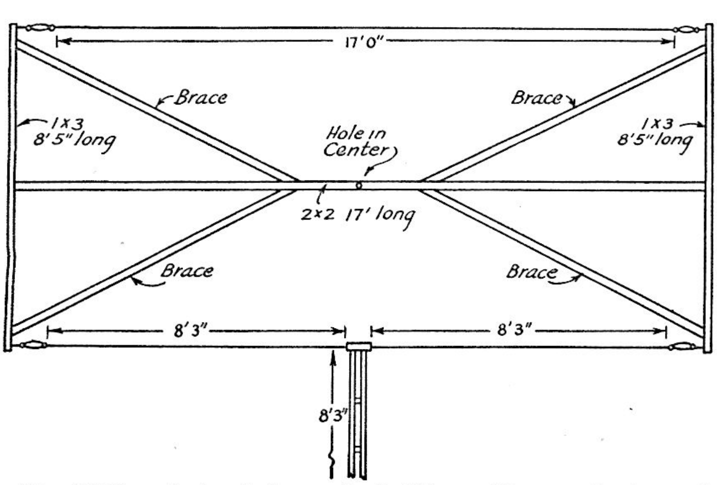


Fig. 1706 — **A simple frame for holding a 10-meter horizontal beam using wire elements. Dimensions can be varied to fit the element spacing desired.**

Another scheme for using wire elements is shown in Figs. 1706 and 1707. This arrangement, built by W5BZR, uses a wood framework to support 28-Mc. antenna elements, in this case to form an antenna-reflector system. As shown in Fig. 1707, the framework is mounted on a short length of pipe which turns in simple bearings on the main pole. The framework is kept horizontal by means of four rope guys which brace the corners of the frame to a short vertical extension at the center. The antenna as pictured is rotated by hand, using the ropes which fasten to the corners of the frame in Fig. 1707. Other methods of rotation could be adapted without much difficulty, however.

A lightweight but rigid wooden framework suitable for supporting a two-element 14-Mc. antenna using horizontal tubing elements, designed by W2DKJ, is shown in Fig. 1708. The distance between the end cross-bars which support the antenna elements on stand-off insulators, can be varied to give the element spacing selected. Following is a list of the material necessary for this framework:

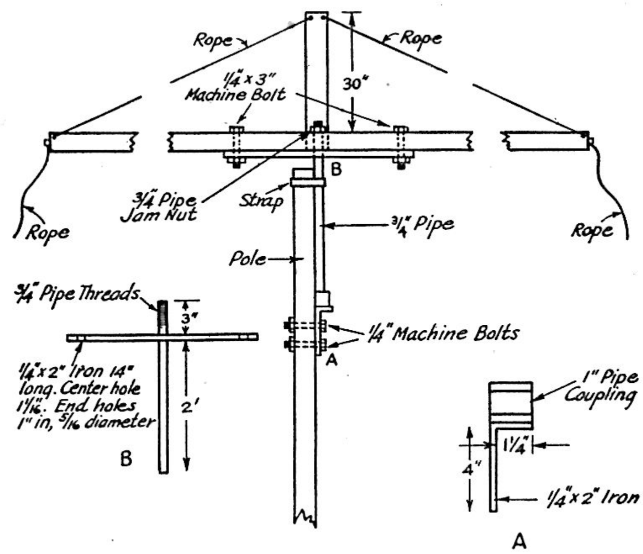


Fig. 1707 — **Another view of the frame of Fig. 1706, showing the rope guys at the top and the method of supporting the frame for rotation.**

2 pieces of ¾″ plywood, 12″ × 12″. These should be perfectly square and are used together to form "A."
2 pieces of 2″ × 2″ × 36″ oak, main supporting members ("C"), free from knots.
4 pieces redwood or white pine, 1″ × 2″ × 9′, free from knots ("D"). 1⅛″ × 1⅛″ will be satisfactory in place of 1″ × 2″.
4 pieces same as "D" but 7′ long ("E").
4 pieces redwood or white pine, ½″ × 1″ × 6′ ("F").
4 square head, 5/16″ × 4″ bolts, used to attach "A" to "B."
4 square head, ¾″ × 5″ bolts, used to join "C," "D" and "F" together, in the center.
4 square head, ¼″ × 3″ bolts, used for joining the outside extremities of "E," to provide the bowing.
2 machine, ¼″ × 1¼″ bolts, with suitable washers and nuts, used to join the centers of the units marked "F."
12 square head, ¼″ × 4″ bolts, used for joining all the other sections together.

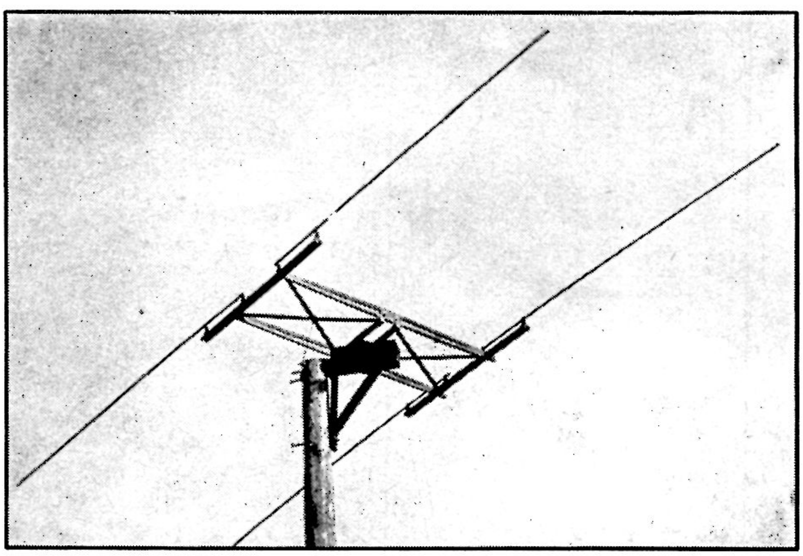


Fig. 1709 — A rotary antenna using the frame shown in Fig. 1708. This antenna is used by W2AZ. *Photo by Arthur Lynch, W2DKJ.*

The center piece, A, forms a base for mounting the frame, and may readily be adapted to various bearings and drives for rotation. A small bakelite plate may be fitted in at "B" to serve as a junction point for feeders.

Fig. 1709 shows such a framework supporting a bi-directional beam of the W8JK type, mounted on an arm on top of a telephone pole.

A rather simple guyed support for two 14-Mc. elements is shown in Fig. 1711, and a photograph of this type of structure on top of a lattice tower is shown in Fig. 1710. A properly-trussed framework will be quite light-weight and its wind resistance will be small, since comparatively few compression members are used. The dimensions given in Fig. 1711 can of course be altered to suit the particular type of antenna to be used.

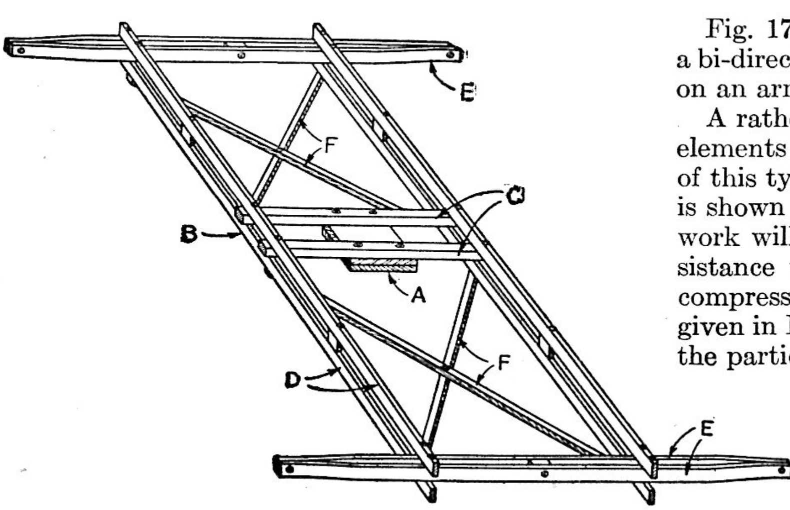


Fig. 1708 — **A light but strong frame for supporting a 14-Mc. beam. Dimensions of the various members are given in the bill of material in the text.**

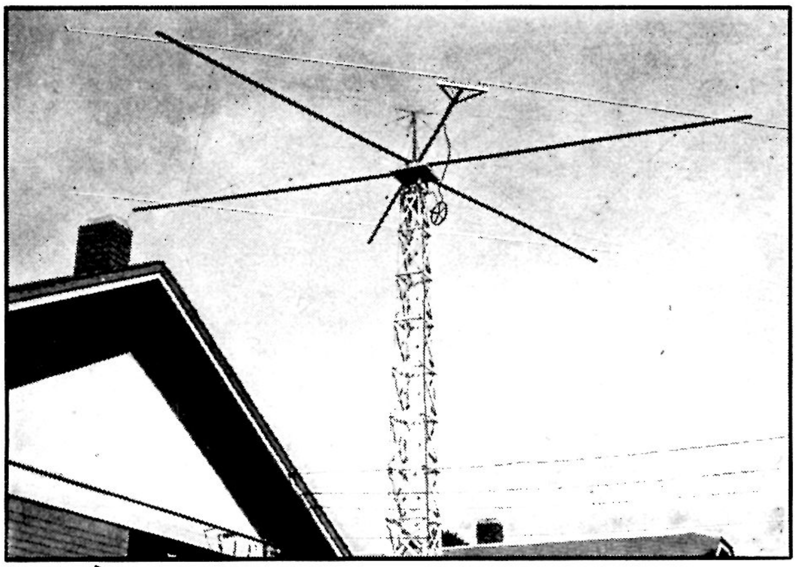


Fig. 1710 — An X-frame for a 14-Mc. antenna, using top guys to maintain rigidity.

Figs. 1712, 1713, and 1714 show a type of support for three-element rotaries, inexpensive to build and capable of standing up under stiff winds. This particular model is intended for mounting on a pole which can be rotated, a system which is not so difficult as it might seem at first thought. The lengths and sizes of the framework members are indicated in Fig. 1713, while the two photographs show the method of bracing. The whole framework is made to balance, after the tubing elements are in place, with respect to the pole by moving the

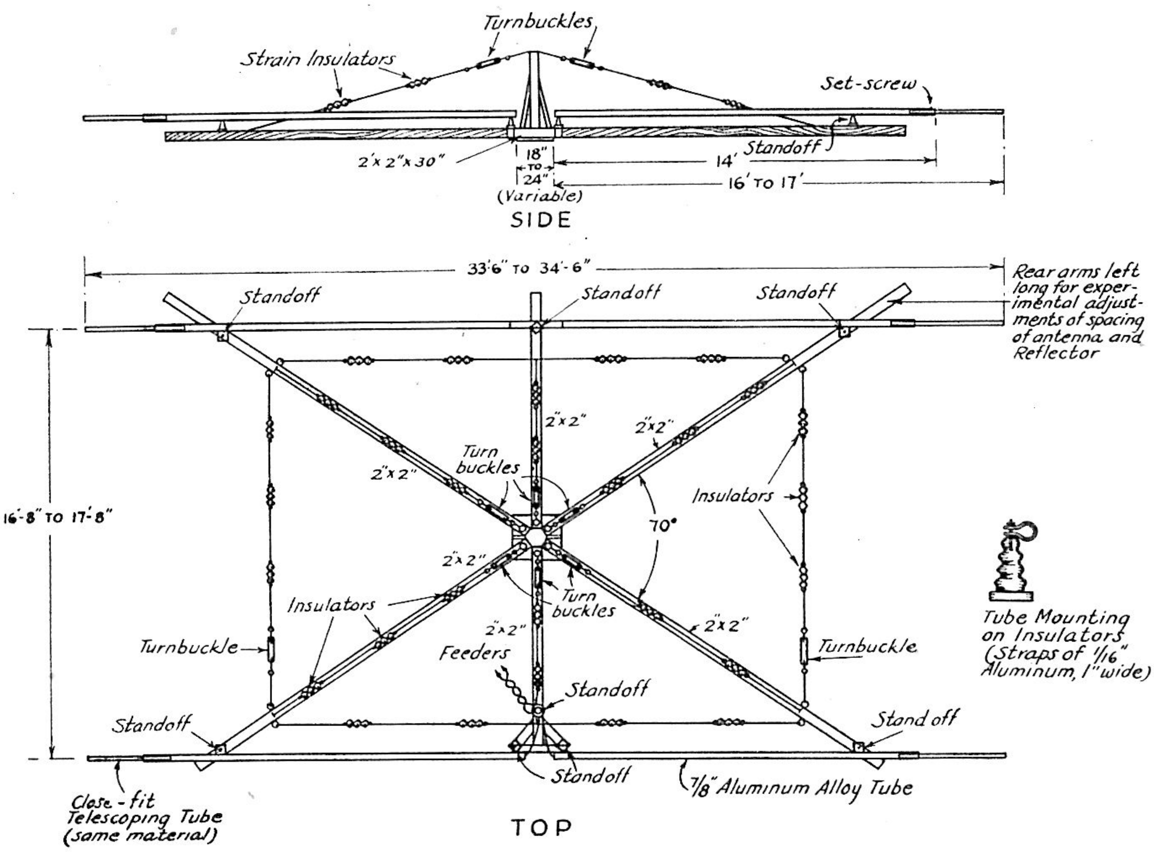


Fig. 1711 — Details of the antenna system shown in Fig. 1710.

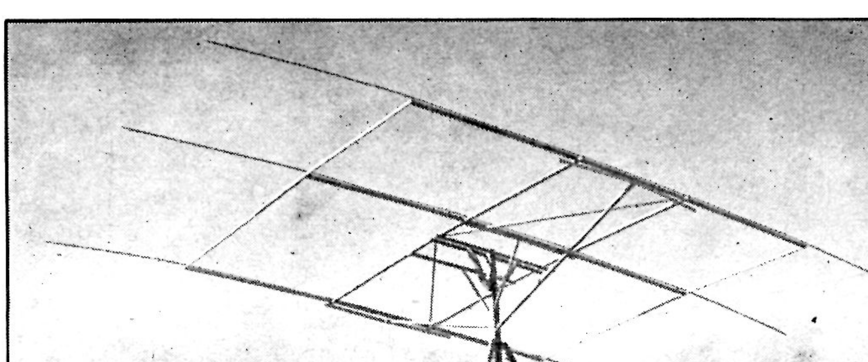


Fig. 1712 — This framework for a three-element beam can be constructed at quite low cost. Essentials of the frame are shown in Fig. 1713.

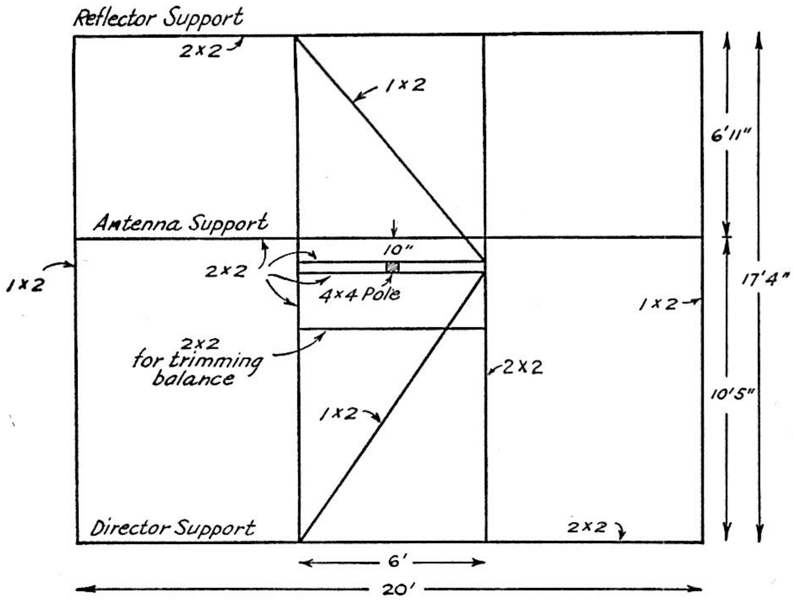


Fig. 1713 — "Schematic" sketch of the antenna shown in Fig. 1712. Antenna elements, not shown, are mounted on stand-off insulators placed on the supports at intervals of 4 feet.

length of 2 × 2 indicated in Fig. 1713 back and forth until the right position for it is found.

Rotating the Antenna

The antenna of Figs. 1712–1714 is typical of the type of system in which the antenna supports are rigidly fastened to the pole and the pole itself is turned. The driving arrangement used by W7GBY is shown in Fig. 1715.

For a bottom bearing, a foot-square hole, two feet deep, is filled with concrete. A half-inch steel pin is set in the concrete before it hardens to serve as a guide for the pole, and an iron plate through which the pin projects five or six inches is set on top. The pin fits into a hole drilled in the center of the bottom of the 4 × 4 pole, and the pole rests on the iron plate, which acts as a bearing surface.

A second bearing some distance up the pole will be necessary. This bearing can be made in a variety of ways. A collar made of strap iron can be fitted to the pole, either by rounding the pole, in case a square pole is used, or by building out a wooden circle over which the strap is fastened. Cut-out wooden blocks fitting around the collar will serve as an outside bearing. These may be rigidly attached to some convenient solid base (the house itself, if the pole is alongside the house) either directly or on a well-braced extension arm. Alternatively, the top bearing, in addition to the collar arrangement mentioned, may also bear on a flange fastened to the pole so that the bearing will not slip down. Ordinary guys may be attached to the outer block. These guys function in the same manner as for a stationary pole, so that the pole is held vertical but is free to rotate.

The rotating mechanism shown in Fig. 1715 uses two gears of the type shown, one mounted on the pole and the other at the end of a rod which does the actual turning. It is often possible to pick up suitable gears for nothing, or almost nothing, in junk yards. This type of turning mechanism is easily adaptable to either hand or motor drive. A somewhat similar system is shown in sketch form in Fig. 1716, with a photograph of the actual installation at W8EEP in Fig. 1717. The bearing details differ from those already described, and a bicycle sprocket and chain are used for the drive. Fig. 1716 also shows a method of making connections to the transmission line, allowing for continuous rotation of the antenna. Obviously the

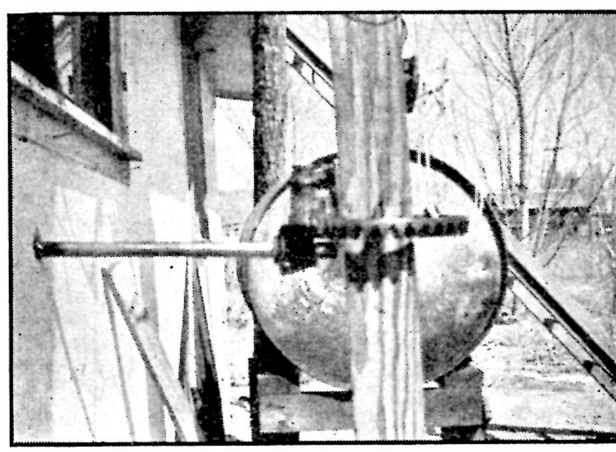


Fig. 1715 — Gear drive for a rotating pole.

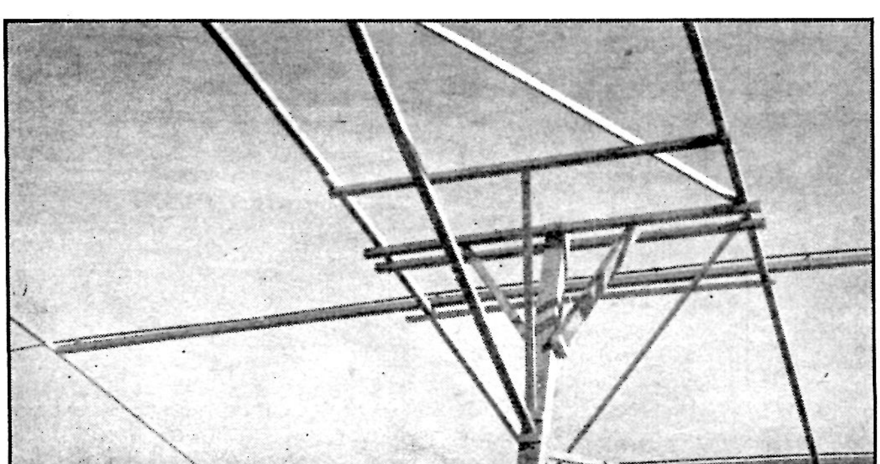
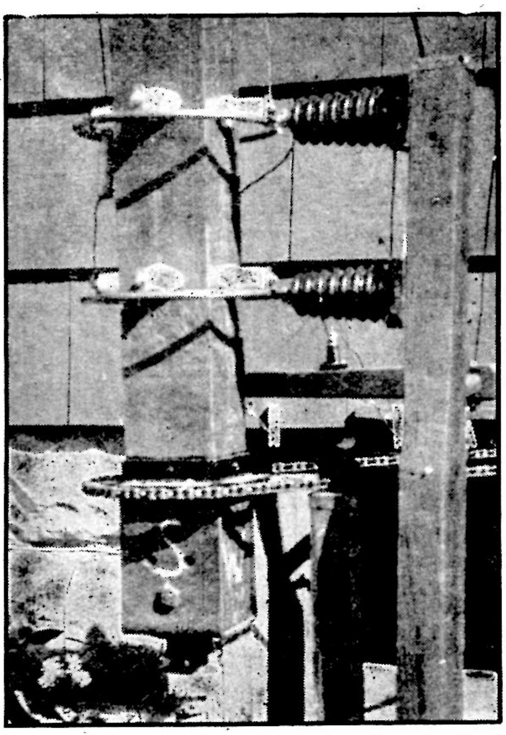


Fig. 1714 — Some of the bracing details of the antenna of Fig. 1712. The braces, 2 × 2s, run to the midpoints of the antenna element supports.



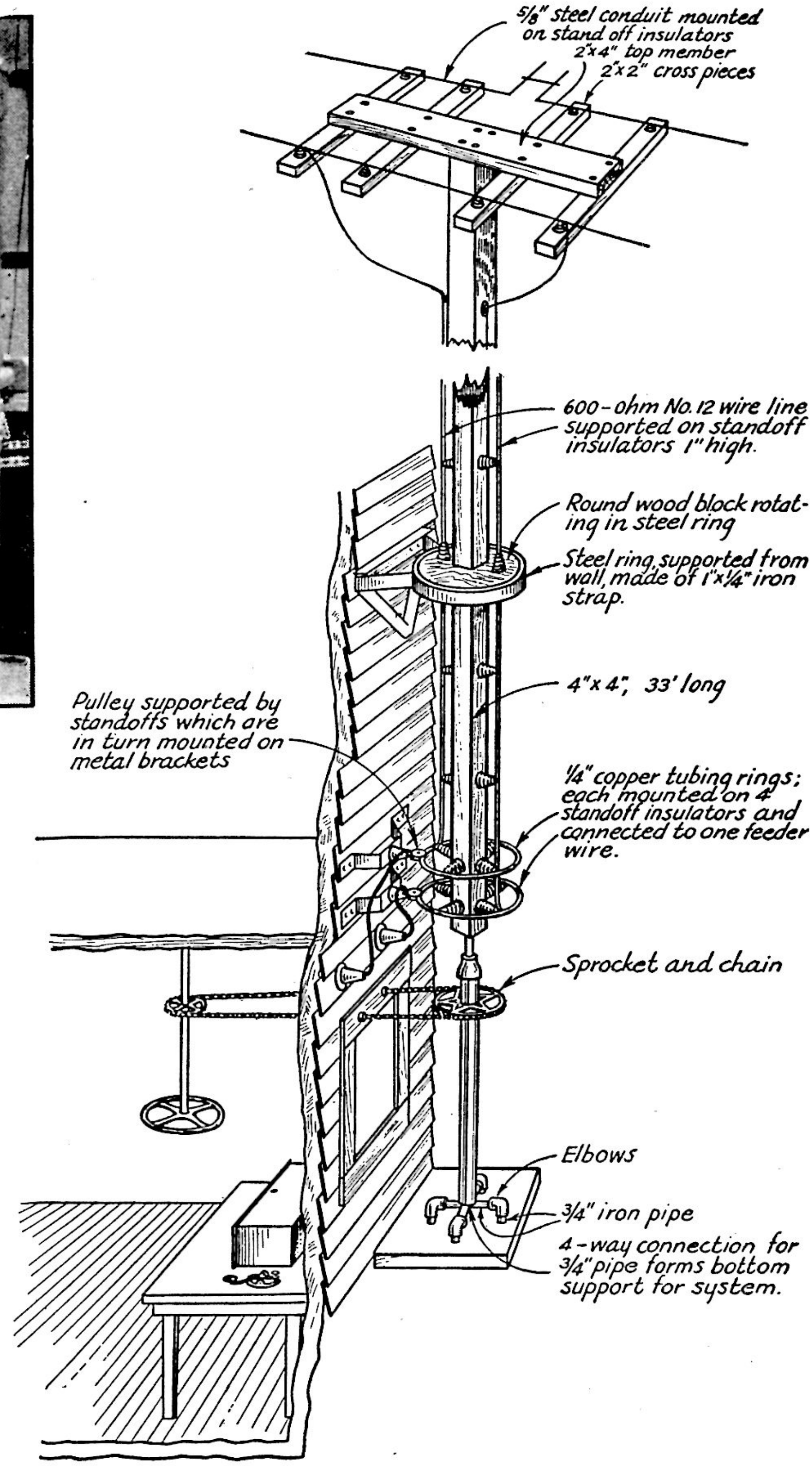


Fig. 1716 — Details of one method of rotating a pole carrying a directive antenna.

♦

Fig. 1717 — A view of the drive mechanism and feeder contacts in an installation built according to Fig. 1716.

♦

detailed working out of the general principle can be accomplished in a variety of ways. Discarded gadgets of various kinds often can be pressed into service to fill a definite need and save money.

A method for remote control of rotation of the horizontal structure, devised by W4CCH, is shown in Fig. 1718. The antenna-support framework is mounted to a length of iron pipe (details not shown) the lower end of which is fastened to the ring gear. The connection is made by fastening the gear to a circular piece of hardwood by screws, then centering a pipe flange on the opposite side of the wooden piece and screwing it down. The end of the pipe is threaded to fit the flange. The remaining details should be quite clear from inspection of the drawing. The gears are taken from a discarded Model T rear end, which usually can be picked up at a junkyard or from a dealer in second-hand auto parts. The bearings for the drive shaft are made from strap iron.

A photograph of the actual installation at the top of a lattice tower is shown in Fig. 1719, and Fig. 1720 shows how the connection is made to the operating room.

Discarded automobile rear ends are readily adaptable to rotary antennas, since they provide right-angle drive and also give a reduction ratio which is necessary for motor drive. Fig. 1721 shows how W1APA utilized a rear end to turn a horizontal beam, employing a system very similar in principle to that just described. The drive chain

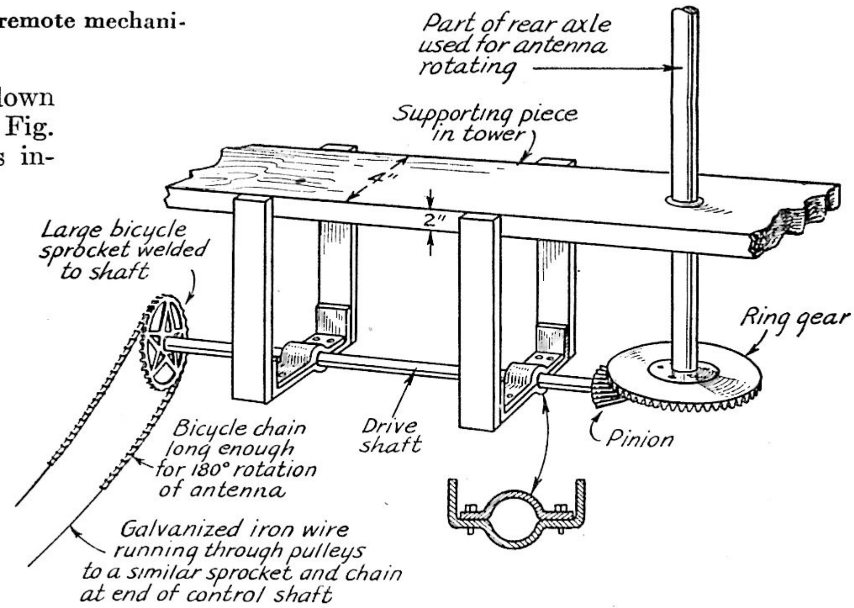


Fig. 1718 — **A drive mechanism for remote mechanical control of rotation.**

and cable, however, go straight down the pole to the housing shown in Fig. 1722, where the driving motor is installed. Pulleys adapted from inexpensive polishing heads provide additional speed reduction to bring the actual turning speed of the antenna down to about 1 rotation per minute.

Motors

The power required to turn a rotatable system depends upon its weight and construction, particularly with respect to friction. Not a great deal of power is needed; a motor capable of delivering 1/8 horsepower is ample for the average rotary, and a 1/4-hp. motor will take care of the largest.

Since high speed of rotation is undesirable, both mechanically and from an operating standpoint — the beam should move slowly enough to enable setting accurately to the right direction — reduction of some type is necessary. The automobile rear ends will provide a step-down gear ratio, but considerably more is needed for the conventional motor turning at 1750 r.p.m. A pulley arrangement such as that shown in Fig. 1721 can be rigged up without much expense, or special gears can be installed to do the same job. Besides reducing speed, a train of gears also acts as a brake on the antenna so that it does not "coast" beyond the position at which the motive power is shut off, and so that it has less tendency to be blown off the desired direction by a wind. On hand-operated systems it may be necessary to rig up a mechanical brake to keep the antenna from swinging back and forth. A drum with improvised brake shoes will serve for remote-control systems, while weights on the pull ropes will do for those antennas which are simply pulled around from the ground.

A reversible motor is an asset in motor driven systems. Usually, when adjusting an antenna for maximum response to a received signal, it is necessary to swing somewhat past the maximum point in order to be sure of the direction. Unless the direction of rotation can be reversed, this means that the antenna must be swung nearly 360 degrees to get back to the desired direction.

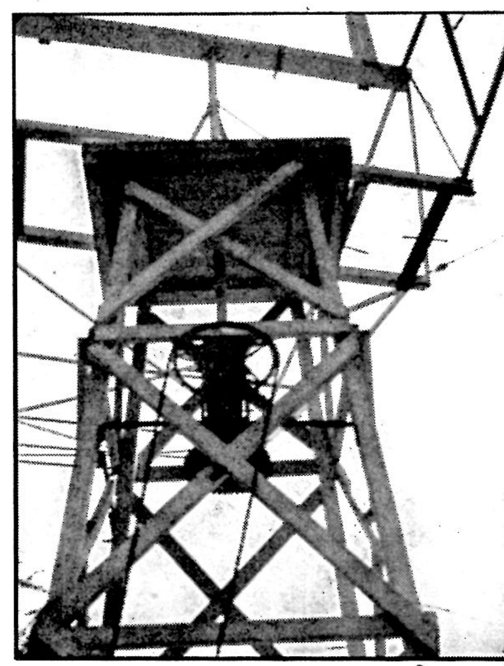


Fig. 1719 — **The drive mechanism of Fig. 1718 installed at the top of a lattice tower.**

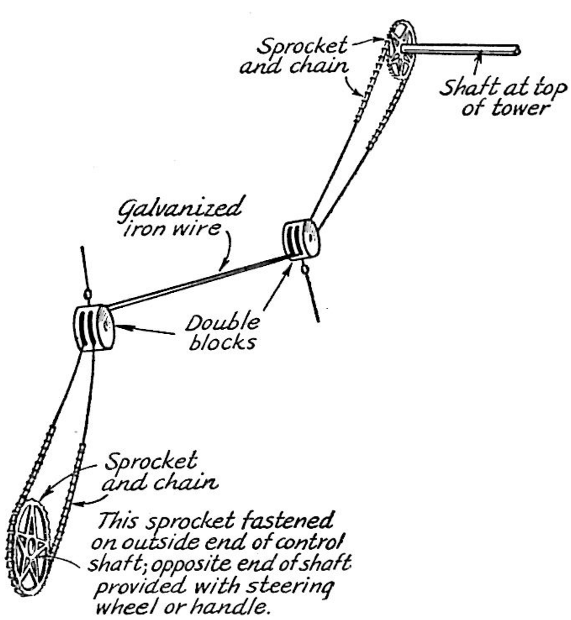


Fig. 1720 — **Hookup of the remote control system used with the drive mechanism shown in Fig. 1719.**

Setting Directions

In most cases the rotary antenna will not be visible from the operating position, so it is an operating convenience to provide some means for determining, without leaving the station, the direction in which the beam is pointing. In those systems which are rotated mechanically from the station, it is possible to calibrate the control wheel so that the direction is known, although in installations involving a speed reduction somewhere along the control line this may become a bit complicated.

A favorite type of direction indicator which is independent of the rotating device is shown in Fig. 1723. The shaft on which the antenna rotates is fitted with a rotary switch which operates indicator lights at the operating position. The lamps may be arranged in a circle according to the points of the compass, and connected to consecutive switch points so that the lamp elected to indicate any particular direction will light when the antenna is in that position. The construction of the switch will depend upon the method by which the antenna is rotated; in most cases the contact arm may be mounted on the rotating member and the switch points on a stationary ring surrounding the rotating shaft. Alternatively, the shaft could be fitted with the points, commutator fashion, and a stationary brush used for the switch arm. For most beams, four or eight lamps will be ample, since few rotary beams have very sharp horizontal-plane patterns. The lamps may be flashlight bulbs or dial lights working from a step-down transformer. The switch should be protected in some fashion from the weather to make its operation reliable. One disadvantage of this system is that a wire is needed for each lamp, which runs into a large number of wires if many lamps are used.

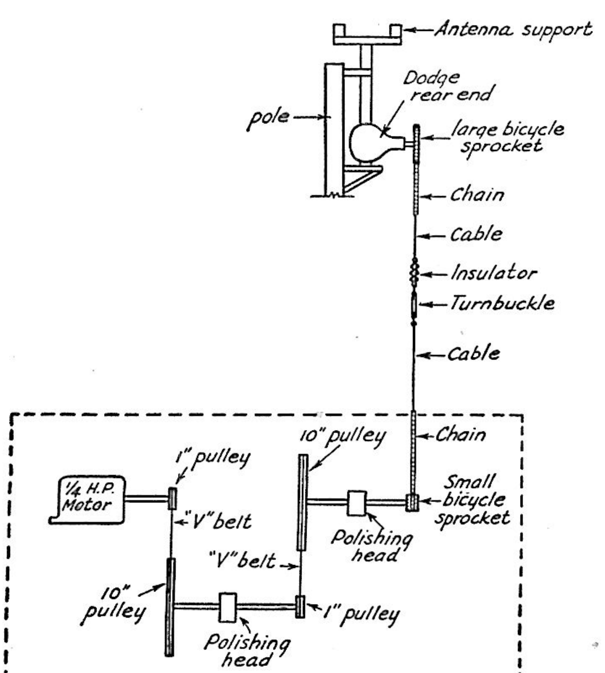


Fig. 1721 — Electrical drive through reduction pulleys and combination chain-cable running from top to bottom of a stationary pole.

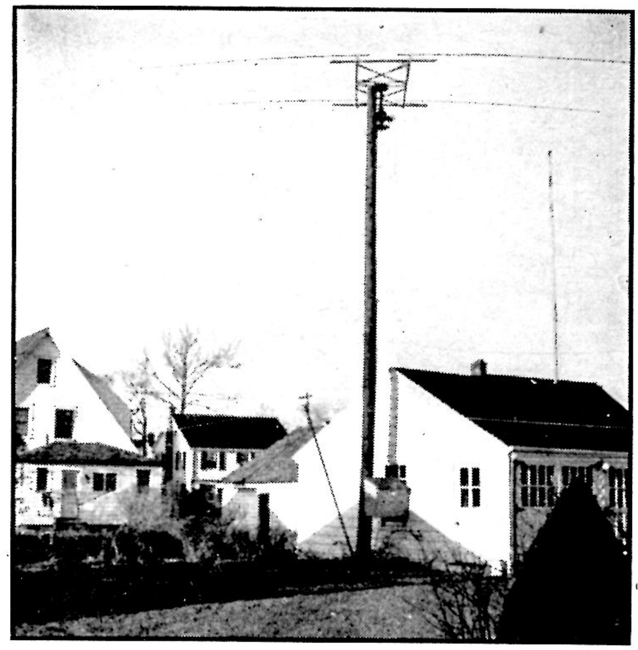


Fig. 1722 — A rotary antenna using the driving system shown in Fig. 1721.

A rather simple mechanical indicator for beams controlled by a rope brought into the station is shown at *B* in Fig. 1724. It hardly needs any comment aside from the necessity for keeping the rope tight enough to prevent slipping, plus an occasional check to make sure that the antenna and indicator are in step.

A different mechanical device, independent of the rotating mechanism, is shown at *A* in Fig. 1724. The rotating shaft of the antenna is fitted with a pulley which is coupled to a similar pulley at the operating position by means of a cord or cable running through a length of copper tubing extending from one pulley to the other. The second pulley, identical with the first, is equipped with a pointer and a scale of compass points. An idler pulley is used to take up any slack in the line, as shown. The part of the line which goes through the tubing should be well greased to reduce friction. If the line is very long, it will be advisable to take an extra turn around each pulley to prevent slipping.

Three systems which use a milliammeter or voltmeter for the indicator are shown in Fig. 1725. These have the advantage of requiring only two or three wires. The one at *A* requires but two wires or one wire and ground. The variable resistance R_1 is arranged to operate with rotation of the antenna system. With R_1 set at zero resistance, R_2 is adjusted to bring the milliammeter reading to full scale. Rotation of the antenna will cause additional resistance to be inserted in series, decreasing the current reading. The meter deflection may be calibrated in terms of compass points. The chief drawbacks of this arrangement are that the accuracy will vary with the condition of the battery (although the accuracy may be checked by rotating the antenna to the zero-resistance position and readjusting R_2) and that the full meter scale cannot be used since the current in the circuit never drops to zero.

This last objection is removed by the circuit of B, which, however, requires an additional wire. Rotation of the antenna operates a potentiometer with the meter in series with the arm. With R_2 set at the extreme right, R_3 is adjusted to bring the meter to full-scale deflection. Then, rotation of the antenna will change the voltage across the meter and R_3 in series, varying the deflection. Since this voltage may be reduced to zero by rotation to the extreme left, the full scale of the meter is usable.

The bridge circuit of Fig. 1725–C eliminates the inaccuracies introduced by changes in battery

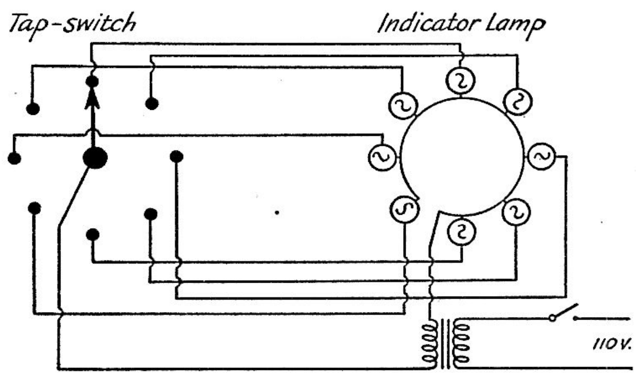


Fig. 1723 — Electrical indicator using lamps for showing the direction in which the antenna is working.

voltage, although it does not provide automatic indication of direction. With this circuit, any setting of R_5 will require a similar setting of R_6 to bring the meter reading to zero. The resistances should be identical. R_5 is varied by rotation of the antenna and R_6 is calibrated in terms of compass points. With the antenna set in any selected direction, this direction may be determined by adjusting R_6 until the meter reading falls to zero and the direction is read from the calibration of R_6. Conversely, R_6 may be set to indicate some particular direction and the antenna, when rotated to the point where the meter reading falls to zero, will be in the desired position.

The variable resistance or potentiometer may be arranged in the form of a ring about the antenna shaft. The arm projects from the shaft and makes contact with the resistance ring. The resistance should be made with the ends as close together as possible to permit practically 360 degree rotation. If the antenna system is capable of continuous rotation in the same direction, the ends of the resistance should be arranged to prevent a short-circuit when the contact arm passes over them. Otherwise, the resistance must be driven by means of a proper reduction gear or belt drive to reduce the travel while the antenna rotates the full 360 degrees.

Since the scale of the meter is not circular, both ends of the scale must denote essentially the same direction. For instance, with North at the low end of the scale, the meter will indicate successively NE, E, SE, S, SW, W, NW and North again at maximum scale. Continued rotation in the same direction will cause the meter to drop back to minimum reading and to repeat the process. This refers to the circuits of Figs. 1725-A and B. The circuit of C will also have two settings for essentially the same direction. These occur also at the extreme ends of the resistances.

Fig. 1726 shows how the antenna can be made to stop at a pre-selected position. The rotating shaft is equipped with a switch having any number of contacts, depending upon the fineness of control desired. At the operating position, a switch having the same number of points, but with a leaf-type contact arm which simultaneously closes all but one contact, is used for control. The station switch is set with the open section over the contact for the desired direction. The motor starts up and continues to operate until the switch arm on the antenna shaft contacts the point connected to the open point on the control switch, when the circuit is broken and the motor stops. With the usual gear drive the antenna will practically stop dead when the power is taken from the motor, so that there is no danger of over-run. The switch at the antenna end should be built so that the arm makes contact with the next switch point before losing contact with the preceding one, so that the power will be applied continuously until the open-circuited contact is reached.

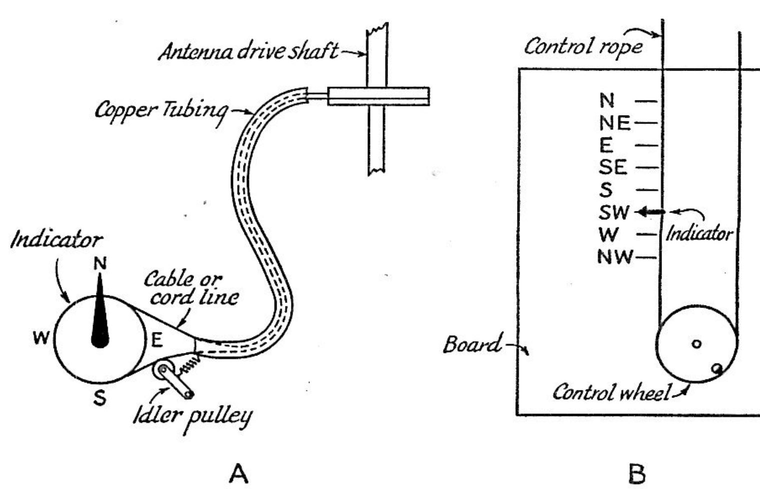


Fig. 1724 — Mechanical direction-indicator systems.

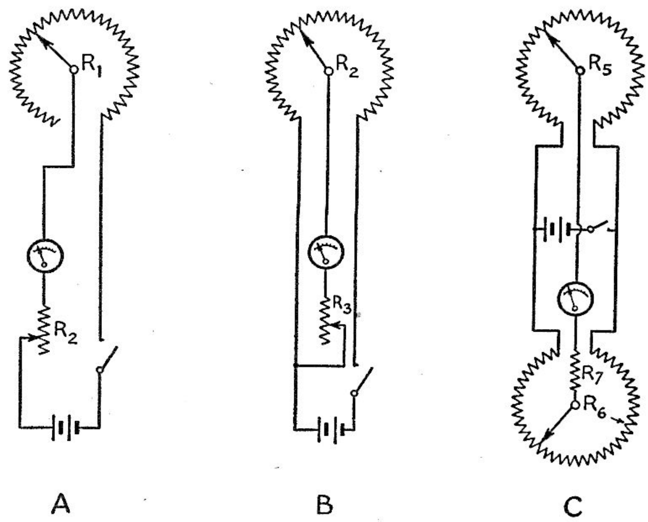


Fig. 1725 — Direction indicators using ordinary d.c. milliammeters. In all cases, the minimum series resistance should be a value large enough to limit the current to the maximum scale range of the meter. For example, with a 10-ma. meter and a 3-volt battery, the minimum resistance should be 300 ohms. In A, the resistance of R_1 should be large enough to bring the pointer to about 10 per cent of full scale when all the resistance is in. $R = E/I$, where E is the battery voltage and I the current in amperes at 10 per cent of full-scale range of the meter. R_2 should be the minimum resistance already indicated.

In B, R_3 is the minimum resistance already mentioned, while R_2 should be considerably smaller. Use the lowest value consistent with good battery life.

In C, R_7 is the minimum resistance mentioned; R_5 and R_6 are identical potentiometers having a value several times that of R_7. The values are not critical.

Feeder Connections

For beams which rotate only 180 degrees, it is relatively simple to bring off feeders by making a short section of the feeder, just where it leaves the rotating member, of flexible wire. Enough slack should be left so that there is no danger of breaking or twisting. Stops should be placed on the rotating shaft of the antenna so that the feeders cannot "wind up." This method also can be used with antennas which rotate the full 360 degrees, but again a stop is necessary to avoid jamming the feeders.

For continuous rotation, the sliding contact is simple and, when properly built, quite practicable. Fig. 1727 shows two methods of making sliding contacts. The chief points to keep in mind are that the contact surfaces should be wide enough to take care of wobble in the rotating shaft, and that the contact surfaces should be kept clean. Spring contacts are essential, and an "umbrella" or other scheme for keeping rain off the contacts is a desirable addition. Sliding contacts preferably should be used with non-resonant open lines where the impedance is of the order of 500 to 600 ohms so that the current is low.

A good, but relatively expensive, contact system can be made by using mercury in ring-shaped grooves for the movable contact, with rods dipping in the mercury for the fixed contacts. A contact system of this type was described in May, 1938, *QST*.

The possibility of poor connections in sliding contacts can be avoided by using inductive coupling at the antenna, with one coil rotating on the antenna and the other fixed in position, the two coils being arranged so that the coupling does not change when the antenna is rotated. Such an arrangement is shown in Fig. 1728, adapted to an antenna system in which the pole itself rotates. A quarter-wave feeder system is connected to a tuned pickup circuit whose inductance is coupled to a link. In the drawing, the link coil connects to a twisted-pair transmission line. The circuit would be adjusted in the same way as any link-coupled circuit, and the number of turns in the link should be varied to give proper loading on the transmitter. The rotating coupling circuit of course tunes to the transmitting frequency. The whole thing is equivalent to a link-coupled antenna tuner mounted on the pole, using a parallel-tuned tank at the end of a quarter-wave line to center-feed the antenna. To maintain constant coupling, the two coils should be quite rigid and the pole should rotate without wobble. The two coils might be made a part of the upper bearing assembly holding the rotating pole in position.

Other variations of the inductive-coupled system might be worked out. The tuned circuit might, for instance, be placed at the end of a 600-ohm line, and a one-turn link used to couple directly to the center of the antenna, if the con-

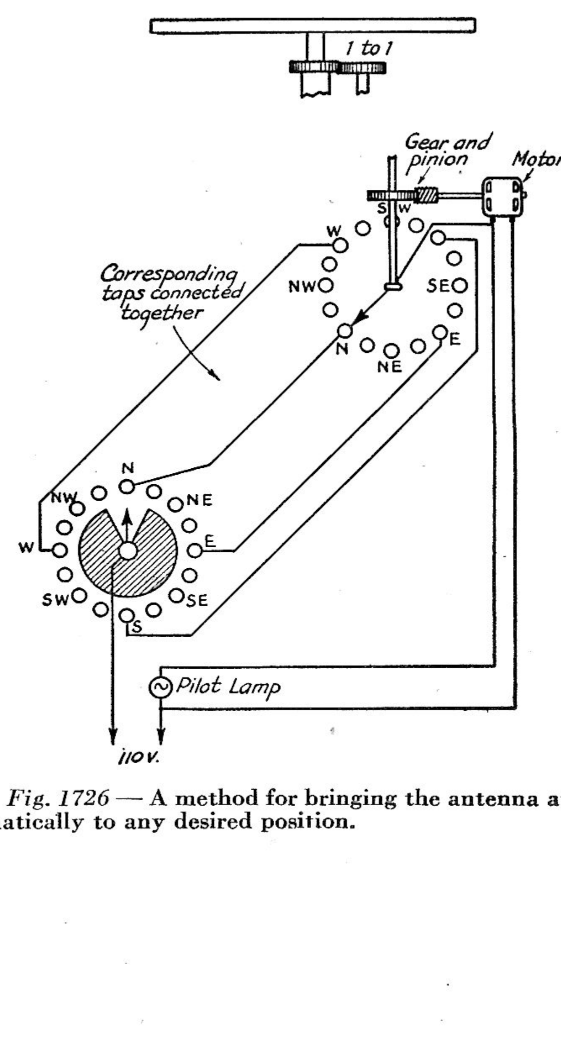


Fig. 1726 — A method for bringing the antenna automatically to any desired position.

struction of the rotary member permits. In this case the coupling can be varied by changing the L/C ratio in the tuned circuit. For mechanical strength the coils preferably should be made of copper tubing, well braced with insulating strips to keep them rigid.

The simplest solution to the feeder problem is to use vertical antenna elements, when circumstances permit, and simply rotate a director or reflector — or both — about a fixed antenna. Systems of this type were shown earlier in the chapter.

Antenna Elements

The majority of rotary beam antennas are constructed with antenna elements of metal tubing, usually dural. Copper and copper-plated steel also are used. Light weight is obviously desirable, since a lighter supporting frame may be used. Suitable units are available commercially. The more rigid the elements the smaller the supporting structure may be. For 28-Mc. work, half-inch dural tubing will be large enough for a center section, with end sections of approximately 3/8-inch diameter sliding in the center sections. Using a center section about 8 feet long, the end sections may be allowed to extend approximately 4 feet on either side. The element length can be adjusted to the proper value by sliding the end sections in and out. Such an element can be supported readily by a frame four feet wide.

For 14-Mc. work larger tubing is needed to give the necessary rigidity with a frame of reasonable size. Tubing 7/8 or 1 inch in diameter is satisfactory for the center section with end sections of the next smaller size which will just slide in comfortably. To avoid excessive droop a support 10 or 12 feet wide will be required for this type of tubing. The width needed can very easily be determined by setting up the element on a pair of chairs or boxes and adjusting the spacing between supports until a width which keeps the element reasonably horizontal is found. The type of antenna system to be used also should be taken into consideration; the elements should not be allowed to whip too much in a wind, since in systems using spacing of the order of 1/10 wavelength the tuning will change considerably when the relative positions of the elements change by only a few inches.

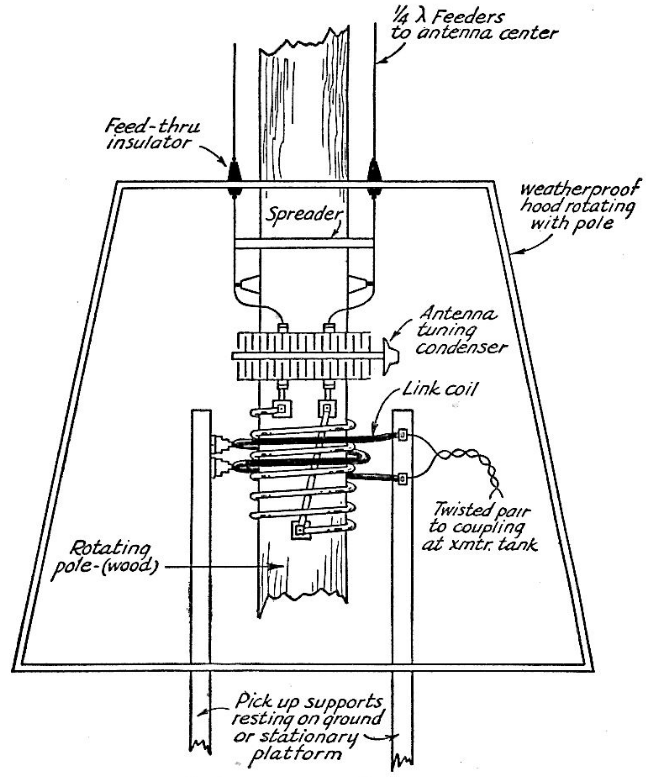


Fig. 1728 — **Inductive coupling to a rotary antenna to permit continuous rotation without sliding contacts.**

The conventional method of mounting tubing elements is to clamp them to standoff insulators by clamps made from brass strip. The clamp is shaped to fit around the tubing, with the ends extending sufficiently to allow holes to be drilled to pass the screw which goes into the top of the insulator.

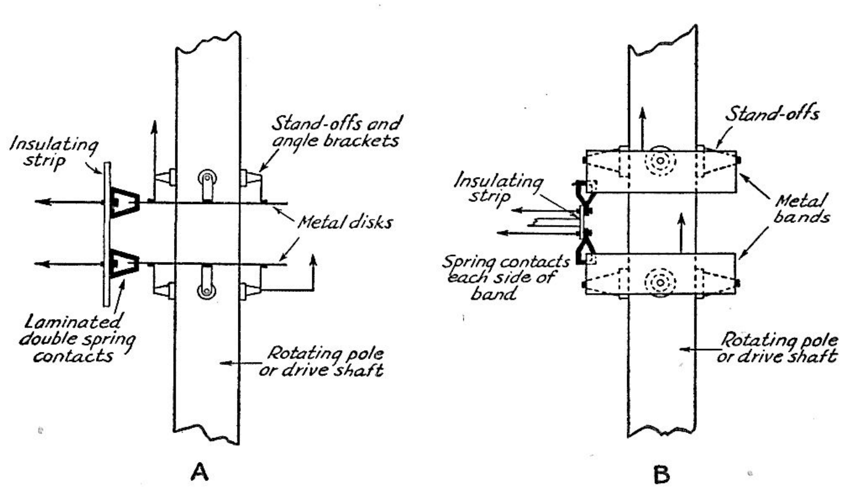
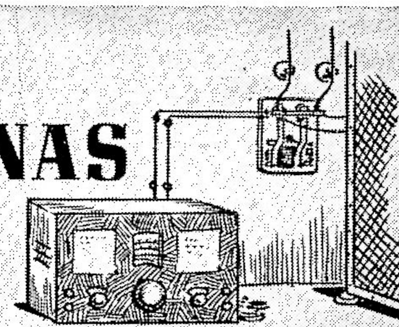


Fig. 1727 — **Two methods of constructing sliding contacts for rotary antenna feeder systems.**

18. RECEIVING ANTENNAS



TRANSMITTING ANTENNAS FOR RECEPTION — TUNING SYSTEMS AND SWITCHING ARRANGEMENTS — LOOPS

For the amateur engaged in traffic work or general ragchewing, where operating convenience overshadows any other factor, a separate straight-wire antenna of random length is normally quite satisfactory for reception. This should preferably be as far removed from the transmitting antenna as possible, so that a minimum of energy from the transmitter will be picked up. If a short wire picks up too much "man-made noise" in the form of hash and interference from motors and other electrical appliances, it is advisable to use a half-wave antenna cut for the frequency band most often used and fed by low-impedance twisted pair such as is sold for "all-wave" broadcast antennas. By placing the antenna at a point removed from the source of noise, the noise will be reduced and, since the line is balanced, the low-impedance line will run back through the noisy area but will not pick up any noise. Low-impedance line will not in itself reduce noise, but it allows the antenna to be placed at a distance and still feed its signal back to the receiver. If a half-wave antenna is used, it should be placed at right angles to the transmitting antenna and as far away as possible.

Receiving with Directive Antennas

The amateur fortunate enough to own a directive antenna, or even the one who is content to work without break-in, should always use his transmitting antenna for receiving. The reason is obvious: signals that are loud when the transmitting antenna is used for receiving indicate that the antenna is favorable for that direction and consequently will put a signal there. If separate antennas are used, a signal might be heard for a direction where the transmitting antenna has a null, and all the calling one could muster probably wouldn't result in a QSO. With rotary antennas, one can rotate the array until the signal peaks up and the operator can then feel assured that his antenna is aimed correctly at the station.

If two or more directive systems are available, some provision should be made for quick switching from one to the other or others, so that when listening one can identify the direction of the signal even before the station signs. Even with antennas with no marked directional characteristics, switching will show which one yields the louder signal and hence should be used for transmitting as well.

Many stations operate with a d.p.t. switch hand-operated by the operator to switch the antenna from the transmitter to the receiver and back again. However, it is far more satisfactory to use one of the antenna change-over relays now available on the market. They are made with good insulation and work from the 115-volt a.c. line, so that it is only necessary to connect them across the primary of a plate transformer and every time the transmitter is switched on the antenna relay operates and switches the antenna from the receiver to the transmitter. The relay should preferably be mounted on the wall where the antenna feeders come in the shack. If untuned line feed is used to the antenna, the line inside the shack should be made of the same impedance as the line that runs outside the station to the antenna. The line inside the shack doesn't have to have the same dimensions, but the wire size and spacing should be such that the impedance of the line is the same as that outside the station. The same applies to the line running to the receiver, but this is not too im-

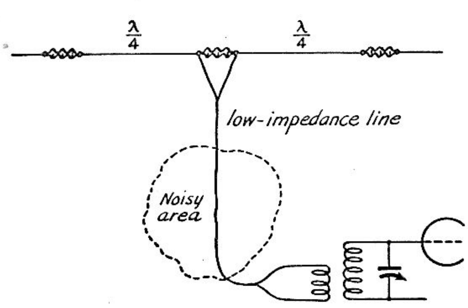


Fig. 1801 — The doublet antenna with low-impedance line is used for noise reduction by placing the antenna outside or away from the noisy area and running a low-impedance line to it. The line itself doesn't reduce the noise but, because it has no pick-up itself, it enables the antenna to be fed through an interference-generating area.

portant and can be disregarded if it seems to be too much trouble. However, for maximum signal into the receiver, the line impedance should remain as nearly constant as possible and the line should be matched at the receiver.

Coupling the Receiver

In most cases, manufactured receivers are designed for an input impedance of from 250 to 600 ohms, and any flat line will match into them fairly well. However, the operator with tuned feeders on his antenna or antennas will do well to tune his antenna for receiving as well as for transmitting. Either matching networks or a conventional tuned circuit can be used, and several types are shown in Fig. 1802 and one is pictured in 1803. The tuner is mounted near the receiver input terminals or, in the case of the link-coupled tuner (Fig. 1802-C), the line can be run from the tuner to the receiver for a distance of several feet if necessary. The link should be an open line of about 400 ohms impedance and can be made of No. 14 spaced one inch. The tuned circuit can easily be made with a midget condenser

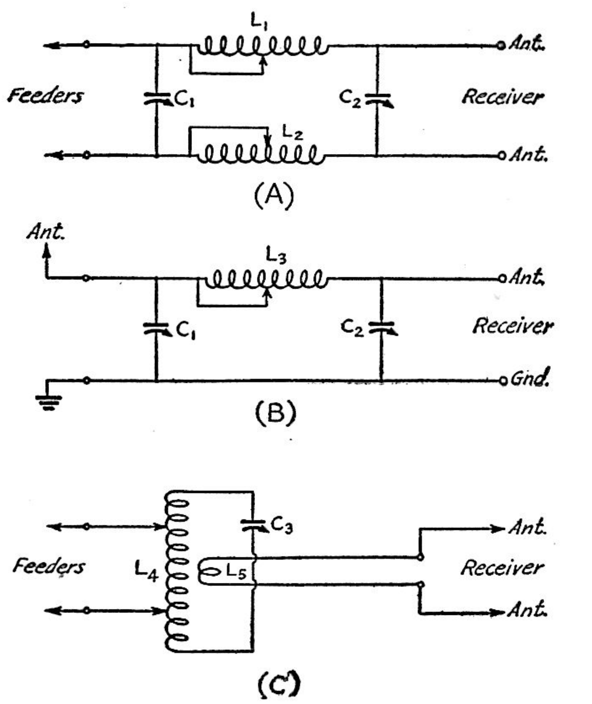


Fig. 1802 — **Three types of circuits for coupling antenna to receiver. A, balanced pi-section network; B, single-ended pi-section network; C, tuned circuit with taps for matching impedances.**

C_1 — 150-μμfd. variable.
C_2 — 100μμfd. variable.
C_3 — 50μμfd. variable or larger.
L_1, L_2, L_3 — 25 turns No. 26, spaced to occupy 1-inch length on 1-inch diameter form; tapped at 2nd, 5th, 9th, and 15th turns.
L_4 — Proportioned to resonate with C_3 in the desired band.
L_5 — 3 or 4 turns wound on L_4; see text.

In C, one side of the line from L_5 can be grounded to reduce capacity coupling.

and small coil of one-inch diameter or so, adjusted to resonate at the operating frequency. If the circuit does not peak up sharply on signals, it indicates that the coupling is too close or that the receiver is slightly out of line. A two-turn link wound over the inductance is satisfactory in most cases. The link can be grounded on one side to eliminate any capacity coupling between the antenna tuner and the receiver which might be responsible for noise pick-up and a poor image ratio.

When the transmitter is equipped with a link-coupled antenna-tuning unit, the same unit may be used without change for the receiver, simply by installing the changeover switch in the coupling link rather than in the feeders. This is shown at *C* in Fig. 1804. The same drawing also shows a series-parallel circuit, with tapped coil, especially adaptable to resonant feeders. Various other switching arrangements also are shown in Fig. 1804.

Using the same antenna-tuning unit for both transmitting and receiving is advantageous in that it reduces the amount of equipment needed; furthermore, the greatest response to incoming signals is automatically secured at and near the frequency to which the transmitter is tuned. However, the separate tuner is more convenient in that it is possible to listen on other frequencies, and on other bands, without loss of signal strength and without disturbing the tuning for transmission.

Grounds

Most modern receivers do not require an external ground, since they are grounded through the power supply by the capacity of the transformer windings. However, in some instances a direct ground to the receiver will boost the signal pickup and, in the case of regenerative receivers, reduce the body capacity. The direct ground can be made by running a wire to a radiator or water pipe or directly to a pipe in the ground.

Loop Antennas

Loop antennas can be used on any band from 1.8 to 30 Mc., although as the frequency becomes higher greater care must be taken to balance the

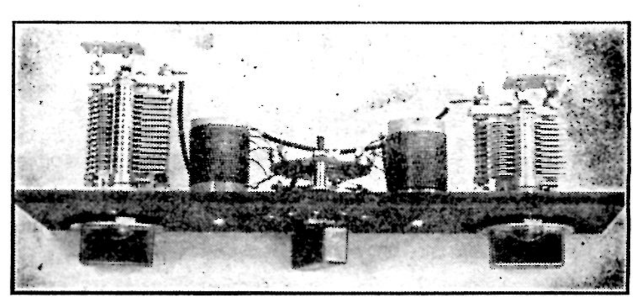


Fig. 1803 — **Receiving-type antenna coupler using the circuit of Fig. 1802-A. A two-section tap-switch is used to vary the inductance of L_1 and L_2. Input and output terminals are mounted on the rear of C_1 and C_2.**

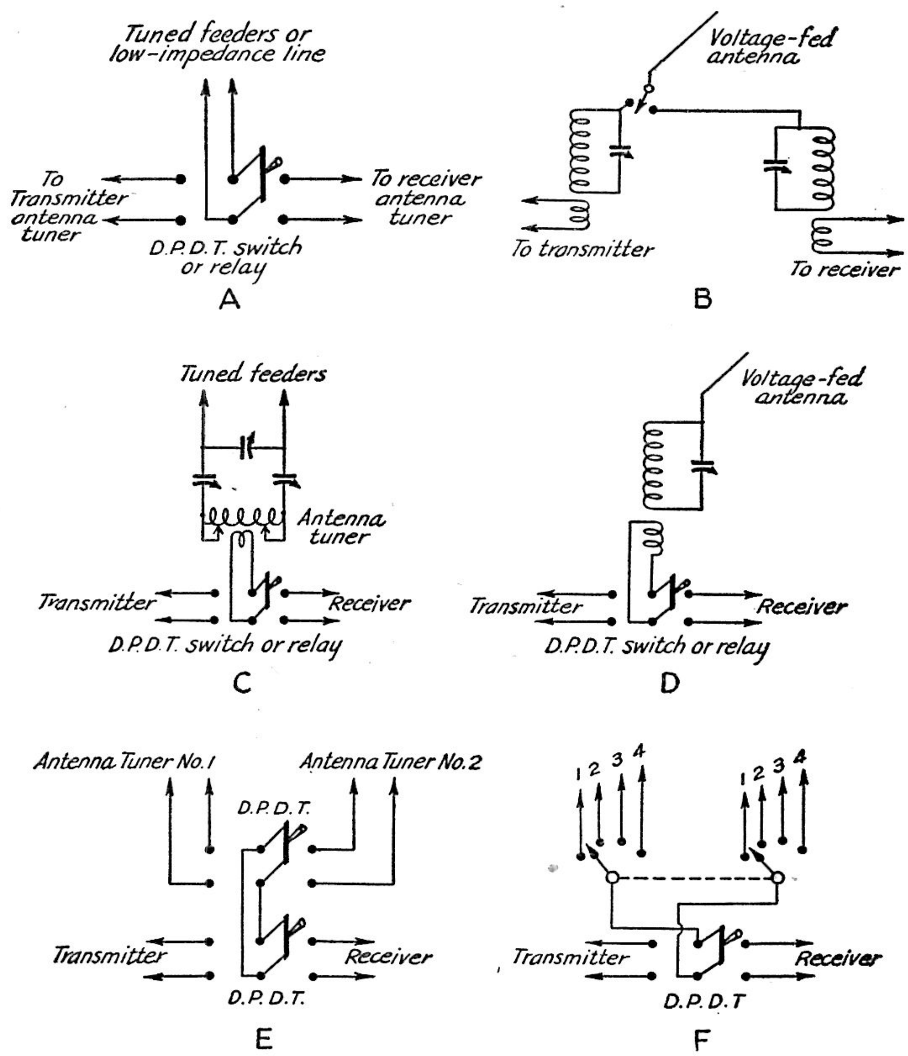


Fig. 1804 — Antenna switching systems. A — For tuned lines with separate antenna tuners or low impedance lines. B — For voltage-fed antenna. C — For tuned line with single tuner. D — For voltage-fed antenna with single tuner. E — For two tuned-line antennas with tuner for each antenna or for low-impedance lines. F — For several two-wire lines.

capacity to ground. The advantage of the loop antenna is that, on reception, it has a very sharp null in the direction perpendicular to the plane of the loop and thus becomes useful in reducing interference.

The loop antenna simply consists of a number of turns of wire wound to a diameter of one to three feet. The two ends of the loop are connected to a variable condenser to form a circuit which tunes to the frequency of the incoming signal.

The schematic diagram of a loop (W6GPY) suitable for the 1.75 and 3.5-Mc. bands is shown in Fig. 1805, while the construction of the loop is indicated by the drawings of Fig. 1806. The link-coupled arrangement is convenient because it provides a means of obtaining at least an approximate match between the input impedance of the receiver and that of the loop.

For most satisfactory directional effects, it is essential that the loop respond only to the magnetic component of the wave and not to the electrostatic component. Response to the electrostatic component can be made negligible by enclosing the loop in a metallic container which forms an open-circuited turn, as indicated in Fig. 1806. The tuning equipment and line to the receiver also should be shielded.

Although the signal strength with a loop antenna is smaller than from a regular antenna, the sharp null of a properly-constructed loop often makes possible reception through noise or interference which could not be carried on with a conventional antenna. Except for the null, the directional characteristics are not very marked, so that the response to an interfering signal or source of man-made noise may be reduced to a very low value without affecting materially the response to the desired signal, providing only that the desired signal is not in exactly the same direction as the QRM.

A loop often will give good results even without

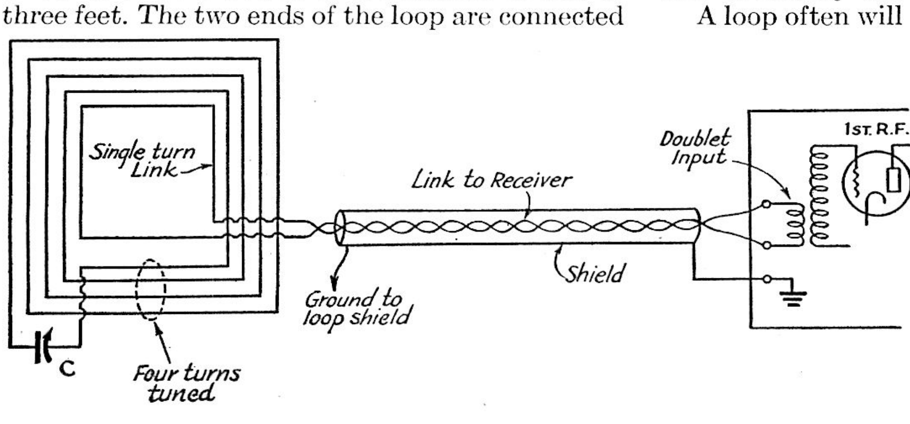
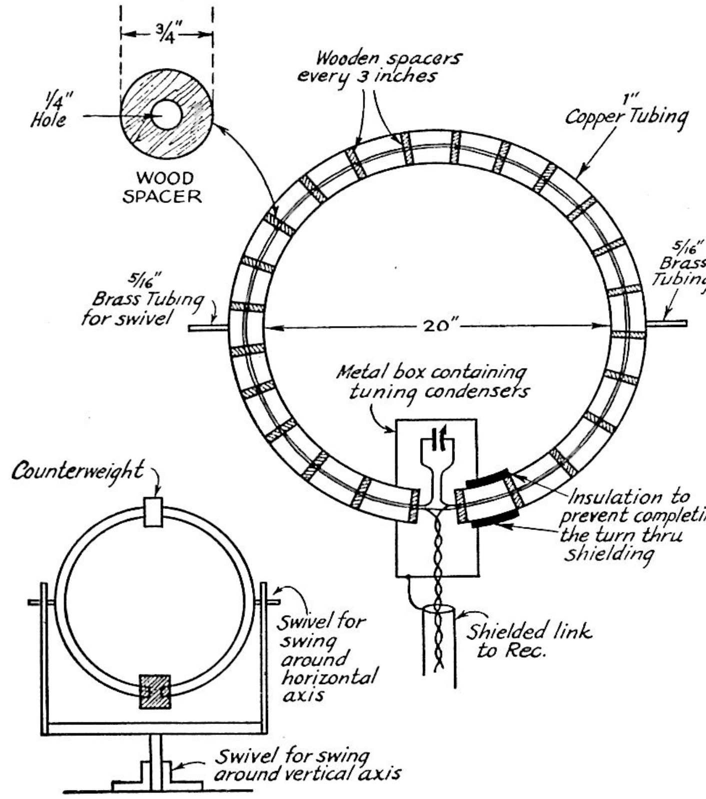


Fig. 1805 — The loop circuit. The four-turn loop is tuned by condenser C, a broadcast-type variable having a maximum capacity of about 370 $\mu\mu$fd. The loop resonates to the 160-meter band with C near maximum capacity, and to 80 meters with C near minimum.

Fig. 1806 — Details of loop construction. The spacers, cut from ¾-inch round stock and drilled in the center, are spaced every three inches along the wires, and taped in place. Five separate wires, of length sufficient to run through the tubing with a little to spare, are used. The wire and spacer assembly is pulled through the tubing and four of the wires spliced at the opening to form the loop proper. The fifth wire is the link for coupling to the receiver. The insulation at one end of the tubing is essential, since a continuous circuit would prevent signal pickup.



shielding, although lack of ability to give a good null may be taken as an indication that shielding is necessary. In using any loop, it is essential to make sure that other antennas in the vicinity are detuned from the receiving frequency, since re-radiation from regular antennas may be as strong or stronger than the direct signal received by the loop. In such case, of course, good nulls cannot be secured because of the supplementary fields of the re-radiating wire or wires.

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