The formula for coaxial lines is approximately correct for lines in which bead spacers are used, provided the beads are not too closely spaced. When the line is filled with a solid dielectric, the characteristic impedance as given by the formula should be multiplied by $1/\sqrt{K}$, where K is the dielectric constant of the material.

ELECTRICAL LENGTH

In the discussion of line operation earlier in this chapter it was assumed that currents traveled along the conductors at the speed of light. Actually, the velocity is somewhat less, the reason being that electromagnetic fields travel more slowly in material dielectrics than they do in free space. In air the velocity is practically the same as in empty space, but a practical line always has to be supported in some fashion by solid insulating materials. The result is that the fields are slowed down; the currents travel a shorter distance in the time of one cycle than they do in space, and so the wavelength along the line is less than the wavelength would be in free space at the same frequency.

Whenever reference is made to a line as being so many wavelengths (such as a "half wavelength" or "quarter wavelength") long, it is to be understood that the *electrical* length of the line is meant. Its actual physical length as measured by a tape always will be somewhat less. The physical length corresponding to an electrical wavelength is given by

$$\textit{Length in feet} = \frac{984V}{f} \qquad \text{(20-F)}$$

where f = Frequency in megahertz
V = Velocity factor

The velocity factor is the ratio of the actual velocity along the line to the velocity in free space. Values of V for several common types of line are given in Table 20-I.

Example: A 75-foot length of 300-ohm Twin-Lead is used to carry power to an antenna at a frequency of 7150 kHz. From Table 20-I, V is 0.82. At this frequency (7.15 MHz) a wavelength is

$$\textit{Length} \text{ (feet)} = \frac{984V}{f} = \frac{984}{7.15} \times 0.82$$

$$= 137.6 \times 0.82 = 112.8 \text{ feet}$$

The line length is therefore 75/112.8 = 0.665 wavelength.

Because a quarter-wavelength line is frequently used as a linear transformer, it is convenient to calculate the length of a quarter-wave line directly. The formula is

$$\textit{Length} \text{ (feet)} = \frac{246V}{f} \qquad \text{(20-G)}$$

where the symbols have the same meaning as above.

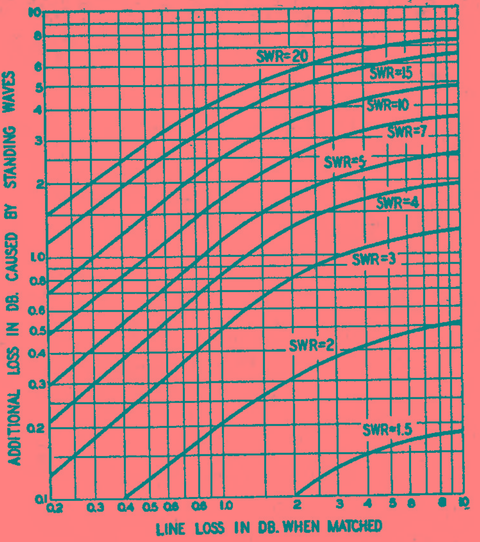

Fig. 20-8 – Effect of standing-wave ratio on line loss. The ordinates give the *additional* loss in decibels for the loss, under perfectly matched conditions, shown on horizontal scale.

LOSSES IN TRANSMISSION LINES

There are three ways by which power may be lost in a transmission line: by radiation, by heating of the conductors (I^2R), and by heating of the dielectric, if any. Radiation losses are in general the result from undesired coupling to the radiating antenna. They cannot readily be estimated or measured, so the following discussion is based only on conductor and dielectric losses.

Heat losses in both the conductor and the dielectric increase with frequency. Conductor losses also are greater the lower the characteristic impedance of the line, because a higher current flows in a low-impedance line for a given power input. The converse is true of dielectric losses because these increase with the voltage, which is greater on high-impedance lines. The dielectric loss in air-insulated lines is negligible (the only loss is in the insulating spacers) and such lines operate at high efficiency when radiation losses are low.

It is convenient to express the loss in a transmission line in decibels per unit length, since the loss in dB is directly proportional to the line length. Losses in various types of lines operated without standing waves (that is, terminated in a resistive load equal to the characteristic impedance of the line) are given in Table 20-I.

When there are standing waves on the line the power loss increases as shown in Fig. 20-8. Whether or not the increase in loss is serious depends on what the original loss would have been if the line were perfectly matched. If the loss with perfect matching is very low, a large SWR will not greatly affect the *efficiency* of the line – i.e., the ratio of the power delivered to the load to the power put into the line.

TABLE 20-I

Characteristics of Commonly-Used Transmission Lines

Type of Line	Z_0 *Ohms*	*Vel. %*	*pF per ft.*	*OD*	*Attenuation in dB per 100 feet* 3.5	7	14	21	28	50	144	420
RG58/A-AU	53	66	28.5	0.195	0.68	1.0	1.5	1.9	2.2	3.1	5.7	10.4
RG58 Foam Diel.	50	79	25.4	0.195	0.52	0.8	1.1	1.4	1.7	2.2	4.1	7.1
RG59/A-AU	73	66	21.0	0.242	0.64	0.90	1.3	1.6	1.8	2.4	4.2	7.2
RG59 Foam Diel.	75	79	16.9	0.242	0.48	0.70	1.0	1.2	1.4	2.0	3.4	6.1
RG8/A-AU	52	66	29.5	0.405	0.30	0.45	0.66	0.83	0.98	1.35	2.5	4.8
RG8 Foam Diel.	50	80	25.4	0.405	0.27	0.44	0.62	0.76	0.90	1.2	2.2	3.9
RG11/A-AU	75	66	20.5	0.405	0.38	0.55	0.80	0.98	1.15	1.55	2.8	4.9
Aluminum Jacket, Foam Diel.[1]												
3/8 inch	50	81	25.0	–	–	–	0.36	0.48	0.54	0.75	1.3	2.5
1/2 inch	50	81	25.0	–	–	–	0.27	0.35	0.40	0.55	1.0	1.8
3/8 inch	75	81	16.7	–	–	–	0.43	0.51	0.60	0.80	1.4	2.6
1/2 inch	75	81	16.7	–	–	–	0.34	0.40	0.48	0.60	1.2	1.9
Open-wire[2]	–	97	–		0.03	0.05	0.07	0.08	0.10	0.13	0.25	–
300-ohm Twin-lead	300	82	5.8		0.18	0.28	0.41	0.52	0.60	0.85	1.55	2.8
300-ohm tubular	300	80	4.6		0.07	0.25	0.39	0.48	0.53	0.75	1.3	1.9
Open-wire, TV type												
1/2 inch	400	95			0.028	0.05	0.09	0.13	0.17	0.30	0.75	–
1 inch	450	95			0.028	0.05	0.09	0.13	0.17	0.30	0.75	–

[1] Polyfoam dielectric type line information courtesy of Times Wire and Cable Co.

[2] Attenuation of open-wire line based on No. 12 conductors, neglecting radiation.

TABLE 20-II

Type of Line	*Power Rating in Watts* 20-MHz	30-	60-	200-
RG58/A-AU	550	430	290	14
RG58 Foam Diel.[1]				
RG59/A-AU	860	680	440	208
RG8/A-AU	2000	1720	1250	680
RG11/A-AU	1800	1400	900	400

[1] Power handling capabilities of foam-type coaxial lines is approximately 30 percent greater than the polyethylene dielectric types.

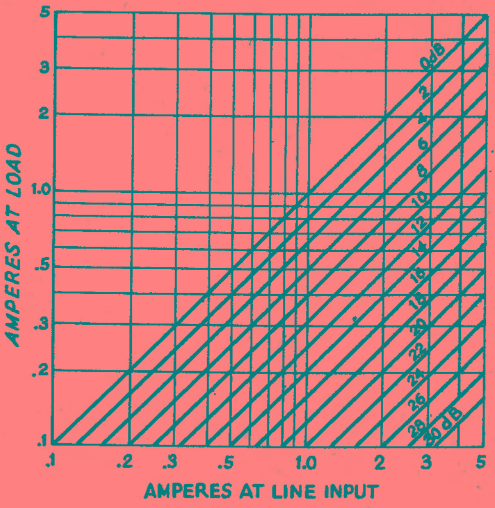

Fig. 20-9 — Graph for calculating losses in transmission lines with an SWR of 1.

Example: A 150-foot length of RG-11/U cable is operating at 7 MHz with a 5-to-1 SWR. If perfectly matched, the loss from Table 20-1 would be 1.5 × 0.55 = 0.825 dB. From Fig. 20-8 the additional loss because of the SWR is 0.73dB. The total loss is therefore 0.825 + 0.95 = 1.775 dB.

TESTING OLD COAXIAL CABLE

Unknown coaxial cable or cable that has been exposed to the weather may have losses above the published figures for the cable type. A simple method for checking the losses in a cable is to use an rf ammeter (mounted in a Minibox with coax fittings). Connect one end of the cable to a nonreactive dummy load of the *same* impedance as the coax. At the other end of the line insert the rf ammeter and connect it to a transmitter. Tune up the rig and make a note of the exact amount of current. Without touching the transmitter tuning, move the ammeter to the other end of the line, at the dummy load, and note the meter reading. Compare the readings to Fig. 20-9 and this will give you the decibel loss that is present in the line. Keep in mind that the cable must be terminated in its characteristic impedance (SWR of 1); otherwise, the figures in Fig. 20-9 will not be accurate.

MATCHING THE ANTENNA TO THE LINE

The load for a transmission line may be any device capable of dissipating rf power. When lines are used for transmitting applications the most common type of load is an antenna. When a transmission line is connected between an antenna and a receiver, the receiver input circuit (not the antenna) is the load, because the power taken from a passing wave is delivered to the receiver.

Whatever the application, the conditions existing at the load, and *only* the load, determine the standing-wave ratio on the line. If the load is purely resistive and equal in value to the characteristic impedance of the line, there will be no standing waves. In case the load is not purely resistive, and/or is not equal to the line Z_0, there will be standing waves. No adjustments that can be made at the input end of the line can change the SWR, nor is it affected by changing the line length.

Only in a few special cases is the load inherently of the proper value to match a practicable transmission line. In all other cases it is necessary either to operate with a mismatch and accept the SWR that results, or else to take steps to bring about a proper match between the line and load by means of transformers or similar devices. Impedance-matching transformers may take a variety of physical forms, depending on the circumstances.

Note that it is essential, if the SWR is to be made as low as possible, that the load at the point of connection to the transmission line be purely resistive. In general, this requires that the load be tuned to resonance. If the load itself is not resonant at the operating frequency the tuning sometimes can be accomplished in the matching system.

THE ANTENNA AS A LOAD

Every antenna system, no matter what its physical form, will have a definite value of impedance at the point where the line is to be connected. The problem is to transform this antenna input impedance to the proper value to match the line. In this respect there is no one "best" type of line for a particular antenna system, because it is possible to transform impedances in any desired ratio. Consequently, any type of line may be used with any type of antenna. There are frequently reasons other than impedance matching that dictate the use of one type of line in preference to another, such as ease of installation, inherent loss in the line, and so on, but these are not considered in this section.

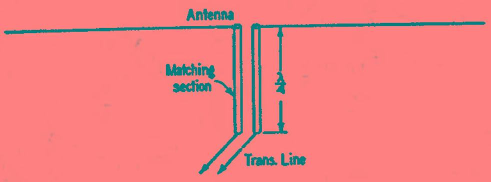

Fig. 20-10A – "Q" matching section, a quarter-wave impedance transformer.

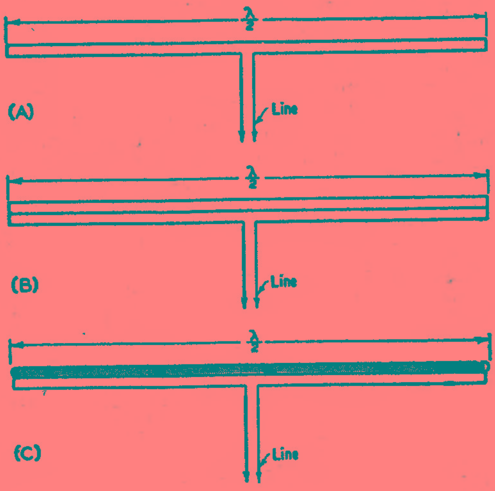

Fig. 20-10B – The folded dipole, a method for using the antenna element itself to provide an impedance transformation.

Although the input impedance of an antenna system is seldom known very accurately, it is often possible to make a reasonably close estimate of its value.

Matching circuits can be built using ordinary coils and capacitors, but are not used very extensively because they must be supported at the antenna and must be weatherproofed. The systems to be described use linear transformers.

The Quarter-Wave Transformer or "Q" Section

As mentioned previously, a quarter-wave transmission line may be used as an impedance transformer. Knowing the antenna impedance and the characteristic impedance of the transmission line to be matched, the required characteristic impedance of a matching section such as is shown in Fig. 20-10A is:

$$Z = \sqrt{Z1\,ZO} \qquad (20\text{-H})$$

Where Z1 is the antenna impedance and ZO is the characteristic impedance of the line to which it is to be matched.

Example: To match a 600-ohm line to an antenna presenting a 72-ohm load, the quarter-wave matching section would require a characteristic impedance of

$$\sqrt{72 \times 600} = \sqrt{43.200} = 208 \text{ ohms}$$

The spacings between conductors of various sizes of tubing and wire for different surge impedances

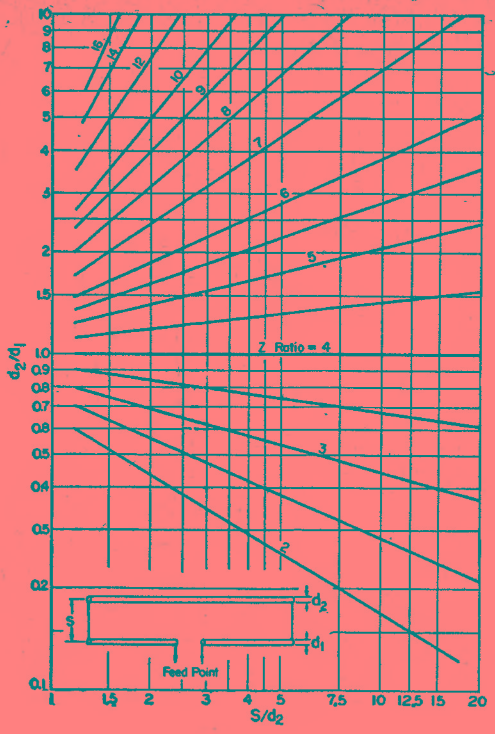

Fig. 20-11 — Impedance transformation ratio, two-conductor folded dipole. The dimensions d1, d2 and s are shown on the inset drawing. Curves show the ratio of the impedance (resistive) seen by the transmission line to the radiation resistance of the resonant antanna system.

are given in graphical form in the chapter on "Transmission Lines." (With 1/2-inch tubing, the spacing in the example above should be 1.5 inches for an impedance of 208 ohms.)

The length of the quarter-wave matching section may be calculated from

$$\textit{Length}\ \text{(feet)} = \frac{246V}{f} \qquad \text{(20-1)}$$

where V = Velocity factor
f = Frequency in MHz

Example: A quarter-wave transformer of RG-11/U is to be used at 28.7 MHz. From the table 20-1, V = 0.66.

$$\textit{Length} = \frac{246 \times 0.66}{28.7} = 5.65 \text{ feet}$$

$$= 5 \text{ feet } 8 \text{ inches}$$

The antenna must be resonant at the operating frequency. Setting the antenna length by formula is amply accurate with single-wire antennas, but in other systems, particularly close-spaced arrays, the antenna should be adjusted to resonance before the matching section is connected.

When the antenna input impedance is not known accurately, it is advisable to construct the matching section so that the spacing between conductors can be changed. The spacing then may be adjusted to give the lowest possible SWR on the transmission line.

Folded Dipoles

A half-wave antenna element can be made to match various line impedances if it is split into two or more parallel conductors with the transmission line attached at the center of only one of them. Various forms of such "folded dipoles" are shown in Fig. 20-10B. Currents in all conductors are in phase in a folded dipole, and since the conductor spacing is small the folded dipole is equivalent in radiating properties to an ordinary single-conductor dipole. However, the current flowing into the input terminals of the antenna from the line is the current in one conductor only, and the entire power from the line is delivered at this value of current. This is equivalent to saying that the input impedance of the antenna has been raised by splitting it up into two or more conductors.

The ratio by which the input impedance of the antenna is stepped up depends not only on the number of conductors in the folded dipole but also on their relative diameters, since the distribution of current between conductors is a function of their diameters. (When one conductor is larger than the other, as in Fig. 20-10B, the larger one carries the greater current.) The ratio also depends, in general, on the spacing between the conductors, as shown by the graphs of Figs. 20-11 and 20-12. An important special case is the 2-conductor dipole with conductors of equal diameter; as a simple antenna, not a part of a directive array, it has an

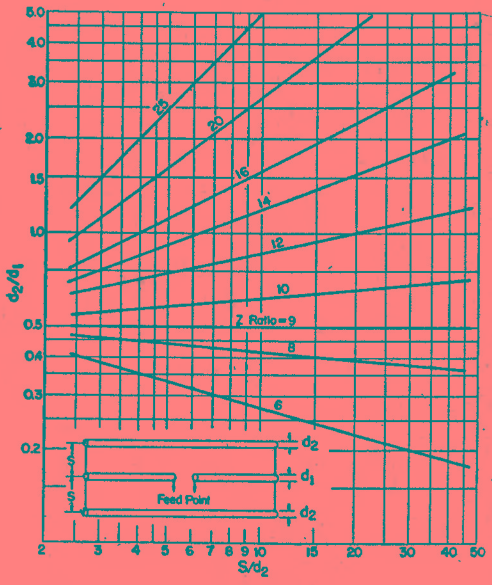

Fig. 20-12 — Impedance transformation ratio, three-conductor folded dipole. The dimensions d1, d2 and s are shown on the inset drawing. Curves show the ratio of the impedance (resistive) seen by the transmission line to the radiation resistance of the resonant antenna system.

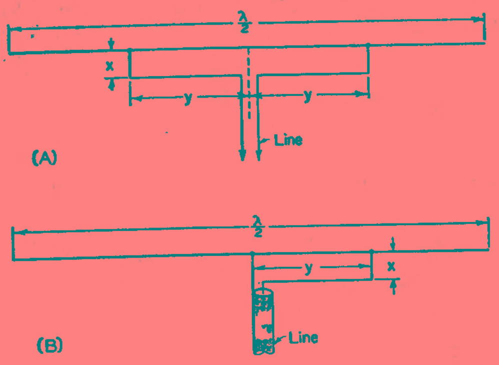

Fig. 20-13 – The "T" match and "gamma" match.

input impedance close enough to 300 ohms to afford a good match to 300-ohm Twin-Lead.

The required ratio of conductor diameters to give a desired impedance ratio using two conductors may be obtained from Fig. 20-11. Similar information for a 3-conductor dipole is given in Fig. 20-12. This graph applies where all three conductors are in the same plane. The two conductors not connected to the transmission line must be equally spaced from the fed conductor, and must have equal diameters. The fed conductor may have a different diameter, however. The unequal-conductor method has been found particularly useful in matching to low-impedance antennas such as directive arrays using close-spaced parasitic elements.

The length of the antenna element should be such as to be approximately self-resonant at the median operating frequency. The length is usually not highly critical, because a folded dipole tends to have the characteristics of a "thick" antenna and thus has a relatively broad frequency-response curve.

"T" and "Gamma" Matching Sections

The method of matching shown in Fig. 20-13A is based on the fact that the impedance between any two points along a resonant antenna is resistive, and has a value which depends on the spacing between the two points. It is therefore possible to choose a pair of points between which the impedance will have the right value to match a transmission line. In practice, the line cannot be connected directly at these points because the distance between them is much greater than the conductor spacing of a practicable transmission line. The "T" arrangement in Fig. 20-13A overcomes this difficulty by using a second conductor paralleling the antenna to form a matching section to which the line may be connected.

The "T" is particularly suited to use with a parallel-conductor line, in which case the two points along the antenna should be equidistant from the center so that electrical balance is maintained.

The operation of this system is somewhat complex. Each "T" conductor (*y* in the drawing) forms with the antenna conductor opposite it a short section of transmission line. Each of these transmission-line sections can be considered to be terminated in the impedance that exists at the point of connection to the antenna. Thus the part of the antenna between the two points carries a transmission-line current in addition to the normal antenna current. The two transmission-line matching sections are in series, as seen by the main transmission line.

If the antenna by itself is resonant at the operating frequency its impedance will be purely resistive, and in such case the matching-section lines are terminated in a resistive load. However, since these sections are shorter than a quarter wavelength their input impedance – i.e., the impedance seen by the main transmission line looking into the matching-section terminals – will be reactive as well as resistive. This prevents a perfect match to the main transmission line, since its load must be a pure resistance for perfect matching. The reactive component of the input impedance must be tuned out before a proper match can be secured.

One way to do this is to detune the antenna just enough, by changing its length, to cause reactance of the opposite kind to be reflected to the input terminals of the matching section, thus cancelling the reactance introduced by the latter. Another method, which is considerably easier to adjust, is to insert a variable capacitor in series with the matching section where it connects to the transmission line, as shown in Fig. 21-39. The capacitor must be protected from the weather.

The method of adjustment commonly used is to cut the antenna for approximate resonance and then make the spacing *x* some value that is convenient constructionally. The distance *y* is then adjusted, while maintaining symmetry with respect to the center, until the SWR on the transmission line is as low as possible. If the SWR is not below 2 to 1 after this adjusment, the antenna length should be changed slightly and the matching section taps adjusted again. This procedure may be continued until the SWR is as close to 1 to 1 as possible.

When the series-capacitor method of reactance compensation is used (Fig. 21-32), the antenna should be the proper length to be resonant at the operating frequency. Trial positions of the matching-section taps are then taken, each time adjusting the capacitor for minimum SWR, until the standing waves on the transmission line are brought down to the lowest possible value.

The unbalanced ("gamma") arrangement in Fig. 20-13B is similar in principle to the "T," but is adapted for use with single coax line. The method of adjustment is the same.

BALANCING DEVICES

An antenna with open ends, of which the half-wave type is an example, is inherently a balanced radiator. When opened at the center and fed with a parallel-conductor line this balance is maintained throughout the system, so long as the causes of unbalance discussed in the transmission-line chapter are avoided.

If the antenna is fed at the center through a coaxial line, as indicated in Fig. 20-14A, this balance is upset because one side of the radiator is connected to the shield while the other is connected to the inner conductor. On the side connected to the shield, a current can flow down over the *outside* of the coaxial line, and the fields thus set up cannot be canceled by the fields from the inner conductor because the fields *inside* the line cannot escape through the shielding afforded by the outer conductor. Hence these "antenna" currents flowing on the outside of the line will be responsible for radiation.

Linear Baluns

Line radiation can be prevented by a number of devices whose purpose is to detune or decouple the line for "antenna" currents and thus greatly reduce their amplitude. Such devices generally are known as baluns (a contraction for "balanced to unbalanced"). Fig. 20-14B shows one such arrangement, known as a bazooka, which uses a sleeve over the transmission line to form, with the outside of the outer line conductor, a shorted quarter-wave line section. As described earlier in this chapter, the impedance looking into the open end of such a section is very high, so that the end of the outer conductor of the coaxial line is effectively insulated from the part of the line below the sleeve. The length is an *electrical* quarter wave, and may be physically shorter if the insulation between the sleeve and the line is other than air. The bazooka has no effect on the impedance relationships between the antenna and the coaxial line.

Another method that gives an equivalent effect is shown at C. Since the voltages at the antenna terminals are equal and opposite (with reference to ground), equal and opposite currents flow on the surfaces of the line and second conductor. Beyond the shorting point, in the direction of the transmitter, these currents combine to cancel out. The balancing section "looks like" an open circuit to the antenna, since it is a quarter-wave parallel-conductor line shorted at the far end, and thus has no effect on the normal antenna operation. However, this is not essential to the line-balancing function of the device, and baluns of this type are sometimes made shorter than a quarter wavelength in order to provide the shunt inductive reactance required in certain types of matching systems.

Fig. 20-14D shows a third balun, in which equal and opposite voltages, balanced to ground, are taken from the inner conductors of the main transmission line and half-wave phasing section. Since the voltages at the balanced end are in series while the voltages at the unbalanced end are in parallel, there is a 4-to-1 step-down in impedance from the balanced to the unbalanced side. This arrangement is useful for coupling between a balanced 300-ohm line and a 75-ohm coaxial line, for example.

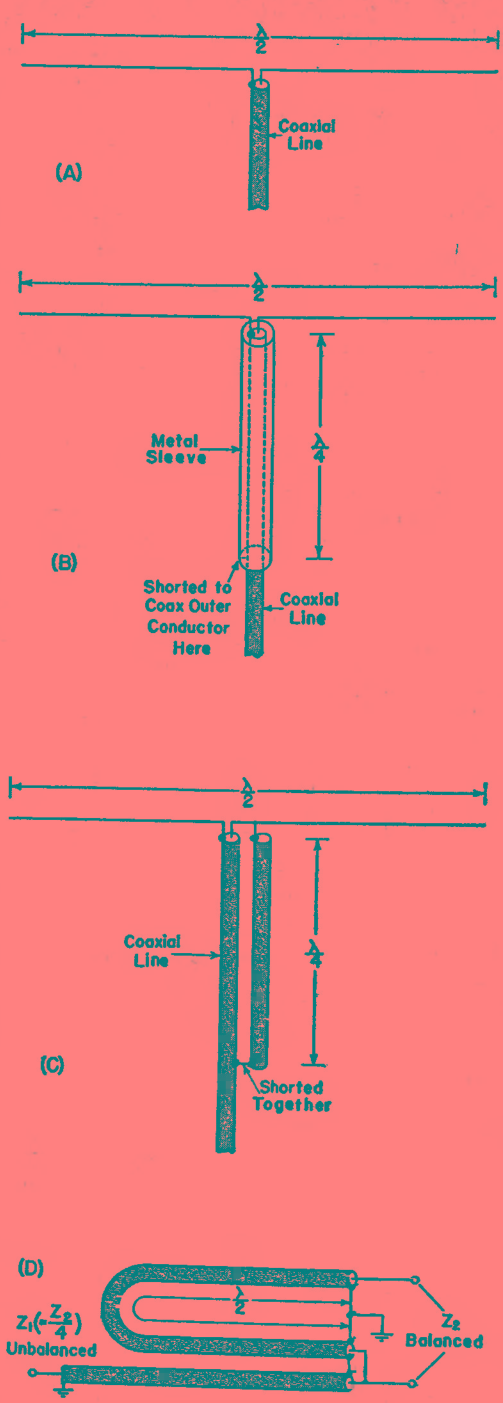

Fig. 20-14 — Radiator with coaxial feed (A) and methods of preventing unbalanced currents from flowing on the outside of the transmission line (B and C). The half-wave phasing section shown at D is used for coupling between an unbalanced and a balanced circuit when a 4-to-1 impedance ratio is desirad or can be accepted.

OTHER LOADS AND BALANCING DEVICES

The most important practical load for a transmission line is an antenna which, in most cases, will be "balanced" – that is, symmetrically constructed with respect to the feed point. Aside from considerations of matching the actual impedance of the antenna at the feed point to the characteristic impedance of the line (if such matching is attempted) a balanced antenna should be fed through a balanced transmission line in order to preserve symmetry with respect to ground and thus avoid difficulties with unbalanced currents on the line and consequent undesirable radiation from the transmission line itself.

If, as is often the case, the antenna is to be fed through coaxial line (which is inherently unbalanced) some method should be used for connecting the line to the antenna without upsetting the symmetry of the antenna itself. This requires a circuit that will isolate the balanced load from the unbalanced line while providing effecient power transfer. Devices for doing this are called **baluns.** The types used between the antenna and transmission line are generally "linear," consisting of transmission-line sections.

The need for baluns also arises in coupling a transmitter to a balanced transmission line, since the output circuits of most transmitters have one side grounded. (This type of output circuit is desirable for a number of reasons, including TVI reduction.) The most flexible type of balun for this purpose is the inductively coupled matching network described in a subsequent section in this chapter. This combines impedance matching with balanced-to-unbalanced operation, but has the disadvantage that it uses resonant circuits and thus can work over only a limited band of frequencies without readjustment. However, if a fixed impedance ratio in the balun can be tolerated, the coil balun described below can be used without adjustment over a frequency range of about 10 to 1 – 3 to 30 MHz, for example.

Coil Baluns

The type of balun known as the "coil balun" is based on the principles of linear-transmission-line balun as shown in the upper drawing of Fig. 20-15. Two transmission lines of equal length having a characteristic impedance (Z_0) are connected in series at one end and in parallel at the other. At the series-connected end the lines are balanced to ground and will match an impedance equal to $2Z_0$. At the parallel-connected end the lines will be matched by an impedance equal to $Z_0/2$. One side may be connected to ground at the parallel-connected end, provided the two lines have a length such that, considering each line as a single wire, the balanced end is effectively decoupled from the parallel-connected end. This requires a length that is an odd multiple of 1/4 wavelength.

A definite line length is required only for decoupling purposes, and so long as there is adequate decoupling the system will act as a 4-to-1 impedance transformer regardless of line length. If each line is wound into a coil, as in the lower drawing, the inductances so formed will act as choke coils and will tend to isolate the series-connected end from any ground connection that may be placed on the parallel-connected end. Balun coils made in this way will operate over a wide frequency range, since the choke inductance is not critical. The lower frequency limit is where the coils are no longer effective in isolating one end from the other; the length of line in each coil should be about equal to a quarter wave-length at the lowest frequency to be used.

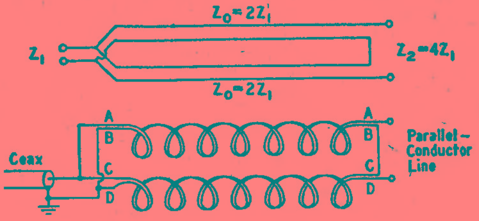

Fig. 20-15 — Baluns for matching between push-pull and single-ended circuits. The impedance ratio is 4 to 1 from the push-pull side to the unbalanced side. Coiling the lines (lower drawing) increases the frequency range over which satisfactory operation is obtained.

The principal application of such coils is in going from a 300-ohm balanced line to a 75-ohm coaxial line. This requires that the Z_0 of the lines forming the coils be 150 ohms.

A balun of this type is simply a fixed-ratio transformer, when matched. It cannot compensate for inaccurate matching elsewhere in the system. With a "300-ohm" line on the balanced end, for example, a 75-ohm coax cable will not be matched unless the 300-ohm line actually is terminated in a 300-ohm load.

TWO BROAD-BAND TOROIDAL BALUNS

Air-wound balun transformers are somewhat bulky when designed for operation in the 1.8- to 30-MHz range. A more compact broad-band transformer can be realized by using toroidal ferrite core material as the foundation for bifilar-wound coil balun transformers. Two such baluns are described here.

In Fig. 20-16 at A, a 1:1 ratio balanced-to-unbalanced-line transformer is shown. This transformer is useful in converting a 50-ohm balanced line condition to one that is 50 ohms, unbalanced. Similarly, the transformer will work between balanced and unbalanced 75-ohm impedances. A 4:1 ratio transformer is illustrated in Fig. 20-16 at B. This balun is useful for converting a 200-ohm balanced condition to one that is 50 ohms, unbalanced. In a like manner, the transformer can be used between a balanced 300-ohm point and a 75-ohm unbalanced line. Both balun transformers will handle 1000 watts of rf power and are designed to operate from 1.8 through 60 MHz.

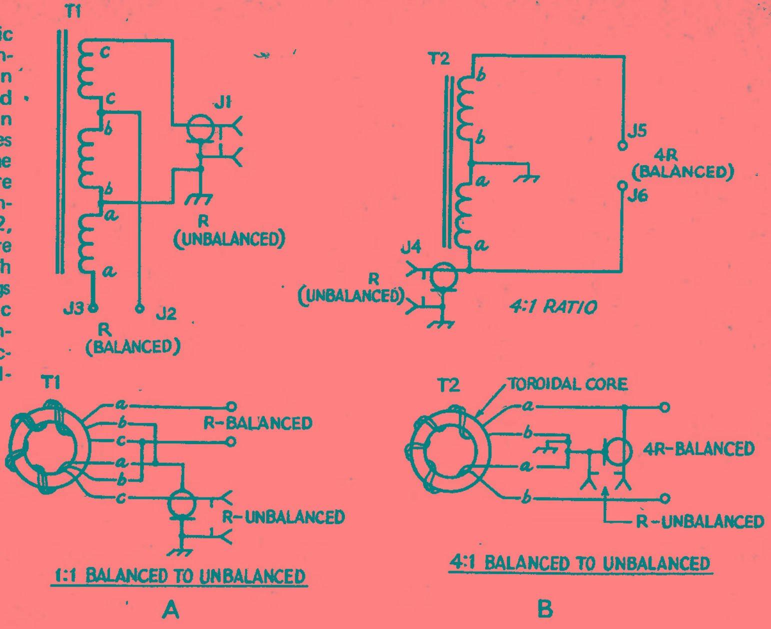

Fig. 20-16— Schematic and pictorial representations of the balun transformers. T1 and T2 are wound on CF-123 toroid cores (see footnote 1, and the text). J1 and J4 are SO-239-type coax connectors, or similar. J2, J3, J5, and J6 are steatite feedthrough bushings. The windings are labeled a, b, and c to show the relationship between the pictorial and schematic illustretions.

Low-loss high-frequency ferrite core material is used for T1 and T2.[1,3] The cores are made from Q-2 material and cost approximately $5.50 in single-lot quantity. They are 0.5 inches thick, have an OD of 2.4 inches, and the ID is 1.4 inches. The permeability rating of the cores is 40. A packaged one-kilowatt balun kit, with winding instructions for 1:1 or 4:1 impedance transformation ratios, is available, but uses a core of slightly different dimensions.[2]

Winding Information

The transformer shown in Fig. 20-16 at A has a trifilar winding consisting of 10 turns of No. 14 formvar-insulated copper wire. A 10-turn bifilar winding of the same type of wire is used for the balun of Fig. 20-16 at B. If the cores have rough edges, they should be carefully sanded until smooth enough to prevent damage to the wire's formvar insulation. The windings should be spaced around the entire core as shown in Fig. 20-17. Insulation can be used between the core material and the windings to increase the power handling capabilities of the core.

Using the Baluns

For indoor applications, the transformers can be assembled open style, without benefit of a protective enclosure. For outdoor installations, such as at the antenna feed point, the balun should be encapsulated in epoxy resin or mounted in a suitable weather-proof enclosure. A Minibox, sealed against moisture, works nicely for the latter.

NONRADIATING LOADS

Typical examples of nonradiating loads for a transmission line are the grid circuit of a power amplifier (considered in the chapter on transmitters), the input circuit of a receiver, and another transmission line. This last case includes the "antenna tuner" – a misnomer because it is

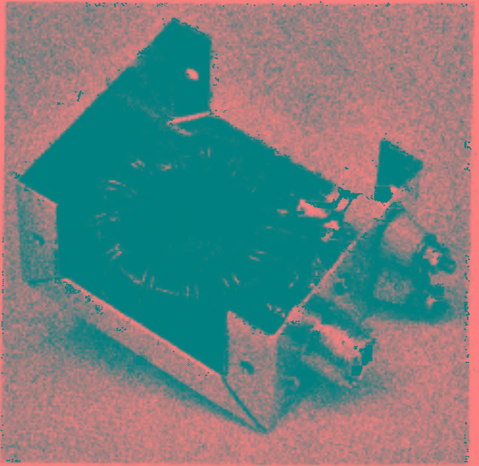

Fig. 20-17 – Layout of a kilowatt 4:1 toroidal balun transformer. Phenolic insulating board is mounted between the transformer and the Minibox wall to prevent short-circuiting. The board is held in place with epoxy cement. Cement is also used to secure the transformer to the board. For outdoor use, the Minibox cover can be installed, then sealed against the weather by applying epoxy cement along the seams of the box.

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[1] Available in single-lot quantity from Permag Corp, 88-06 Van Wyck Expy, Jamaica, NY 11418.

[2] Amidon Associates, 12033 Otsego Street, North Hollywood, CA 91601.

[3] Toroid cores are also available from Ferroxcube Corp. of America, Saugerties, NY 12477.

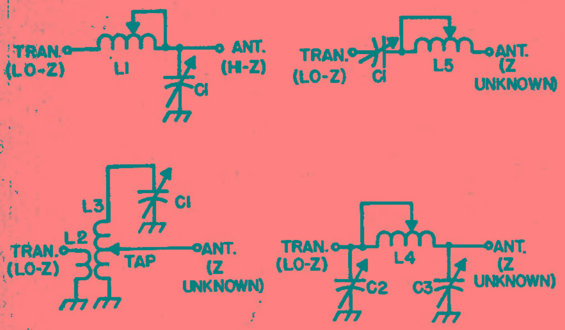

Fig. 20-18 — Networks for matching a low-*Z* transmitter output to random-length end-fed wire antennas.

actually a device for coupling a transmission line to the transmitter. Because of its importance in amateur installations, the antenna coupler is considered separately in a later part of this chapter.

Coupling to a Receiver

A good match between an antenna and its transmission line does not guarantee a low standing-wave ratio on the line when the antenna system is used for receiving. The SWR is determined wholly by what the line "sees" at the receiver's antenna-input terminals. For minimum SWR the receiver input circuit must be matched to the line. The rated input impedance of a receiver is a nominal value that varies over a considerable range with frequency. Most hf receivers are sensitive enough that exact matching is not necessary. The most desirable condition is that in which the receiver is matched to the line Z_0 and the line in turn is matched to the antenna. This transfers maximum power from the antenna to the receiver with the least loss in the transmission line.

COUPLING TO RANDOM-LENGTH ANTENNAS

Several impedance-matching schemes are shown in Fig. 20-18, permitting random-length wires to be matched to normal low-*Z* transmitter outputs. The circuit used will depend upon the length of the antenna wire and its impedance at the desired operating frequency. Ordinarily, one of the four methods shown will provide a suitable impedance match to an end-fed random wire, but the configuration will have to be determined experimentally. For operation between 3.5 and 30 MHz, C1 can be a 200-pF type with suitable plate spacing for the power level in use. C2 and C3 should be 500-pF units to allow for flexibility in matching. L1, L4, and L5 should be tapped or rotary inductors with sufficient *L* for the operating frequency. L3 can be a tapped Miniductor coil with ample turns for the band being used. An SWR bridge should be used as a match indicator.

COUPLING THE TRANSMITTER TO THE LINE

The type of coupling system that will be needed to transfer power adequately from the final rf amplifier to the transmission line depends almost entirely on the input impedance of the line. As shown earlier in this chapter, the input impedance is determined by the standing-wave ratio and the line length. The simplest case is that where the line is terminated in its characteristic impedance so that the SWR is 1 to 1 and the imput impedance is equal to the Z_0 of the line, regardless of line length.

Coupling systems that will deliver power into a flat line are readily designed. For all practical purposes the line can be considered to be flat if the SWR is no greater than about 1.5 to 1. That is, a coupling system designed to work into a pure resistance equal to the line Z_0 will have enough leeway to take care of the small variations in input impedance that will occur when the line length is changed, if the SWR is higher than 1 to 1 but no greater than 1.5 to 1.

Current practice in transmitter design is to

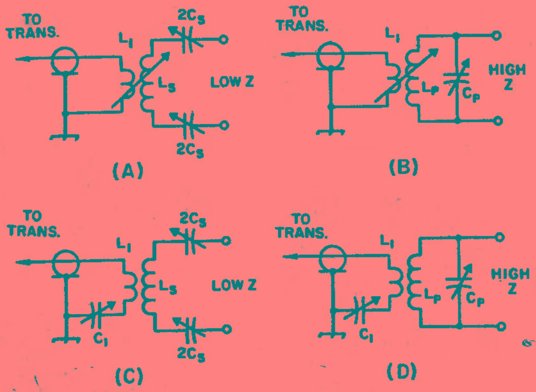

Fig. 20-19 — Simple circuits for coupling a transmitter to a balanced line that presents a load different than the transmitter output impedance. (A) and (B) are respectively series- and parallel-tuned circuits using variable inductive coupling between coils, and (C) and (D) are similar but use fixed inductive coupling and a variable series capacitor, C1. A series-tuned circuit works well with a low-impedance load; the parallel circuit is better with high-impedance loads (several hundred ohms or more).

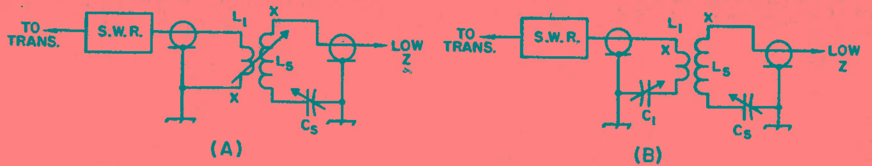

Fig. 20-20 — Coupling from a transmitter designed for 50- to 75-ohm output to a coaxial line with a 3- or 4-to-1 SWR is readily accomplished with these circuits. Essential difference between the circuits is (A) adjustable inductive coupling and (B) fixed inductive coupling with variable series capacitor.

In either case the circuit can be adjusted to give a 1-to-1 SWR on the meter in the line to the transmitter. The coil ends marked "x" should be adjacent, for minimum capacitive coupling.

provide an output circuit that will work into such a line, usually a coaxial line of 50 to 75 ohms characteristic impedance. The design of such output circuits is discussed in the chapter on high-frequency transmitters. If the input impedance of the transmission line that is to be connected to the transmitter differs appreciably from the value of impedance into which the transmitter output circuit is designed to operate, an impedance-matching network must be inserted between the transmitter and the line input terminals.

IMPEDANCE-MATCHING CIRCUITS FOR TRANSMISSION LINES

As shown earlier in this chapter, the input impedance of a line that is operating with a high standing-wave ratio can vary over quite wide limits. The simplest type of circuit that will match such a range of impedances to 50 to 75 ohms is a simple series- or parallel-tuned circuit, approximately resonant at the operating frequency. If the load presented by the line at the operating frequency is low (below a few hundred ohms), a series-tuned circuit should be used. When the load is higher than this, the parallel-tuned circuit is easier to use.

Typical simple circuits for coupling between the transmitter with 50- to 75-ohm coaxial-line output and a balanced transmission line are shown in Fig. 20-19. The inductor L1 should have a reactance of about 60 ohms when adjustable inductive coupling is used (Figs. 20-19A and 20-19B). When a variable series capacitor is used, L1 should have a reactance of about 120 ohms. The variable capacitor, C1, should have a reactance at maximum capacitance of about 100 ohms.

On the secondary side, L_s and C_s should be capable of being tuned to resonance at about 80 percent of the operating frequency. In the series-tuned circuits, for a given low-impedance load looser coupling can be used between L1 and L_s as the L_s-to-C_s ratio is increased. In the parallel-tuned circuits, for a given high-impedance load looser coupling can be used between L1 and L_p as the C_p-to-L_p ratio is increased. The constants are not critical; the rules of thumb are mentioned to assist in correcting a marginal condition where sufficient transmitter loading cannot be obtained.

Coupling to coaxial lines that have a high SWR, and consequently may present a transmitter with a load it cannot couple to, is done with an unbalanced version of the series-tuned circuit, as shown in Fig. 20-20. The rule given above for coupling ease and L_s-to-C_s ratio applies to these circuits as well.

The most satisfactory way to set up initially any of the circuits of Fig. 20-19 or 20-20 is to connect a coaxial SWR bridge in the line to the transmitter, as shown in Fig. 20-20. The "Monimatch" type of bridge, which can handle the full transmitter power and may be left in the line for continuous monitoring, is excellent for this purpose. However, a simple resistance bridge such as is described in the chapter on measurements is perfectly adequate, requiring only that the transmitter output be reduced to a very low value so that the bridge will not be overloaded. To adjust the circuit, make a trial setting of the coupling (coil spacing in Figs. 20-19A and B and 20-20A, C1 setting in others) and adjust C_s or C_p for minimum SWR as indicated by the bridge. If the SWR is not close to practically 1 to 1, readjust the coupling and return C_s or C_p, continuing this procedure until the SWR is practically 1 to 1. The settings may then be logged for future reference.

In the series-tuned circuits of Figs. 20-20A and 20-20C, the two capacitors should be set at similar settings. The "$2C_s$" indicates that a balanced series-tuned coupler requires twice the capacitance in each of two capacitors as does an unbalanced series-tuned circuit, all other things being equal.

It is possible to use circuits of this type without initially setting them up with an SWR bridge. In such a case it is a matter of cut-and-try until adequate power transfer between the amplifier and main transmission line is secured. However, this method frequently results in a high SWR in the link, with consequent power loss, "hot spots" in the coaxial cable, and tuning that is critical with frequency. The bridge method is simple and gives the optimum operating conditions quickly and with certainty.

A TRANSMATCH FOR BALANCED OR UNBALANCED LINES

Nearly all commercially made transmitters are designed to work into a 50- to 70-ohm load, and they are not usually equipped to handle loads that depart far from these values. However, many antenna systems (the antenna plus its feed line) have complex impedances that make it difficult, if not impossible, to load and tune a transmitter

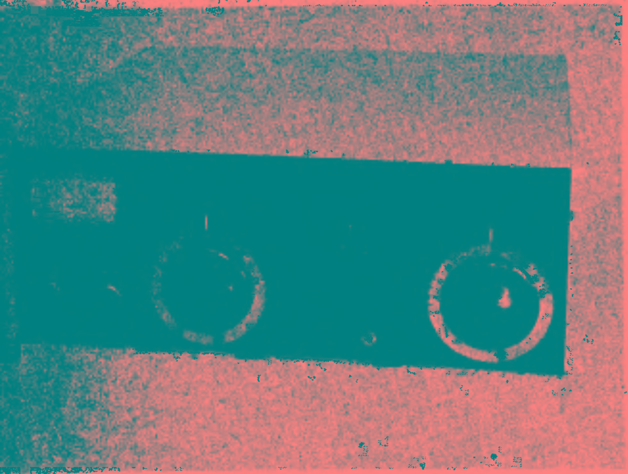

Fig. 20-21 — The universal Transmatch shown here will couple a transmitter to almost any antenna system. If the amateur already has a matching indicator, the Monimatch section of the circuit can be eliminated. The counter dial and knobs are James Millen & Co. components.

properly. What is required is a coupling method to convert the reactive/resistive load to a non-reactive 50-ohm load. This task can be accomplished with a Transmatch, a device that consists of one or more *LC* circuits. It can be adjusted to tune out any load reactance plus, when necessary, transforming the load impedance to 50 or 70 ohms.

As has been discussed earlier in this chapter, losses in transmission lines depend on several factors: the size of the conductors, the spacing between conductors, the dielectric material used in the construction of the feed line, and the frequency at which the line is used. Coaxial lines can be classed as lossy lines when compared to a low-loss line such as open-wire feeders, at least below 100 MHz. Because losses increase as the SWR increases, the type of line used to feed an antenna should be chosen carefully. If the transmission line has very low-loss characteristics, high standing wave ratios can be tolerated with no practical loss of power in the line.

A wire antenna, fed at the center with open-wire line, is the most efficient multiband antenna devised to date. For all practical purposes, the feed line is lossless, so extremely high SWRs can be tolerated. This should not be construed to mean that coaxial feed lines cannot be used because of a high SWR, but only the very expensive types are really suitable in this application.

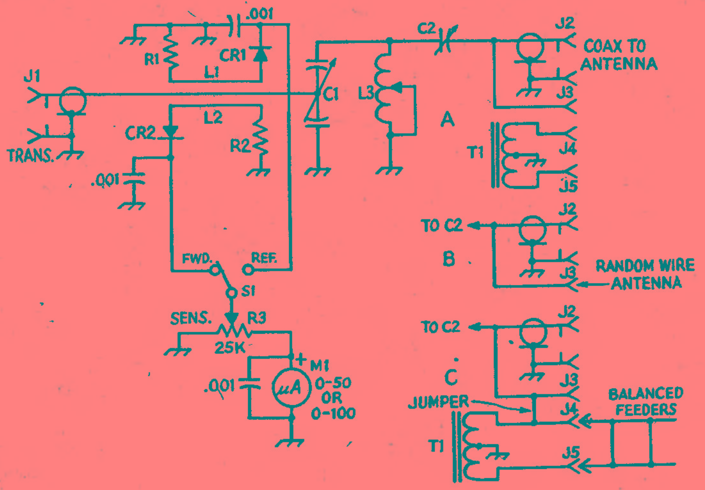

Fig. 20-22 — Circuit diagram of the Transmatch. The .001-μF capacitors used are disk caramic.

C1 — Duel-section or air variable, 200 pF per section (E. F. Johnson 154-507 or Millen 18250).

C2 — Air variable 350 pF, (E. F. Johnson 154-10 or Millen 16520A).

CR1, CR2 — 1N34A germanium diode.

J1, J2 — Coax chassis connector, type SO-239.

J3, J4, J5 — Isolantite feedthrough insulators.

L1, L2 — See Fig. 20-25.

L3 — Roller inductor, 28 μH (E. F. Johnson 229-203).

M1 — 50 or 100 μA.

R1, R2 — 68-ohm, 1/2-watt carbon or composition.

R3 — 25,000-ohm control, linear taper.

S1 — Spst toggle.

T1 — Balun transformer, see text and Fig. 20-23.

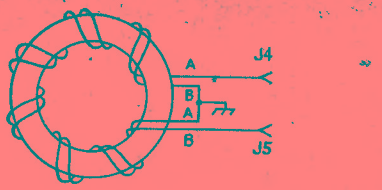

Fig. 20-23 — Details of the balun bifilar windings. The drawing shows the connections required. In the actual balun, the turns should be closed spaced on the inside of the core and spread evenly on the outside.

The Transmatch shown in Fig. 20-22 is designed to handle practically any mismatch that an amateur is likely to encounter. The unit can be used with either open-wire feeders, balanced lines, coaxial lines, or even an end-fed single wire. Frequency range of the unit is from 3 to 30 MHz, accomplished without the use of bandswitching. Basically, the circuit is designed for use with unbalanced lines, such as "coax." For balanced lines, a 1:4 (unbalanced-to-balanced) balun is connected to the output of the Transmatch.

The chassis used for the Transmatch is made of a 16 X 25-inch sheet of aluminum. When bent to form a U, the completed chassis measures 16 X 13 X 6 inches. When mounting the variable capacitors, the roller inductor and the balun, allow at least 1/2-inch clearance to the chassis and adjoining components. The capacitors should be mounted on insulated standoff insulators. The balun can be mounted on a cone insulator or piece of Plexiglas.

The balun requires three ferrite cores stacked for 2-kW or two cores for 1-kW power levels. Amidon type T-200-2 cores are used in making the balun.[1] Each core should be covered with two layers of 3M No. 27 glass-cloth insulating tape. Next, the cores are stacked and covered with another layer of the tape. The winding consists of 15 bifilar turns of No. 14, Teflon-covered wire. Approximately 20 feet of wire (two 10-foot lengths) are required.

A template for the etched-circuit Monimatch is shown in Fig. 20-25. Details for making etched circuits are given in the Construction Practices chapter. If the builder desires, a power-type bridge can be substituted. Such a unit is described in the Measurements chapter. In addition to providing standing-wave indications for Transmatch adjustment purposes, the power bridge will accurately measure transmitter output power.

For coax-to-coax feeder matching, the antenna feed line should be connected to J2 of Fig. 20-22. C1 and C2 should be set at maximum capacitance and power applied to the transmitter. The SWR indicator should be switched to read reflected power. Then, adjust L3 until there is a drop in the reflected reading. C1 and C2 should then be reset, along with L3, until a perfect match is obtained. It will be found that with many antenna systems, several different matching combinations can be obtained. Always use the matching setting that uses the most capacitance from C1 and C2, as maximum *C* provides the best harmonic attenuation.

Fig. 20-24 — Interior view of the Transmatch. The etched-circuit Monimatch is mounted 1/2 inch above the chassis. Both C1 and C2 must be mounted on insulated stand-offs and insulated shaft couplers used between the capecitors and the panel knobs. Likewise, T1 should be installed on an insulated mounting. An isolantite cone is used in the unit shown (the balun could be mounted on a piece of Plexiglas). Feedthrough isolantite insulators, mounted through the rear deck, are used for the antenna connectors.

End-fed wires should be connected to J3. Use the same adjustment procedures for setting up the Transmatch as outlined above. For balanced feeders, the feed line should be connected to J4 and J5, and a jumper must be connected between J3 and J4 (see Fig. 20-22 at C).

A slight modification will permit this Transmatch to be used on the 160-meter band. Fixed capacitors, 100 pF each (Centralab type 850S-100N), can be installed across each of the stator sections of C1, providing sufficient *C* to tune to 1.8 MHz. But, the fixed capacitors must be removed when using the Transmatch on the other hf bands.

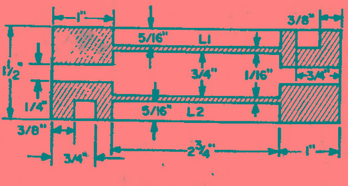

Fig. 20-25 — Template for the etched-circuit Monimatch, foil side shown, etched portion shaded.

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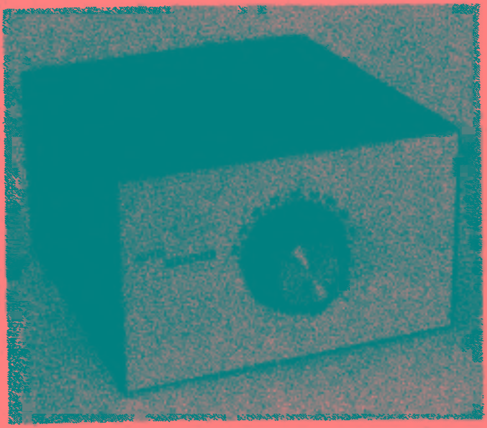
[1] Amidon Associates, 12033 Otsego Street, North Hollywood, CA 91601.

A SIMPLE COUPLER FOR BALANCED LINES



Generally speaking, antenna balance can be neglected with many of the systems commonly used by amateurs. Such closed-loop configurations as the quad and the folded dipole tend to cancel out the effects of imbalance even though they are inherently balanced antennas in nature. Other antennas have only a limited vulnerability (the ordinary half-wave dipole for example) to imbalance effects and often can be operated with no balancing networks being necessary. However, some antennas require a balanced source and the best approach is to tailor the coupler design accordingly. These systems usually have a high input impedance also.

The coupler shown in Fig. 1 can be used to match the transmitter to a balanced load with a high input impedance. Typical examples would be short dipoles fed with short lengths of open-wire line or a half-wave dipole fed with a quarter-wave section of high-impedance line. For instance, the coupler was used with an 80-meter dipole fed with 67-feet of 450-ohm line on both 80 and 160 meters with the values given for L1 and C1.

In most instances, values for this type of coupler are not critical and any number of combinations could be used. If desired, a link could be substituted for the phase-reversing transformer. However, the latter provides a simple means for getting a voltage with the necessary 180-degree phase shift for the opposite half of a balanced load. This allows tap adjustment over a wide range of values eliminating the need for changing coils (usually necessary with such couplers). Recommended power limit with the components given would be approximately 100 watts which means the coupler should handle any transmitter in the 150-watt, PEP class without any difficulty on either phone or cw.

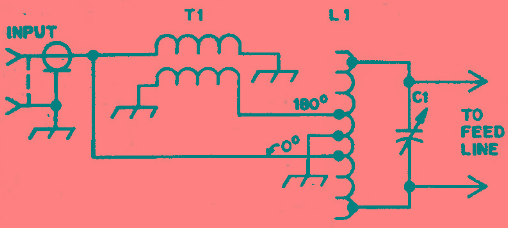


Fig. 1 — Schematic diagram for the coupler.

C1 — Air variable, 325 pF (Millen 19335 or equiv.).

L1 — Air-wound inductor, 2-1/2-inch dia., 6 tpi (B&W 3029 or equiv.), 7 inches long.

T1 — Phase-reversal transformer, stack two Amidon FT-61-601 ferrite cores and wrap with glass tape. Wind 18 turns of twisted pair made from two strands of No. 20 enam. wire twisted such that there are approximately 34 "bumps" or notches per foot as the pair is pulled between the thumb and forefinger.

To construct the twisted pair, bend a four-foot piece of wire in the middle and clamp this end in a vice. Pull the wires taut and twist slightly so that the wires come together over the entire length. Roll the free ends into a ball large enough to ba clamped in the chuck of a small hand-powered drill. Twist slowly until the desired pitch is obtained.

Construction of the coupler. Note method of mounting T1 (seen to the left of the coil L1).

Adjustment of the coupler should proceed as follows. First, tune the receiver to the band segment of interest. Next, adjust the taps and tune C1 until signals begin to peak up (the taps should be adjusted equally with the same number of turns from ground to the outer taps on each side and likewise with the inner ones). If a high-impedance load is suspected, start with the inner taps close to the ground connection and adjust the outer taps. With medium-impedance levels, the inner taps will be farther out. Finally, turn the transmitter on and adjust for minimum SWR with the meter connected *between the transmitter and the coupler*. With the antenna mentioned earlier, only minor retuning of C1 was required to cover the 75-meter phone band.

Economy Coupler

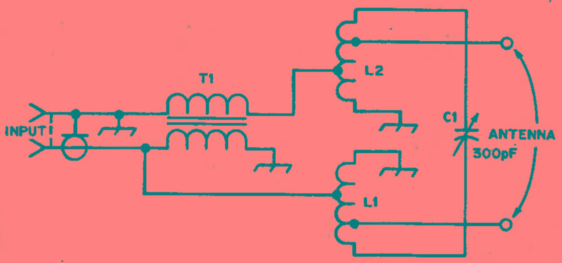


Fig. 1 — Circuit diagram for the Economy Coupler. C1 may be any value between 200 and 350 pF for most installations. L1 and L2 are 2-1/2 inch diameter, eight turns per inch of No. 14 wire. (Suitable Miniductor stock would be Barker and Williamson 3030). A total of 25 turns is used; however, depending on the antenna characteristics, a large portion of each coil may be shorted as shown here. Since the builder must select the taps to match his installation, the dimensions of the inductors are uncritical and any coil with similar characteristics may be used. T1 is wound with 25 turns of twisted No. 14 PVC covered wire (house wiring) on a 1/2-inch diameter seven-inch long ferrite rod from Amidon.

THE ECONOMY COUPLER

The coupler described here may be used to match almost any balanced transmission line in conjunction with an 80-meter half-wave antenna. The primary feature of this device is its ability to match a wide variety of loads under high-power conditions with a minimum number of expensive components. Typically, a dipole fed with 450-ohm balanced feed line (open wire or Twinlead) will operate satisfactorily across the entire band if the coil taps are selected correctly. Alligator clips are used to set the initial adjustment positions. However, for high-power operation, the alligator clips should be replaced with bus wire soldered directly to the inductors.

The circuit is a bit unconventional in that the phase-reversal transformer is located at the input rather than the output. The purpose is to keep the transformer in the low-impedance portion of the circuit which allows the use of PVC covered wire. When the transformer is used in the output section, as is done in the "Ultimate" circuit given earlier in this chapter, the wire must be Teflon coated.

Inside view of the Economy Coupler. The capacitor must have plate spacing sufficiently large to handle the power of the transmitter. For low-power inputs (up to 250 watts) a plate spacing of .03 inch is suitable; for two-kilowatt operation, a spacing of 0.125 inch or greater is needed.

Two tuning coils are used, one for each leg of the transmission line. The coils should be mounted at right angles to each other to minimize mutual coupling. The tuning control, C1, is mounted on ceramic pillar insulators and the rotor shaft is insulated from ground. The alligator clips attached to the copper braid serve to short out an appropriate amount of the coil; the tap points for the antenna and the phase reversal transformer are soldered in place.

Chapter 21

HF Antennas

HF ANTENNAS

An *antenna system* can be considered to include the antenna proper (the portion that radiates the rf energy), the feed line, and any coupling devices used for transferring power from the transmitter to the line and from the line to the antenna. Some simple systems may omit the transmission line or one or both of the coupling devices. This chapter will describe the antenna proper, and in many cases will show popular types of lines, as well as line-to-antenna couplings where they are required. However, it should be kept in mind that *any* antenna proper can be used with *any* type of feedline if a suitable impedance matching is used between the antenna and the line.

ANTENNA SELECTION AND CONSIDERATIONS

In choosing an antenna one must base his selection upon available space, the number of bands to be operated, and the type of propagation he will most often make use of. Frequently, because of limitations in available antenna space, the hf operator must settle for relatively simple antenna systems. It is wise to choose an antenna that will offer the best performance for its size. The "compromise antenna" – those offering multiband possibilities, and those using physically shortened elements – cannot perform as efficiently as full-size antennas cut for a single band of operation. However, many of the so-called compromise antennas are suitable for DX work even though they have less gain than other types. Ideally, one should attempt to have separate antennas – full size – for the bands to be operated. Also, erecting the antennas as high as possible, and away from trees and man-made objects, will greatly enhance their operational effectiveness.

In general, antenna construction and location become more critical and important on the higher frequencies. On the lower frequencies (1.8, 3.5, and 7 MHz) the vertical angle of radiation and the plane of polarization may be of relatively little importance; at 28 MHz they may be all-important.

Definitions

The **polarization** of a straight-wire antenna is determined by its position with respect to the earth. Thus a vertical antenna radiates vertically polarized waves, while a horizontal antenna radiates horizontally polarized waves in a direction broadside to the wire and vertically polarized waves at high vertical angles off the ends of the wire. The wave from an antenna in a slanting position, or from the horizontal antenna in directions other than mentioned above, contains components of both horizontal and vertical polarization.

The **vertical angle of maximum radiation** of an antenna is determined by the free-space pattern of the antenna, its height above ground, and the nature of the ground. The angle is measured in a vertical plane with respect to a tangent to the earth at that point, and it will usually vary with the horizontal angle, except in the case of a simple vertical antenna. The **horizontal angle of maximum radiation** of an antenna is determined by the free-space pattern of the antenna.

The **impedance** of the antenna at any point is the ratio of the voltage to the current at that point. It is important in connection with feeding power to the antenna, since it constitutes the load to the line offered by the antenna. It can be either resistive or complex, depending upon whether or not the antenna is resonant.

The **field strength** produced by an antenna is proportional to the current flowing in it. When there are standing waves on an antenna, the parts of the wire carrying the higher current have the greater radiating effect. All resonant antennas have standing waves – only terminated types, like the terminated rhombic and terminated "V" have substantially uniform current along their length.

The ratio of power required to produce a given field strength with a "comparison" antenna to the power required to produce the same field strength with a specified type of antenna is called the **power gain** of the latter antenna. The field is measured in the optimum direction of the antenna under test. The comparison antenna is generally a half-wave antenna at the same height and having the same polarization as the antenna under consideration. Gain usually is expressed in decibels.

In unidirectional beams (antennas with most of the radiation in only one direction) the **front-to-back** ratio is the ratio of power radiated in the maximum direction to power radiated in the opposite direction. It is also a measure of the reduction in received signal when the beam direction is changed from that for maximum response to the opposite direction. Front-to-back ratio is usually expressed in decibels.

The **bandwidth** of an antenna refers to the frequency range over which a property falls within acceptable limits. The **gain bandwidth**, the **front-to-back-ratio bandwidth** and the **standing-wave-ratio bandwidth** are of prime interest in amateur work. The gain bandwidth is of interest because, generally, the higher the antenna gain is the narrower the gain bandwidth will be. The SWR bandwidth is of interest because it is an indication of the transmission-line efficiency over the useful frequency range of the antenna.

The radiation pattern of any antenna that is many wavelengths distant from the ground and all other objects is called the free-space pattern of the antenna. The free-space pattern of an antenna is almost impossible to obtain in practice, except in the vhf and uhf ranges. Below 30 MHz, the height of the antenna above ground is a major factor in determining the radiation pattern of the antenna.

When any antenna is near the ground the free-space pattern is modified by reflection of radiated waves from the ground, so that the actual pattern is the resultant of the free-space pattern and ground reflections. This resultant is dependent upon the height of the antenna, its position or orientation with respect to the surface of the ground, and the electrical characteristics of the ground. The effect of a perfectly reflecting ground is such that the original free-space field strength may be multiplied by a factor which has a maximum value of 2, for complete reinforcement, and having all intermediate values to zero, for complete cancellation. These reflections only affect the radiation pattern in the vertical plane – that is, in directions upward from the earth's surface – and not in the horizontal plane, or the usual geographical directions.

Fig. 21-1 shows how the multiplying factor varies with the vertical angle for several representative heights for horizontal antennas. As the height is increased the angle at which complete reinforcement takes place is lowered, until for a height equal to one wavelength it occurs at a vertical angle of 15 degrees. At still greater heights, not shown on the chart, the first maximum will occur at still smaller angles.

Radiation Angle

The vertical angle of maximum radiation is of primary importance, especially at the higher frequencies. It is advantageous, therefore, to erect the antenna at a height that will take advantage of ground reflection in such a way as to reinforce the space radiation at the most desirable angle. Since low angles usually are most effective, this generally means that the antenna should be high – at least one-half wavelength at 14 MHz, and preferably three-quarters or one wavelength, and at least one wavelength, and preferably higher, at 28 MHz. The physical height required for a given height in wavelengths decreases as the frequency is increased, so that good heights are not impracticable; a half wavelength at 14 MHz is only 35 feet, approximately, while the same height represents a full wavelength at 28 MHz. At 7 MHz and lower frequencies the higher radiation angles are effective, so that again a useful antenna height is not difficult to attain. Heights between 35 and 70 feet are suitable for all bands, the higher figures being preferable. It is well to remember that most simple horizontally polarized antennas do not exhibit the directivity they are capable of unless they are one half wavelength above ground, or greater, at their operating frequency. Therefore, with dipole-type antennas it is not important to choose a favored broadside direction unless the antenna is at least one-half wavelength above ground.

Imperfect Ground

Fig. 21-1 is based on ground having perfect conductivity, whereas the actual earth is not a perfect conductor. The principal effect of actual ground is to make the curves inaccurate at the lowest angles; appreciable high-frequency radiation at angles smaller than a few degrees is practically impossible to obtain over horizontal ground. Above 15 degrees, however, the curves are accurate enough for all practical purposes, and may be taken as indicative of the result to be expected at angles between 5 and 15 degrees.

The effective ground plane – that is, the plane from which ground reflections can be considered to take place – seldom is the actual surface of the ground but is a few feet below it, depending upon the characteristics of the soil.

Impedance

Waves that are reflected directly upward from the ground induce a current in the antenna in passing, and, depending on the antenna height, the phase relationship of this induced current to the original current may be such as either to increase or decrease the total current in the antenna. For the same power input to the antenna, an increase in current is equivalent to a decrease in impedance, and vice versa. Hence, the impedance of the antenna varies with height. The theoretical curve of variation of radiation resistance for a very thin half-wave antenna above perfectly reflecting ground is shown in Fig. 21-2. The impedance approaches the free-space value as the height becomes large, but at low heights may differ considerably from it.

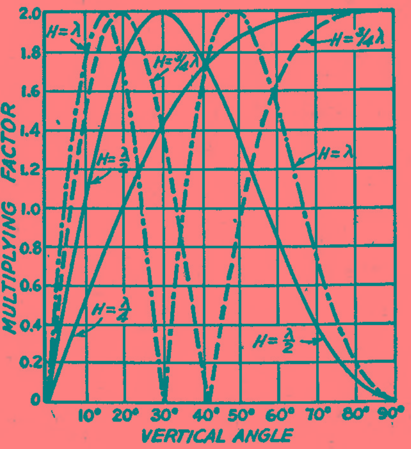


Fig. 21-1 – Effect of ground on radiation of horizontal antennas at vertical angles for four antenna heights. This chart is based on perfectly conducting ground.

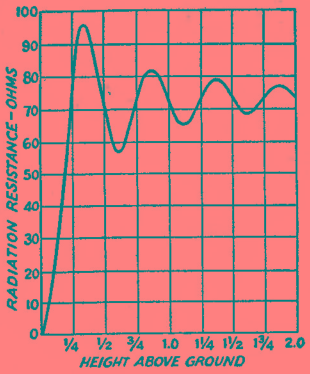


Fig. 21-2 — Theoretical curve of variation of radiation resistance for a very thin half-wave horizontal antenna as a function of height in wavelength above perfectly reflecting ground.

Choice of Polarization

Polarization of the transmitting antenna is generally unimportant on frequencies between 3.5 and 30 MHz, when considering sky-wave communications. However, the question of whether the antenna should be installed in a horizontal or vertical position deserves consideration for other reasons. A vertical half-wave or quarter-wave antenna will radiate equally well in all *horizontal* directions, so that it is substantially nondirectional, in the usual sense of the word. If installed horizontally, however, the antenna will tend to show directional effects, and will radiate best in the direction at right angles, or broadside, to the wire. The radiation in such a case will be *least* in the direction toward which the wire points.

The vertical angle of radiation also will be affected by the position of the antenna. If it were not for ground losses at high frequencies, the vertical antenna would be preferred because it would concentrate the radiation horizontally, and this low-angle radiation is preferable for practically all work. Another advantage to the use of a vertically polarized antenna, especially at 1.8, 3.5, and 7 MHz, is that local communications during night-time hours are improved. The vertical antenna is not as subject to signal fading as is the horizontal antenna.

THE HALF-WAVE ANTENNA

A fundamental form of antenna is a single wire whose length is approximately equal to half the transmitting wavelength. It is the unit from which many more-complex forms of antennas are constructed. It is known as a dipole antenna.

The length of a half-wave in space is:

$$\textit{Length}\ \text{(feet)} = \frac{492}{\textit{Freq.}\ \text{(MHz)}} \qquad \text{21-A}$$

The actual length of a half-wave antenna will not be exactly equal to the half-wave in space, but depends upon the thickness of the conductor in relation to the wavelength as shown in Fig. 21-3, where *K* is a factor that must be multiplied by the half wavelength in free space to obtain the resonant antenna length. An additional shortening effect occurs with wire antennas supported by insulators at the ends because of the capacitance added to the system by the insulators (end effect). The following formula is sufficiently accurate for wire antennas for frequencies up to 30 MHz:

$$\textit{Length of half-wave antenna}\ \text{(feet)} = \frac{492 \times 0.95}{\textit{Freq.}\ \text{(MHz)}} = \frac{468}{\textit{Freq.}\ \text{MHz)}} \qquad \text{21-B}$$

Example: A half-wave antenna for 7150 kHz (7.15 MHz) is $\frac{468}{7.15} = 65.45$ feet, or 65 feet 5 inches.

Above 30 MHz the following formulas should be used, particularly for antennas constructed from rod or tubing. *K* is taken from Fig. 21-3.

$$\textit{Length of half-wave antenna}\ \text{(feet)} = \frac{492 \times K}{\textit{Freq.}\ \text{(MHz)}} \qquad \text{21-C}$$

$$\textit{or length}\ \text{(inches)} = \frac{5905 \times K}{\textit{Freq.}\ \text{(MHz)}} \qquad \text{21-D}$$

Example: Find the length of a half wavelength antenna at 28.7 MHz, if the antenna is made of 1/2-inch diameter tubing. At 28.7 MHz, a half wavelength in space is

$$\frac{492}{28.7} = 17.14 \text{ feet}$$

from Equation 21-A. Ratio of half wavelength to conductor diameter (changing wavelength to inches) is

$$\frac{(17.14 \times 12)}{0.5} = 411$$

From Fig. 21-3, K = 0.97 for this ratio. The length of the antenna, from Equation 21-C, is

$$\frac{(492 \times 0.97)}{28.7} = 16.63 \text{ feet}$$

or 16 feet 7 1/2 inches. The answer is obtained directly in inches by substitution of Equation 21-D:

$$\frac{(5905 \times 0.97)}{28.7} = 199.6 \text{ inches.}$$

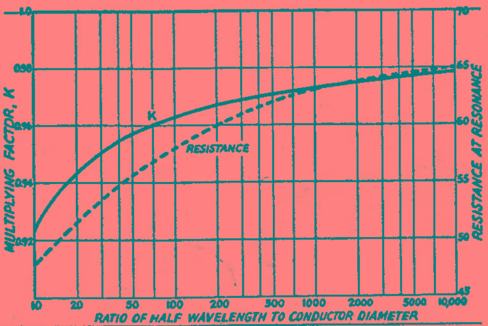


Fig. 21-3 — Effect of antenna diameter on length for half-wave resonance, shown as a multiplying factor, *K*, to be applied to the free-space half wavelength (Equation 21-A). The effect of conductor diameter on the center impedance also is shown.

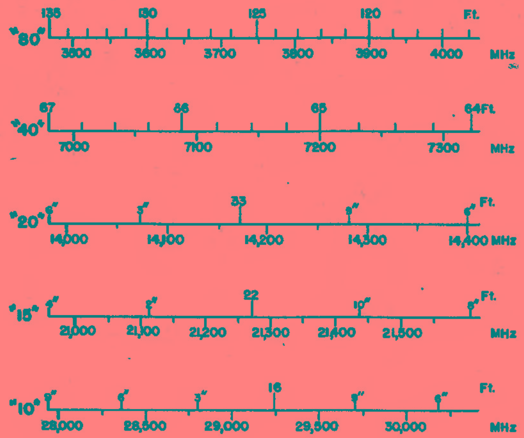


Fig. 21-4 — The above scales, based on Eq. 21-B, can be used to determine the length of a half-wave antenna of wira.

Current and Voltage Distribution

When power is fed to an antenna, the current and voltage vary along its length. The current is maximum (loop) at the center and nearly zero (node) at the ends, while the opposite is true of the rf voltage. The current does not actually reach zero at the current nodes, because of the end effect; similarly, the voltage is not zero at its node because of the resistance of the antenna, which consists of both the rf resistance of the wire (*ohmic resistance*) and the radiation resistance. The radiation resistance is an *equivalent* resistance, a convenient conception to indicate the radiation properties of an antenna. The radiation resistance is the equivalent resistance that would dissipate the power the antenna radiates, with a current flowing in it equal to the antenna current at a current loop (maximum). The ohmic resistance of a half-wavelength antenna is ordinarily small enough, compared with the radiation resistance, to be neglected for all practical purposes.

Impedance

The radiation resistance of an infinitely-thin half-wave antenna in free-space is about 73 ohms. The value under practical conditions is commonly taken to be in the neighborhood of 60 to 70 ohms, although it varies with height in the manner of Fig. 21-2. It increases toward the ends. The actual value at the ends will depend on a number of factors, such as the height, the physical construction, the insulators at the ends, and the position with respect to ground.

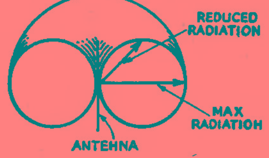


Fig. 21-5 — The free-space radiation pattern of a half-wave antenna. The antanna is shown in the vertical position, and the actual "doughnut" pattern is cut in half to show how the line from the centar of the antenna to the surface of the pattern veries. In practice this pattern is modified by the height above ground and if the antenna is vertical or horizontal. Fig. 21-1 shows some of the effects of height on the vertical angele of radiation.

Conductor Size

The impedance of the antenna also depends upon the diameter of the conductor in relation to the wavelength, as indicated in Fig. 21-3. If the diameter of the conductor is increased the capacitance per unit length increases and the inductance per unit length decreases. Since the radiation resistance is affected relatively little, the decreased L/C ratio causes the Q of the antenna to decrease, so that the resonance curve becomes less sharp. Hence, the antenna is capable of working over a wide frequency range. This effect is greater as the diameter is increased, and is a property of some importance at the very high frequencies where the wavelength is small.

Fig. 21-6 — Illustrating the importance of vertical angle of radiation in determining antenna directional effects. Off the end, the radiation is greater at higher angles. Ground reflection is neglected in this drawing of the free-space pattern of a horizontal antenna.

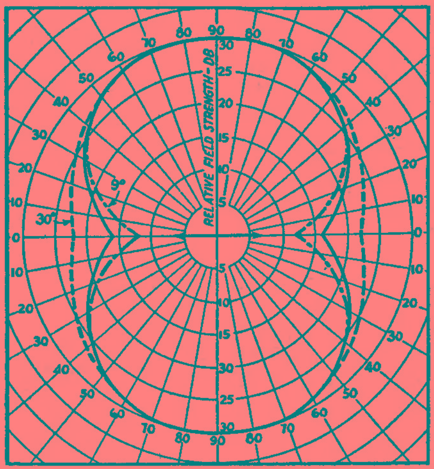


Fig. 21-7 — Horizontal pattern of a horizontal half-wave antenna at three vertical radiation angles. Tha solid line is relative rediation at 15 degrees. Dotted lines show deviation from the 15-degree pattern for angles of 9 and 30 degrees. The patterns ara useful for shape only, since the amplitude will depend upon the height of the antanna above ground and the vertical angle considerad. The patterns for all three angles have been proportioned to the same scale, but this does not mean that the maximum amplitudes necessarily will be the same. The arrow indicates the direction of the horizontal antanna wire.

Radiation Characteristics

The radiation from a dipole antenna is not uniform in all directions but varies with the angle with respect to the axis of the wire. It is most intense in directions perpendicular to the wire and zero along the direction of the wire, with intermediate values at intermediate angles. This is shown by the sketch of Fig. 21-5, which represents the radiation pattern in free space. The relative intensity of radiation is proportional to the length of a line drawn from the center of the figure to the perimeter. If the antenna is vertical, as shown, then the field strength will be uniform in all horizontal directions; if the antenna is horizontal, the relative field strength will depend upon the direction of the receiving point with respect to the direction of the antenna wire. The variation in radiation at various vertical angles from a half-wavelength horizontal antenna is indicated in Figs. 21-6 and 21-7.

FEEDING A DIPOLE ANTENNA

Since the impedance at the center of a dipole is in the vicinity of 70 ohms, it offers a good match for 75-ohm transmission lines. Several types are available on the market, with different power-handling capabilities. They can be connected in the center of the antenna, across a small strain insulator to provide a convenient connection point. Coaxial line should be used with a 1:1 balun transformer to assure symmetry. Direct feed (without a balun) is also acceptable, but may cause a slight skew in the radiation pattern. The transmission line should be run away at right angles to the antenna for at least one-quarter wavelength, if possible, to avoid current unbalance in the line caused by pickup from the antenna. The antenna length is calculated from Equation 21-B, for a half wavelength antenna. When No. 12 or No. 14 enameled wire is used for the antenna, as is generally the case, the length of the wire is the overall length measured from the loop through the insulator at each end. This is illustrated in Fig. 21-8.

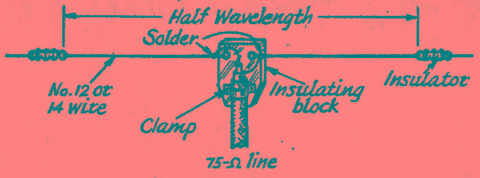


Fig. 21-8 — Construction of a dipole fed with 75-ohm line. The length of the antenna is calculeted from Equation 21-B or Fig. 21-4.

The use of 75-ohm line results in a "flat" line over most of any amateur band. However, by making the half-wave antenna in a special manner, called the two-wire or folded dipole, a good match is offered for a 300-ohm line. Such an antenna is shown in Fig. 21-9. The open-wire line shown in Fig. 21-9 is made of No. 12 or No. 14 enameled wire, separated by lightweight spacers of Plexiglas or other material (it doesn't have to be a *low-loss* insulating material), and the spacing can be on the order of from 4 to 8 inches, depending upon what is convenient, and what the operating frequency is. At 14 MHz, 4-inch separation is satisfactory, and 8-inch spacing can be used at 3.5 MHz.

The half-wavelength antenna can also be made from the proper length of 300-ohm line, opened on one side in the center and connected to the feedline. After the wires have been soldered together, the joint can be strengthened by molding some of the excess insulating material (polyethylene) around the joint with a hot iron, or a suitable lightweight clamp of two pieces of Plexiglas can be devised.

Similar in some respects to the two-wire folded dipole, the three-wire folded dipole of Fig. 21-10 offers a good match for a 600-ohm line. It is favored by amateurs who prefer to use an open-wire line instead of the 300-ohm insulated line. The three wires of the antenna proper should all be of the same diameter.

Another method for offering a match to a 600-ohm open-wire line with a half wavelength antenna is shown in Fig. 21-11. The system is called a **delta match**. The line is "fanned" as it approaches the antenna, to have a gradually increasing impedance that equals the antenna impedance at the point of connection. The dimensions are fairly critical, but careful measurement before installing the antenna and matching section is generally all that is necessary. The length of the antenna, L, is calculated from Equation 21-B or Fig. 21-4. The length of section C is computed from:

$$C \text{ (feet)} = \frac{118}{\textit{Freq.} \text{ (MHz)}} \qquad \text{21-E}$$

The feeder clearance, E, is found from

$$E \text{ (feet)} = \frac{148}{\textit{Freq.} \text{ (MHz)}} \qquad \text{21-F}$$

Example: For a frequency of 7.1 MHz, the length

$L = \frac{468}{7.1} = 65.91$ feet, or 65 feet 11 inches.

$C = \frac{118}{7.1} = 16.62$ feet, or 16 feet 7 inches.

$E = \frac{148}{7.1} = 20.84$ feet, or 20 feet 10 inches.

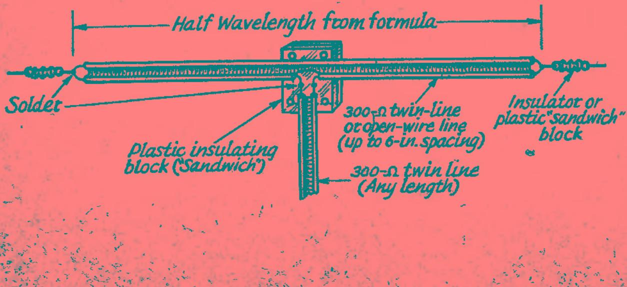


Fig. 21-9 — The construction of an open-wire or twin-line folded dipole fed with 300-ohm line. The length of the antenna is calculated from Equation 21-B or Fig. 21-4.

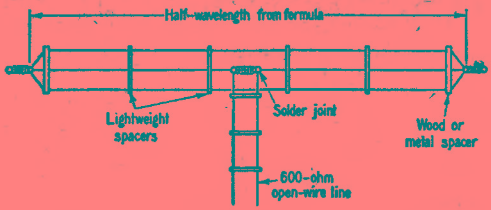


Fig. 21-10 – The construction of a 3-wire folded dipole is similar to that of the 2-wire folded dipole. The and spacers may have to be slightly stronger than the others because of the greater compression force on them. The length of the antenna is obteined from Equation 21-B or Fig. 21-4. A suitable line can be made from No. 14 wire spaced 5 inches, or from No. 12 wire spacad 6 inches.

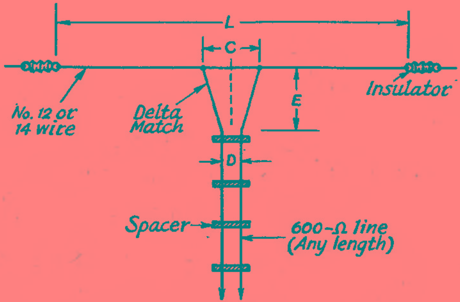


Fig. 21-11 – Delta-matched antenna systems. Tha dimensions, C, D, and E are found by formulas given in tha text. It is important that the matching section, E, come straight away from the antenna.

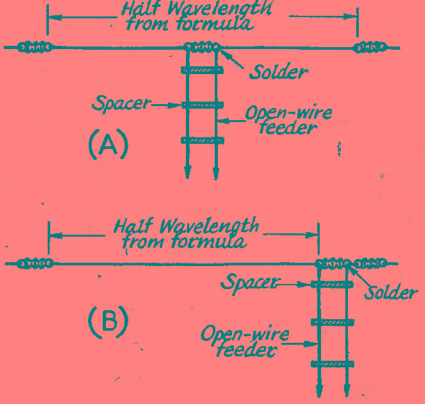


Fig. 21-12 – The half-wave antennas can be fad at the center or at one and with open-wire feeders. Tha length of the antennas can be computed from Equation 21-B or Fig. 21-4.

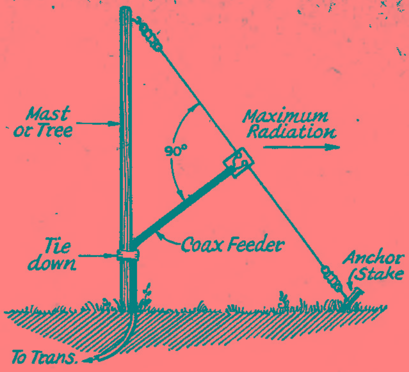


Fig. 21-13 – Method of supporting a half-wave dipole from a single upright such as a tree or wooden mast. Maximum directivity will be in the direction of the arrow, and the signal will be vertically polarized at a fairly low radiation angle. By having anchor stekes at diffarent compass points, the directivity can be changed to favor different DX regions.

Since the equations hold only for 600-ohm line, it is important that the line be close to this value. This requires 5-inch spaced No. 14 wire, 6-inch spaced No. 12 wire, or 3 3/4-inch spaced No. 16 wire.

If a half-wavelength antenna is fed at the center with other than 75-ohm line, or if a two-wire dipole is fed with other than 300-ohm line, standing waves will appear on the line and coupling to the transmitter may become awkward for some line lengths, as described in Chapter 20. However, in many cases it is not convenient to feed the half-wave antenna with the correct line (as is the case where multiband operation of the same antenna is desired), and sometimes it is not convenient to feed the antenna at the center. Where multiband operation is desired (to be discussed later) or when the antenna must be fed at one end by a transmission line, an open-wire line of from 450 to 600 ohms impedance is generally used. The impedance at the end of a half-wavelength antenna is in the vicinity of several thousand ohms, and hence a standing-wave ratio of 4 or 5 is not unusual when the line is connected to the end of the antenna. It is advisable, therefore, to keep the losses in the line as low as possible. This requires the use of ceramic or Micalex feeder spacers, if any appreciable power is used. For low-power installations in dry climates, dry wood spacers boiled in paraffin are satisfactory. Mechanical details of half wavelength antennas fed with open-wire lines are given in Fig. 21-12.

THE "INVERTED V" ANTENNA

A popular nondirectional antenna is the so-called "inverted V" or "drooping doublet." Its principal advantages are that it requires but one supporting structure, and that it exhibits more or less omnidirectional radiation characteristics when cut for a single band. The multiband version of Fig. 21-14 is somewhat directional above 7 MHz, off the ends (not broadside) of the antenna. This is because the legs of the "V" are long in terms of wavelength at 14, 21 and 28 MHz. The antenna offers a good compromise between vertical and horizontal polarization, thus making it effective for local as well as DX communications. Its low-angle radiation compares favorably with that of a full-

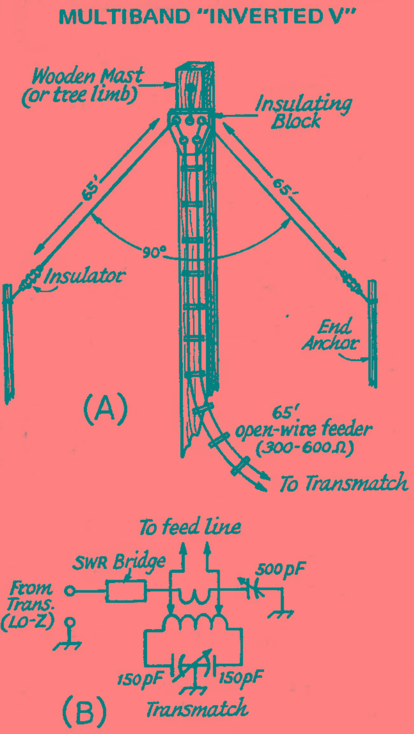


Fig. 21-14 — Details for an Inverted-V antenna (sometimes called a "drooping doublet"). At A, a wooden mast supports the antenna at its center. Open-wire feeders permit the antenna to be used for multiband operation. If this is done, a Transmatch of the type shown at B should be used to tune the system to resonance, and to match the feeder to the transmitter and receiver.

size one quarter wavelength vertical worked against ground. When fed as shown in Fig. 21-14 it serves as an excellent multiband antenna.

For single-band operation the "V" is cut to the same length as a half-wavelength doublet, and is fed with 52-ohm coaxial line. Its center (feed point) should be as high above ground as possible, preferably one-quarter wavelength or more at the operating frequency. The apex angle should be as close to 90 degrees as possible, but in practice any angle between 90 and 120 degrees provides good results. Less than a 90-degree angle causes excessive cancellation of the signal, and should be avoided.

Though some operators have reported satisfactory results when supporting the "V" from a metal mast or tower, it is best to use a wooden mast to keep the field of the antenna unobstructed. Good results can be had by supporting the center of the antenna from a limb on a tall tree, provided the area below the limb is completely open.

Single-band, coax-fed inverted Vs will normally require some pruning to make them resonant at the desired frequency. The standard doublet formula is recommended for a starting point, but because the ends of the "V" are normally in close proximity to ground this antenna will be slightly shorter than a horizontal dipole. No formula can be given because of the variations in the ground properties in different areas. Also, the actual height above ground in a particular installation, plus the proximity of the ends of the antenna to nearby objects, will have a marked effect upon resonance. The best way to tune the antenna is to insert an SWR bridge in the coax feed line and prune an inch at a time off each end of the "V" until the lowest SWR is obtained.

LONG-WIRE ANTENNAS

An antenna is a long wire only when it is long *in terms of wavelength.* An antenna, simply because it is a long piece of wire is not a long-wire antenna. Space permitting, these antennas are effective for DX work, and when erected high above ground offer considerable power gain over a dipole. The longer the antenna, the greater the gain. Maximum directivity occurs off the ends of the antenna, and not off the broad side of it. A long-wire antenna, unless terminated at the far end in its characteristic impedance by a noninductive resistance, is bidirectional. A terminated long wire is directional only off the terminated end. This antenna radiates minor lobes at many wave angles in the vertical and horizontal planes. The longer the wire, the greater and more complex the lobes become. It is not uncommon to find a long-wire antenna outperforming a beam antenna on DX contacts under certain propagation conditions. This is because it can respond to a variety of incoming wave angles (and can radiate a signal in a like manner), which is not the case with a well-designed beam-type antenna.

Long-Wire Characteristics

An antenna will be resonant so long as an integral number of standing waves of current and voltage can exist along its length; in other words, so long as its length is some integral multiple of a half wavelength.

Current and Voltage Distribution

Fig. 21-15 shows the current and voltage distribution along a wire operating at its fundamental frequency (where its length is equal to a half wavelength) and at its second, third, and fourth harmonics. For example, if the fundamental frequency of the antenna is 7 MHz, the current and voltage distribution will be as shown at A. The same antenna excited at 14 MHz would have current and voltage distribution as shown at B. At 21 MHz, the third harmonic of 7 MHz, the current and voltage distribution would be as in C; and at 28 MHz, the fourth harmonic, as in D. The number of the harmonic is the number of half waves

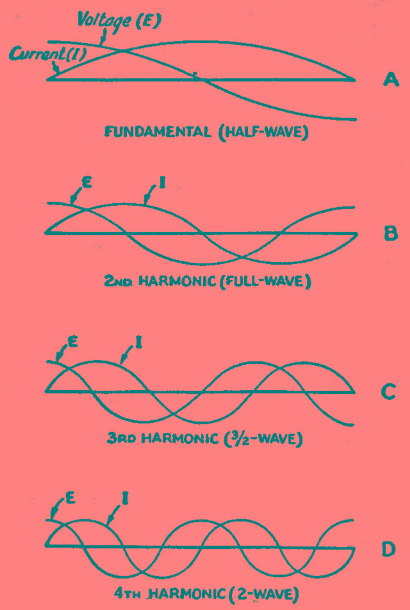


Fig. 21-15 — Standing-wave current and voltage distribution along an antenna when it is operated at various harmonics of its fundamental resonant frequancy.

contained in the antenna at the particular operating frequency.

The polarity of current or voltage in each standing wave is opposite to that in the adjacent standing waves. This is shown in the figure by drawing the current and voltage curves successively above and below the antenna (taken as a zero reference line), to indicate that the polarity reverses when the current or voltage goes through zero. Currents flowing in the same direction are *in phase*; in opposite directions, *out of phase.*

Physical Lengths

The length of a long-wire antenna is not an exact multiple of that of a half-wave antenna because the end 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, therefore, is

$$\mathit{Length}\ \text{(feet)} = \frac{492\,(N-0.05)}{\mathit{Freq.}\ \text{(MHz)}} \qquad \text{21-G}$$

where N is the number of *half*-waves on the antenna.

Example: An antenna 4 half-waves long at 14.2 MHz would be

$$\frac{492\,(4-0.05)}{14.2} = \frac{492 \times 3.95}{14.2}$$

= 136.7 feet, or 136 feet 8 inches

It is apparent that an antenna cut as a half wave for a given frequency will be slightly off resonance at exactly twice that frequency (the second harmonc), because of the decreased influence of the end effects when the antenna is more than one-half wavelength long. The effect is not very important, except for a possible unbalance in the feeder system and consequent radiation from the feed line. If the antenna is fed in the exact center, no unbalance will occur at any frequency, but end-fed systems will show an unbalance on all but one frequency in each harmonic range.

Impedance and Power Gain

The radiation resistance as measured at a current loop becomes higher as the antenna length is increased. Also, a long-wire antenna radiates more power in its most favorable direction than does a half-wave antenna in its most favorable direction. This power gain is secured at the expense of radiation in other directions. Fig. 21-16 shows how the radiation resistance and the power in the lobe of maximum radiation vary with the antenna length.

Directional Characteristics

As the wire is made longer in terms of the number of half wavelengths, the directional effects change. Instead of the "doughnut" pattern of the half-wave antenna, the directional characteristic splits up into "lobes" which make various angles with the wire. In general, as the length of the wire is increased the direction in which maximum radiation occurs tends to approach the line of the antenna itself.

Methods of Feeding

In a long-wire antenna, the currents in adjacent half-wave sections must be out of phase, as shown in Fig. 21-15. The feeder system must not upset this phase relationship. This is satisfied by feeding the antenna at either end or at any current loop. A two-wire feeder cannot be inserted at a current node, however, because this invariably brings the currents in two adjacent half-wave sections in phase. A long-wire antenna is usually made a half wavelength at the lowest frequency and fed at the end.

MULTIBAND ANTENNAS

One of the most simple antenna systems for multiband use is one which is a half wavelength long at the lowest operating frequency, and which is fed either at the center, or at one end with open-wire tuned feeders, Fig. 21-12. The center-fed system is superior to the end-fed type in that it will have less feeder radiation, but the end-fed variety is often more practical from an installation viewpoint. The center-fed antenna will not have the same radiation pattern as an end-fed one of the same length, except on frequencies where the length of the antenna is a half wavelength. The end-fed antenna acts like a long-wire antenna on all bands (for which it is longer than a half wavelength), but the center-fed one acts like two antennas of half that length fed in phase. For

TABLE 21-I

Multiband Tuned-Line-Fed Antennas

Antenna Length (Ft.)	*Feeder Length (Ft.)*	*Band*	*Type of Coupling Circuit*
With end feed:			
135	45	3.5–21 28	Series Parallel
67	45	7–21 28	Series Parallel
With center feed:			
135	42	3.5–21 28	Parallel Series
135	77 1/2	3.5–28	Parallel
67	42 1/2	3.5 7–28	Series Parallel
67	65 1/2	3.5,14,28 7,21	Parallel Series

Antenna lengths for end-fed antennas are approximate and should be cut to formula length at favorite operating frequency.

Where parallel tuning is specified, it will be necessary in some cases to tap in from the ends of the coil for proper loading – see Chapter 20 for examples of antenna couplers.

example, if a full-wavelength antenna is fed at one end, it will have a radiation pattern somewhat like a four-leaf clover. With either of these multiband antennas the SWR will never be 1, but these antennas will be efficient provided low-loss tuned feeders are used.

Since multiband operation of an antenna does not permit matching of the feed line, some attention should be paid to the length of the feed line if convenient transmitter-coupling arrangements are to be obtained. Table 21-I gives some suggested antenna and feeder length for multiband operation. In general, the length of the feed line can be other than that indicated, but the type of coupling circuit may change.

Since open-wire line is recommended for this antenna, TV-type (open-wire) 300- or 450-ohm feeders are satisfactory. Home made open-wire line can be made up from lengths of No. 14 or 12 soft-drawn copper wire. The spacers can be made from Plexiglas strips or similar low-loss material. Some amateurs have had success using plastic hair curlers or plastic clothespins. Any line spacing from 1 to 6 inches will give satisfactory results since the line impedance is not an important consideration with this antenna.

If antenna space is at a premium, a shortened version of the multiband antenna can be erected. The feeders are lengthened, and the flat-top portion is shortened as shown in Fig. 21-17. The antenna can be as short as a quarter wavelength long, but will still radiate fairly well if tuned to resonance. This method will not give as good results as the full-size version, but will still be useful. A Transmatch tuner of the type described in Chapter 20 can be used with this system.

MULTIBAND OPERATION WITH COAXIAL LINE FEED

The proper use of coaxial line requires that the standing-wave ratio be held to a low value, preferably below 3:1. Since the impedance of an ordinary antenna changes widely from band to band, it is not possible to feed a simple antenna with coaxial line and use it on a number of bands without tricks of some kind. One exception to this is the use of 75-ohm coaxial line to feed a 7-MHz half-wave antenna, as in Fig. 21-18; this antenna can also be used on 21 MHz and the SWR in the line will not run too high.

However, the diagram shows a separate dipole element for 21-MHz use. Though the 7-MHz element will operate as a 1 1/2 wavelength doublet on 21 MHz, and will present a low impedance feed point at its center, some may wish to add a separate dipole for 21-MHz operation. This antenna is capable of radiating harmonics from the transmitter, so it is important to make sure the transmitter output is clean. A coax-to-coax type antenna coupler can also be installed at the transmitter end to help reduce harmonic radiation from the antenna.

A MULTIBAND "TRAP" ANTENNA

Another method of obtaining multiband operation from a single antenna, with a single feed line, is the use of parallel-tuned traps in each leg of a two-wire doublet. If the traps are installed in the right points of the antenna they "divorce" the remainder of the antenna from the center portion as the transmitter is changed to operate a higher

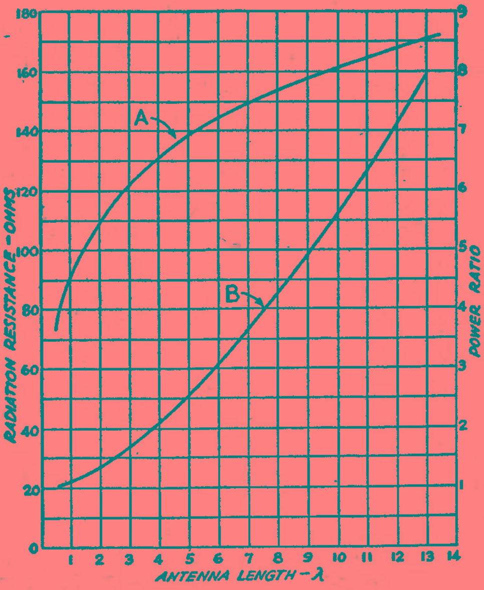


Fig. 21-16 – Curve A shows variation in radiation resistance with antenna length. Curve B shows power in lobes of maximum radiation for long-wire antennas as a retio to the maximum radiation for e half-wave antenna.

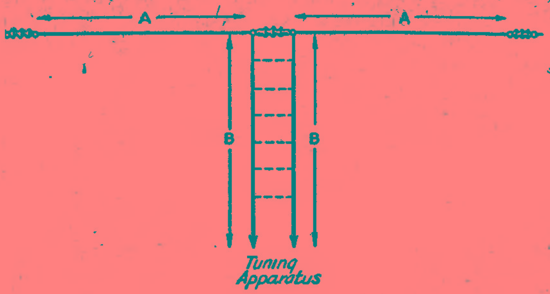


Fig. 21-17 — Practical arrangements of a shortened antenna. When the total length, A + B + B + A, is the same as the antenna length plus twice the feeder length of the center-fed antennas of Table 21-1, the same type of coupling circuit will be used. When the feeder length or antenna length, or both, makes the sum different, the type of coupling circuit may be different but the effectiveness of the antenna is not changed, unless A + A is less than a quarter wavelength.

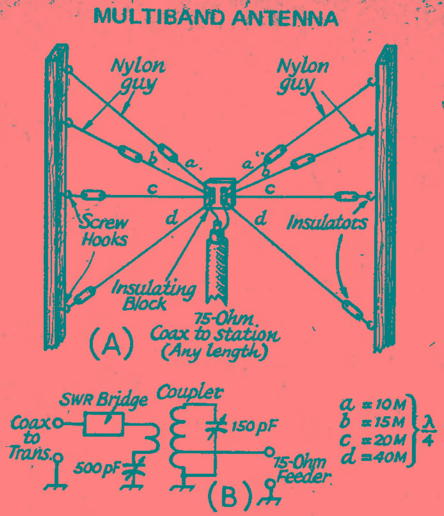


Fig. 21-1B — Illustration of a multiband coax-fed antenna. Wooden support poles are recommended so that they will not interfere with the radiation pattern of the antenna. At B, a representative diagram of a coax-to-coax coupler that will reduce harmonic radiation from the system. It should be installed in the operating room, near the transmitter, and adjusted for a 1:1 SWR.

band. On the lowest operating band the traps act as loading inductors, thus allowing a shorter overall length for the doublet than would be possible if it were cut for use without the traps.

The trap-antenna concept has been adopted by several manufacturers who produce multiband beam antennas, multiband doublets, and vertical antennas for several bands of operation.

The antenna of Fig. 21-19 may be of interest to those amateurs not having sufficient room to erect a full-size 80-meter doublet. The overall length of this system is 106 feet. If need be, the ends can be bent slightly downward so that the horizontal portion will occupy even less space. It is best, however, to keep the entire antenna horizontal if possible. The antenna is fed with 75-ohm coax, or balanced line of the same impedance. The latter is recommended, or system balance can be enhanced by using a 1:1 balun transformer at the feed point if coaxial line is used. This antenna is an adaptation of the W3DZZ design described in the *ARRL Antenna Book.*

As shown in Fig. 21-20, each trap is literally built around a "strain" insulator. With this insulator, the hole at one end is at right angles to the hole at the opposite end, and the wires are fastened as illustrated in Fig. 21-21. This style of insulator has greater compressive strength than tensile strength and will not permit the antenna to fall should the insulator break. There is plenty of space inside the inductor to install the insulator and the trap capacitor. The plastic protective covers are not essential, but are used to protect the traps from ice, snow, and soot which could cause a deterioration in performance.

Electrically, each trap consists of a 50-pF capacitor which is shunted by a 10-μH inductor. A Centralab 850S-50Z capacitor is used. It is rated at 7500 volts, and should safely handle a kilowatt. Miniductor coil stock is used for the inductor. Those wishing to optimize the antenna for a specific portion of the 40-meter band can experimentally adjust the number of turns in the trap coil for resonance in the desired segment. Similarly, the end sections of the dipole can be adjusted for lowest SWR in the portion of the 80-meter band most favored. With the dimensions given in Fig. 21-19, the antenna performs well from 3.5 to 30 MHz. The lowest SWR on 80

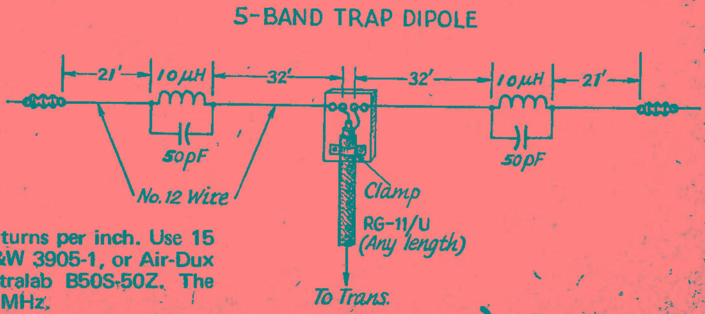


Fig. 21-19 — Sketch of a trap dipole for use on 80 through 10 meters. SWR on all of the bands is less than 2.5:1. With the dimensions given here the SWR rises at each end of the 80-meter band, but is approximately 1.5:1 at the center of the band. The 10-μH trap coils consist of 15 turns No. 12 wire, 2 1/2 inches in diameter, 6 turns per inch. Use 15 turns from Polycoils No. 1774, B&W 3905-1, or Air-Dux 2006T. Trap capacitors are Centralab B50S-50Z. The traps are tuned to resonance at 7.1 MHz.

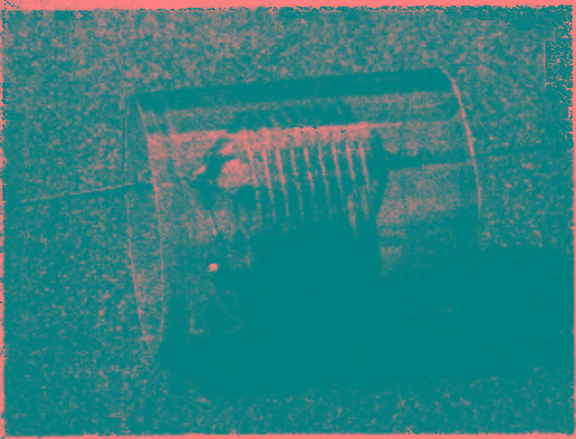


Fig. 21-20 — Photo of a typical trap. The unit shown hera is cut for resonance at 14 MHz, but construction techniques are the same as for the traps used in the antenna of Fig. 21-19. A weatherproof cover can be made from plastic tubing, sheeting which is heated and formed, or from a plastic refrigerator container. The capacitor and strain insulator are inside the coil.

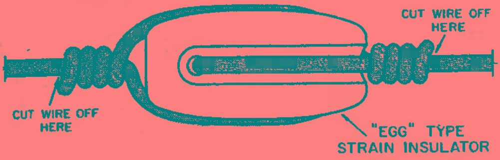


Fig. 21-21 — Mathod of connecting the antenna wire to the strain insulator. The antenna wire is cut off close to the wrap.

meters occurs at midband. SWR on all other bands is less than 2.5 to 1, an acceptable figure for all but the most critical operator. Most modern-day transmitters will load into this antenna without difficulty.

Trap Adjustment

As a preliminary step, loops of No. 12 wire are fitted to one of the egg insulators in the normal manner (see Fig. 21-21), except that after the wraps are made, the end leads are snipped off close to the wraps. A capacitor is then placed in position and bridged with short leads across the insulator and soldered sufficiently to provide temporary support. The combination is then slipped inside about 10 turns of the inductor, one end of which should be soldered to an insulator-capacitor lead. Adjustment to the resonant frequency can now proceed, using a grid-dip meter.

Coupling between the GDO and the trap should be very loose. To assure accuracy, the station receiver should be used to check the GDO frequency. The inductance should be reduced 1/4 turn at a time. If one is careful, the resonant frequency can easily be set to within a few kilohertz of the chosen figure.

The reason for snipping the end leads close to the wraps and the inclusion of the loops through the egg insulator soon becomes apparent. The resonant frequency of the capacitor and inductor alone is reduced about 10 kHz per inch of end lead length and about 150 kHz by the insulator loops. The latter add approximately 2 pF to the fixed capacitor value.

Assembly

Having determined the exact number of inductor turns, the trap is taken apart and reassembled with leads of any convenient length. One may, of course, connect the entire lengths of the antenna sections to the trap at this time, if desired. But, if more convenient, a foot or two of wire can be fastened and the remaining lengths soldered on just before the antenna is raised.

The protective covers are most readily formed by wrapping two turns (plus an overlap of 1/2 inch) of 0.020-inch polystyrene or Lucite sheeting around a 3-inch plastic disk held at the center of the cylinder so formed. The length of the cover should be about 4 inches. A very small amount of plastic solvent (a cohesive cement that actually softens the plastic surfaces) should then be applied under the edge of the overlap and the joint held firmly for about two minutes to insure a strong, tight seal. The disk is pushed out and the inner seam of the sheeting sealed.

The trap is then placed in the plastic cylinder and the end disks marked where the antenna wires are to pass through. After drilling these holes, the disks are slipped over the leads, pressed into the ends of the cylinder and a small amount of solvent applied to the periphery to obtain a good seal.

Some air can flow in and out of the trap through the antenna-wire holes, and this will prevent the accumulation of condensation.

AN END-FED HERTZ

One of the more simple multiband antennas is the end-fed Hertz of Fig. 21-22. It consists of an end-fed length of No. 12 wire, 130 feet long. This type of antenna performs in the same manner as the end-fed half-wave system of Fig. 21-12B, but has no feeder. One end of the wire connects directly into an L-network impedance matcher, as shown in the diagram. This type of antenna is very convenient for those who have their stations on the top floor of the house, thus enabling the user to bring one end of the antenna in through a window and to the coupler. Ideally, the entire antenna should be in a horizontal plane for best results. However, either end can be bent to make the system fit into whatever space is available. First-floor dwellers can drop the fed end of the wire to the window of the radio room, as shown in Fig. 21-22A. Or, the wire can be kept straight and rise diagonally to the support at the far end. Height is important with antennas of this type, so an effort should be made to get the system as high above ground as possible, and clear of power lines and other structures.

This antenna is intended for operation from 3.5 to 28 MHz. A coupler of the kind shown in Fig. 21-43 (L-Network Coupler) will match the antenna on all of the hf amateur bands mentioned. It will also perform well as an end-fed quarter wavelength on 1.8 MHz if the reactance is tuned out by means

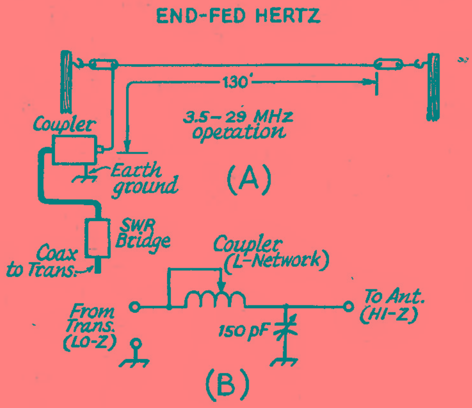


Fig. 21-22 — Diagram of an end-fed Hertz. It is cut for the lowest desired operating frequency (1/2 wavelength), and is opereted on its harmonic frequencies on the remaining bands above. An L-network is used to match it to 50- or 75-ohm unbalanced transmitter terminals. At B, schematic representation of an L-network tuner. The value of L and C is adjusted until a 1:1 match is obtained.

of a 1500-pF series variable capacitor. A good earth ground will be needed for proper operation on 1.8 MHz. For hf-band use, a good earth ground is also important in order to keep unwanted rf voltages from appearing on the transmitter and receiver chassis. No one wants (or needs) a "hot" key or microphone. Sometimes a good water-pipe ground is sufficient for preventing rf potentials on the equipment.

It must be remembered that the ends of this antenna are voltage points (high impedance), and bringing the end of the antenna into the "shack" can often introduce rf into the equipment as mentioned. During phone operation the rf can get into the microphone circuit and cause howling and hum if the ground system is not used. Similarly, the operation of some electronic keyers can be made erratic by the introduction of rf chassis currents. The operator, therefore, may wish to locate the tuner at the window and have the ham station across the room at some distant point. If this is done, coaxial cable can be used to connect the station to the tuner. Operation with this antenna at W1CKK has been without problems for nearly three years, operating all bands with a kilowatt of power. The fed end of the wire is three feet from the station equipment. A water pipe and an earth ground are used. The L network provides a 1:1 match on all of the bands, and DX operation has been quite successful on the 20-, 15- and 10-meter bands. While using a parallel-tuned antenna coupler, successful 6- and 2-meter operation has been realized.

It should be remembered that the antenna will perform as a long wire on those bands above 3.5 MHz. At the higher end of the hf range – particularly 15 and 10 meters – the antenna will tend to be directional off its ends (bidirectional), and will begin to have some gain. It exhibits more or less omnidirectional characteristics on 7 and 14 MHz, the pattern being somewhat like the shape of a four-leaf clover. There will not be much directivity on 3.5 MHz unless the antenna is at least a half wavelength above ground at that frequency.

A BROAD-BAND DIPOLE

Most untuned doublet antennas are not broad enough to provide a low SWR across an entire amateur band. This is a particularly troublesome situation on the 80- and 40-meter bands. The antenna of Fig. 21-23, sometimes called a "double-bazooka" antenna, was developed by the staff of M.I.T. for radar use, and was later popularized by W8TV for amateur use (*QST*, July 1968). An 80-meter version of this system, cut for

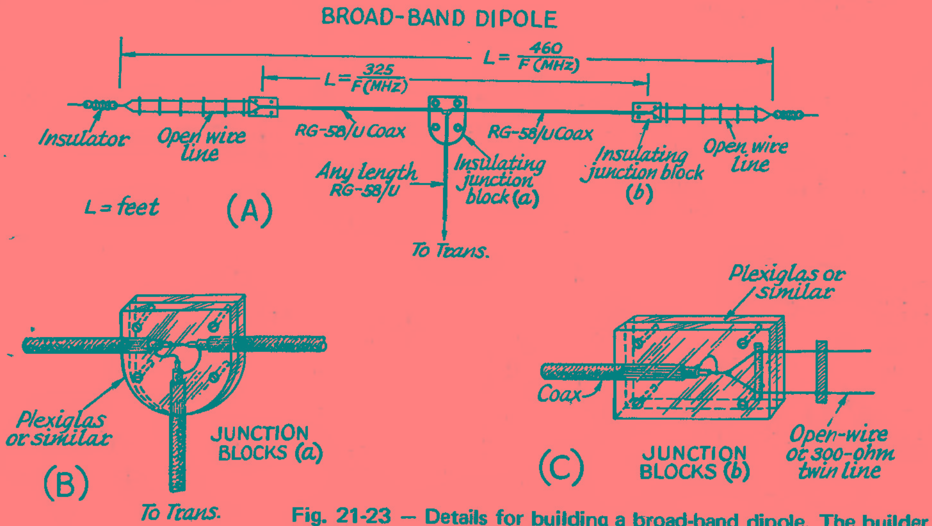


Fig. 21-23 — Details for building a broad-band dipole. The builder may choose to employ other methods for joining the sections, but the illustrations at B and C represent one of the better, more secure techniques.

3.7 MHz, provides an SWR of less than 2:1 across the entire band, and shows a 1:1 reading at 3.7 MHz. SWR at 3.5 MHz is 1.7:1, and is 1.9:1 at 4 MHz.

The antenna consists of a half-wavelength section of coax line with the sheath opened at the center and the feed line attached to the open ends of the sheath. The *outside* conductor of the coax thus acts as a half-wave dipole, in combination with the open-wire end sections of the antenna. The inside sections, which *do not* radiate, are quarter-wave shorted stubs which present a very high resistive impedance to the feed point at resonance. At frequencies off resonance the stub reactance changes in such a way as to tend to cancel the antenna reactance, thus increasing its bandwidth. This antenna can be cut for any operating frequency, including that of the 160-meter band. Formulas are given in Fig. 21-23. RG-58/U coax line is capable of handling a full kilowatt from the transmitter with the SWR figures given earlier. Details are given for making up the junction blocks where connections are made. Other construction techniques are possible, and this will be pretty much up to the builder. If the plastic blocks of Fig. 21-23 are used, their inner surfaces can be grooved to provide a snug fit for the coax cables when the two halves are bolted together. After assembly, the mating outer surfaces of the junction blocks can be sealed with epoxy cement to assure a weatherproof bond. This antenna can be mounted from a single center support and used as an "inverted V" if desired. Single-wire end sections can be substituted for the open-wire stubs, but the open-wire sections contribute to the antenna's broadband characteristics.

VERTICAL ANTENNAS

A vertical quarter-wavelength antenna is often used in the lower-frequency amateur bands to obtain low-angle radiation. It is also used when there isn't enough room for the supports for a horizontal antenna. For maximum effectiveness it should be located free of nearby objects and it should be operated in conjunction with a good ground system, but it is still worth trying where these ideal conditions cannot be obtained.

Four typical examples and suggested methods for feeding a vertical antenna are shown in Fig. 21-24. The antenna may be wire or tubing supported by wood or insulated guy wires. When tubing is used for the antenna, or when guy wires (broken up by insulators) are used to reinforce the structure, the length given by the formula is likely to be long by a few percent. A check of the standing-wave ratio on the line will indicate the frequency at which the SWR is minimum, and the antenna length can be adjusted accordingly.

A good ground connection is necessary for the most effective operation of a vertical antenna (other than the ground-plane type). In some cases a short connection to the cold-water system of the house will be adequate. But maximum performance usually demands a separate ground system. A single 4- to 6-foot ground rod driven into the earth at the base of the antenna is usually not sufficient, unless the soil has exceptional conductivity. A minimum ground system that can be depended upon is 6 to 12 quarter-wavelength radials laid out as the spokes of a wheel from the base of the antenna. These radials can be made of heavy aluminum wire, of the type used for grounding TV antennas, buried at least 6 inches in the ground. This is normally done by slitting the earth with a spade and pushing the wire into the slot, after which the earth can be tamped down.

The examples shown in Fig. 21-24 all require an antenna insulated from the ground, to provide for the feed point. A *grounded* tower or pipe can be used as a radiator by employing "shunt feed," which consists of tapping the inner conductor of the coaxial-line feed up on the tower until the best match is obtained, in much the same manner as the "gamma match" (described later) is used on a horizontal element. If the antenna is not an electrical quarter wavelength long, it is necessary to tune out the reactance by adding capacitance or inductance between the coaxial line and the shunting conductor. A metal tower supporting a TV antenna or rotary beam can be shunt fed only if all of the wires and leads from the supported antenna run down the center of the tower and underground away from the tower.

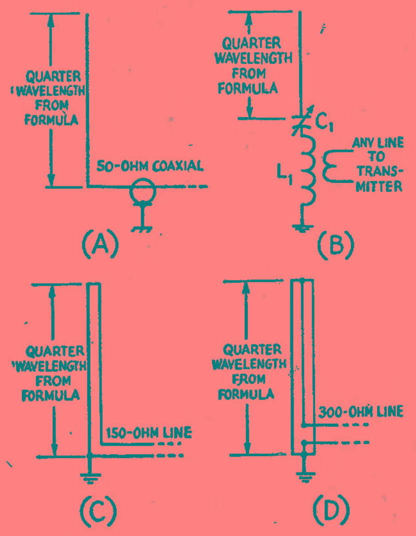


Fig. 21-24 — A quarter-wavelength antenna can be fed directly with 50-ohm coaxial line (A), with a low standing-wave ratio, or a coupling network can be used (B) that will permit a line of any impedance to be used. In (B), L1 and C1 should resonate to the operating frequancy and L1 should be larger than is normally used in a plate tank circuit at the same frequency. By using multiwire antennas, the quarter-wave vertical can be fed with (C) 150- or (D) 300-ohm line.

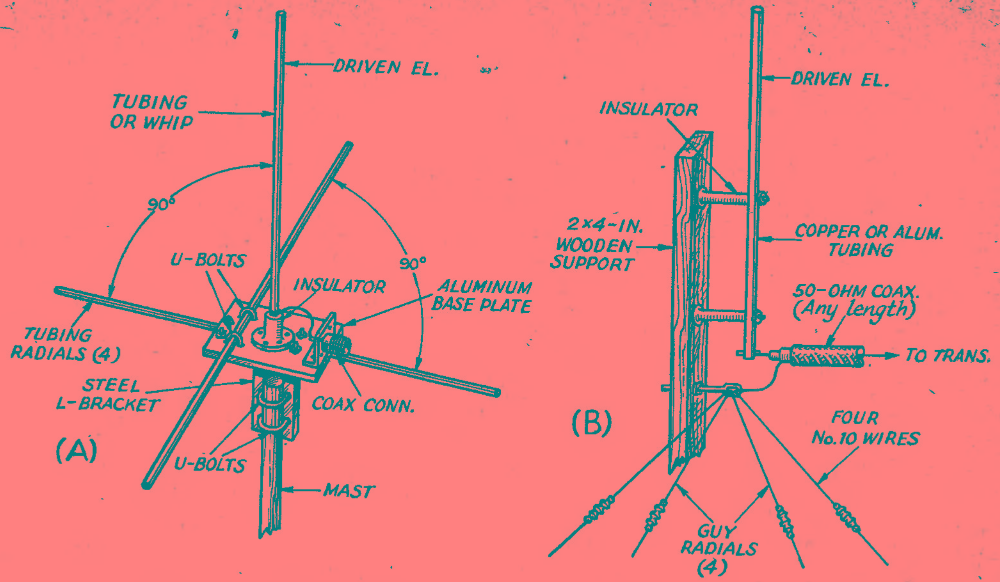


Fig. 21-25 — All-metal construction of a vertical ground-plane antenna can be effected as shown at A. The driven element is insulated from the remainder of the system, but the tubing radials ere common to the mounting plate, and to one another. The outer conductor of the coax connects to the base plate and radials. The center conductor of the feed line attaches to the base of the driven element with as short a lead as possible. If a metal mast is used, it, too, can be common to the base plete and radials. At B, the radials are made of No. 10 wire (approximately 5 percent longer than the resonant vertical element) end are used as guy wiras. Drooping the wires at a 45-degree angle raisas the feed-point impedence to approximately 50 ohms for direct connection to RG-8/U.

THE GROUND-PLANE ANTENNA

A ground-plane antenna is a vertical quarter-wavelength antenna using an artificial metallic ground, usually consisting of four rods or wires perpendicular to the antenna and extending radially from its base, Fig. 21-25. Unlike the quarter-wavelength vertical antennas without an artificial ground, the ground-plane antenna will give low-angle radiation regardless of the height above actual ground. However, to be a true ground-plane antenna, the plane of the radials should be at least a quarter-wavelength above ground. Despite this one limitation, the antenna is useful for DX work in any band below 30 MHz.

The vertical portion of the ground-plane antenna can be made of self-supported aluminum tubing, or a top-supported wire, depending upon the necessary length and the available supports. The radials are also made of tubing or heavy wire depending upon the available supports and necessary lengths. They need not be exactly symmetrical about the base of the vertical portion.

The radiation resistance of a ground-plane antenna varies with the diameter of the vertical element. The radiation resistance is usually in the vicinity of 30 ohms, and the antenna can be fed with 75-ohm coaxial line with a quarter-wavelength section of 50-ohm line between line and antenna. For multiband operation, a ground-plane antenna can be fed with tuned open-wire line, or the vertical section can be quarter-wavelength pieces for each band. The radials should be a quarter wavelength at the lowest frequency.

Matching by Length Adjustment

The radiation resistance as measured at the base of a ground-plane antenna also changes as a function of the length of the radiating element. It is possible to choose a length such that the base radiation resistance will equal the characteristic impedance (Zo) of the transmission line to be used. The lengths of most interest are a little over 100 degrees (0.28 wavelength), where the resistance is approximately 52 ohms, and about 113 degrees (0.31 wavelength), where the resistance is 75 ohms, to match the two common types of coaxial line. These lengths are quite practicable for ground-plane antennas for 14 MHz and higher frequencies. The lengths in degrees as given above do not require any correction for length/diameter ratio; i.e., they are free-space lengths.

Since the antenna is not resonant at these lengths, its input impedance will be reactive as well as resistive. The reactance must be tuned out in order to make the line see a purely resistive load equal to its characteristic impedance. This can be done with a *series capacitor* of the proper value, when the lengths given above are used. The approximate value of capacitive reactance required, for antennas of typical length/diameter ratio, is about 100 ohms for the 52-ohm case and about 175 ohms for the 75-ohm case. The corresponding capacitance values for the frequency in question can be determined from appropriate charts or by equation. Variable capacitors of sufficient range may be used and adjustment made for the lowest SWR.

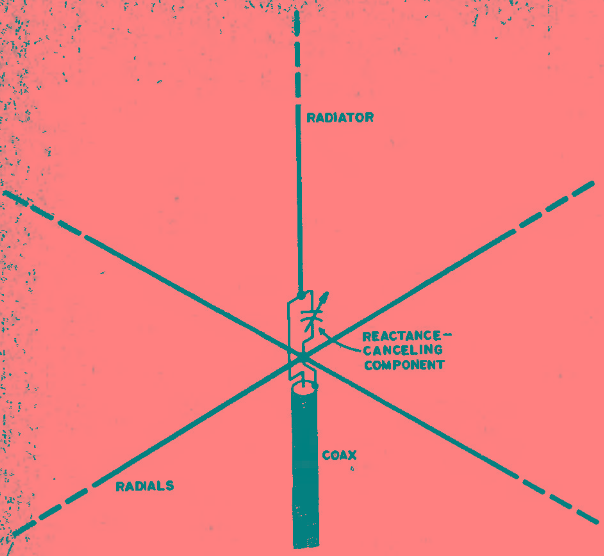


Fig. 21-26 — Matching to ground-plane antenna with shunt reactance. If the length of the radiator (but not the radials) is slightly more than that required for resonance, a capacitive shunt will provide a match to either 52- or 75-ohm line, depending on the exact radiator length. Similarly, a shorter-than-resonant radiator length may be used with a shunt inductor to offer a 52- or 75-ohm match.

From a practical construction standpoint it may be preferable to connect the reactance-canceling component in parallel or shunt with the base feed point, rather than in series with the radiating element. If a capacitor is used, for example, this would eliminate the requirement for insulating its frame from the supporting structure, as may be seen from Fig. 21-26. To obtain a match to 52- or 75-ohm line, radiator lengths must be different than those given above when the reactance-canceling component is shunt connected, however. As a matter of fact, there are *two* lengths where a match may be obtained for 52-ohm line, and *two* lengths for matching 75-ohm line. One of these two lengths for either impedance is somewhat less than that required for resonance. This results in the base feed point being capacitive, therefore requiring a shunt inductor for a resistive line termination. The other length is somewhat longer than that for resonance, requiring a shunt capacitor. So far as radiation is concerned, one is as good as the other, and the choice becomes the one of the simpler mechanical approach, or perhaps one of economy. The following information applies to conductor half-wavelength/diameter ratios in the order of 1000, but will not be greatly different for other length/diameter ratios. Radiator lengths are free-space lengths, requiring no correction for length/diameter ratios.

Feed-Line Zo, Ohms	*Radiator Length*	*Shunt-Canceling Component*
52	82.5 degrees 0.229 wavelength	Inductor, 57.1 ohms
52	93.6 degrees 0.260 wavelength	Capacitor, 78.1 ohms
75	84.0 degrees 0.233 wavelength	Inductor, 58.1 ohms
75	92.0 degrees 0.256 wavelength	Capacitor, 80.6 ohms

It may be seen from the above that, for an inductive shunt-canceling component, the radiator lengths are not much different for a 52-ohm or for a 75-ohm termination. The same is true for a capacitive shunt for the two impedances. This indicates that the radiator length for a proper match is somewhat critical. This causes no problems, however, as the final length can merely be adjusted for the lowest SWR in the feed line. Similarly, it may be seen that there is little difference in the required reactance values for 52 versus 75 ohms terminating impedance. If matching by final length adjustment is performed, this means that the reactance value is not critical. In other words, a shunt inductor having a reactance in the order of 57 ohms will afford a close match to either 52 or 75 ohms.

Construction and Adjustment

From an economy standpoint, inductors are generally more satisfactory than capacitors as shunt elements, if one considers that the component will be required to handle rf currents in the order of 1 ampere or more, even at modest power levels. Suitable inductors may be made from heavy bus wire or from available coil stock.

The photographs of Fig. 21-27 show the construction of a sturdy ground-plane system. As pictured, the antenna is constructed for 6-meter operation, but provisions for telescoping additional lengths of aluminum tubing to extend the radials and radiator make it readily adaptable to 10, 15, or even 20 meters. The base-plate assembly is made from 1/4-inch thick aluminum stock, obtained at a modest price as salvaged scrap from a local machine shop. Two pieces of this material are joined at right angles with short lengths of 3/4-inch angle aluminum and No. 8 nickel-plated brass hardware. A length of angle stock is attached to either side of the vertical plate, which is drilled to accept U bolts for attachment to the mast. A 2-inch circular hole is cut in the 9-inch-square horizontal plate to clear the hardware which supports the radiator. A 4-inch square piece of 1/4-inch thick phenolic material is used as the insulator for the radiator, the insulator being mounted atop the base plate with No. 10 hardware at each corner. A 1/2- by 6-inch hex-head cap screw (with head removed) serves to support the radiator, and electrical connection is made by means of a solder lug which is attached by drilling and tapping the wrought-iron flat washer underneath the insulating phenolic. Flat washers and nuts are used above and below the phenolic insulator, and lock washers are used on all hardware. The radials are attached directly to the base plate by drilling through them, but the method shown in Fig. 21-25 with U bolts would avoid weakening the tubing material by drilling. The radiator, consisting of 1/2-inch ID aluminum tubing for the lower portion, is slipped over the cap

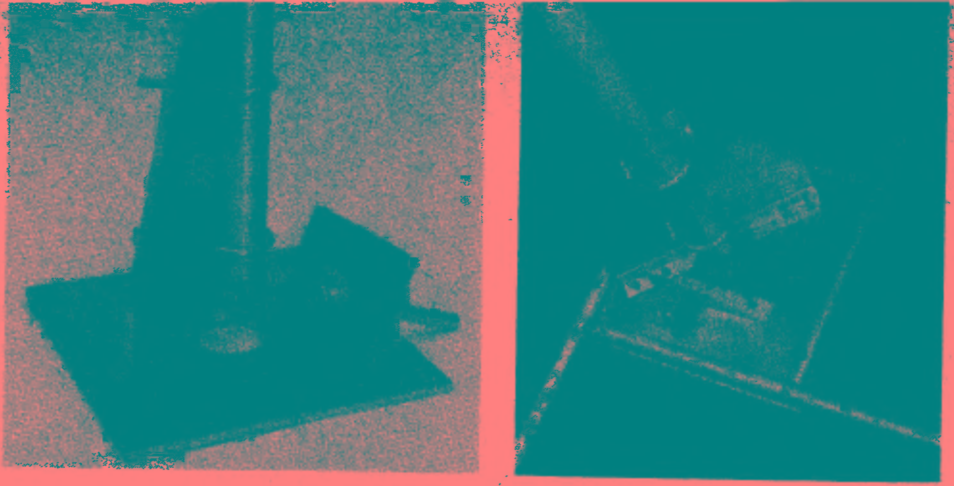


Fig. 21-27 — The ground-plane antenna partially assembled (left) and completely assembled, ready for installation (right). Both views are looking down on the base plate, which is in an inverted position in these photos. In the view at the right may be seen an added bracket which supports a coaxial chassis connector, type SO-239, and the shunt inductor. A right-angle connector is used at the chassis connector to avoid a bend in the coax, which is secured to the mast during installation.

TABLE I — Coil and dimension data for ground-plane antennas.

Freq., MHz	*Impedance, ohms*	*Each Radial Length*	*Approx. Radiator Length*	*Coil Value, µH*	*Coil Data*
14.2	52	17'7"	15'5"	0.64	6-1/3 turns, 1"dia, 6 tpi
14.2	75	17'7"	15'B"	0.65	6-1/2 turns, 1"dia, 6 tpi
21.25	52	11'9"	10'3"	0.43	4-1/2 turns, 1"dia, 6 tpi
21.25	75	11'9"	10'6"	0.44	4-3/4 turns, 1"dia, 6 tpi
28.5	52	8'9"	7'B"	0.32	4-1/2 turns, 1"dia, 4 tpi
28.5	75	8'9"	7'10"	0.32	4-1/2 turns, 1"dia, 4 tpi
29.5	52	B'6"	7'5"	0.31	4-1/3 turns, 1"dia, 4 tpi
29.5	75	8'6"	7'7"	0.31	4-1/3 turns, 1"dia, 4 tpi
51	52	4'11"	4'3"	0.18	3 turns, 1"dia, 4 tpi
51	75	4'11"	4'4"	0.1B	3 turns, 1"dia, 4 tpi
53	52	4'9"	4'1"	0.17	2-3/4 turns, 1"dia, 4 tpi
53	75	4'9"	4'2"	0.17	2-3/4 turns, 1"dia, 4 tpi

screw and secured with a No. 6 screw which passes through both the tubing and the cap screw. A "weep" hole, 1/16-inch or so diameter, is drilled through one wall of the tubing just above the top of the cap screw, to permit an escape point for condensed moisture. The length of the radiator is adjusted during final pruning by varying the amount of telescoping of the tubing at the top of the element. Table I gives dimensions and coil data for the construction of ground-plane antennas for which this construction technique is suitable.

ANTENNAS FOR 160 METERS

Results on 1.8 MHz will depend to a large extent on the type of antenna used and the time of day or night that operations will take place. Almost any random length of wire that is tuned to resonance and matched to the transmitter will give fair results at night. During daylight hours the absorption is high, and such high-angle radiators become ineffective. For this reason a vertically polarized, low-radiation-angle antenna is best for use on the 160-meter band, day and night. Fig. 21-29 shows three effective 160-meter antennas. At A, a shortened inverted V is made resonant by means of *L*, a loading coil in each leg of the doublet. This antenna will give vertical polarization, and will perform well for day and night use. A full-size inverted V with tuned feeders would be better, even if the voltage ends were but a few inches off the ground. However, when antenna space is at a premium, a 75-meter doublet can be equipped with loading inductors as shown, and the antenna will perform on 1.8 MHz. Two-band operation can be had by merely shorting the loading coils with clip leads during 75-meter use. For use on 1.8 MHz the coils are experimentally pruned, a half turn at a time, until the lowest SWR is obtained.

As a starting point, the coils should be 70 µH each, 16 feet, 5 inches for the length between the coil and antenna center (one side), and 46 feet from the coil to the end insulator. Resonate the antenna on the desired 80-meter frequency by shorting out turns on the coil, looking for the lowest SWR. Note that point and follow the same

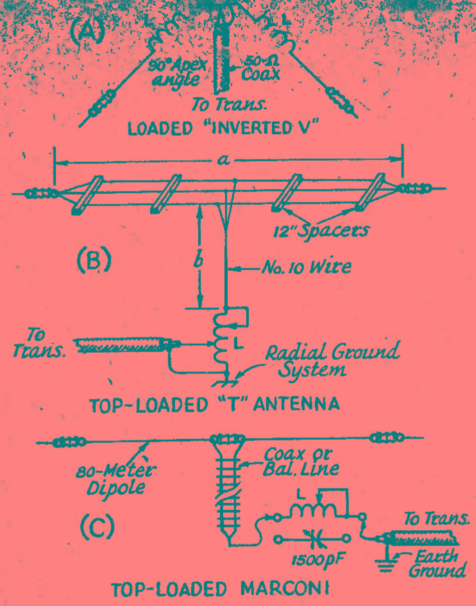


Fig. 21-29 — Illustrations of three vertically polarized short antennas for use on 1.8 to 2 MHz. They are described in tha text.

procedure for 160. Of course, the shorting taps must be changed each time one changes bands.

The antenna at B is nothing more than a top-loaded quarter-wavelength Marconi. The flat-top section, *a*, can be any convenient length – 25 to 50 feet – and should be as high in the air as possible. Its three wires are joined at the ends and center, and a single vertical wire drops down to the loading/matching inductor, *L*. The flat-top section serves as a capacitance hat for the vertical member, *b*. The larger that *a* is made, the less coil will be needed at *L*. A good earth ground is essential to proper performance. A buried radial system is recommended, but if the soil has good conductivity it may be possible to get by with six or eight ground rods driven into the earth, 4 feet apart, and bonded together by means of No. 10 wire. They should be centered around the bottom end of section *b*. There are two taps on *L*. The bottom one is adjusted for a match to the coax feeder. The top tap is adjusted for antenna resonance. There will be some interaction between the adjustments, so several attempts may be necessary before the system is tuned up. Section *b* should be made as long as possible – 30 feet or more – for best results.

An adaptation of the antenna just described is shown at C in Fig. 21-29. Here an 80-meter doublet is used as a quarter-wavelength top-loaded Marconi. The feeders, whether coax or balanced line, are twisted together at the transmitter end and tuned with series *L* or *C*. The method used will depend upon the length of the feed line. Ordinarily, an 80-meter dipole with a quarter wavelength feeder will require the series *C* to tune out reactance. If the feed line is much less than one quarter wavelength, the series *L* will be needed. An SWR bridge should be used during these adjustments. A good earth ground is necessary with this antenna.

Other Antennas

Most of the full-size horizontal and vertical antennas described earlier in this chapter are suitable for 1.8 MHz, too. When space is available for a large antenna one should try to make use of this advantage on "160." The helically-wound short vertical described in the section on "limited-space antennas" should be of interest to the 160-meter operator, too.

LIMITED-SPACE ANTENNAS

Reducing losses which detract from the radiated power is the key to success in any limited-space antenna system. In fact, if there were no losses present, the radiating efficiency of a shortened antenna would be as good as its full-sized counterpart. The only difference between the two is that the bandwidth over which the input impedance remains relatively constant is less for the former than it is for the latter. As the length of a radiator becomes shorter in comparison to the wavelength of operation, less rf energy is radiated during each rf cycle and most of the energy is stored in the electric field surrounding the antenna. This means the *Q* of the antenna is very high and consequently the bandwidth becomes very narrow. From a circuit point of view, the radiator looks like a small-value capacitor (large capacitive reactance) in series with a small resistance or in parallel with large resistance value. The problem reduces to one of tuning out the reactance and matching the transmitter or feed line to the antenna radiation resistance. While this sounds relatively simple to do in theory, the effects of losses complicate the problem considerably. It is the unwanted losses which set practical limits on how small an antenna can be made and still be useful for communication purposes.

Electrical length, and not physical size, determine whether or not an antenna is "small." For instance, a 20-meter dipole is approximately 34 feet long and could easily be installed in an attic or other area. The same length antenna would be quite short on 75 meters and would present formidable matching and loss problems. Antenna height is subject to the same considerations in regards to physical versus electrical size and the effects of height are covered elsewhere in this *Handbook*. Since the high-current parts of an antenna are responsible for most of the radiation, they should be kept as high as possible. This will improve the angle of radiation somewhat.

A Multiple-Tuned Short Dipole

The use of limited-space antennas is becoming more of a necessity than formerly. Therefore, any possibilities for new or different designs should be explored. Shown in Fig. 21-30 is an antenna

Fig. 21-30 — At left, construction of the dipole. Heavier spreaders with insulators were used at the ends with a lighter one in the middle. The weight of the feed line is distributed on both sides of the spreader by means of a cord, forming the Y-shaped object in the middle. Also shown are the four loading coils. At right, close-up view of a loading coil showing tap connection and polypropylene insulator.

utilizing a technique seldom found in amateur antennas with the exception of the folded dipole. The method is called multiple tuning and has been used extensively in vlf antenna installations.

Some advantages to the technique are as follows: if two or more resonant radiators are paralleled in folded-dipole fashion then the impedance ($R_a + R_o/N$) is stepped up by a factor of N^2 (where N is the number of radiators and R_a is the radiation resistance of each radiator). The loss resistance is R_o which is associated with loading-coil losses, wire conductivity, and other sources. R_o is decreased by a factor of $1/N$. Antenna efficiency is equal to $100\%/(1 + R_o/NR_a)$ and improves as N is increased. These effects are of less importance when the electrical length of the resonant radiator is large since efficiency is high to begin with. Also, reasonable input impedances make matching to the feed line or transmitter relatively simple. However, the advantages become pronounced when the efficiency is poor (R_o/R_a large) and $R_a + R_o$ is small making matching difficult. This is the case when the length of the resonant radiator becomes short compared to the wavelength being used.

While space is usually available for full-size dipoles on the higher amateur frequencies, the idea of using multiple tuning for a high-efficiency short dipole for one of the lower bands seemed attractive. Some experimental antennas for the 75-meter band were constructed and one is shown in Fig. 21-31. Even though only 30 feet long, performance on both receiving and transmitting of this antenna seemed to compare favorably with much larger ones. Using a 180-watt transceiver in a temporary setup, a number of contacts were made and the reports were generally good in comparison with stations running higher power and with larger antennas.

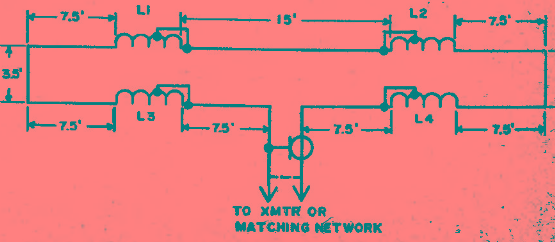
If the value of $R_a + R_o/N$ is on the order of 13 ohms, an impedance step up of four will give 52 ohms. This would allow matching to a transmitter or 52-ohm feed line without additional networks. While not an advantage in particular (since other values could be used with an appropriate matching network), it turned out that this occured with the length and antenna height used. The latter would be realistic ones for many limited-space installations, however.

Bandwidth of the antenna was quite narrow (20 kHz) indicating an antenna Q of approximately 190. However, this is as it should be (as pointed out previously) and a broad bandwidth would be suspect with an antenna this short. In many applications, the narrow bandwidth would not prove to be a great objection. Since nets and round tables tend to operate on a fixed-frequency basis, the inconvenience of retuning would not pose a problem. Improved performance because of the increased efficiency may offset this disadvantage in some instances. Tuning was accomplished by lowering the antenna and changing the taps on the loading coils. The SWR was then checked until a point where a minimum occured was found.

Initial values for the loading-coil inductance were calculated for a single dipole from curves in *The ARRL Antenna Book*, 13th edition. The chart in Fig. 10-2 was used to determine these starting values and good agreement with the actual value needed was observed. Antennas for other lengths and frequencies could be designed with these curves. Keeping the coils approximately midway between the center and the outer end of the antenna is advisable, however. It is also a good idea to make the L of coils somewhat larger than calculated and then tap down to get the correct value. Tap connections should be soldered for highest conductivity. In order to avoid disappointment, it is advisable to reduce *all* the losses as much as possible. This philosophy holds for other types of limited-space antennas as well. Compromises made for convenience or other reasons will normally result in poorer efficiency.

Construction of the dipole can follow the

Fig. 21-31 — Dipole dimensions and coil data.
L1-L4, incl. — 82 μH for 3.86 MHz. Air wound preferable, 57 turns, 2-1/2-inch dia., 10 tpi of No. 16 solid wire (B&W 3031).



builder's requirements but the factors mentioned previously should be kept in mind. Using the antenna in an attic installation might be attractive since it could be strung from the rafters by means of standoff insulators. Caution should be taken that no contact with metallic or flammable objects occurs. When used in outdoor setups, construction of the loading-coil supports may be improved by using fiberglass rods instead of the polypropylene rope insulators shown in the experimental dipole. However, polypropylene has very low-loss dielectric properties which makes it adequate for insulating applications. Generally speaking, weatherproofing is unadvisable since a poor job tends to keep moisture in once it gets there while an open-type construction quickly dries out once inclement weather clears up. If air-wound coil stock is used for the loading coils, alternate windings near the tap points should be pushed in slightly to ease the task of soldering connections and insure that no unwanted shorts between turns occur. While many types of homemade coils are possible, it should be pointed out that PVC plastics have relatively poor dielectric-loss properties. This may or may not be an important factor in loading-coil operation and will depend upon the voltage across the coil.

Other types of limited-space antennas may be of interest and *The ARRL Antenna Book*, 13th edition, contains additional designs. The particular type selected will depend upon factors such as ground conductivity, ability to install ground planes, height available, and proximity to surrounding objects.

HELICALLY-WOUND SHORT VERTICAL ANTENNAS

An effective physically-short radiator can be built by helically-winding a length of wire on a long insulating rod or pole as shown in the sketch. Supporting poles such as bamboo rods, fiber glass tubing, or treated dowel rod, serve as practical foundation material for such an antenna. This type of antenna is most often used as a vertical radiator and is worked against ground as a quarter-wavelength system. The voltage and current distribution is more linear than when a lumped-inductance (loading coil and whip) is employed, a possible reason for its effective performance.

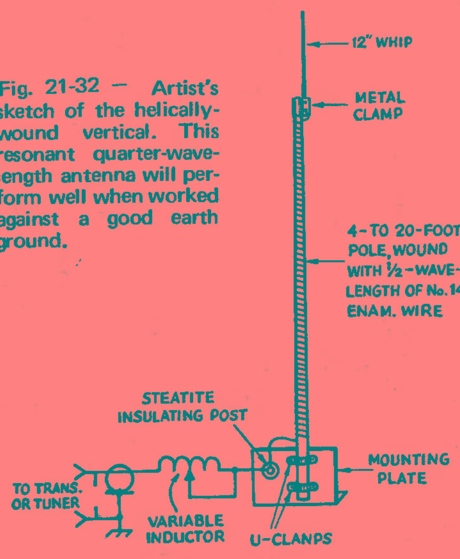


Fig. 21-32 — Artist's sketch of the helically-wound vertical. This resonant quarter-wavelength antenna will perform well when worked against a good earth ground.

This type of antenna is particularly useful for limited-space applications in the lower part of the hf spectrum – 1.8, 3.5 and 7.0 MHz. It can be used for 14 MHz and higher, but is desirable only if an antenna shorter than a natural quarter wavelength is required.

Construction

The length of the supporting pole can be anything between 4 feet and 20 feet in length. The longer the rod, the better the performance. Fiber glass spreader poles for cubical-quad antennas are ideal for this application. Alternatively, bamboo fishing poles, covered with fiber glass, work well. Some lumber yards carry 16-foot long hand-rail stock (wooden) which can be coated with fiber glass or several coats of exterior spar varnish and used as a coil form. The main consideration is that the antenna pole be of good dielectric properties and that it be weatherproofed.

So that the antenna will be approximately 1/4-wavelength long *electrically*, a 1/2-wavelength piece of insulated wire is needed for the radiating element. When helically-wound as shown, the antenna becomes approximately one-quarter wavelength long, electrically. No. 14 or No. 12 Formvar-insulated copper wire is recommended for the antenna winding. It should be space-wound in as linear a manner as possible. The far end of the vertical should have a 6-inch diameter metal disk, or 12-inch spike, to add sufficient capacitance to lower the impedance at the far end of the radiator sufficiently to prevent corona effects which can burn the far end of the element during medium- and high-power operation. An aluminum base-mounting plate and two U clamps can serve as a support for the antenna.

Operation

To build the antenna for use on 160 meters, for example, wind approximately 248 feet of wire on the pole as shown. Since this will fall just short of natural resonance at one-quarter wavelength, some type of variable inductor will be needed at the base of the antenna. A rotary inductor from an old Command Set transmitter will do the job. It should be enclosed in a weatherproof box of plastic or metal. The inductor is adjusted by means of an SWR indicator for the best match obtainable at the operating frequency. An earth ground is required for proper operation, and a buried radial system is recommended. Alternatively, several ground rods can be driven into the earth near the base of the antenna and bonded together with heavy wire.

It may not be possible to secure a 1:1 SWR without using some form of impedance-matching system. After the antenna is made resonant at the operating frequency, a tuning network such as that

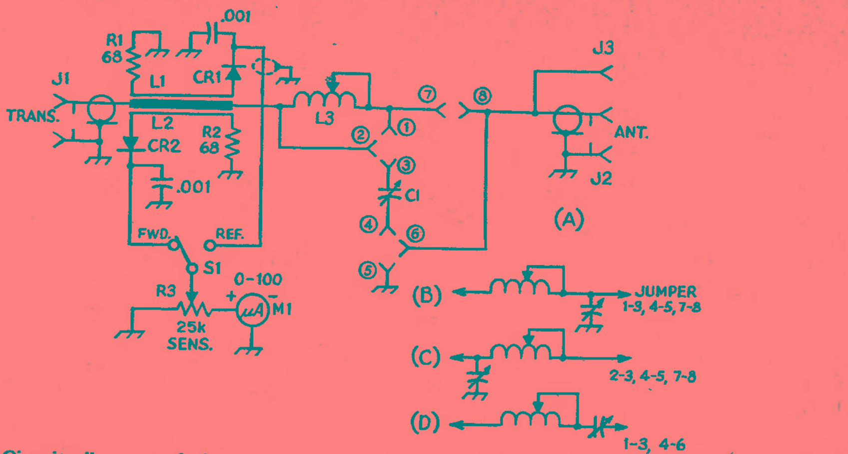


Fig. 21-33 — Circuit diagram of the L-network Transmatch. The eight banana jacks are E. F. Johnson type 108-900, and three dual banana plugs are required, E. F. Johnson type 108-200.

C1 — Variable capacitor, 350 pF (E. F. Johnson 154-10).

CR1, CR2 — 1N34A germanium diode.

J1, J2 — Chassis connector, type SO-239.

J3 — Feedthrough terminal, isolantite.

L1, L2 — See Fig. 21-34, part of etched-circuit assembly.

L3 — Variable inductor 28 µH (E. F. Johnson 229-203).

M1 — 100-µA meter.

R1, R2 — 68-ohm, 1/2-watt carbon or composition, *not wirewound.*

R3 — 25,000-ohm carbon control, linear taper.

S1 — Spst toggle.

of Fig. 21-33 can be employed to provide the desired 1:1 SWR. Since antennas of this type are relatively "frequency conscious," it will be necessary to retune the matching network when moving from one part of the band to another. The completed antenna should be given a coating of fiber glass or spar varnish to seal it against the weather, and to secure the coil turns. It has been observed that this antenna has exceptional immunity to man-made electrical noises. It also cuts down the response to broadcast-band signals which sometimes tend to overload the station receiver. The foregoing attributes result from the fact that it is a narrow-band antenna.

INDOOR ANTENNAS

Amateurs residing in apartment buildings may not be able to put up outdoor antennas or to use limited-space antennas such as shown in Fig. 21-30. The answer to the problem is to use a window-mounted mobile antenna, or random-length wire fed at one end.

Some General Considerations

There are exceptions to the following rules but, in general, they can be depended upon.

1) An outdoor antenna will work better than an indoor one.

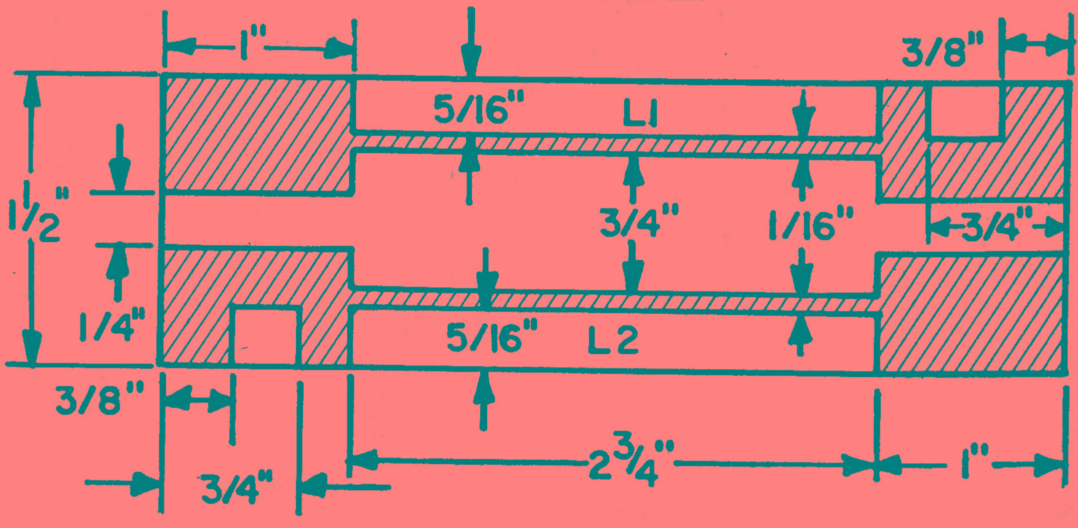


Fig. 21-34 — Etched circuit-board template. The foil side is shown, the etched portion is shaded.