Chapter 7

Multiband Antennas

For operation in a number of bands such as those between 3.5 and 30 MHz it would be impractical, for most amateurs, to put up a separate antenna for each band. But this is not necessary; a dipole, cut for the lowest frequency band to be used, can be operated readily on higher frequencies. To do so, one must be willing to accept the fact that such harmonic-type operation leads to a change in the directional pattern of the antenna (see Chapter 2). The user must also be willing to use "tuned" feeders. A center-fed single-wire antenna can be made to accept power and radiate it with high efficiency on any frequency higher than its fundamental resonant frequency and, with some reduction in efficiency and bandwidth, on frequencies as low as one half the fundamental.

In fact, it is not necessary for an antenna to be a full half-wavelength long at the lowest frequency. It has been determined that an antenna can be considerably shorter than $^1/_2\ \lambda$, as short as $^1/_4\ \lambda$, and still be a very efficient radiator.

In addition, methods have been devised for making a single antenna structure operate on a number of bands while still offering a good match to a transmission line, usually of the coaxial type. It should be understood, however, that a "multiband antenna" is not *necessarily* one that will match a given line on all bands on which it is intended to be used. Even a relatively short whip type of antenna can be operated as a multiband antenna with suitable loading for each band. Such loading may be in the form of a coil at the base of the antenna on those frequencies where loading is needed, or it may be incorporated in the tuned feeders which run from the transmitter to the base of the antenna.

This chapter describes a number of systems that can be used on two or more bands. Beam antennas are treated separately in later chapters.

DIRECTLY FED ANTENNAS

The simplest multiband antenna is a random length of #12 or #14 wire. Power can be fed to the wire on practically any frequency by one or the other of the methods shown in **Fig 1**. If the wire is made

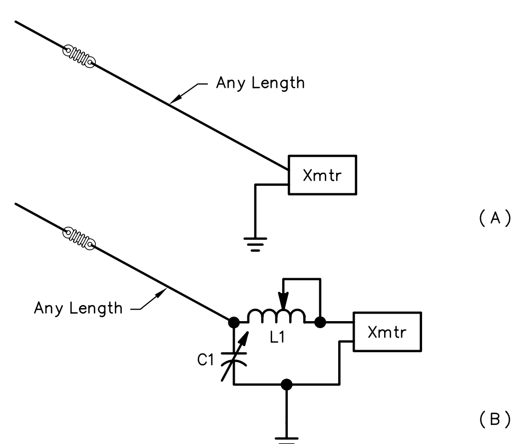


Fig 1—At A, a random-length wire driven directly from the pi-network output of a transmitter. At B, an L network for use in cases where sufficient loading cannot be obtained with the arrangement at A. C1 should have about the same plate spacing as the final tank capacitor in a vacuum-tube type of transmitter; a maximum capacitance of 100 pF is sufficient if L1 is 20 to 25 µH. A suitable coil would consist of 30 turns of #12 wire, 2$^1/_2$ inches diameter, 6 turns per inch. Bare wire should be used so the tap can be placed as required for loading the transmitter.

either 67 or 135 feet long, it can also be fed through a tuned circuit, as in **Fig 2**. It is advantageous to use an SWR bridge or other indicator in the coax line at the point marked "X."

If a 28 or 50-MHz rotary beam has been installed, in many cases it will be possible to use the beam feed line as an antenna on the lower frequencies. Connecting the two wires of the feeder together at the station end will give a random-length wire that can be conveniently coupled to the transmitter as in Fig 1. The rotary system at the far end will serve only to "end load" the wire and will not have much other effect.

One disadvantage of all such directly fed systems is that part of the antenna is practically within the station, and there is a good chance that trouble with RF feedback will be encountered. The RF within the station can often be minimized by choosing a length of wire so that a current loop occurs at or near the transmitter. This means using a wire length of $^1/_4$ λ (65 feet at 3.6 MHz, 33 feet at 7.1 MHz), or an odd multiple of $^1/_4$ λ ($^3/_4$ λ is 195 feet at 3.6 MHz, 100 feet at 7.1 MHz). Obviously, this can be done for only one band in the case of even harmonically related bands, since the wire length that presents a current loop at the transmitter will present a voltage loop at two (or four) times that frequency.

When one is operating with a random-length wire antenna, as in Figs 1 and 2, it is wise to try different types of grounds on the various bands, to see which will give the best results. In many cases it will be satisfactory to return to the transmitter chassis for the ground, or directly to a convenient metallic water pipe. If neither of these works well (or the metallic water pipe is not available), a length of #12 or #14 wire (approximately $^1/_4$ λ long) can often be used to good advantage. Connect the wire at the point in the circuit that is shown grounded, and run it out and down the side of the house, or support it a few feet above the ground if the station is on the first floor or in the basement. It should not be connected to actual ground at any point.

END-FED ANTENNAS

When a straight-wire antenna is fed at one end by a two-wire line, the length of the antenna portion becomes critical if radiation from the line is to be held to a minimum. Such an antenna system for multiband operation is the "end-fed" or "Zepp-fed" antenna shown in **Fig 3**. The an-

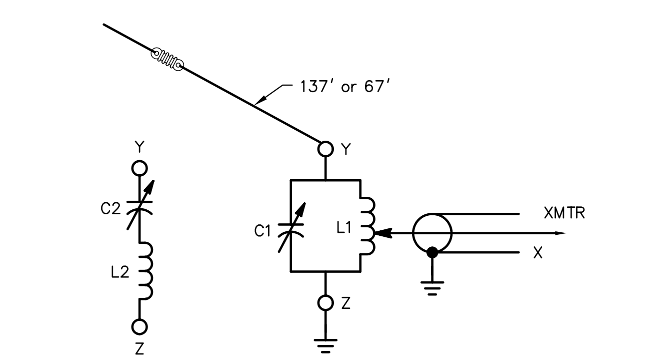


Fig 2—If the antenna length is 135 feet, a parallel-tuned coupling circuit can be used on each amateur band from 3.5 through 30 MHz, with the possible exception of the 10, 18 and 24-MHz bands. C1 should duplicate the final tank tuning capacitor and L1 should have the same dimensions as the final tank inductor on the band being used. If the wire is 67 feet long, series tuning can be used on 3.5 MHz as shown at the left; parallel tuning will be required on 7 MHz and higher frequency bands. C2 and L2 will in general duplicate the final tank tuning capacitor and inductor, the same as with parallel tuning. The L network shown in Fig 1B is also suitable for these antenna lengths.

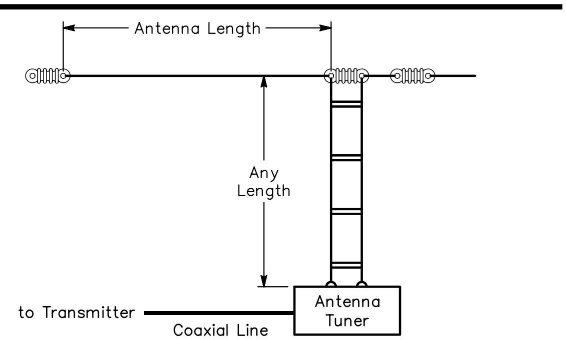


Fig 3—An end-fed Zepp antenna for multiband use.

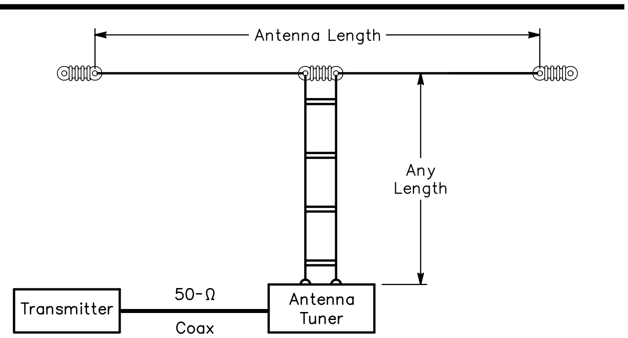


Fig 4—A center-fed antenna system for multiband use.

tenna length is made $^1/_2$ λ long at the lowest operating frequency. The feeder length can be anything that is convenient, but feeder lengths that are multiples of $^1/_4$ λ generally give trouble with parallel currents and radiation from the feeder portion of the system. The feeder can be an open-wire line of #14 solid copper wire spaced 4 or 6 inches with ceramic or plastic spacers. Open-wire TV line (not the type with a solid web of dielectric) is a convenient type to use. This type of line is available in approximately 300 and 450-Ω characteristic impedances.

If one has room for only a 67-foot flat top and yet wants to operate in the 3.5-MHz band, the two feeder wires can be tied together at the transmitter end and the entire system treated as a random-length wire fed directly, as in Fig 1.

The simplest precaution against parallel currents that could cause feed-line radiation is to use a feeder length that is not a multiple of $^1/_4$ λ. A Transmatch can be used to provide multiband coverage with an end-fed antenna with any length of open-wire feed line, as shown in Fig 3.

CENTER-FED ANTENNAS

The simplest and most flexible (and also least expensive) all-band antennas are those using open-wire parallel-conductor feeders to the center of the antenna, as in **Fig 4**. Because each half of the flat top is the same length, the feeder currents will be balanced at all frequencies unless, of course, unbalance is introduced by one half of the antenna being closer to ground (or a grounded object) than the other. For best results and to maintain feed-current balance, the feeder should run away at right angles to the antenna, preferably for at least $^1/_4$ λ.

Center feed is not only more desirable than end feed because of inherently better balance, but generally also results in a lower standing wave ratio on the transmission line, provided a parallel-conductor line having a characteristic impedance of 450 to 600 Ω is used. TV-type open-wire line is satisfactory for all but possibly high power installations (over 500 W), where heavier wire and wider spacing is desirable to handle the larger currents and voltages.

The length of the antenna is not critical, nor is the length of the line. As mentioned earlier, the length of the antenna can be considerably less than $^1/_2$ λ and still be very effective. If the overall length is at least $^1/_4$ λ at the lowest frequency, a quite usable system will result. The only difficulty that may exist with this type of system is the matter of coupling the antenna-system load to the transmitter. Most modern transmitters are designed to work into a 52-Ω coaxial load. With this type of antenna system a coupling network (a Transmatch) is required.

Feed-Line Radiation

The preceding sections have pointed out means of reducing or eliminating feed-line radiation. However, it should be emphasized that any radiation from a transmission line is not "lost" energy and is not necessarily harmful. Whether or not feed-line radiation is important depends entirely on the antenna system being used. For example, feed-line radiation is *not* desirable when a directive array is being used. Such radiation can distort the desired pattern of such an array, producing responses in unwanted directions. In other words, one wants radiation *only* from the directive array.

On the other hand, in the case of a multiband dipole where general coverage is desired, if the feed line happens to radiate, such energy could actually have a desirable effect. Antenna purists may dispute such a premise, but from a practical standpoint where one is not concerned with a directive pattern, much time and labor can be saved by ignoring possible transmission-line radiation.

MULTIPLE-DIPOLE ANTENNAS

The antenna system shown in **Fig 5** consists of a group of center-fed dipoles, all connected in parallel at the point where the transmission line joins them. The dipole elements are stagger tuned. That is, they are individually cut to be $^1/_2$ λ at different frequencies. Chapter 9 discusses the stagger tuning of dipole antennas to attain a low SWR across a broad range of frequencies. An extension of the stagger tuning idea is to construct multiwire dipoles cut for different bands.

In theory, the 4-wire antenna of Fig 5 can be used with a coaxial feeder on five bands. The four wires are prepared as parallel-fed dipoles for 3.5, 7, 14, and 28 MHz. The 7-MHz dipole can be operated on its 3rd harmonic for 21-MHz operation to cover the 5th band. However, in practice it has been found difficult to get a good match to coaxial line on all bands. The $^{1}/_{2}$-λ resonant length of any one dipole in the presence of the others is not the same as for a dipole by itself, and attempts to optimize all four lengths can become a frustrating procedure. The problem is compounded because the optimum tuning changes in a different antenna environment, so what works for one amateur may not work for another. Even so, many amateurs with limited antenna space are willing to accept the mismatch on some bands just so they can operate on those frequencies.

Since this antenna system is balanced, it is desirable to use a balanced transmission line to feed it. The most desirable type of line is 75-Ω transmitting twin-lead. However, either 52-Ω or 75-Ω coaxial line can be used; coax line introduces some unbalance, but this is tolerable on the lower frequencies.

The separation between the dipoles for the various frequencies does not seem to be especially critical. One set of wires can be suspended from the next larger set, using insulating spreaders (of the type used for feeder spreaders) to give a separation of a few inches.

An interesting method of construction used successfully by Louis Richard, ON4UF, is shown in **Fig 6**. The antenna has four dipoles (for 7, 14, 21 and 28 MHz) constructed from 300-Ω ribbon transmission line. A single length of ribbon makes two dipoles. Thus, two lengths, as shown in the sketch, serve to make dipoles for four bands. Ribbon with copper-clad steel conductors (Amphenol type 14-022) should be used because all of the weight, including that of the feed line, must be supported by the uppermost wire.

Two pieces of ribbon are first cut to a length suitable for the two halves of the longest dipole. Then one of the conductors in each piece is cut to proper length for the next band higher in frequency. The excess wire and insulation is stripped away. A second pair of lengths is prepared in the same manner, except that the lengths are appropriate for the next two higher frequency bands.

A piece of thick polystyrene sheet drilled with holes for anchoring each wire serves as the central insulator. The shorter pair of dipoles is suspended the width of the ribbon below the longer pair by clamps also made of poly sheet. Intermediate spacers are made by sawing slots in pieces of poly sheet so they will fit the ribbon snugly.

The multiple-dipole principle can also be applied to vertical antennas. Parallel or fanned $^{1}/_{4}$-λ elements of wire or tubing can be worked against ground or tuned radials from a common feed point.

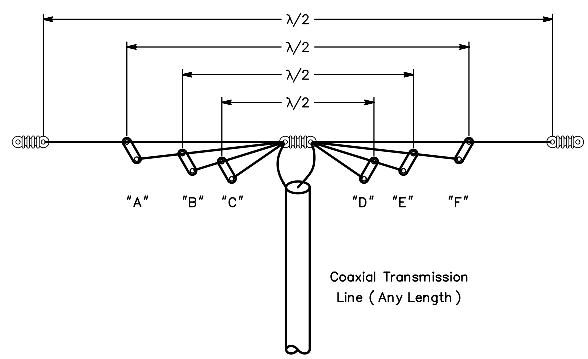
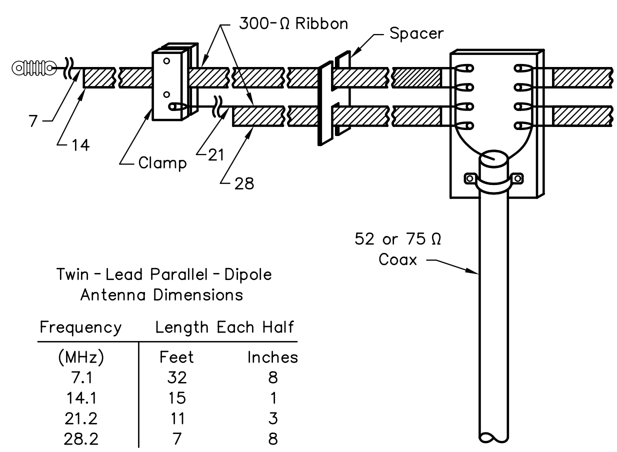


Fig 5—Multiband antenna using paralleled dipoles all connected to a common low-impedance transmission line. The half-wave dimensions may be either for the centers of the various bands or selected to fit favorite frequencies in each band. The length of a half wave in feet is 468/frequency in MHz, but because of interaction among the various elements, some pruning for resonance may be needed on each band.



Frequency (MHz)	Length Each Half Feet	Inches
7.1	32	8
14.1	15	1
21.2	11	3
28.2	7	8

Fig 6—Sketch showing how the twin-lead multiple-dipole antenna system is assembled. The excess wire and insulation are stripped away.

The Open-Sleeve Antenna

Although only recently adapted for the HF and VHF amateur bands, the open-sleeve antenna has been around since 1946. The antenna was invented by Dr. J. T. Bolljahn, of Stanford Research Institute. This section on sleeve antennas was written by Roger A. Cox, WBØDGF.

The basic form of the open-sleeve monopole is shown in **Fig 7**. The open-sleeve monopole consists of a base-fed central monopole with two parallel closely spaced parasites, one on each side of the central element, and grounded at each base. The lengths of the parasites are roughly one half that of the central monopole.

Impedance

The operation of the open sleeve can be divided into two modes, an antenna mode and a transmission line mode. This is shown in **Fig 8**.

The antenna mode impedance, Z_A, is determined by the length and diameter of the central monopole. For sleeve lengths less than that of the monopole, this impedance is essentially independent of the sleeve dimensions.

The transmission line mode impedance, Z_T, is determined by the characteristic impedance, end impedance, and length of the 3-wire transmission line formed by the central monopole and the two sleeve elements. The characteristic impedance, Z_c, can be determined by the element diameters and spacing if all element diameters are equal, and is found from

$$Z_c = 207 \log 1.59 \, (D/d)$$

where

D = spacing between the center of each sleeve element and the center of the driven element

d = diameter of each element

This is shown graphically in **Fig 9**. However, since the end impedance is usually unknown, there is

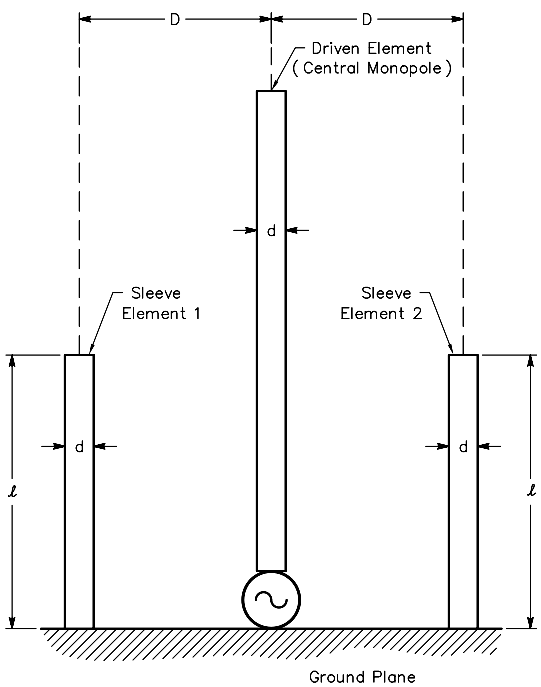


Fig 7—Diagram of an open-sleeve monopole.

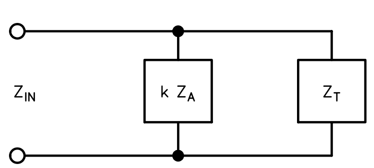


Fig 8—Equivalent circuit of an open-sleeve antenna.

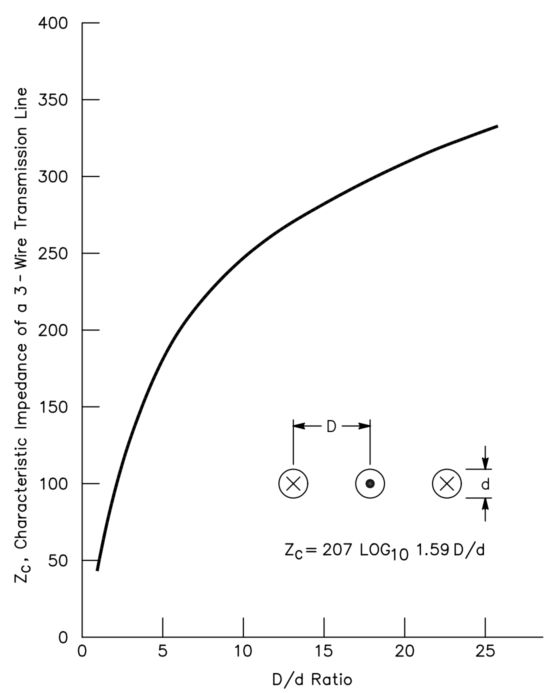


Fig 9—Characteristic impedance of transmission line mode in an open-sleeve antenna.

little need to know the characteristic impedance. The transmission line mode impedance, Z_T, is usually determined by an educated guess and experimentation.

As an example, let us consider the case where the central monopole is $^1/_4$ λ at 14 MHz. It would have an antenna mode impedance, Z_A, of approximately 52 Ω, depending upon the ground conductivity and number of radials. If two sleeve elements were added on either side of the central monopole, with each approximately half the height of the monopole and at a distance equal to their height, there would be very little effect on the antenna mode impedance, Z_A, at 14 MHz.

Also, Z_T at 14 MHz would be the end impedance transformed through a $^1/_8$-λ section of a very high characteristic impedance transmission line. Therefore, Z_T would be on the order of 500-2000 Ω resistive plus a large capacitive reactance component. This high impedance in parallel with 52 Ω would still give a resultant impedance close to 52 Ω.

At a frequency of 28 MHz, however, Z_A is that of an end-fed half-wave antenna, and is on the order of 1000-5000 Ω resistive. Also, Z_T at 28 MHz would be on the order of 1000-5000 Ω resistive, since it is the end impedance of the sleeve elements transformed through a quarter-wave section of a very high characteristic impedance 3-wire transmission line. Therefore, the parallel combination of Z_A and Z_T would still be on the order of 500-2500 Ω resistive.

If the sleeve elements were brought closer to the central monopole such that the ratio of the spacing to element diameter was less than 10:1, then the characteristic impedance of the 3-wire transmission line would drop to less than 250 Ω. At 28 MHz, Z_A remains essentially unchanged, while Z_T begins to edge closer to 52 Ω as the spacing is reduced. At some particular spacing the characteristic impedance, as determined by the D/d ratio, is just right to transform the end impedance to exactly 52 Ω at some frequency. Also, as the spacing is decreased, the frequency where the impedance is purely resistive gradually increases.

The actual impedance plots of a 14/28 MHz open-sleeve monopole appear in **Figs 10** and **11**. The length of the central monopole is 195.5 inches, and of the sleeve elements 89.5 inches. The element diameters range from 1.25 inches at the bases to 0.875 inch at each tip. The measured impedance of the 14 MHz monopole alone, curve A of Fig 10, is quite high. This is probably because of a very poor ground plane under the antenna. The addition of the sleeve elements raises this impedance slightly, curves B, C and D.

As curves A and B in Fig 11 show, an 8-inch sleeve spacing gives a resonance near 27.8 MHz at 70 Ω, while a 6 inch spacing gives a resonance near

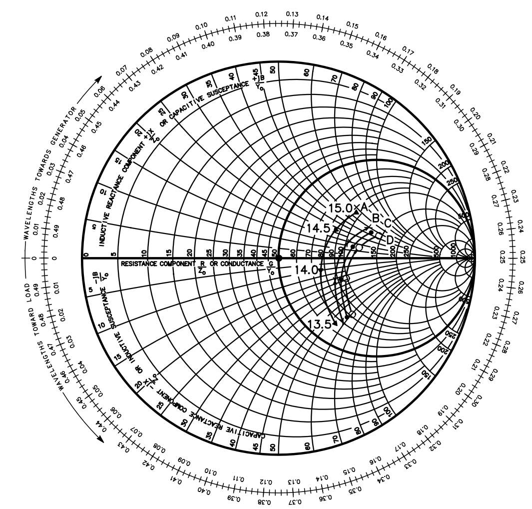


Fig 10—Impedance of an open-sleeve monopole for the frequency range 13.5-15 MHz. Curve A is for a 14-MHz monopole alone. For curves B, C and D, the respective spacings from the central monopole to the sleeve elements are 8, 6 and 4 inches. See text for other dimensions.

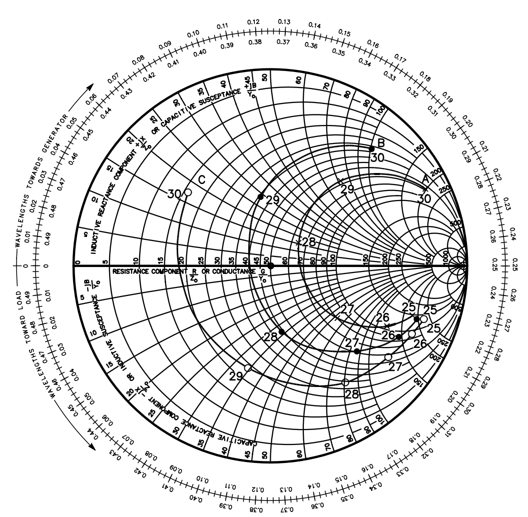


Fig 11—Impedance of the open-sleeve monopole for the range 25-30 MHz. For curves A, B and C the spacings from the central monopole to the sleeve elements are 8, 6 and 4 inches, respectively.

28.5 MHz at 42 Ω. Closer spacings give lower impedances and higher resonances. The optimum spacing for this particular antenna would be somewhere between 6 and 8 inches. Once the spacing is found, the lengths of the sleeve elements can be tweaked slightly for a choice of resonant frequency.

In other frequency combinations such as 10/21, 10/24, 14/21 and 14/24 MHz, spacings in the 6 to 10-inch range work very well with element diameters in the 0.5-1.25 inch range.

Bandwidth

The open-sleeve antenna, when used as a multiband antenna, does not exhibit broad SWR bandwidths unless, of course, the two bands are very close together. For example, **Fig 12** shows the return loss and SWR of a single 10-MHz vertical antenna. Its 2:1 SWR bandwidth is 1.5 MHz, from 9.8–11.3 MHz. Return loss and SWR are related as given by the following equation.

$$SWR = \frac{1+k}{1-k}$$

where

$$k = 10^{-\frac{RL}{20}}$$

RL = return loss, dB

When sleeve elements are added for a resonance near 22 MHz, the 2:1 SWR bandwidth at 10 MHz is still nearly 1.5 MHz, as shown in **Fig 13**. The total amount of spectrum under 2:1 SWR increases, of course, because of the additional band, but the individual bandwidths of each resonance are virtually unaffected.

The open-sleeve antenna, however, can be used as a broadband structure, if the resonances are close enough to overlap. With the proper choices of resonant frequencies, sleeve and driven element diameters and sleeve spacing, the SWR "hump" between resonances can be reduced to a value less than 3:1. This is shown in **Fig 14**.

Current Distribution

According to H. B. Barkley (see Bibliography at the end of this chapter), the total current flowing into the base of the open-sleeve antenna may be broken down into two components, that contributed by the antenna mode, I_A, and that contributed by the transmission line mode, I_T. Assuming that the sleeves are approximately half the height of the central monopole, the impedance of

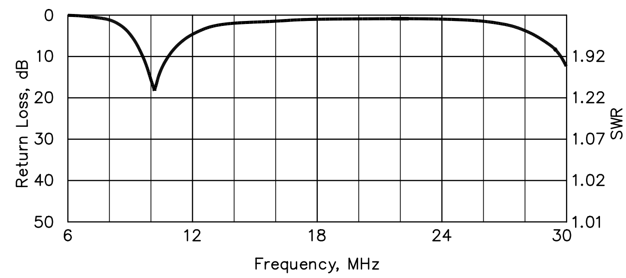


Fig 12—Return loss and SWR of a 10-MHz vertical antenna. A return loss of 0 dB represents an SWR of infinity. The text contains an equation for converting return loss to an SWR value.

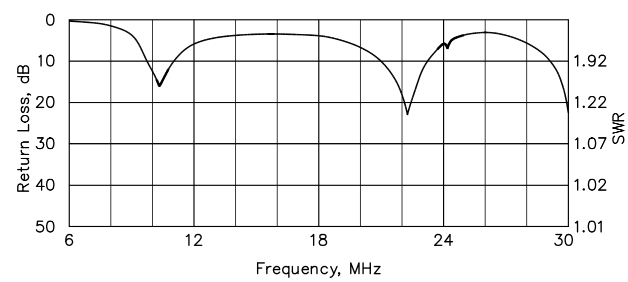


Fig 13—Return loss and SWR of a 10/22 MHz open-sleeve vertical antenna.

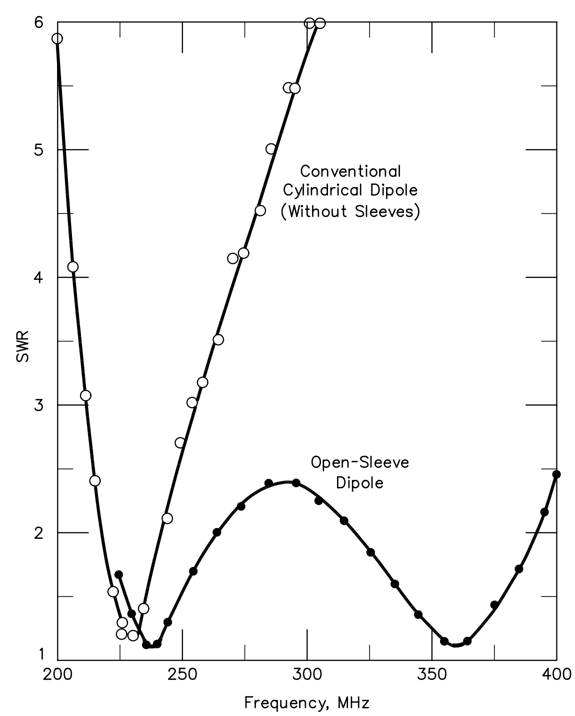


Fig 14—SWR response of an open-sleeve dipole and a conventional dipole.

the antenna mode, Z_A, is very low at the resonant frequency of the central monopole, and the impedance of the transmission line mode, Z_T, is very high. This allows almost all of the current to flow in the antenna mode, and I_A is very much greater than I_T. Therefore, the current on the central $^1/_4$-λ monopole assumes the standard sinusoidal variation, and the radiation and gain characteristics are much like those of a normal $^1/_4$-λ vertical antenna.

However, at the resonant frequency of the sleeves, the impedance of the central monopole is that of an end fed half-wave monopole and is very high. Therefore I_A is small. If proper element diameters and spacings have been used to match the transmission line mode impedance, Z_T, to 52 Ω; then I_T, the transmission line mode current, is high compared to I_A.

This means that very little current flows in the central monopole above the tops of the sleeve elements, and the radiation is mostly from the transmission line mode current, I_T, in all three elements below the tops of the sleeve elements. The resulting current distribution is shown in **Figs 15** and **16** for this case.

Radiation Pattern and Gain

The current distribution of the open-sleeve antenna where all three elements are nearly equal in length is nearly that of a single monopole antenna. If, at a particular frequency, the elements are approximately $^1/_4$ λ long, the current distribution is sinusoidal.

If, for this and other length ratios, the chosen diameters and spacings are such that the two sleeve elements approach an interelement spacing of $^1/_8$ λ; the azimuthal pattern will show directivity typical of two in-phase vertical radiators, approximately $^1/_8$ λ apart. If a bidirectional pattern is needed, then this is one way to achieve it.

Spacings closer than this will produce nearly circular azimuthal radiation patterns. Practical designs in the 10-30 MHz range using 0.5-1.5 inch diameter elements will produce azimuthal patterns that vary less than plus or minus 1 dB.

If the ratio of the length of the central monopole to the length of the sleeves approaches 2:1, then the elevation pattern of the open-sleeve vertical antenna at the resonant frequency of the sleeves becomes slightly compressed. This is because of the in-phase contribution of radiation from the $^1/_2$-λ central monopole.

As shown in **Fig 17**, the 10/21 MHz open-sleeve vertical antenna produces a lower angle of

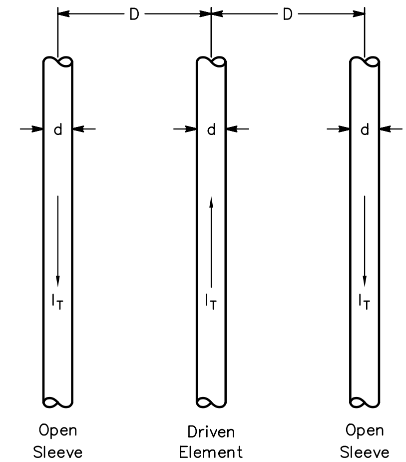


Fig 15—Current distribution in the transmission line mode. The amplitude of the current induced in each sleeve element equals that of the current in the central element but the phases are opposite, as shown.

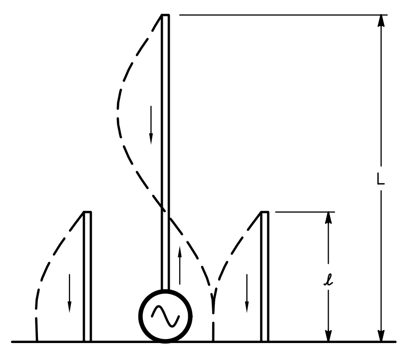


Fig 16—Total current distribution with ℓ = L/2.

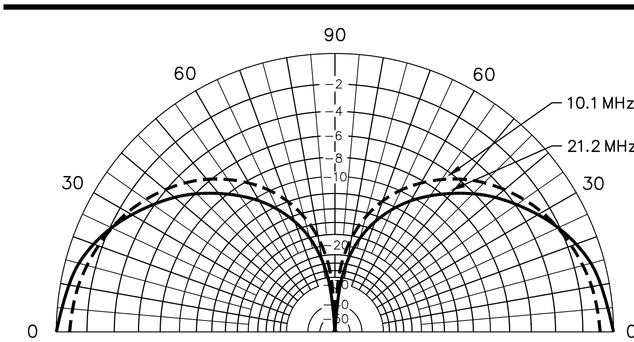


Fig 17—Vertical-plane radiation patterns of a 10/21 MHz open-sleeve vertical antenna on a perfect ground plane. At 10.1 MHz the maximum gain is 5.09 dBi, and 5.75 dBi at 21.2 MHz.

radiation at 21.2 MHz with a corresponding increase in gain of 0.66 dB over that of the 10-MHz vertical alone.

At length ratios approaching 3:1, the antenna mode and transmission line mode impedance become nearly equal again, and the central monopole again carries a significant portion of the antenna current. The radiation from the top $^1/_2$ λ combines constructively with the radiation from the $^1/_4$-λ sleeve elements to produce gains of up to 3 dB more than just a quarter-wave vertical element alone.

Length ratios in excess of 3.2:1 produce higher level sidelobes and less gain on the horizon, except for narrow spots near the even ratios of 4:1, 6:1, 8:1, etc. These are where the central monopole is an even multiple of a halfwave, and the antenna mode impedance is too high to allow much antenna mode current.

Up to this point, it has been assumed that only $^1/_4$-λ resonance could be used on the sleeve elements. The third, fifth and seventh-order resonances of the sleeve elements and the central monopole element can be used, but their radiation patterns normally consist of high-elevation lobes, and the gain on the horizon is less than that of a $^1/_4$-λ vertical.

Practical Construction and Evaluation

The open-sleeve antenna lends itself very easily to home construction. For the open-sleeve vertical antenna, only a feed-point insulator and a good supply of aluminum tubing are needed. No special traps or matching networks are required. The open-sleeve vertical can produce up to 3 dB more gain than a conventional $^1/_4$-λ vertical. Further, there is no reduction in bandwidth, because there are no loading coils.

The open-sleeve design can also be adapted to horizontal dipole and beam antennas for HF, VHF and UHF. A good example of this is Telex/Hy-Gain's Explorer 14 triband beam which utilizes an open sleeve for the 10/15 meter driven element. The open-sleeve antenna is also very easy to model in computer programs such as *NEC* and *MININEC*, because of the open tubular construction and lack of traps or other intricate structures.

In conclusion, the open-sleeve antenna is an antenna experimenter's delight. It is not difficult to match or construct, and it makes an ideal broadband or multiband antenna.

Trap Antennas

By using tuned circuits of appropriate design strategically placed in a dipole, the antenna can be made to show what is essentially fundamental resonance at a number of different frequencies. The general principle is illustrated by **Fig 18**.

Even though a trap-antenna arrangement is a simple one, an explanation of how a trap antenna works is elusive. For some designs, traps are resonated in our amateur bands, and for others (especially commercially made antennas) the traps are resonant far outside any amateur band.

A trap in an antenna system can perform either of two functions, depending on whether or not it is resonant at the operating frequency. A familiar case is where the trap is resonant in an amateur band. For the moment, let us assume that dimension A in Fig 18 is 33 feet and that each L/C combination is resonant in the 7-MHz band. Because of its resonance, the trap presents a high impedance at that point in the antenna system. The electrical effect at 7 MHz is that the trap behaves as an insulator. It serves to divorce the outside ends, the B sections, from the antenna. The result is easy to visualize—we have an antenna system that is resonant in the 7-MHz band. Each 33-foot section (labeled A in the drawing) represents $^1/_4$ λ, and the trap behaves as an insulator. We therefore have a full-size 7-MHz antenna.

The second function of a trap, obtained when

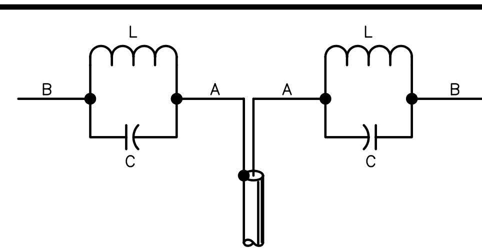


Fig 18—A trap dipole antenna. This antenna may be fed with 52-Ω coaxial line. Depending on the L/C ratio of the trap elements and the lengths chosen for dimensions A and B, the traps may be resonant either in an amateur band or at a frequency far removed from an amateur band for proper two-band antenna operation.

the frequency of operation is *not* the resonant frequency of the trap, is one of electrical loading. If the operating frequency is below that of trap resonance, the trap behaves as an inductor; if above, as a capacitor. Inductive loading will electrically lengthen the antenna, and capacitive loading will electrically shorten the antenna.

Let's carry our assumption a bit further and try using the antenna we just considered at 3.5 MHz. With the traps resonant in the 7-MHz band, they will behave as inductors when operation takes place at 3.5 MHz, electrically lengthening the antenna. This means that the total length of sections A and B (plus the length of the inductor) may be something less than a physical $^1/_4$ λ for resonance at 3.5 MHz. Thus, we have a two-band antenna that is shorter than full size on the lower frequency band. But with the electrical loading provided by the traps, the overall electrical length is $^1/_2$ λ. The total antenna length needed for resonance in the 3.5-MHz band will depend on the L/C ratio of the trap elements.

The key to trap operation off resonance is its L/C ratio, the ratio of the value of L to the value of C. At resonance, however, within practical limitations the L/C ratio is immaterial as far as electrical operation goes. For example, in the antenna we've been discussing, it would make no difference for 7-MHz operation whether the inductor were 1 µH and the capacitor were 500 pF (the reactances would be just below 45 Ω at 7.1 MHz), or whether the inductor were 5 µH and the capacitor 100 pF (reactances of approximately 224 Ω at 7.1 MHz). But the choice of these values will make a significant difference in the antenna size for resonance at 3.5 MHz. In the first case, where the L/C ratio is 2000, the necessary length of section B of the antenna for resonance at 3.75 MHz would be approximately 28.25 feet. In the second case, where the L/C ratio is 50,000, this length need be only 24.0 feet, a difference of more than 15%.

The above example concerns a two-band antenna with trap resonance at one of the two frequencies of operation. On each of the two bands, each half of the dipole operates as an electrical $^1/_4$ λ. However, the same band coverage can be obtained with a trap resonant at, say, 5 MHz, a frequency quite removed from either amateur band. With proper selection of the L/C ratio and the dimensions for A and B, the trap will act to shorten the antenna electrically at 7 MHz and lengthen it electrically at 3.5 MHz. Thus, an antenna that is intermediate in physical length between being full size on 3.5 MHz and full size on 7 MHz can cover both bands, even though the trap is not resonant at either frequency. Again, the antenna operates with electrical $^1/_4$-λ sections.

Additional traps may be added in an antenna section to cover three or more bands. Or a judicious choice of dimensions and the L/C ratio may permit operation on three or more bands with just a pair of identical traps in the dipole.

An important point to remember about traps is this. *If the operating frequency is below that of trap resonance, the trap behaves as an inductor; if above, as a capacitor.* The above discussion is based on dipoles that operate electrically as $^1/_2$-λ antennas. This is not a requirement, however. Elements may be operated as electrical $^3/_2$ λ, or even $^5/_2$ λ, and still present a reasonable impedance to a coaxial feeder. In trap antennas covering several HF bands, using electrical lengths that are odd multiples of $^1/_2$ λ is often done at the higher frequencies.

To further aid in understanding trap operation, let's now choose trap L and C components which each have a reactance of 20 Ω at 7 MHz. Inductive reactance is directly proportional to frequency, and capacitive reactance is inversely proportional. When we shift operation to the 3.5-MHz band, the inductive reactance becomes 10 Ω, and the capacitive reactance becomes 40 Ω. At first thought, it may seem that the trap would become capacitive at 3.5 MHz with a higher capacitive reactance, and that the extra capacitive reactance would make the antenna electrically shorter yet. Fortunately, this is not the case. The inductor and the capacitor are connected in parallel *with each other*, but the *series equivalent* of this parallel combination is what affects the electrical operation of the antenna. The series equivalent of unlike reactances in parallel may be determined from the equation

$$Z = \frac{-j\,X_L\,X_C}{X_L - X_C}$$

where *j* indicates a reactive impedance component, rather than resistive. A positive result indicates inductive reactance, and a negative result indicates capacitive. In this 3.5-MHz case, with 40 Ω of capacitive reactance and 10 Ω of inductive, the equivalent series reactance is 13.3 Ω inductive. This inductive loading lengthens the antenna to an electrical 1/2 λ overall, assuming the B end sections in Fig 18 are of the proper length.

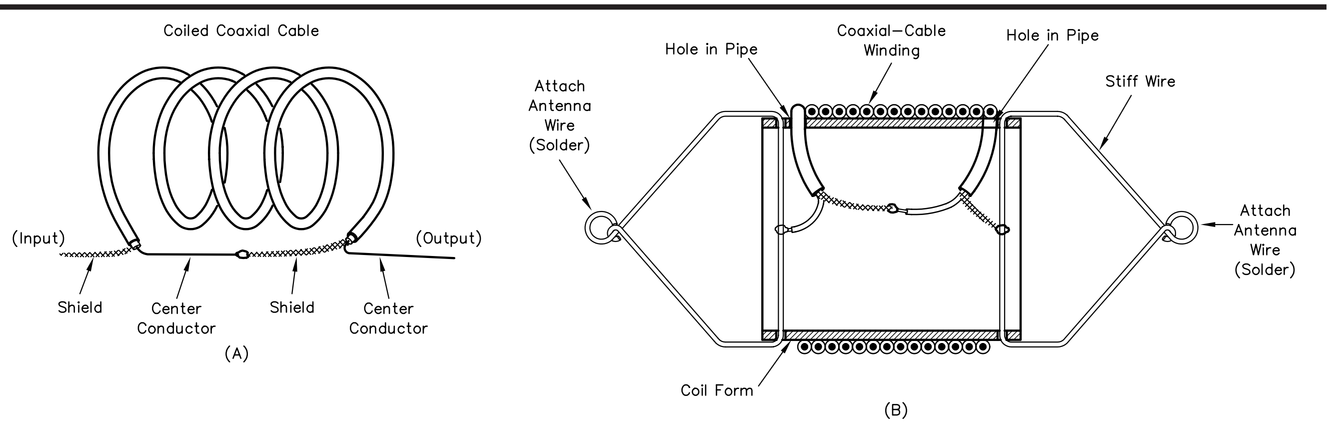
With the above reactance values providing resonance at 7 MHz, X_L equals X_C, and the theoretical series equivalent is infinity. This provides the insulator effect, divorcing the ends.

At 14 MHz, where X_L = 40 Ω and X_C = 10 Ω, the resultant series equivalent trap reactance is 13.3 Ω capacitive. If the total physical antenna length is slightly longer than 3/2 λ at 14 MHz, this trap reactance at 14 MHz can be used to shorten the antenna to an electrical 3/2 λ. In this way, 3-band operation is obtained for 3.5, 7 and 14 MHz with just one pair of identical traps. The design of such a system is not straightforward, however, for any chosen L/C ratio for a given total length affects the resonant frequency of the antenna on both the 3.5 and 14-MHz bands.

Trap Losses

Since the tuned circuits have some inherent losses, the efficiency of a trap system depends on the Q values of the tuned circuits. Low-loss (high-Q) coils should be used, and the capacitor losses likewise should be kept as low as possible. With tuned circuits that are good in this respect—comparable with the low-loss components used in transmitter tank circuits, for example—the reduction in efficiency compared with the efficiency of a simple dipole is small, but tuned circuits of low unloaded Q can lose an appreciable portion of the power supplied to the antenna.

The above commentary applies to traps assembled from conventional components. The important function of a trap that is resonant in an amateur band is to provide a high isolating impedance, and this impedance is directly proportional to Q. Unfortunately, high Q restricts the antenna bandwidth, because the traps provide maximum isolation only at trap resonance. A type of trap described by Gary O'Neil, N3GO, in October 1981 *Ham Radio* achieves high impedance with low Q, effectively overcoming the bandwidth problem. Shown in **Fig 19**, the N3GO trap is fabricated from a single length of coaxial cable. The cable is wound around a form as a single-layer coil, and the shield



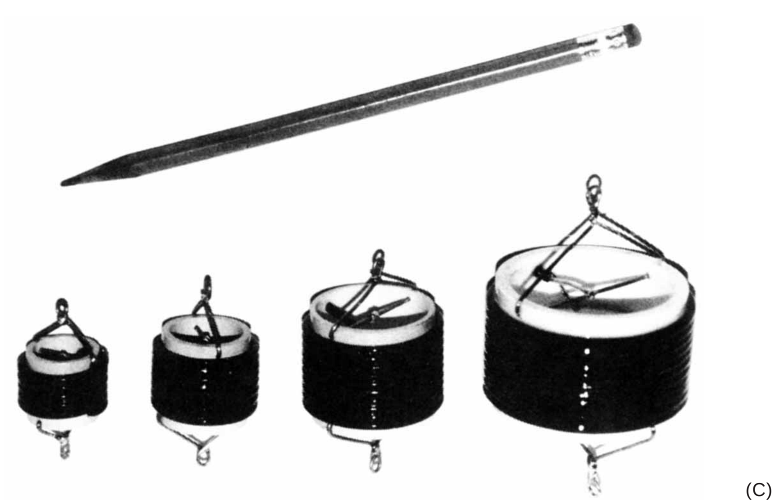


Fig 19—Connections for the N3GO coaxial-cable trap are shown at A. Construction by R.C. Sommer, N4UU, is shown at B and C.

becomes the trap inductor. The capacitance between the center conductor and shield resonates the trap. At each end of the coil the center conductor and shield are separated. At the “inside” end of the trap, nearer the antenna feed point, the shield is connected to the outside antenna wire. At the outside end, the center conductor is attached to the outside antenna wire. The center conductor from the inside end is joined to the shield from the outside end to complete the trap. Constructed in this way, the trap provides high isolation over a greater bandwidth than is possible with conventional traps.

Robert C. Sommer, N4UU, in December 1984 *QST* described how to optimize the N3GO trap. The analysis shows that best results are realized when the trap diameter is from 1 to 2.25 times greater than the length. Trap diameters toward the higher end of that range are better.

Five-Band Antenna

A trap antenna system has been worked out by C. L. Buchanan, W3DZZ, for the five pre-WARC amateur bands from 3.5 to 30 MHz. Dimensions are given in **Fig 20**. Only one set of traps is used, resonant at 7 MHz to isolate the inner (7-MHz) dipole from the outer sections, which cause the overall system to be resonant in the 3.5-MHz band. On 14, 21 and 28 MHz the antenna works on the capacitive-reactance principle just outlined. With a 75-Ω twin-lead feeder, the SWR with this antenna is under 2:1 throughout the three highest frequency bands, and the SWR is comparable with that obtained with similarly fed simple dipoles on 3.5 and 7 MHz.

Trap Construction

Traps frequently are built with coaxial aluminum tubes (usually with polystyrene tubing between them for insulation) for the capacitor, with the coil either self-supporting or wound on a form of larger diameter than the tubular capacitor. The coil is then mounted coaxially with the capacitor to form a unit assembly that can be supported at each end by the antenna wires. In another type of trap devised by William J. Lattin, W4JRW (see Bibliography at the end of this chapter), the coil is supported inside an aluminum tube, and the trap capacitor is obtained in the form of capacitance between the coil and the outer tube. This type of trap is inherently weatherproof.

A simpler type of trap, easily assembled from readily available components, is shown in **Fig 21**. A small transmitting-type ceramic capacitor is used, together with a length of commercially available coil material, these being supported by an ordinary antenna strain insulator. The circuit constants and antenna dimensions differ slightly from those of Fig 20, in order to bring the antenna resonance points closer to the centers of the various phone bands. Construction data are given in **Fig 22**. If a 10-turn length of inductor is used, a half turn from each end may be used to slip through the anchor holes in the insulator to act as leads.

The components used in these traps are suffi-

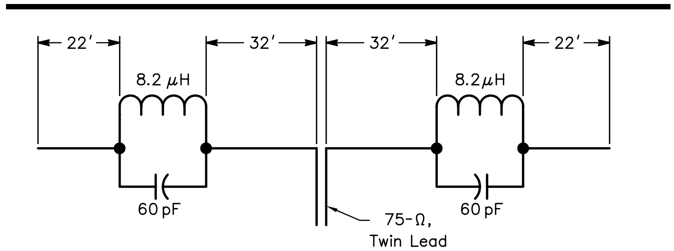


Fig 20—Five-band (3.5, 7, 14, 21 and 28 MHz) trap dipole for operation with 75-Ω feeder at low SWR (C. L. Buchanan, W3DZZ). The balanced (parallel-conductor) line indicated is desirable, but 75-Ω coax can be substituted with some sacrifice of symmetry in the system. Dimensions given are for resonance (lowest SWR) at 3.75, 7.2, 14.15 and 29.5 MHz. Resonance is very broad on the 21-MHz band, with SWR less than 2:1 throughout the band.

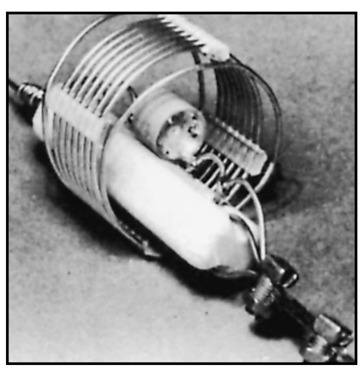


Fig 21—Easily constructed trap for wire antennas (A. Greenburg, W2LH). The ceramic insulator is 4 1/4 inches long (Birnback 688). The clamps are small service connectors available from electrical supply and hardware stores (Burndy KS90 servits).

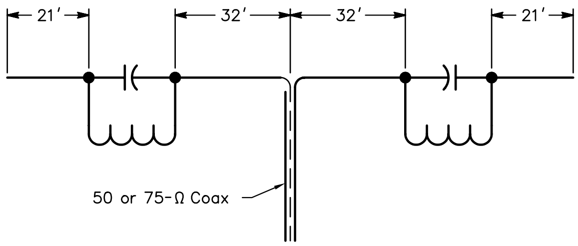


Fig 22—Layout of multiband antenna using traps constructed as shown in Fig 21. The capacitors are 100 pF each, transmitting type, 5000-V dc rating (Centralab 850SL-100N). Coils are 9 turns of #12 wire, 2 1/2 inches diameter, 6 turns per inch (B&W 3029) with end turns spread as necessary to resonate the traps to 7.2 MHz. These traps, with the wire dimensions shown, resonate the antenna at approximately the following frequencies on each band: 3.9, 7.25, 14.1, 21.5 and 29.9 MHz (based on measurements by W9YJH).

ciently weatherproof in themselves so that no additional weatherproofing has been found necessary. However, if it is desired to protect them from the accumulation of snow or ice, a plastic cover can be made by cutting two discs of polystyrene slightly larger in diameter than the coil, drilling at the center to pass the antenna wires, and cementing a plastic cylinder on the edges of the discs. The cylinder can be made by wrapping two turns or so of 0.02-inch poly or Lucite sheet around the discs, if no suitable ready-made tubing is available. Plastic drinking glasses and soft 2-liter soft-drink bottles are easily adaptable for use as trap covers.

Four-Band Trap Dipole

In case there is not enough room available for erecting the 100-odd-foot length required for the five-band antenna just described, **Fig 23** shows a four-band dipole operating on the same principle that requires only half the space. This antenna covers the 7, 14, 21 and 28-MHz bands. The trap construction is the same as shown in Fig 21. With the dimensions given in Fig 23 the resonance points are 7.2, 14.1, 21.15 and 28.4 MHz. The capacitors are 27-pF transmitting type ceramic (Centralab type 857). The inductors are 9 turns of #12 wire, 2 1/2 inches diameter, 6 turns per inch (B&W 3029), adjusted so that the trap resonates at 14.1 MHz before installation in the antenna.

Vertical Antennas

There are two basic types of vertical antennas; either type can be used in multiband configurations. The first is the ground-mounted vertical and the second, the ground plane. These antennas are described in detail in Chapter 6.

The efficiency of any ground-mounted vertical depends a great deal on earth losses. As pointed out in Chapter 3, these losses can be reduced or eliminated with an adequate radial system. Considerable experimentation has been conducted on this subject by Jerry Sevick, W2FMI, and several important results were obtained. It was determined that a radial system consisting of 40 to 50 radials, 0.2 λ long, would reduce the earth losses to about 2 Ω when a 1/4-λ radiator was being used. These radials should be on the earth's surface, or if buried, placed not more than an inch or so below ground. Otherwise, the RF current would have to travel through the lossy earth before reaching the radials. In a multiband vertical system, the radials should be 0.2 λ long for the lowest band, that is, 55 feet long for 3.5-MHz operation. Any wire size may be used for the radials. The radials should fan out in a circle, radiating from the base of the antenna. A metal plate, such as a piece of sheet copper, can be used at the center connection.

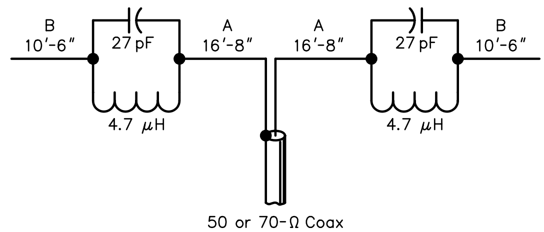


Fig 23—Sketch showing dimensions of a trap dipole covering the 7, 14, 21 and 28-MHz bands (D. P. Shafer, K2GU).

The other common type of vertical is the ground-plane antenna. Normally, this antenna is mounted above ground with the radials fanning out from the base of the antenna. The vertical portion of the antenna is usually an electrical $^1/_4$ λ, as is each of the radials. In this type of antenna, the system of radials acts somewhat like an RF choke, to prevent RF currents from flowing in the supporting structure, so the number of radials is not as important a factor as it is with a ground-mounted vertical system. From a practical standpoint, the customary number of radials is four or five. In a multiband configuration, $^1/_4$-λ radials are required for each band of operation with the ground-plane antenna. This is not so with the ground-mounted antenna, where the ground plane is relied on to provide an image of the radiating section. In the ground-mounted case, as long as the ground-screen radials are approximately 0.2 λ long at the lowest frequency, the length will be more than adequate for the higher frequency bands.

Short Vertical Antennas

A short vertical antenna can be operated on several bands by loading it at the base, the general arrangement being similar to Figs 1 and 2. That is, for multiband work the vertical can be handled by the same methods that are used for random-length wires.

A vertical antenna should not be longer than about $^3/_4$ λ at the highest frequency to be used, however, if low-angle radiation is wanted. If the antenna is to be used on 28 MHz and lower frequencies, therefore, it should not be more than approximately 25 feet high, and the shortest possible ground lead should be used.

Another method of feeding is shown in **Fig 24**. L1 is a loading coil, tapped to resonate the antenna on the desired band. A second tap permits using the coil as a transformer for matching a coax line to the transmitter. C1 is not strictly necessary, but may be helpful on the lower frequencies, 3.5 and 7 MHz, if the antenna is quite short. In that case C1 makes it possible to tune the system to resonance with a coil of reasonable dimensions at L1. C1 may also be useful on other bands as well, if the system cannot be matched to the feed line with a coil alone.

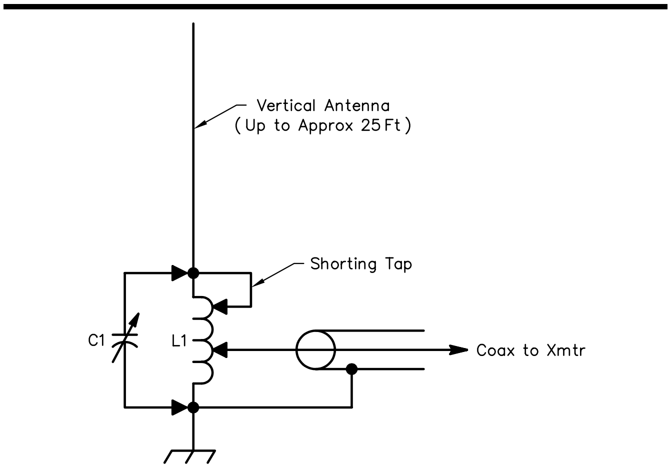


Fig 24—Multiband vertical antenna system using base loading for resonating on 3.5 to 28 MHz. L1 should be wound with bare wire so it can be tapped at every turn, using #12 wire. A convenient size is $2^1/_2$ inches diameter, 6 turns per inch (such as B&W 3029). Number of turns required depends on antenna and ground lead length, more turns being required as the antenna and ground lead are made shorter. For a 25-foot antenna and a ground lead of the order of 5 feet, L1 should have about 30 turns. The use of C1 is explained in the text. The smallest capacitance that will permit matching the coax cable should be used; a maximum capacitance of 100 to 150 pF will be sufficient in any case.

The coil and capacitor should preferably be installed at the base of the antenna, but if this cannot be done a wire can be run from the antenna base to the nearest convenient location for mounting L1 and C1. The extra wire will of course be a part of the antenna, and since it may have to run through unfavorable surroundings it is best to avoid its use if at all possible.

This system is best adjusted with the help of an SWR indicator. Connect the coax line across a few turns of L1 and take trial positions of the shorting tap until the SWR reaches its lowest value. Then vary the line tap similarly; this should bring the SWR down to a low value. Small adjustments of both taps then should reduce the SWR to close to 1:1. If not, try adding C1 and go through the same procedure, varying C1 each time a tap position is changed.

Trap Verticals

The trap principle described in Fig 18 for center-fed dipoles also can be used for vertical antennas. There are two principal differences. Only one half of the dipole is used, the ground connection taking the place of the missing half, and the feed-point impedance is one half the feed-point impedance of a dipole. Thus it is in the vicinity of 30 Ω (plus the ground-connection resistance), so 52-Ω cable should be used since it is the commonly available type that comes closest to matching.

As in the case of any vertical antenna, a good ground is essential, and the ground lead should be short. Some amateurs have reported successfully using a ground plane dimensioned for the lowest frequency to be used; for example, if the lowest frequency is 7 MHz, the ground-plane radials can be approximately 34 feet long.

A Trap Vertical For 21 and 28 MHz

Simple antennas covering the upper HF bands can be quite compact and inexpensive. The two-band vertical ground plane described here is highly effective for long-distance communication when installed in the clear.

Figs 25, **26** and **27** show the important assembly details. The vertical section of the antenna is mounted on a $^{3}/_{4}$-inch thick piece of plywood that measures 7×10 inches. Several coats of exterior varnish or similar material will help protect the wood from inclement weather. Both the mast and

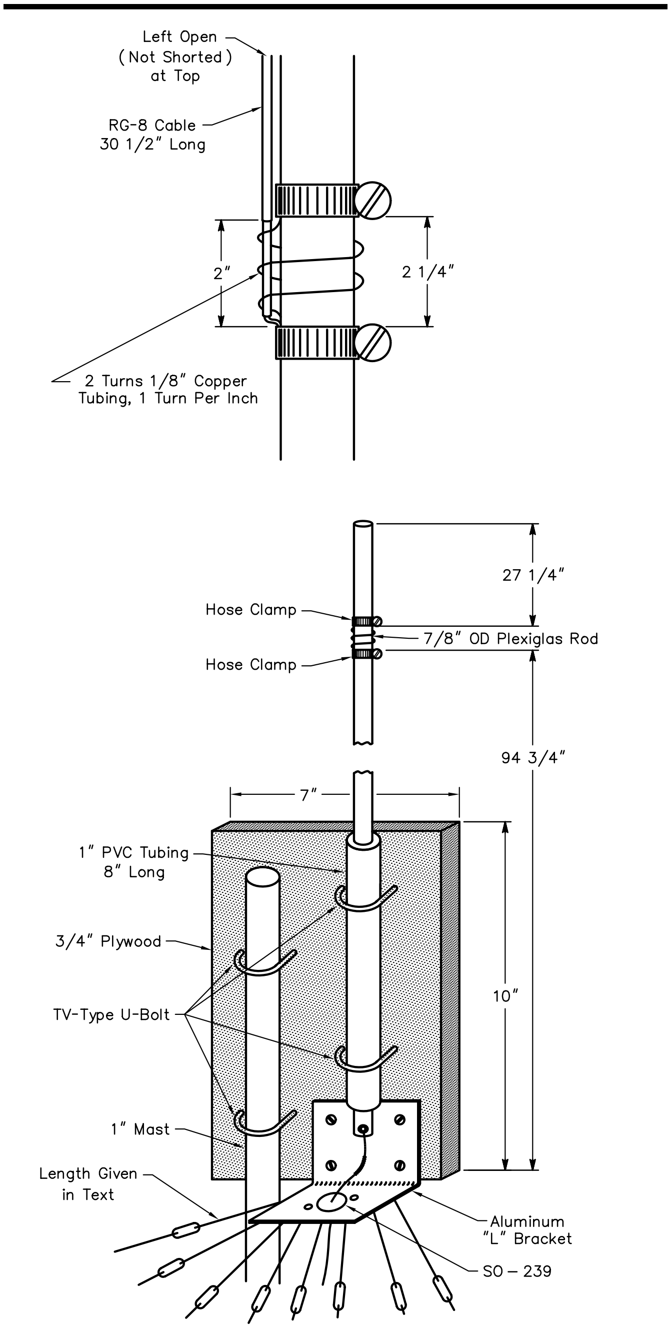


Fig 25—Construction details of the 21 and 28-MHz dual-band antenna system.

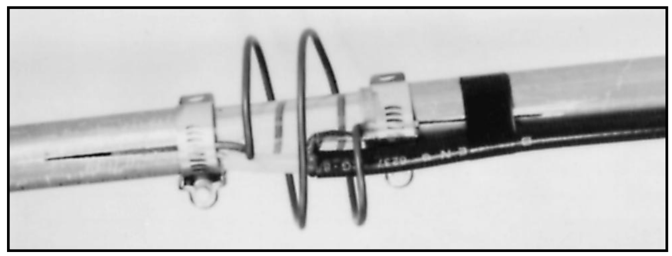


Fig 26—A close-up view of a trap. The coil is 3 inches in diameter. The leads from the coaxial-cable capacitor should be soldered directly to the pigtails of the coil. These connections should be coated with varnish after they have been secured under the hose clamps.

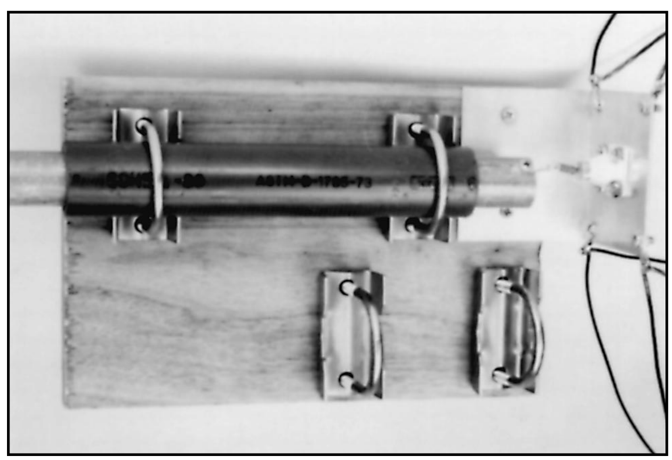


Fig 27—The base assembly of the 21 and 28-MHz vertical. The SO-239 coaxial connector and hood can be seen in the center of the aluminum L bracket. The U bolts are TV-type antenna hardware. The plywood should be coated with varnish or similar material.

the radiator are mounted on the piece of wood by means of TV U-bolt hardware. The vertical is electrically isolated from the wood with a piece of 1-inch diameter PVC tubing. A piece approximately 8 inches long is required, and it is of the schedule-80 variety. To prepare the tubing it must be slit along the entire length on one side. A hacksaw will work quite well. The PVC fits rather snugly on the aluminum tubing and will have to be "persuaded" with the aid of a hammer. The mast is mounted directly on the wood with no insulation. An SO-239 coaxial connector and four solder lugs are mounted on an L-shaped bracket made from a piece of aluminum sheet. A short length of test probe wire, or inner conductor of RG-58 cable, is soldered to the inner terminal of the connector. A UG-106 connector hood is then slid over the wire and onto the coaxial connector. The hood and connector are bolted to the aluminum bracket. Two wood screws are used to secure the aluminum bracket to the plywood as shown in the drawing and photograph. The free end of the wire coming from the connector is soldered to a lug that is mounted on the bottom of the vertical radiator. Any space between the wire and where it passes through the hood is filled with GE silicone glue and seal or similar material to keep moisture out. The eight radials are soldered to the four lugs on the aluminum bracket. The two sections of the vertical member are separated by a piece of clear acrylic rod. Approximately 8 inches of $^{7}/_{8}$-inch OD material is required. The aluminum tubing must be slit lengthwise for several inches so the acrylic rod may be inserted. The two pieces of aluminum tubing are separated by $2^{1}/_{4}$ inches.

The trap capacitor is made from RG-8 coaxial cable and is 30.5 inches long. RG-8 cable has 29.5 pF of capacitance per foot and RG-58 has 28.5 pF per foot. RG-8 cable is recommended over RG-58 because of its higher breakdown-voltage characteristic. The braid should be pulled back 2 inches on one end of the cable, and the center conductor soldered to one end of the coil. Solder the braid to the other end of the coil. Compression type hose clamps are placed over the capacitor/coil leads and put in position at the edges of the aluminum tubing. When tightened securely, the clamps serve a two-fold purpose—they keep the trap in contact with the vertical members and prevent the aluminum tubing from slipping off the acrylic rod. The coaxial-cable capacitor runs upward along the top section of the antenna. This is the side of the antenna to which the braid of the capacitor is connected. A cork or plastic cap should be placed in the very top of the antenna to keep moisture out.

Installation and Operation

The antenna may be mounted in position using a TV-type tripod, chimney, wall or vent mount. Alternatively, a telescoping mast or ordinary steel TV mast may be used, in which case the radials may be used as guys for the structure. The 28-MHz radials are 8 feet 5 inches long, and the 21-MHz radials are 11 feet 7 inches.

Any length of 52-Ω cable may be used to feed the antenna. The SWR at resonance should be on the order of 1.2:1 to 1.5:1 on both bands. The reason the SWR is not 1 is that the feed-point resistance is something other than 52 Ω—closer to 35 or 40 Ω.

Adapting Manufactured Trap Verticals to 10, 18 and 24 MHz

The frequency coverage of a multiband HF vertical antenna can be modified simply by altering the lengths of the tubing sections and/or adding a trap. Several companies manufacture trap verticals covering 7, 14, 21 and 28 MHz. Many amateurs roof-mount these antennas for any of a number of reasons—because an effective ground radial system isn't practical, to keep children away from the antenna, or to clear metal-frame buildings. On the three highest frequency bands, the tubing and radial lengths are convenient for rooftop installations, but 7 MHz sometimes presents problems. Prudence dictates erecting an antenna with the assumption that it will fall down. When the antenna falls, it and the radial system must clear any nearby power lines. Where this consideration rules out 7-MHz operation, careful measurement may show that 10-MHz dimensions will allow adequate safety. The antenna is resonated by pruning the tubing above the 14-MHz trap and installing tuned radials.

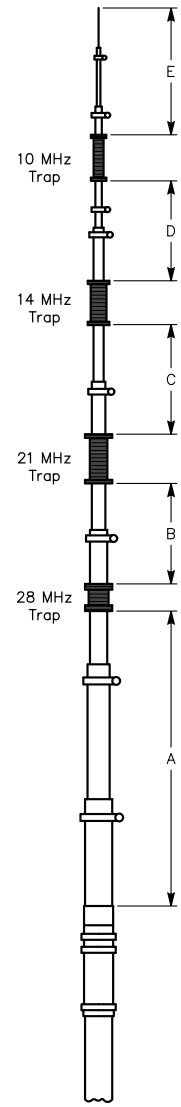
Several new frequency combinations are possible. The simpler ones are 24/28, 18/21/28, and 7/10/14/21/28 MHz. These are shown in **Fig 28** as applied to the popular ATV series of trap verticals manufactured by Cushcraft. Operation in the 10-MHz band requires an additional trap—use Fig 26 as a guide for constructing this component.

Combining Vertical and Horizontal Conductors

The performance of vertical antennas such as just described depends a great deal on the quality of the ground system. If you can eliminate the ground connection as a part of the antenna system, it simplifies things. **Fig 29** shows how it can be done. Instead of a ground, the system is completed by a wire—preferably, but not necessarily, horizontal—of the same length as the antenna. This makes a center-fed system somewhat like a dipole.

It is desirable that the length of each conductor be on the order of 30 feet, as shown in the drawing, if the 3.5-MHz band is to be used. At 7 MHz, this length doesn't really represent a compromise, since the total length is almost $^1/_2$ λ overall on that band. Because the shape of the antenna differs from that of a regular $^1/_2$-λ dipole, the radiation characteristics will be different, but the efficiency will be high on 7 MHz and higher frequencies. Although the vertical radiating part is only about $^1/_8$ λ at 3.5 MHz, the efficiency on this band, too, will be higher than it would be with a grounded system. If one is not interested in 3.5 MHz and can't use the dimensions shown, the lengths can be reduced. Fifteen feet in both the vertical and horizontal conductors will not do too badly on 7 MHz and will not be greatly handicapped, as compared with a $^1/_2$-λ dipole, on 14 MHz and higher.

The vertical part can be mounted in a number of ways. However, if it can be put on the roof of your house, the extra height will be worthwhile. **Fig 30** suggests a simple base mount using a glass bottle as an insulator. Get one with a neck diameter that will fit into the tubing used for the vertical part of the antenna. To help prevent possible breakage, put a



Band, MHz	A	B	C	D	E
			Dimension		
24/28	95-1/2″	2-1/4″	–	–	–
18/21/28	95-1/2″	15″	4-3/4″	–	–
7/10/14/21/28	95-1/2″	15″	28-1/4″	19-3/4″	44-1/8″

Fig 28—Modified dimensions for the ATV series Cushcraft vertical antennas for some frequency combinations that include the WARC bands. The 10-MHz trap inductor consists of 20 turns of #16 enameled wire close-wound on a $^5/_8$-inch diam-eter Plexiglas rod. The capacitor is a 29$^3/_4$-inch length of RG-58 cable.

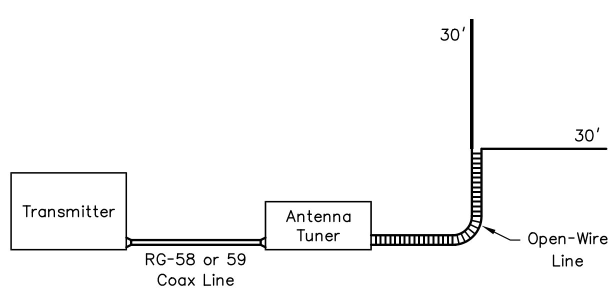


Fig 29—Vertical and horizontal conductors combined. This system can be used on all bands from 3.5 to 28 MHz with good results.

piece of some elastic material such as rubber sheet around the bottle where the tubing rests on it.

The lower wire conductor doesn't actually have to be horizontal. It can be at practically any angle that will let it run off in a straight line to a point where it can be secured. Use an insulator at this point, of course.

TV ladder line should be used for the feeder in this system. On most bands the standing wave ratio will be high, and you will lose a good deal of power in the line if you try to use coax, or even 300-Ω twin-lead. This system can be tuned up by using an SWR indicator in the coax line between the transmitter and a Transmatch.

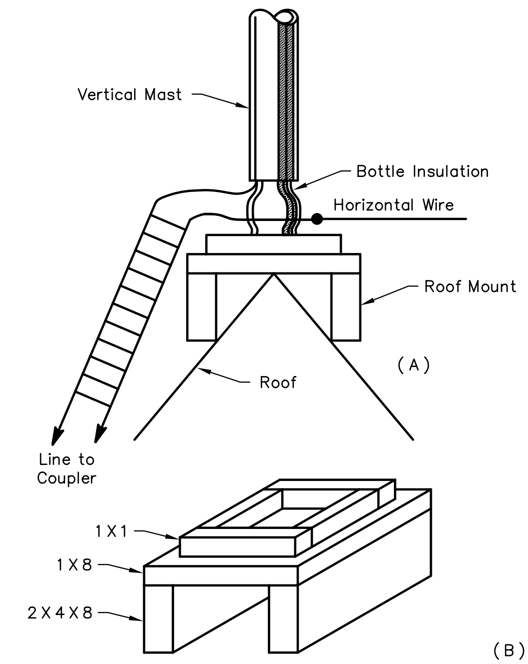


Fig 30—One method of mounting the vertical section on a rooftop. The mounting base dimensions can be adjusted to fit the pitch of the roof. The 1 × 1 pieces should fit snugly around the bottom of the bottle to keep it from shifting position.

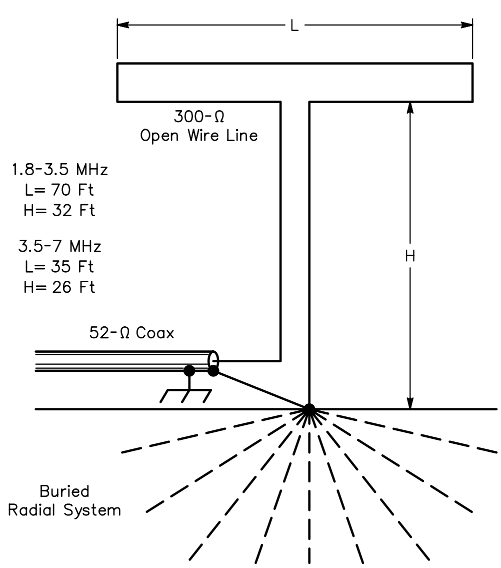


Fig 31—Two-band operation in limited space may be obtained with the multee antenna. The portion identified as H should remain as vertical as possible, as it does the radiating on the lower frequency band.

The Multee Antenna

Two-band operation may be obtained on 1.8/3.5 MHz or on 3.5/7 MHz within the confines of the average city lot by using the multee antenna shown in **Fig 31**. Dimensions are given for either pair of bands in the drawing. If built for the lower frequencies, the top portion will do little radiating on 1.8 MHz; it acts merely as top loading for the 52-foot vertical section. On 3.5 MHz, the horizontal portion radiates and the vertical section acts as a matching stub to transform the high feed-point impedance to the coaxial cable impedance.

Since the antenna must work against ground on its lower frequency band, it is necessary to install a good ground system. Minimum requirements in this regard would include 20 radials, each 55 to 60 feet long for the 1.8/3.5-MHz version, or half that for the 3.5/7-MHz version. If not much area is available for the radial system, wires as short as 25 feet long (12 feet for 3.5/7-MHz) may be used if many are installed, but some reduction in efficiency will result.

With suitable corrections in length to account for the velocity factor, 300-Ω TV twin-lead may be substituted for the open wire. The velocity factor should be taken into account for both the vertical and horizontal portions, to preserve the impedance relationships.

HARMONIC RADIATION FROM MULTIBAND ANTENNAS

Since a multiband antenna is intentionally designed for operation on a number of different frequencies, any harmonics or spurious frequencies that happen to coincide with one of the antenna resonant frequencies will be radiated with very little, if any, attenuation. Particular care should be exercised, therefore, to prevent such harmonics from reaching the antenna.

Multiband antennas using tuned feeders have a certain inherent amount of built-in protection against such radiation, since it is nearly always necessary to use a tuned coupling circuit (Transmatch) between the transmitter and the feeder. This adds considerable selectivity to the system and helps to discriminate against frequencies other than the desired one.

Multiple dipoles and trap antennas do not have this feature, since the objective in design is to make the antenna show as nearly as possible the same resistive impedance in all the amateur bands the antenna is intended to cover. It is advisable to conduct tests with other amateur stations to determine whether harmonics of the transmitting frequency can be heard at a distance of, say, a mile or so. If they can, more selectivity should be added to the system since a harmonic that is heard locally, even if weak, may be quite strong at a distance because of propagation conditions.

THE DISCONE ANTENNA

The discone is a vertically polarized broadband antenna which maintains an SWR of 1.5:1 or less, over several octaves in frequency. **Fig 32** shows the configuration of the antenna. Dimension L of the equilaterally skirted bottom section is approximately equal to the free-space $^1/_4$-wavelength at the lowest frequency for which the antenna is built.

Below the design frequency, the SWR rises rapidly, but within its "resonant" region the antenna provides an excellent match to the popular 52-Ω coax.

Because of its physical bulk at HF, the antenna has not enjoyed much use by amateurs working in that part of the spectrum. However, the antenna has much to offer at VHF and UHF. If designed for 50 MHz, for example, the antenna will also work well on 144 and 222 MHz. Construction at HF would best be done by simulating the skirt with a grid of wires. On VHF and UHF there would be no problem in fashioning a solid skirt of some easily workable metal, such as flashing copper.

The disc-like top-hat section should be insulated from the skirt section. This is usually done with a block of material strong enough to support the disc. The inner conductor of the coax runs up through this block and is attached to the disc; the shield of the coax is connected to the skirt section.

The optimum spacing of the disc from the skirt varies as a function of the part of the spectrum for which the antenna is designed. At HF this spacing may be as much as 6 inches for 14 MHz, while at 144 MHz the spacing may be only 1 inch. It does not appear to be particularly critical.

The gain of the discone is essentially constant across its useful frequency range. The angle of radiation is very low, for the most part, rising only slightly at some frequencies.

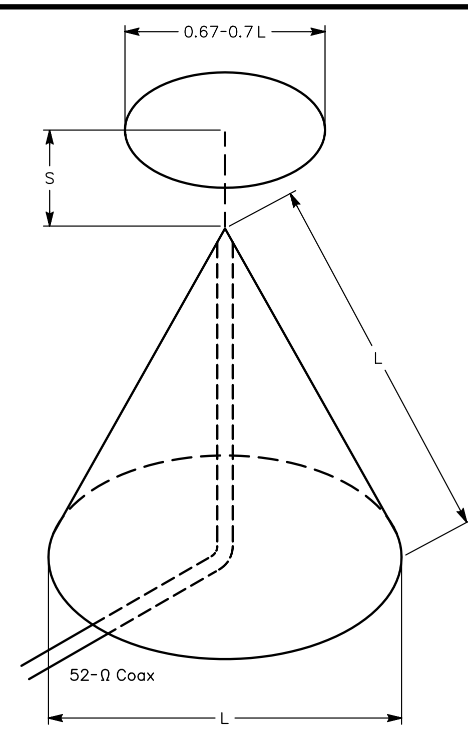


Fig 32—The discone antenna is a wideband, coaxially fed type best suited to VHF and UHF coverage because of its cumbersome size at HF. Dimension L is equal to a free-space quarter wavelength at the lowest operating frequency. The profile of the skirt is an equilateral triangle; the skirt itself can be of a cage type of construction, with adjoining wires separated by not more than 0.02 λ at the bottom of the cone. Dimension S varies from 1 to 6 inches, depending on the low-frequency cutoff of the design.

AN HF DISCONE ANTENNA

The problem of covering all of the existing amateur HF allocations without complications or compromises seems formidable. A discone (a contraction of disc and cone) is one possible solution. Developed in 1945 by Armig G. Kandoian, this antenna can provide efficient radiation and low SWR over a decade of bandwidth. (See Bibliography.) Thus, it should be possible to cover the 3.5 to 29.7-MHz spectrum with a single antenna and transmission line. However, this would require a 75-foot vertical structure and a clear circular area 65 feet in diameter on the ground. These dimensions are impractical for many amateurs, but a 7 through 29.7-MHz version should be practical at most locations. John Belrose, VE2CV, described the design presented here in July 1975 *QST*.

The antenna comprises a vertical cone beneath a horizontal disc (see Fig 33). For frequencies within the range of the antenna, radiation results from a resonance between the fields caused by current flow over the disc and over the surface of the cone, which is established by its flare angle. The apex of the cone, which is vertical, approaches and becomes common with the outer conductor of the coaxial feeder at its extremity. The center conductor of the coaxial feeder terminates at the center of the disc, which is perpendicular to the axis of the cone and the feed line. The discone can be thought of as an upside-down conical monopole.

The advantages of the discone are that it can be operated remote from and independent of ground. Furthermore, since the current maximum is at the top instead of at the bottom of the antenna, and since its structural configuration lends itself to mounting on a pole or on top of a building, the radiation characteristics of a practical discone antenna can approximate an ideal dipole antenna in free space. The change of impedance versus frequency is, however, very much less than for any ordinary dipole, even dipoles with rather small length to diameter ratios. The same is true for the radiation characteristics of the discone.

The antenna exhibits good impedance characteristics over a 10:1 frequency range and low-angle radiation with little change in the radiation pattern over a 3:1 or 4:1 frequency range. At the high-frequency end, the pattern begins to turn upward, with a resulting decrease in the radiation at low elevation angles. The discone antenna may be visualized as a radiator intermediate between a conventional dipole and a biconical horn. A biconical horn is essentially a conical dipole operated at frequencies for which the physical dimensions of the antenna become large compared with a wavelength. At the lower frequencies the antenna behaves very much like a dipole; at much higher frequencies it becomes essentially a horn radiator.

Design Considerations

Refer to the sketch of the discone radiator in **Fig 33**. The following nomenclature is used:

ϕ = cone flare angle (total)
L_S = slant height of cone
L_V = vertical distance from the disc to the base of the cone
C_{max} = maximum diameter of cone
C_{min} = minimum diameter of cone
D = diameter of disc
S = disc-to-cone spacing

The optimum parameters for discone antennas are as follows:

$S = 0.3\ C_{min}$
$D = 0.7\ C_{max}$

and typically, for an optimum design

$L_S/C_{min} > 22$
$\phi = 60°$

The performance of the antenna is not critical in regard to the value of flare angle ϕ, except there is less irregularity in the SWR versus frequency if ϕ is greater than 50°, although values of ϕ above 90° were not investigated. Since the bandwidth is

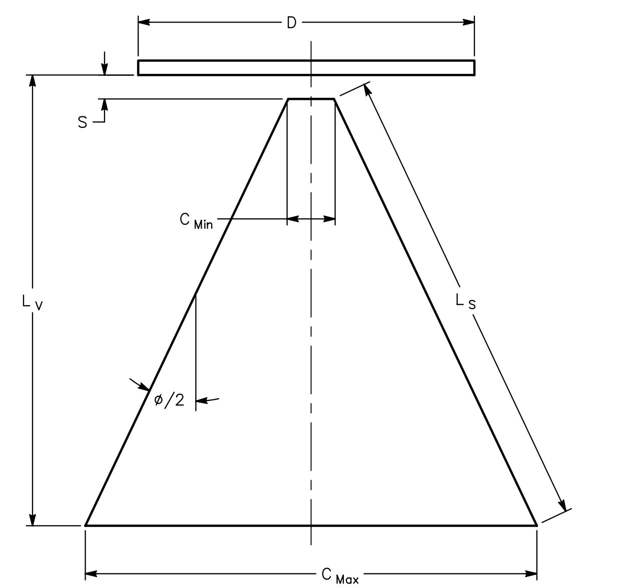


Fig 33—Cross-section sketch of the discone antenna. See text for definitions of terms.

inversely proportional to C_{min}, that dimension must be small. For a frequency range of 10 to 1, L_s/C_{min} should be greater than 22.

From the circuit standpoint, the discone antenna behaves essentially as a high-pass filter. It has an effective cutoff frequency, f_c, below which it becomes very inefficient, causing severe standing waves on the coaxial feed line. Above the cutoff frequency, little mismatch exists and the radiation pattern remains essentially the same over a wide range of frequencies (from some minimum frequency, f_{min}, to some maximum frequency, f_{max}). The slant height of the cone, L_s, is approximately equal to a quarter wavelength at the cutoff frequency, f_c, and the vertical height (or altitude) of the cone is approximately a quarter wavelength at the lowest operating frequency, f_{min}.

The radiation from the discone can be viewed in this somewhat oversimplified way. A traveling wave, excited by the antenna input between the apex of the cone and the disc, travels over the surface of the cone toward the base until it reaches a distance along the slant surface of the cone where the vertical dimension between that point and the disc is a quarter wavelength. The wave field therefore sees a resonant situation and is almost entirely radiated.

For f_{min} = 7.0 MHz and a velocity factor for propagation along the surface of the cone equal to 0.96,

$$L_V = \frac{2834}{f_{min}} = 405 \text{ in.}$$

If $\phi = 60°$, then L_s = 468 in. and

$$f_C = \frac{2834}{L_S} = 6.22 \text{ MHz}$$

The disc diameter is $D = 0.7\ C_{max} = 0.7 \times 456 = 319.2$ in.

For C_{min} = 13.5 in. (a practical dimension, as we shall see later),$S = 0.3\ C_{min} = 0.3 \times 13.5 = 4$ in.

The ratio L_s/C_{min} = 456/13.5 = 33.7.

The frequency response of a discone antenna constructed with these dimensions is shown in **Fig 34**. Here we see that the SWR is 3.25:1 at f_c and decreases rapidly with increasing frequency to about 1.5:1 at f_{min}. The SWR is less than 1.5 over the frequency range 7 to 23 MHz. While this ratio increases for frequencies above 23 MHz, the SWR is less than 2.5:1 over the frequency range 6.5 to 30 MHz, except for the irregularity for frequencies 23.5 to 25.5 MHz. The SWR peak in the frequency range 23.5 to 25.5 MHz is thought to be caused by a resonance in the metal structure of a nearby part of the building on which the discone antenna was mounted. During these measurements the antenna was mounted on a flat roof, 70 feet from a penthouse that is 21.25 feet high (including the grounded metal rail around the top). This height is a resonant $\lambda/2$ at 24.4 MHz.

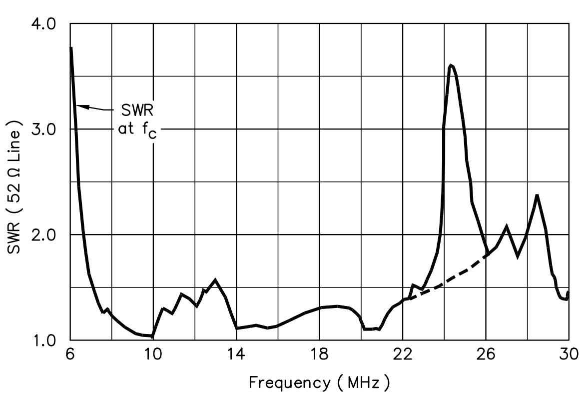


Fig 34—Standing-wave ratio versus frequency for the discone antenna designed for operation on 7 MHz and above. The “spike” in the curve at approximately 24 MHz is believed to be caused by an adjacent metal structure, as explained in the text.

Practical Construction

At HF, the discone can be built using closely spaced wires to simulate the surface of the cone. The disc can be simulated by a structure consisting of eight spreaders with wires connected between them. It is important that a skirt wire connect the bottom ends of all slant wires simulating the cone, and another connect the outer ends of the spreaders which simulate the disc. These wires increase the effectiveness of the wire structures to a considerable extent. An antenna constructed in this way closely approximates the performance of a solid disc and a cone over the frequency range of the antenna.

The discone assembly and construction details are given in **Fig 35**. The antenna is supported by an eight-inch triangular aluminum mast (item 1) that is 36 feet high. The insulator separating the disc and the cone (item 2) is detailed in **Fig 36**. Basically it is two metal plates separated by an insulating section. The lower plate has a coaxial feedthrough connector mounted at its center, and the outer edge is drilled with 24 equally spaced holes, 5/32-inch diameter, on a 13.5-inch diameter circle for the guy wires that simulate the cone. The end of each wire is soldered to a spade lug that is attached to the plate by a self-tapping screw. This plate is bolted to the top of the mast. Eight 1-inch diameter disc spreaders (item 3) are bolted to the top plate. A short 3-foot rod (item 4) is flange-mounted at the center of the upper plate. Supporting cables for the far ends of the spreaders are connected to this rod. The center conductor of the coaxial feed line is attached to the center of the top plate, as shown in Fig 36.

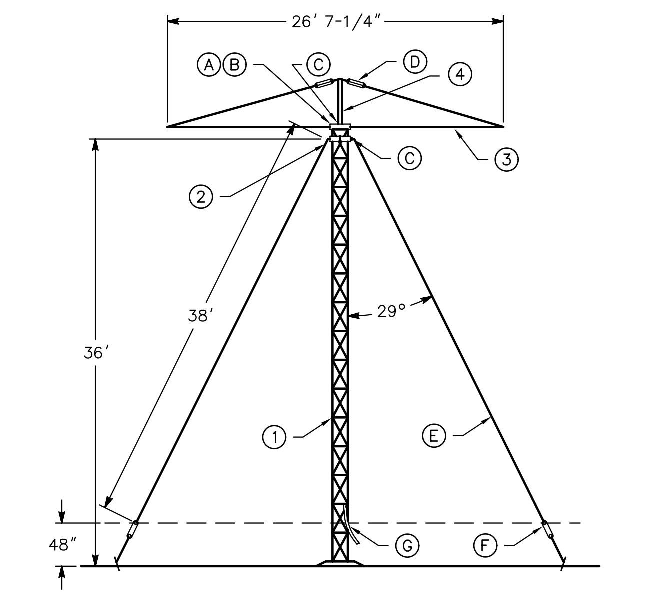


Fig 35—Construction details for the HF discone antenna.

A—Hex-head screw, 1/4-20 × 2 in. long, 16 req'd.
B—Hex nut, 1/4-20 thread, 16 req'd.
C—Hex-head screw, 3/8-16 × 1 in. long, 8 req'd.
D—6-in. turnbuckle, 8 req'd.
E—#12 Copperweld wire, 1400 ft req'd.
F—Porcelain or ceramic insulators, 24 req'd.
G—52-Ω coaxial feed line, length as required. Line is secured to mast and connected at feed point shown in Fig 36.
1—Antenna mast with cap.
2—Insulator subassembly. See Fig 36.
3—Spreaders, made from 1-in. aluminum tubing, 8 req'd.
4—Spreader support, 3-ft length of steel or aluminum pipe or tubing, flange mounted.

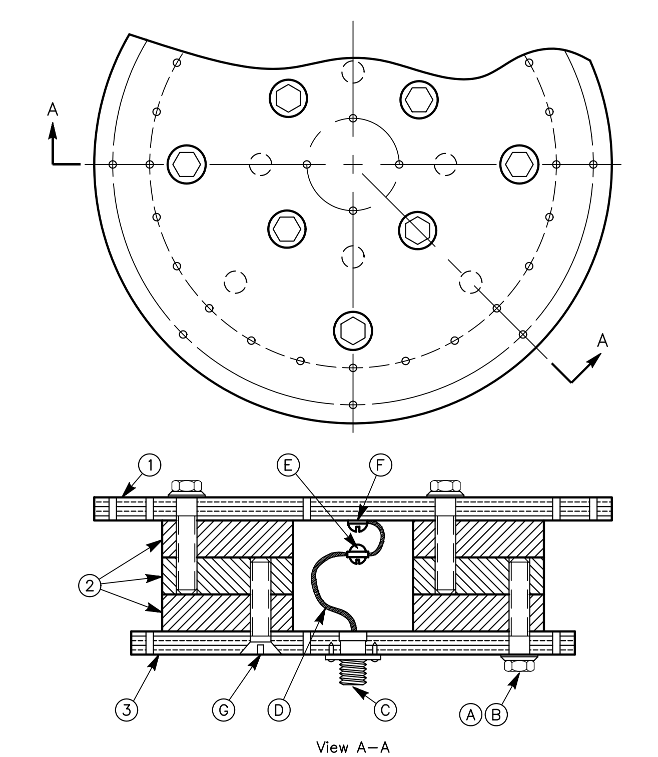


Fig 36—Construction details of insulator subassembly.

A—Hex-head screw, 1/2-13 XB—Flat washers, 1/2-in., 12 req'd.
C—RF connector, as required.
D—6-in. length of copper wire.
E—Wire lug, Emco 14-6 or equiv.
F—Round-head screw, 10-32 × 3/8 in. long.
G—Flat-head screw, 1/2-13 × 2-1/2 in. long, 4 req'd.
1—Aluminum mounting plate for disc spreaders.
2—Phenolic insulator rings.
3—Guy mounting plate.

As shown in **Fig 37**, the antenna is mounted on the flat roof of a three-story building. The height of the lower edge of the cone is 4 feet above the roof. The 24 guy wires simulating the cone are broken by 12-inch porcelain insulators (item F) at their bottom ends. As previously mentioned, the ends of each wire are joined by a skirt, as shown in the drawing.

Performance

The discone antenna shown in the photograph has survived more than one freezing rain ice storm. The entire antenna and all supporting wires on at least one occasion were covered with a 1/2-inch radial thickness of ice. A three-element triband amateur beam covered with this thickness of ice also survived the ice storm but it was unusable at the time; it was detuned too much by the ice sheath. The performance of the discone was unaffected by the ice. In fact, at an operating frequency of about 14 MHz, the SWR was marginally lower when the antenna was covered with ice compared to normal.

The antenna exhibits most of the usual characteristics of a vertical monopole. However, vertical monopole antennas have a characteristic overhead null in the radiation pattern, and for short-distance sky-wave communications a horizontal dipole is generally the better antenna. But communication has always been possible with the discone, to distances beyond that over which the ground wave could be received, provided of course that the ionosphere would reflect a frequency of 7 MHz (the lowest frequency for which the antenna could be used). While there is certainly a null overhead, it is not a very deep one.

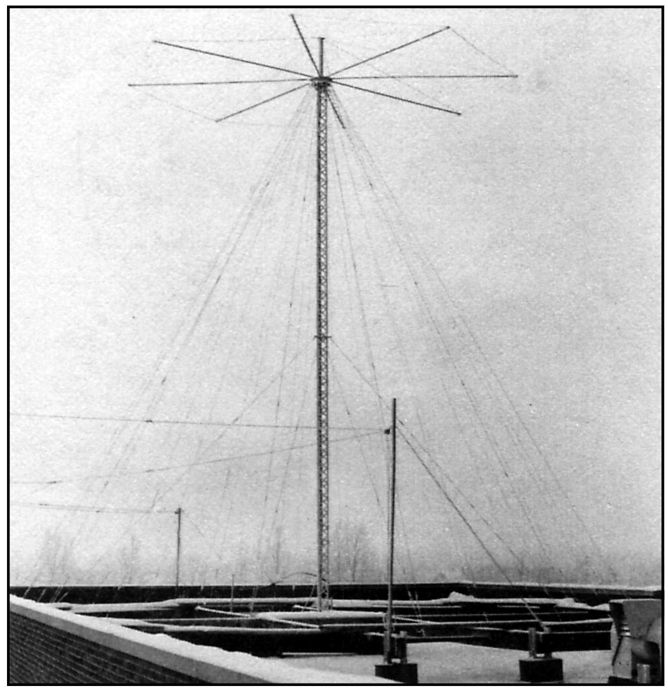


Fig 37—The completed discone antenna, installed on the roof of a three-story building.

THE G5RV MULTIBAND ANTENNA

A multiband antenna that does not require a lot of space, is simple to construct, and is low in cost is the G5RV. Designed in England by Louis Varney, G5RV, some years ago, it has become quite popular in the US. The G5RV design is shown in **Fig 38**. The antenna may be used from 3.5 through 30 MHz. Although some amateurs claim it may be fed directly with 50-Ω coax on several amateur bands with a low SWR, Varney recommends the use of a matching network on bands other than 14 MHz (see Bibliography). In fact, an analysis of the G5RV antenna-terminal impedance shows there is *no* length of balanced line of *any* characteristic impedance that will transform the terminal impedance to the 50-75 Ω range on all bands. In short, a *matching network is required* for multiband operation. (Low SWR indications with coax feed and no matching network on bands other than 14 MHz may indicate excessive losses in the coaxial line.)

The portion of the antenna shown as horizontal in Fig 38 may be installed in an inverted-V dipole arrangement. Or instead, up to 1/6 of the total length of the antenna at each end may be dropped vertically, semi-vertically, or bent at a convenient angle to the main axis of the antenna.

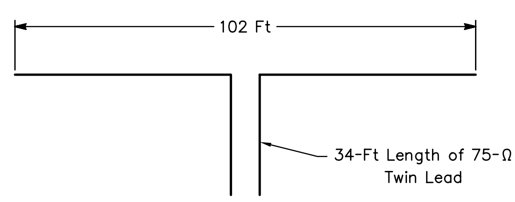


Fig 38—The G5RV multiband antenna covers 3.5 through 30 MHz. Although many amateurs claim it may be fed directly with 50-Ω coax on several amateur bands, Louis Varney, its originator, recommends the use of a matching network on bands other than 14 MHz.

THE WINDOM ANTENNA

An antenna that enjoyed popularity in the 1930s and into the 1940s was what we now call the Windom. It was known at the time as a "single-feeder Hertz" antenna, after being described in September 1929 *QST* by Loren G. Windom, W8GZ (see Bibliography).

The Windom antenna, shown in **Fig 39**, is fed with a single wire, attached approximately 14% off center. The system is worked against an earth ground. Because the feed line is brought to the operating position, "RF in the shack" and a potential radiation hazard may be experienced with this antenna.

OFF-CENTER-FED DIPOLES

Fig 40 shows the off-center-fed or OCF dipole. Because it is similar in appearance to the Windom of Fig 39, this antenna is often mistakenly called a "Windom," or sometimes a "coax-fed Windom." The two antennas are not the same, as the Windom is worked against its image in the ground, while one leg is worked against the other in the OCF dipole.

It is not necessary to feed a dipole antenna at its center, although doing so will allow it to be operated with a relatively low feed-point impedance on its fundamental and odd harmonics. (For example, a 7-MHz center-fed half-wave dipole can also be used for 21-MHz operation.) By contrast, the OCF dipole of Fig 40, fed $^1/_3$ of its length from one end, may be used on its fundamental and *even* harmonics. Its free-space antenna-terminal impedance at 3.5, 7 and 14 MHz is on the order of 150 to 200 Ω. A 1:4 step-up transformer at the feed point should offer a reasonably good match to 50 or 75-Ω line, although some commercially made OCF dipoles use a 1:6 transformer.

At the 6th harmonic, 21 MHz, the antenna is three wavelengths long and fed at a voltage loop (maximum), instead of a current loop. The feed-point impedance at this frequency is high, a few thousand ohms, so the antenna is unsuitable for use on this band.

Balun Requirement

Because the OCF dipole is not fed at the center of the radiator, the RF impedance paths of the two wires at the feed point are unequal. If the antenna is fed directly with coax (or a balanced line), or if a voltage step-up transformer is used, then voltages of equal magnitude (but opposite polarity) are applied to the wires at the feed point. Because of unequal impedances, the resulting antenna currents flowing in the two wires will not be equal. (This also means that antenna current can flow on the feeder—on the outside of the coaxial line. How much current flows there depends on the impedance of the RF current path down the outside of the feed line.) This is not a desirable situation. Rather, equal *currents* are required at the feed point, with the same current flowing in and out of the short leg as in and out of the long leg of the radiator. A *current* or *choke* type of balun provides just such operation. (Current baluns are discussed in detail in Chapter 26.)

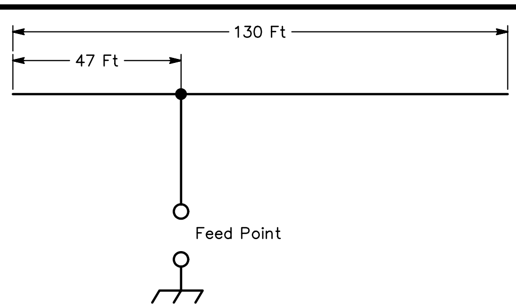


Fig 39—The Windom antenna, cut for a fundamental frequency of 3.75 MHz. The single-wire feeder, connected 14% off center, is brought into the station and the system is fed against ground. The antenna is also effective on its harmonics.

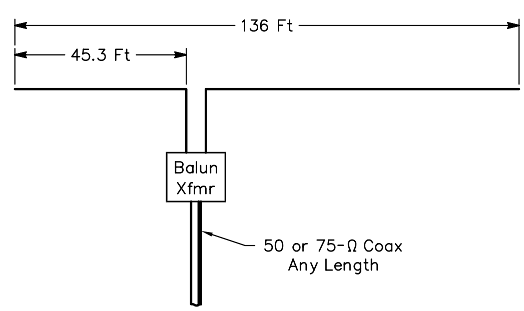


Fig 40—The off-center-fed (OCF) dipole for 3.5, 7 and 14 MHz. A 1:4 or 1:6 step-up current balun is used at the feed point.

BIBLIOGRAPHY

Source material and more extended discussion of topics covered in this chapter can be found in the references given below and in the textbooks listed at the end of Chapter 2.

H. B. Barkley, *The Open-Sleeve As A Broadband Antenna*, Technical Report No. 14, U.S. Naval Postgraduate School, Monterey, CA, Jun 1955.

W. M. Bell, "A Trap Collinear Antenna," *QST*, Aug 1963, pp 30-31.

J. S. Belrose, "The HF Discone Antenna," *QST*, Jul 1975, pp 11-14, 56.

J. Belrose and P. Bouliane, "The Off-Center-Fed Dipole Revisited: A Broadband, Multiband Antenna," *QST*, Aug 1990, pp 28-32. Also see "Feedback," *QST*, Oct 1990, p 40.

H. J. Berg, "Multiband Operation with Paralleled Dipoles," *QST*, Jul 1956.

E. L. Bock, J. A. Nelson and A. Dorne, "Sleeve Antennas," *Very High Frequency Techniques*, H.J. Reich, ed. (New York: McGraw-Hill, 1947), Chapter 5.

J. T. Bolljahn and J. V. N. Granger, "Omnidirectional VHF and UHF Antennas," *Antenna Engineering Handbook*, H. Jasik, ed. (New York: McGraw-Hill, 1961) pp 27-32 through 27-34.

G. H. Brown, "The Phase and Magnitude of Earth Currents Near Radio Transmitting Antennas," *Proc. IRE*, Feb 1935.

G. H. Brown, R. F. Lewis and J. Epstein, "Ground Systems as a Factor in Antenna Efficiency," *Proc. IRE*, Jun 1937, pp 753-787.

C. L. Buchanan, "The Multimatch Antenna System," *QST*, Mar 1955.

R. A. Cox, "The Open-Sleeve Antenna," *CQ*, Aug 1983, pp 13-19.

D. DeMaw, "Lightweight Trap Antennas–Some Thoughts," *QST*, Jun 1983, p 15.

W. C. Gann, "A Center-Fed 'Zepp' for 80 and 40," *QST*, May 1966.

A. Greenberg, "Simple Trap Construction for the Multiband Antenna," *QST*, Oct 1956.

G. L. Hall, "Trap Antennas," Technical Correspondence, *QST*, Nov 1981, pp 49-50.

W. Hayward, "Designing Trap Antennas," Technical Correspondence, *QST*, Aug 1976, p 38.

R. H. Johns, "Dual-Frequency Antenna Traps," *QST*, Nov 1983, p 27.

A. G. Kandoian, "Three New Antenna Types and Their Applications," *Proc IEE*, Vol 34, Feb 1946, pp 70W-75W.

R. W. P. King, *Theory of Linear Antennas* (Cambridge, MA: Harvard Univ Press, 1956), pp 407-427.

W. J. Lattin, "Multiband Antennas Using Decoupling Stubs," *QST*, Dec 1960.

W. J. Lattin, "Antenna Traps of Spiral Delay Line," *QST*, Nov 1972, pp 13-15.

M. A. Logan, "Coaxial-Cable Traps," Technical Correspondence, *QST*, Aug 85, p 43.

J. R. Mathison, "Inexpensive Traps for Wire Antennas," *QST*, Aug 1977, p 18.

L. McCoy, "An Easy-to-Make Coax-Fed Multiband Trap Dipole," *QST*, Dec 1964.

G. E. O'Neil, "Trapping the Mysteries of Trapped Antennas," *Ham Radio*, Oct 1981, pp 10-16.

L. Richard, "Parallel Dipoles of 300-Ω Ribbon," *QST*, Mar 1957.

D. P. Shafer, "Four-Band Dipole with Traps," *QST*, Oct 1958.

R. C. Sommer, "Optimizing Coaxial-Cable Traps," *QST*, Dec 1984, p 37.

L. Varney, "The G5RV Multiband Antenna . . . Up-to-Date," *The ARRL Antenna Compendium, Volume 1* (Newington: ARRL)

L. G. Windom, "Notes on Ethereal Antennas," *QST*, Sep 1929, pp 19-22, 84.