

Mobile and Maritime Antennas

Mobile antennas are those designed for use while antennas, most amateurs think of a whip mounted on an automobile or other highway vehicle, perhaps on a recreational vehicle (RV) or maybe on an off-road vehicle. While it is true that most mobile antennas are vertical whips, mobile antennas can also be found in other places. For example, antennas mounted aboard a boat or ship are mobile, and are usually called *maritime antennas*. **Fig 1** shows yet another type of mobile antenna—those for use on handheld transceivers. Because they may be used while in motion, even these antennas are mobile by literal definition.

Pictured in Fig 1 is a telescoping full-size quarter-wave antenna for 144 MHz, and beside it a *stubby* antenna for the same band. The stubby is a helically wound radiator, made of stiff copper wire enclosed in a protective covering of rubber-like material. The inductance of the helical windings provides electrical loading for the antenna. For frequencies above 28 MHz, most mobile installations

permit the use of a full-size antenna, but sometimes smaller, loaded antennas are used for convenience. The stubby, for example, is convenient for short-range communications, avoiding the problems of a lengthier, cumbersome antenna attached to a handheld radio.

Below 28 MHz, physical size becomes a problem with full-size whips, and some form of electrical loading (as with the stubby) is usually employed. Commonly used loading techniques are to place a coil at the base of the whip (base loading), or at the center of the whip (center loading). These and other techniques are discussed in this chapter.

Few amateurs construct their own antennas for HF mobile and maritime use, since safety reasons dictate very sound mechanical construction. Several construction projects are included, however, in this chapter for those who may wish to build their own mobile antenna. Even if commercially made antennas are installed, most require some adjustment for the particular installation and type of operation desired and the information given here may provide a better understanding of the optimization requirements.

HF-MOBILE FUNDAMENTALS

Fig 2 shows a typical bumper-mounted center-loaded whip suitable for operation in the HF range. Jack Schuster, W1WEF, operates 80 through 2 meters from his car. The antenna could also be mounted on the car body itself (such as a fender), and mounts are available for this purpose. The base spring and tennis ball act as shock absorbers for the bottom of the whip, as the continual flexing while in motion would otherwise weaken the antenna. A short heavy mast section is mounted between the base spring and loading coil. Some models have a mechanism that allows the antenna to be tipped over for adjustment or for fastening to the roof of the car when not in use.

It is also advisable to extend a couple of guy lines from the base of the loading coil to clips or hooks fastened to the roof gutter on the car, or to the trunk and

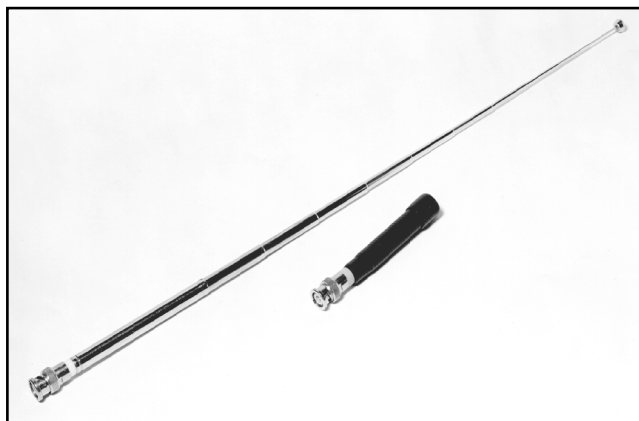


Fig 1—Two mobile antennas—mobile because they may be used while in motion. Shown here are a telescoping $\frac{1}{4}$ - λ antenna and a “stubby” antenna, both designed for use at 144 MHz. The $\frac{1}{4}$ - λ antenna is 19 inch long, while the stubby antenna is only 3½ inch long. (Both dimensions exclude the length of the BNC connectors. The stubby is a helically wound radiator.



Fig 2—A typical bumper-mounted HF mobile antenna, as used by W1WEF. Note the nylon guy lines and the tennis ball used as a shock absorber. (Photo courtesy W1WEF.)

rear bumper, as W1WEF has done. Nylon fishing line (about 40-pound test) is suitable for this purpose. The guy lines act as safety cords and also reduce the swaying motion of the antenna considerably. The feed line to the transmitter is connected to the bumper and base of the antenna. Good low-resistance connections are important here.

Tune-up of the antenna is usually accomplished by changing the height of the adjustable whip section above the precut loading coil. First, tune the receiver and try to determine where the signals seem to peak up. Once this frequency is found, check the SWR with the transmitter on, and find the frequency where the SWR is lowest. Shortening the adjustable section will increase the resonant frequency, and making it longer will lower the frequency. It is important that the antenna be away from surrounding objects such as overhead wires by ten feet or more, as considerable detuning can occur. Once the setting is found where the SWR is lowest at the center of the desired frequency range, the length of the adjustable section should be recorded.

Propagation conditions and ignition noise are usually the limiting factors for mobile operation on 10 through 28 MHz. Antenna size restrictions affect operation somewhat on 7 MHz and much more on 3.5 and 1.8 MHz. From this standpoint, perhaps the optimum band for HF-mobile operation is 7 MHz. The popularity of the regional mobile nets on 7 MHz is perhaps the best indication of its suitability. For local work, 28 MHz is also useful, as antenna efficiency is high and relatively simple antennas without loading coils are easy to build.

As the frequency of operation is lowered, an antenna

of fixed length looks (at its feed point) like a decreasing resistance in series with an increasing capacitive reactance. The capacitive reactance must be tuned out, necessitating the use of an equivalent series inductive reactance or loading coil. The amount of inductance required will be determined by the placement of the coil in the antenna system.

Base loading requires the lowest value of inductance for a fixed-length antenna, and as the coil is placed farther up the whip, the necessary value increases. This is because the capacitance of the shorter antenna section (above the coil) to the car body is now lower (higher capacitive reactance), requiring more inductance to tune the antenna to resonance. The advantage is that the current distribution on the whip is improved, increasing the radiation resistance. The disadvantage is that requirement of a larger coil also means the coil size and losses increase. Center loading has been generally accepted as a good compromise with minimal construction problems. Placing the coil $\frac{2}{3}$ the distance up the whip seems to be about the optimum position.

For typical antenna lengths used in mobile work, the difficulty in constructing suitable loading coils increases as the frequency of operation is lowered. Since the required resonating inductance gets larger and the radiation resistance decreases at lower frequencies, most of the power is dissipated in the coil's loss resistance and in other ohmic losses. This is one reason why it is advisable to buy a commercially made loading coil with the highest power rating possible, even if only low-power operation is planned.

Coil losses in the higher-power loading coils are usually less (percentage-wise), with subsequent improvement in radiation efficiency, regardless of the power level used. Of course, the above philosophy also applies to home-made loading coils, and design considerations will be considered in a later section.

Once the antenna is tuned to resonance, the input impedance at the antenna terminals will look like a pure resistance. Neglecting losses, this value drops from nearly 15 Ω at 21 MHz to 0.1 Ω at 1.8 MHz for an 8-foot whip. When coil and other losses are included, the input resistance increases to approximately 20 Ω at 1.8 MHz and 16 Ω at 21 MHz. These values are for relatively high-efficiency systems. From this it can be seen that the radiation efficiency is much poorer at 1.8 MHz than at 21 MHz under typical conditions.

Since most modern gear is designed to operate with a 50- Ω transmission line, a matching network is usually necessary, especially with the high-efficiency antennas previously mentioned. This can take the form of either a broadband transformer, a tapped coil, or an LC matching network. With homemade or modified designs, the tapped-coil arrangement is perhaps the easiest one to build, while the broadband transformer requires no adjustment. As the losses go up, so does the input resis-

tance, and in less efficient systems the matching network may not be needed.

The Equivalent Circuit of a Typical Mobile Antenna

In the previous section, some of the general considerations were discussed, and these will now be taken up in more detail. It is customary in solving problems involving electric and magnetic fields (such as antenna systems) to try to find an equivalent network with which to replace the antenna for analysis reasons. In many cases, the network may be an accurate representation over only a limited frequency range. However, this is often a valuable method in matching the antenna to the transmission line.

Antenna resonance is defined as the frequency at which the input impedance at the antenna terminals is purely resistive. The shortest length at which this occurs for a vertical antenna over a ground plane is when the antenna is an electrical quarter wavelength at the operating frequency; the impedance value for this length (neglecting losses) is about 36Ω . The idea of resonance can be extended to antennas shorter (or longer) than a quarter wave, and means only that the input impedance is purely resistive. As pointed out previously, when the frequency is lowered, the antenna looks like a series RC circuit, as shown in **Fig 3**. For the average 8-foot whip, the capacitive reactance of C_A may range from about -150Ω at 21 MHz to as high as -8000Ω at 1.8 MHz, while the radiation resistance R_R varies from about 15Ω at 21 MHz to as low as 0.1Ω at 1.8 MHz.

For an antenna less than 0.1λ long, the approximate radiation resistance may be determined from the following:

$$R_R = 273 \times (\ell f)^2 \times 10^{-8} \quad (\text{Eq 1})$$

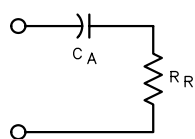


Fig 3—At frequencies below resonance, the whip antenna will show capacitive reactance as well as resistance. R_R is the radiation resistance, and C_A represents the antenna capacitance.

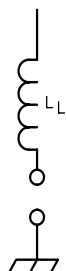


Fig 4—The capacitive reactance at frequencies below the resonant frequency of the whip can be canceled by adding an equivalent inductive reactance in the form of a loading coil in series with the antenna.

where ℓ is the length of the whip in inches, and f is the frequency in megahertz.

Since the resistance is low, considerable current must flow in the circuit if any appreciable power is to be dissipated in the form of radiation in R_R . Yet it is apparent that little current can be made to flow in the circuit as long as the comparatively high series reactance remains.

Antenna Capacitance

Capacitive reactance can be canceled by connecting an equivalent inductive reactance, (coil L_L) in series, as shown in **Fig 4**, thus tuning the system to resonance.

The capacitance of a vertical antenna shorter than a quarter wavelength is given by:

$$C_A = \frac{17\ell}{\left[\left(\ln \frac{24\ell}{D} \right) - 1 \right] \left[1 - \left(\frac{f\ell}{234} \right)^2 \right]} \quad (\text{Eq 2})$$

where

C_A = capacitance of antenna in pF

ℓ = antenna height in feet

D = diameter of radiator in inches

f = operating frequency in MHz

$$\ln \frac{24\ell}{D} = 2.3 \log_{10} \frac{24\ell}{D}$$

Fig 5 shows the approximate capacitance of whip antennas of various average diameters and lengths. For 1.8, 4 and 7 MHz, the loading coil inductance required (when the loading coil is at the base) would be approximately the inductance required to resonate in the desired band (with the whip capacitance taken from the graph). For 10 through 21 MHz, this rough calculation will give more than the required inductance, but it will serve as a

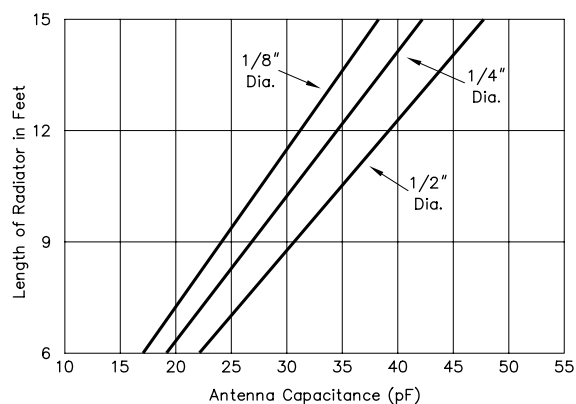


Fig 5—Graph showing the approximate capacitance of short vertical antennas for various diameters and lengths. These values should be approximately halved for a center-loaded antenna.

starting point for the final experimental adjustment that must always be made.

LOADING COIL DESIGN

To minimize loading coil loss, the coil should have a high ratio of reactance-to-resistance (that is, a high unloaded Q). A 4-MHz loading coil wound with small wire on a small-diameter solid form of poor quality, and enclosed in a metal protector, may have a Q as low as 50, with a loss resistance of 50 Ω or more. High- Q coils require a large conductor, air-wound construction, large spacing between turns, and the best insulating material available. A diameter not less than half the length of the coil (not always mechanically feasible) and a minimum of metal in the field of the coil are also necessities for optimum efficiency. Such a coil for 4 MHz may show a Q of 300 or more, with a resistance of 12 Ω or less.

The coil could then be placed in series with the feed line at the base of the antenna to tune out the unwanted capacitive reactance, as shown in Fig 4. Such a method is often referred to as *base-loading*, and many practical mobile antenna systems have been built using this scheme.

Over the years, the question has come up as to whether or not more efficient designs are possible compared with simple base loading. While many ideas have been tried with varying degrees of success, only a few have been generally accepted and incorporated into actual systems. These are center loading, continuous loading, and combinations of the latter with more conventional antennas.

Base Loading and Center Loading

If a whip antenna is short compared to a wavelength and the current is uniform along the length ℓ , the electric field strength E , at a distance d , away from the antenna is approximately:

$$E = \frac{120 \pi I f}{D \lambda} \quad (\text{Eq 3})$$

where

I is the antenna current in amperes

λ is the wavelength in the same units as D and ℓ .

A uniform current flowing along the length of the whip is an idealized situation, however, since the current is greatest at the base of the antenna and goes to a minimum at the top. In practice, the field strength will be less than that given by the above equation, because it is a function of the current distribution on the whip.

The reason that the current is not uniform on a whip antenna can be seen from the circuit approximation shown in Fig 6. A whip antenna over a ground plane is similar in many respects to a tapered coaxial cable where the center conductor remains the same diameter along its length, but with an increasing diameter outer conductor. The inductance per unit length of such a cable would increase along the line, while the capacitance per unit

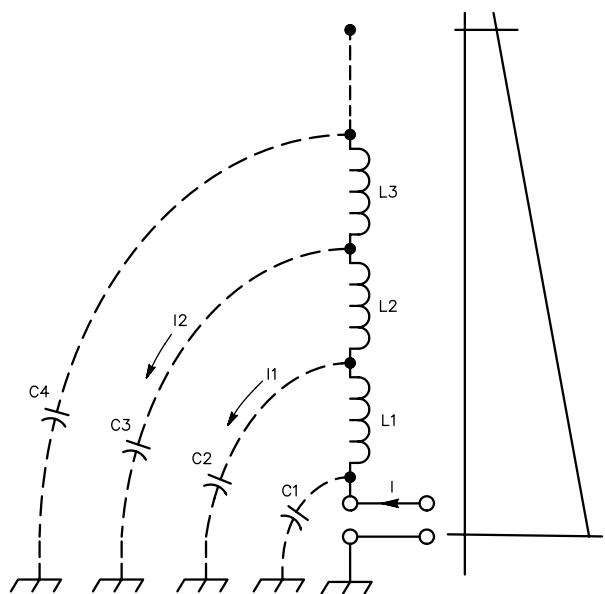


Fig 6—A circuit approximation of a simple whip over a perfectly conducting ground plane. The shunt capacitance per unit length gets smaller as the height increases, and the series inductance per unit length gets larger. Consequently, most of the antenna current returns to the ground plane near the base of the antenna, giving the current distribution shown at the right.

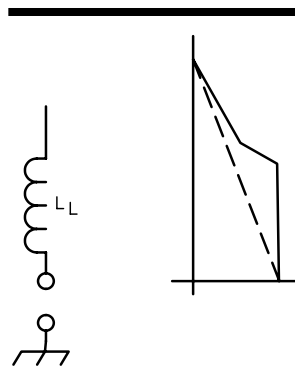


Fig 7—Improved current distribution resulting from center loading.

length would decrease. In Fig 6 the antenna is represented by a series of LC circuits in which C_1 is greater than C_2 , which is greater than C_3 , and so on. L_1 is less than L_2 , which is less than succeeding inductances. The net result is that most of the antenna current returns to ground near the base of the antenna, and very little near the top.

Two things can be done to improve this distribution and make the current more uniform. One would be to increase the capacitance of the top of the antenna to ground through the use of top loading or a capacitance hat, as discussed in Chapter 6. Unfortunately, the wind resistance of the hat makes it somewhat unwieldy for mobile use. The other method is to place the loading coil farther up the whip, as shown in Fig 7, rather than at the base. If the coil is resonant (or nearly so) with the

Table 1**Approximate Values for 8-ft Mobile Whip**

<i>f</i> (MHz)	Loading <i>L</i> μ H	<i>R</i> _C (Q50) Ω	<i>R</i> _C (Q300) Ω	<i>R</i> _R Ω	Feed <i>R</i> * Ω	Matching <i>L</i> μ H
Base Loading						
1.8	345	77	13	0.1	23	3
3.8	77	37	6.1	0.35	16	1.2
7.2	20	18	3	1.35	15	0.6
10.1	9.5	12	2	2.8	12	0.4
14.2	4.5	7.7	1.3	5.7	12	0.28
18.1	3.0	5.0	1.0	10.0	14	0.28
21.25	1.25	3.4	0.5	14.8	16	0.28
24.9	0.9	2.6	—	20.0	22	0.25
29.0	—	—	—	—	36	0.23
Center Loading						
1.8	700	158	23	0.2	34	3.7
3.8	150	72	12	0.8	22	1.4
7.2	40	36	6	3.0	19	0.7
10.1	20	22	4.2	5.8	18	0.5
14.2	8.6	15	2.5	11.0	19	0.35
18.1	4.4	9.2	1.5	19.0	22	0.31
21.25	2.5	6.6	1.1	27.0	29	0.29

*R*_C = loading coil resistance; *R*_R = radiation resistance.

*Assuming loading coil Q = 300, and including estimated ground-loss resistance.

Table 2**Suggested Loading Coil Dimensions**

Req'd <i>L</i> (μ H)	Turns	Wire Size	Dia. Inches	Length Inches
700	190	22	3	10
345	135	18	3	10
150	100	16	2½	10
77	75	14	2½	10
77	29	12	5	4¼
40	28	16	2½	2
40	34	12	2½	4¼
20	17	16	2½	1¼
20	22	12	2½	2¾
8.6	16	14	2	2
8.6	15	12	2½	3
4.5	10	14	2	1¼
4.5	12	12	2½	4
2.5	8	12	2	2
2.5	8	6	2¾	4½
1.25	6	12	1¾	2
1.25	6	6	2¾	4½

capacitance to ground of the section above the coil, the current distribution is improved as also shown in Fig 7. The result with both top loading and center loading is that the radiation resistance is increased, offsetting the effect of losses and making matching easier.

Table 1 shows the approximate loading coil inductance for the various amateur bands. Also shown in the table are approximate values of radiation resistance to be

expected with an 8-foot whip, and the resistances of loading coils—one group having a Q of 50, the other a Q of 300. A comparison of radiation and coil resistances will show the importance of reducing the coil resistance to a minimum, especially on the three lower frequency bands. **Table 2** shows suggested loading-coil dimensions for the inductance values given in Table 1.

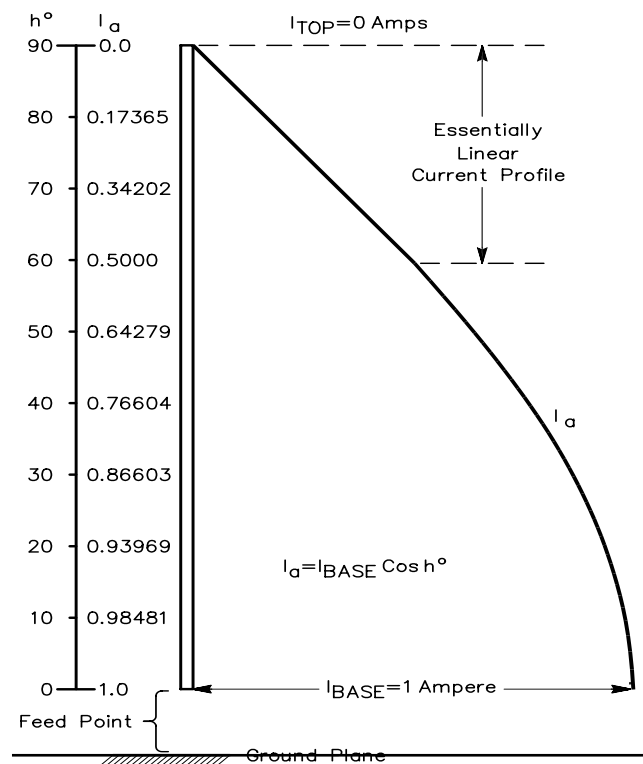
OPTIMUM DESIGN OF SHORT COIL-LOADED HF MOBILE ANTENNAS

Optimum design of short HF mobile antennas results from a careful balance of the appropriate loading coil Q-factor, loading coil position in the antenna, ground loss resistance, and the length-to-diameter ratio of the antenna. The optimum balance of these parameters can be realized only through a thorough understanding of how they interact. This section presents a mathematical approach to designing mobile antennas for maximum radiation efficiency. Bruce Brown, W6TWW, in *The ARRL Antenna Compendium Volume 1*, first presented this approach. (See the Bibliography at the end of this chapter.)

The optimum location for a loading coil in an antenna can be found experimentally, but it requires many hours of designing and constructing models and making measurements to ensure the validity of the design. A faster and more reliable way of determining optimum coil location is through the use of a personal computer. This approach allows the variation of any single variable, while observing the cumulative effects on the system. When plotted graphically, the data reveals that the placement of the loading coil is critical if maximum radiation efficiency

Table 3**Variables used in Eqs 4 through 20**

A	= area in degree-amperes
a	= antenna radius in English or metric units
dB	= signal loss in decibels
E	= efficiency in percent
f (MHz)	= frequency in megahertz
H	= height in English or metric units
h	= height in electrical degrees
h ₁	= height of base section in electrical degrees
h ₂	= height of top section in electrical degrees
I	= I _{base} = 1 ampere base current
k	= 0.0128
k _m	= mean characteristic impedance
k _{m1}	= mean characteristic impedance of base section
k _{m2}	= mean characteristic impedance of top section
L	= length or height of the antenna in feet
P _I	= power fed to the antenna
P _R	= power radiated
Q	= coil figure of merit
R _C	= coil loss resistance in Ω
R _G	= ground loss resistance in Ω
R _R	= radiation resistance in Ω
X _L	= loading-coil inductive reactance

**Fig 8—Relative current distribution on a vertical antenna of height h = 90 electrical degrees.**

is to be realized. (See the program *MOBILE.EXE*, which is included on the CD-ROM in the back of this book.)

Radiation Resistance

The determination of radiation efficiency requires the knowledge of resistive power losses and radiation losses. Radiation loss is expressed in terms of radiation resistance. Radiation resistance is defined as the resistance that would dissipate the same amount of power that is radiated by the antenna. The variables used in the equations that follow are defined once in the text, and are summarized in **Table 3**. Radiation resistance of vertical antennas shorter than 45 electrical degrees ($1/8$ wavelength) is approximately:

$$R_R = \frac{h^2}{312} \quad (\text{Eq 4})$$

where

R_R = radiation resistance in Ω

h = antenna length in electrical degrees.

Antenna height in electrical degrees is expressed by:

$$h = \frac{\ell}{984} \times f (\text{MHz}) \times 360 \quad (\text{Eq 5})$$

where

ℓ = antenna length in feet

f (MHz) = operating frequency in megahertz.

End effect is purposely omitted to ensure that an

antenna is electrically long. This is so that resonance at the design frequency can be obtained easily by removing a turn or two from the loading coil.

Eq 4 is valid only for antennas having a sinusoidal current distribution and no reactive loading. However, it can be used as a starting point for deriving an equation that is useful for shortened antennas with other than sinusoidal current distributions.

Refer to **Fig 8**. The current distribution on an antenna 90° long electrically ($1/4$ wavelength) varies with the cosine of the length in electrical degrees. The current distribution of the top 30° of the antenna is essentially linear. It is this linearity that allows for derivation of a simpler, more useful equation for radiation resistance.

The radiation resistance of an electrically short base-loaded vertical antenna can be conveniently defined in terms of a geometric figure, a triangle, as shown in **Fig 9**. The radiation resistance is given by:

$$R_R = KA^2 \quad (\text{Eq 6})$$

where

K is a constant (to be derived shortly)

A = area of the triangular current distribution in degree-amperes.

Degree-ampere area is expressed by

$$A = \frac{1}{2} h \times I_{\text{base}} \quad (\text{Eq 7})$$

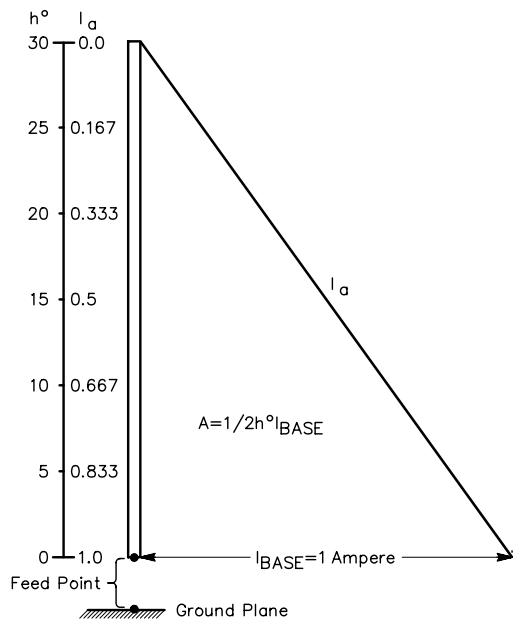


Fig 9—Relative current distribution on a base-loaded vertical antenna of height $H = 30$ electrical degrees (linearized). The base loading coil is not shown here.

By combining Eqs 4 and 6 and solving for K, we get

$$K = \frac{h^2}{312 \times A^2} \quad (\text{Eq 8})$$

By substituting the values from Fig 9 into Eq 8 we get

$$K = \frac{30^2}{312 \times (0.5 \times 30 \times 1)^2} = 0.0128$$

and by substituting the derived value of K into Eq 6 we get

$$R_R = 0.0128 \times A^2 \quad (\text{Eq 9})$$

Eq 9 is useful for determining the radiation resistance of coil-loaded vertical antennas less than 30° in length. The derived constant differs slightly from that presented by Laport (see Bibliography), as he used a different equation for radiation resistance Eq 4.

When the loading coil is moved up an antenna (away from the feed point), the current distribution is modified as shown in **Fig 10**. The current varies with the cosine of the height in electrical degrees at any point in the base section. Therefore, the current flowing into the bottom of the loading coil is less than the current flowing at the base of the antenna.

But what about the current in the top section of the antenna? The loading coil acts as the lumped constant that it is, and disregarding losses and coil radiation, main-

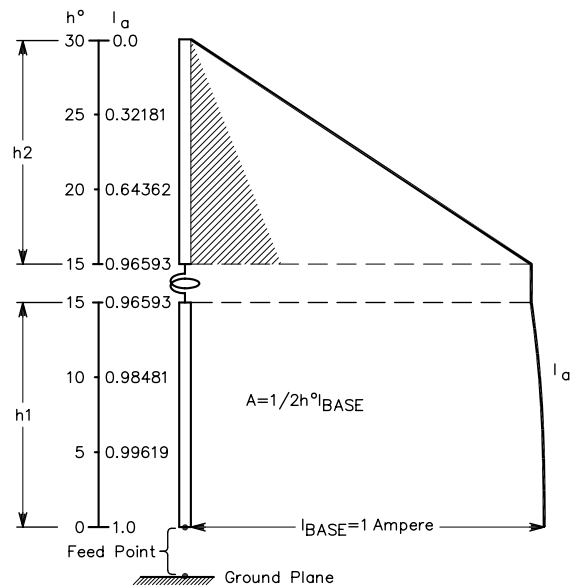


Fig 10—Relative current distribution on a center-loaded antenna with base and top sections each equal to 15° electrical degrees in length. The cross-hatched area shows the current distribution that would exist in the top 15° of a 90° -high vertical fed with 1 ampere at the base.

tains the same current flow throughout. As a result, the current at the top of a high-Q coil is essentially the same as that at the bottom of the coil. This is easily verified by installing RF ammeters immediately above and below the loading coil in a test antenna. Thus, the coil “forces” much more current into the top section than would flow in the equivalent section of a full 90° long antenna. This occurs as a result of the extremely high voltage that appears at the top of the loading coil. This higher current flow results in more radiation than would occur from the equivalent section of a quarter-wave antenna. (This is true for conventional coils. However, radiation from long thin coils allows coil current to decrease, as in helically wound antennas.)

The cross-hatched area in Fig 10 shows the current that would flow in the equivalent part of a 90° high antenna, and reveals that the degree-ampere area of the whip section of the short antenna is greatly increased as a result of the modified current distribution. The current flow in the top section decreases almost linearly to zero at the top. This can be seen in Fig 10.

The degree-ampere area of Fig 10 is the sum of the triangular area represented by the current distribution in the top section, and the nearly trapezoidal current distribution in the base section. Radiation from the coil is not included in the degree-ampere area because it is small and difficult to define. Any radiation from the coil can be considered a bonus.

The degree-ampere area is expressed by:

$$A = \frac{1}{2} [h_1 (1 + \cos h_1) + h_2 (\cos h_1)] \quad (\text{Eq 10})$$

where

h_1 = electrical length in degrees of the base section

h_2 = electrical height in degrees of the top section.

The degree-ampere area (calculated by substituting Eq 10 into Eq 9) can be used to determine the radiation resistance when the loading coil is at any position other than the base of the antenna. Radiation resistance has been calculated with these equations and plotted against loading coil position at three different frequencies for 8- and 11-foot antennas, **Fig 11**. Eight feet is a typical length for commercial antennas, and 11-foot antennas are about the maximum practical length that can be installed on a vehicle.

In Fig 11, the curves reveal that the radiation resistance rises almost linearly as the loading coil is moved up the antenna. They also show that the radiation resistance rises rapidly as the frequency is increased. If the analysis were stopped at this point, one might conclude that the loading coil should be placed at the top of the antenna. This is not so, and will become apparent shortly.

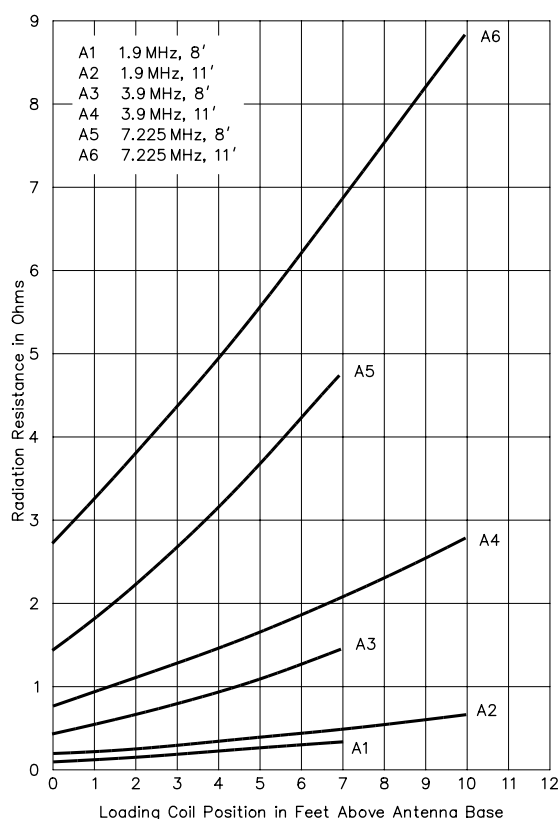


Fig 11—Radiation resistance plotted as a function of loading coil position.

Required Loading Inductance

Calculation of the loading coil inductance needed to resonate a short antenna can be done easily and accurately by using the antenna transmission-line analog described by Boyer in *Ham Radio*. For a base-loaded antenna, Fig 9, the loading coil reactance required to resonate the antenna is given by

$$X_L = -j K_m \cot h \quad (\text{Eq 11})$$

where

X_L = inductive reactance required

K_m = mean characteristic impedance (defined in Eq 12).

The $-j$ term indicates that the antenna presents capacitive reactance at the feed point. A loading coil must cancel this reactance.

The mean characteristic impedance of an antenna is expressed by

$$K_m = 60 \left[\left(\ln \frac{2H}{a} \right) - 1 \right] \quad (\text{Eq 12})$$

where

H = physical antenna height (excluding the length of the loading coil)

a = radius of the antenna in the same units as H .

From Eq 12 you can see that decreasing the height-to-diameter ratio of an antenna by increasing the radius results in a decrease in K_m . With reference to Eq 11, a decrease in K_m decreases the inductive reactance required to resonate an antenna. As will be shown later, this will increase radiation efficiency. In mobile applications, we quickly run into wind-loading problems if we attempt to use an antenna that is physically large in diameter.

If the loading coil is moved away from the base of the antenna, the antenna is divided into a base and top section, as depicted in Fig 10. The loading coil reactance required to resonate the antenna when the coil is away from the base is given by

$$X_L = j K_{m2} (\cot h_2) - j K_{m1} (\tan h_1) \quad (\text{Eq 13})$$

In mobile-antenna design and construction, the top section is usually a whip with a much smaller diameter than the base section. Because of this, it is necessary to compute separate values of K_m for the top and base sections. K_{m1} and K_{m2} are the mean characteristic impedances of the base and top sections, respectively.

Loading coil reactance curves for the 3.8-MHz antennas of Fig 11 have been calculated and plotted in **Fig 12**. These curves show the influence of the loading coil position on the reactance required for resonance. The curves in Fig 12 show that the required reactance decreases with longer antennas. The curves also reveal that the required loading coil reactance grows at an increasingly rapid rate after the coil passes the center of the antenna. Because the highest possible loading coil Q

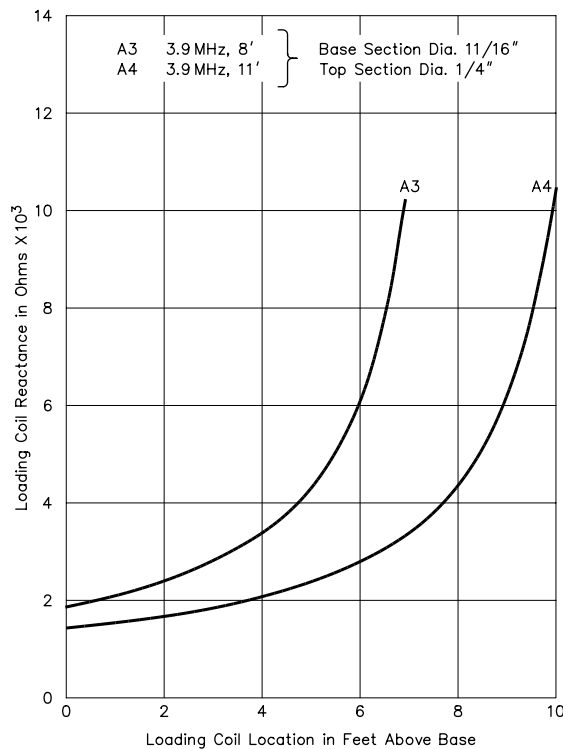


Fig 12—Loading coil reactance required for resonance, plotted as a function of coil height above the antenna base. The resonant frequency is 3.9 MHz.

factor is needed, and because optimum Q is attained when the loading coil diameter is twice the loading coil length, the coil would grow like a smoke ring above the center of the antenna, and would quickly reach an impractical size. It is for this reason that the highest loading coil position is limited to one foot from the top of the antenna in all computations.

Loading Coil Resistance

Loading coil resistance constitutes one of the losses that consumes power that could otherwise be radiated by the antenna. Heat loss in the loading coil is not of any benefit, so it should be minimized by using the highest possible loading coil Q . Loading coil loss resistance is a function of the coil Q and is given by

$$R_C = \frac{X_L}{Q} \quad (\text{Eq 14})$$

where

R_C = loading coil loss resistance in Ω

X_L = loading coil reactance

Q = coil figure of merit

Inspection of Eq 14 reveals that, for a given value of inductive reactance, loss resistance will be lower for higher Q coils. Measurements made with a Q meter show that typical, commercially manufactured coil stock pro-

duces a Q between 150 and 160 in the 3.8-MHz band.

Higher Q values can be obtained by using larger diameter coils having a diameter-to-length ratio of two, by using larger diameter wire, by using more spacing between turns, and by using low-loss polystyrene supporting and enclosure materials. In theory, loading coil turns should not be shorted for tuning purposes because shorted turns somewhat degrade Q . Pruning to resonance should be done by removing turns from the coil.

In fairness, it should be pointed out that many practical mobile antennas use large-diameter loading coils with shorted turns to achieve resonance. The popular "Texas Bug Catcher" coils come to mind here. Despite general proscriptions against shorting turns, these systems are often more efficient than antennas with small, relatively low- Q , fixed loading coils.

Radiation Efficiency

The ratio of power radiated to power fed to an antenna determines the radiation efficiency. It is given by:

$$E = \frac{P_R}{P_I} \times 100\% \quad (\text{Eq 15})$$

where

E = radiation efficiency in percent

P_R = power radiated

P_I = power fed to the antenna at the feed point.

In a short, coil-loaded mobile antenna, a large portion of the power fed to the antenna is dissipated in ground and coil resistances. A relatively insignificant amount of power is also dissipated in the antenna conductor resistance and in the leakage resistance of the base insulator. Because these last two losses are both very small and difficult to estimate, they are here neglected in calculating radiation efficiency.

Another loss worth noting is matching network loss. Because we are concerned only with power fed to the antenna in the determination of radiation efficiency, matching network loss is not considered in any of the equations. Suffice it to say that matching networks should be designed for minimum loss in order to maximize the transmitter power available at the antenna.

The radiation efficiency equation may be rewritten and expanded as follows:

$$E = \frac{I^2 R_R \times 100}{I^2 R_R + I^2 R_G + (I \cos h_1)^2 R_C} \quad (\text{Eq 16})$$

where

I = antenna base current in amperes

R_G = ground loss resistance in Ω

R_C = coil loss resistance in Ω .

Each term of Eq 16 represents the power dissipated in its associated resistance. All the current terms cancel,

simplifying this equation to

$$E = \frac{R_R \times 100}{R_R + R_G + R_C (\cos^2 h_1)} \quad (\text{Eq 17})$$

For base-loaded antennas the term $\cos^2 h_1$ drops to unity and may be omitted.

Ground Loss

Eq 14 shows that the total resistive losses in the antenna system are:

$$R_T = R_R + R_G + R_C (\cos^2 h_1) \quad (\text{Eq 18})$$

where R_T is the total resistive loss. Ground loss resistance can be determined by rearranging Eq 18 as follows:

$$R_G = R_T - R_R - R_C \cos^2 h_1 \quad (\text{Eq 19})$$

R_T may be measured in a test antenna installation on a vehicle using an R-X noise bridge or an SWR analyzer. You can then calculate R_R and R_C .

Ground loss is a function of vehicle size, placement of the antenna on the vehicle, and conductivity of the ground over which the vehicle is traveling. Only the first two variables can be feasibly controlled. Larger vehicles provide better ground planes than smaller ones. The vehicle ground plane is only partial, so the result is considerable RF current flow (and ground loss) in the ground around and under the vehicle.

By raising the antenna base as high as possible on the vehicle, ground losses are decreased. This results from a decrease in antenna capacitance to ground, which increases the capacitive reactance to ground. This, in turn, reduces ground currents and ground losses.

This effect has been verified by installing the same antenna at three different locations on two different vehicles, and by determining the ground loss from Eq 19. In the first test, the antenna was mounted 6 inches below the top of a large station wagon, just behind the left rear window. This placed the antenna base 4 feet 2 inches above the ground, and resulted in a measured ground loss resistance of 2.5Ω . The second test used the same antenna mounted on the left rear fender of a mid-sized sedan, just to the left of the trunk lid. In this test, the measured ground loss resistance was 4Ω . The third test used the same mid-sized car, but the antenna was mounted on the rear bumper. In this last test, the measured ground loss resistance was 6Ω .

The same antenna therefore sees three different ground loss resistances as a direct result of the antenna mounting location and size of the vehicle. It is important to note that the measured ground loss increases as the antenna base nears the ground. The importance of minimizing ground losses in mobile antenna installations cannot be overemphasized.

Efficiency Curves

With the equations defined previously, a computer

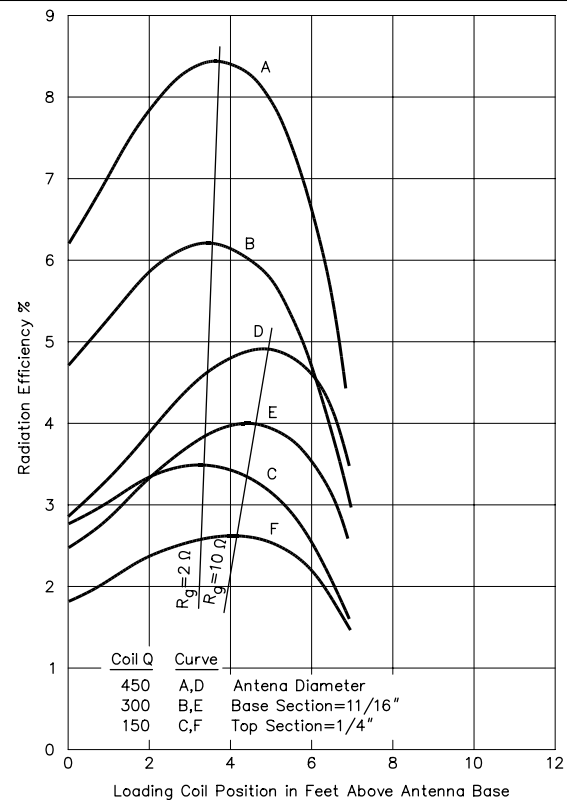


Fig 13—Radiation efficiency of 8-foot antennas at 3.9 MHz.

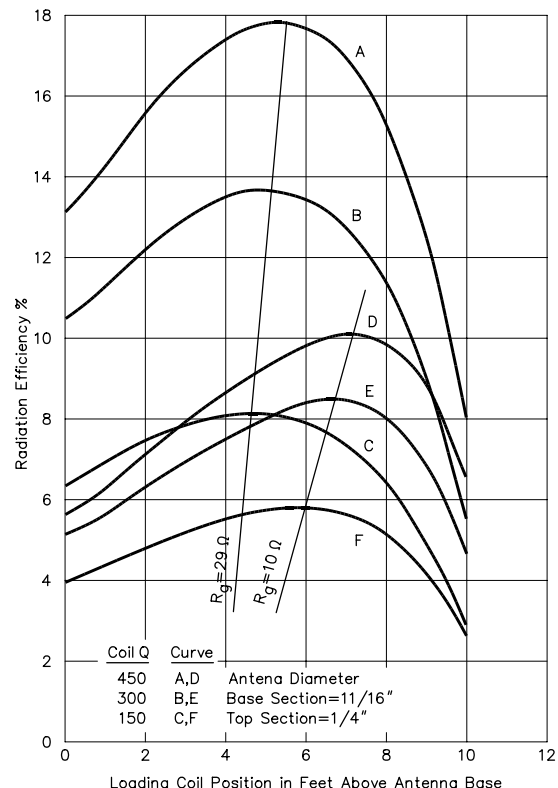


Fig 14—Radiation efficiency of 11-foot antennas at 3.9 MHz.

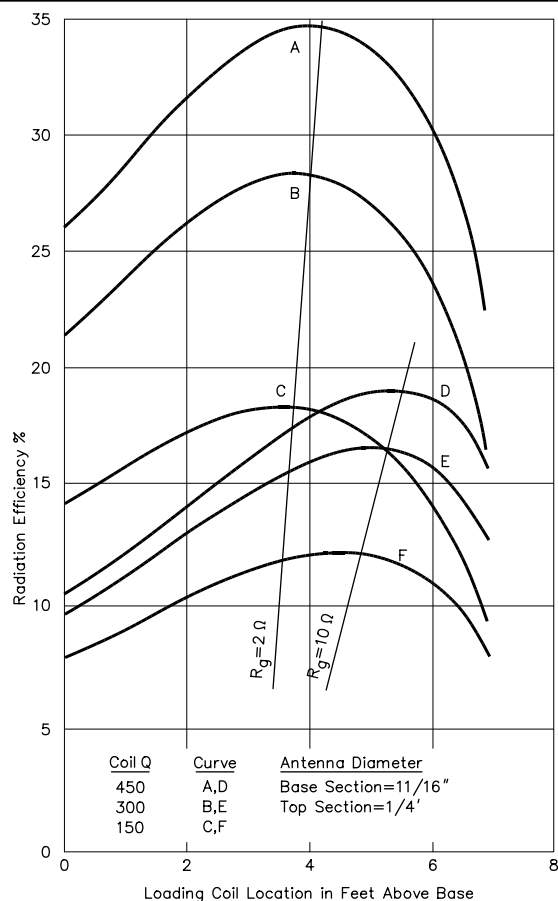


Fig 15—Radiation efficiency of 8-foot antennas at 7.225 MHz.

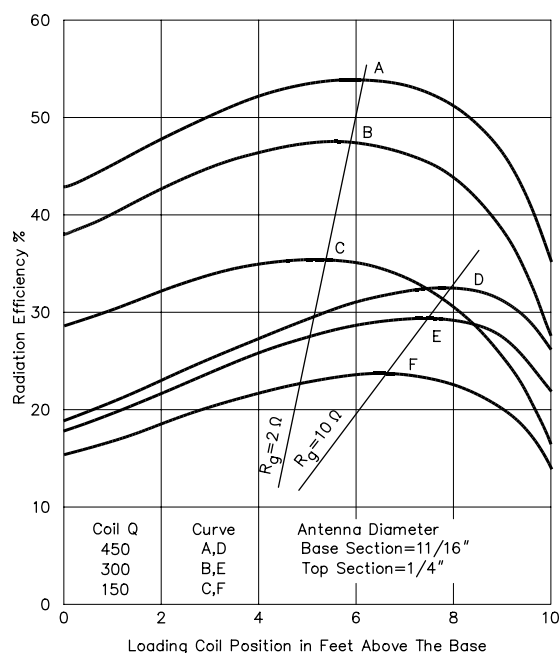


Fig 16—Radiation efficiency of 11-foot antennas at 7.225 MHz.

was used to calculate the radiation efficiency curves depicted in **Figs 13 through 16**. These curves were calculated for 3.8- and 7-MHz antennas of 8- and 11-foot lengths. Several values of loading coil Q were used, for both 2 and 10 Ω of ground loss resistance. For the calculations, the base section is $1/2$ -inch diameter electrical EMT, which has an outside diameter of $11/16$ inch. The top section is fiberglass bicycle-whip material covered with Belden braid. These are readily available materials, which can be used by the average amateur to construct an inexpensive but rugged antenna.

Upon inspection, these radiation-efficiency curves reveal some significant information:

- 1) Higher coil Q produces higher radiation efficiencies,
- 2) longer antennas produce higher radiation efficiencies,
- 3) higher frequencies produce higher radiation efficiencies,
- 4) lower ground loss resistances produce higher radiation efficiencies,
- 5) higher ground loss resistances force the loading coil above the antenna center to reach a crest in the radiation-efficiency curve, and
- 6) higher coil Q sharpens the radiation-efficiency curves, resulting in the coil position being more critical for optimum radiation efficiency.

Note that the radiation efficiency curves reach a peak and then begin to decline as the loading coil is raised farther up the antenna. This is because of the rapid increase in loading coil reactance required above the antenna center. Refer to Fig 12. The rapid increase in coil size required for resonance results in the coil loss resistance increasing much more rapidly than the radiation resistance. This results in decreased radiation efficiency, as shown in Fig 11.

A slight reverse curvature exists in the curves between the base-loaded position and the one-foot coil-height position. This is caused by a shift in the curve resulting from insertion of a base section of larger diameter than the whip when the coil is above the base.

The curves in Figs 13 through 16 were calculated with constant (but not equal) diameter base and whip sections. Because of wind loading, it is not desirable to increase the diameter of the whip section. However, the base-section diameter can be increased within reason to further improve radiation efficiency. **Fig 17** was calculated for base-section diameters ranging from $11/16$ inch to 3 inches. The curves reveal that a small increase in radiation efficiency results from larger diameter base sections.

The curves in Figs 13 through 16 show that radiation efficiencies can be quite low in the 3.8-MHz band compared to the 7-MHz band. They are lower yet in the 1.8-MHz band. To gain some perspective on what these low efficiencies mean in terms of signal strength, **Fig 18** was calculated using the following equation:

$$dB = \log \frac{100}{E} \quad (\text{Eq 20})$$

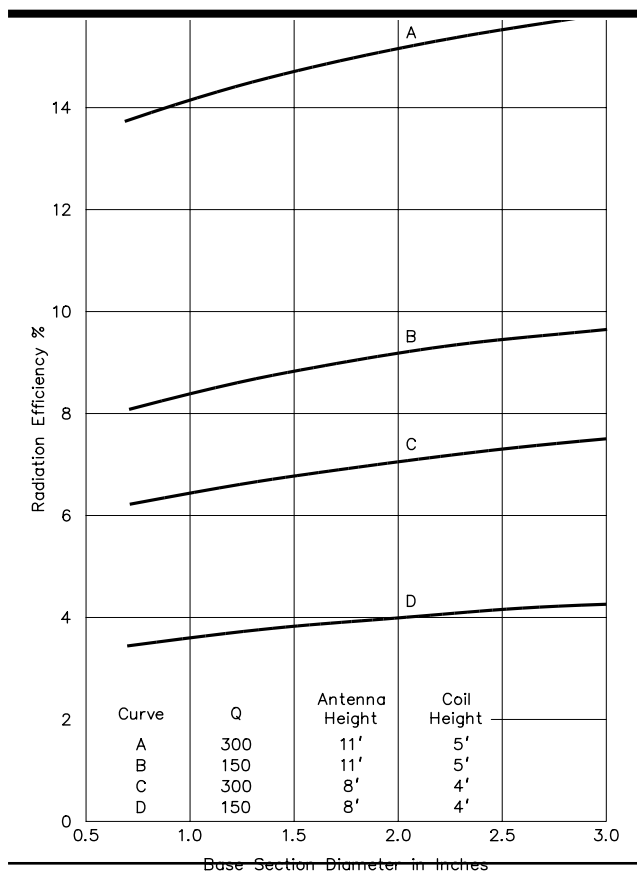


Fig 17—Radiation efficiency plotted as a function of base section diameter. Frequency = 3.9 MHz, ground loss resistance = $2\ \Omega$, and whip section = $\frac{1}{4}$ -inch diameter.

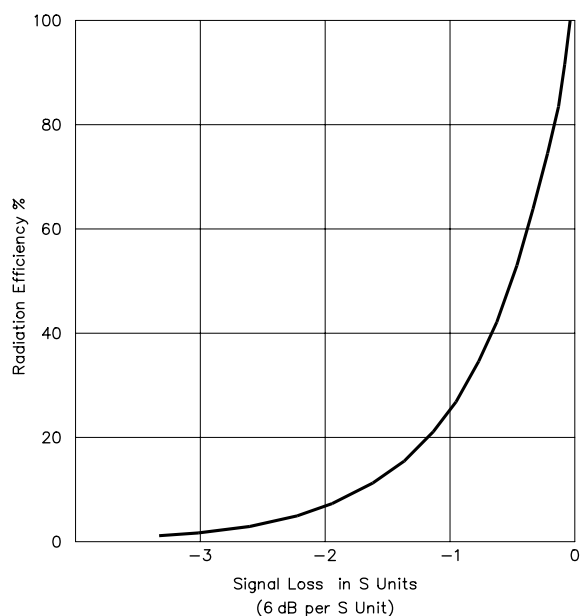


Fig 18—Mobile antenna signal loss as a function of radiation efficiency, compared to a quarter-wave vertical antenna over perfect ground.

where

dB = signal loss in decibels

E = efficiency in percent.

The curve in Fig 18 reveals that an antenna having 25% efficiency has a signal loss of 6 dB (approximately one S unit) below a quarter-wave vertical antenna over perfect ground. An antenna efficiency in the neighborhood of 6% will produce a signal strength on the order of two S units or about 12 dB below the same quarter-wave reference vertical. By careful optimization of mobile-antenna design, signal strengths from mobiles can be made fairly competitive with those from fixed stations using comparable power. And don't forget: Moving your car near saltwater, with its high conductivity, can result in surprisingly strong signals from a mobile station!

Impedance Matching

The input impedance of short, high-Q coil-loaded antennas is quite low. For example, an 8-foot antenna optimized for 3.9 MHz with a unloaded coil Q of 300 and a ground-loss resistance of $2\ \Omega$ has a base input impedance of about $13\ \Omega$. This low impedance value causes a standing wave ratio of 4:1 on a $50\text{-}\Omega$ coaxial line at resonance. This high SWR is not compatible with the requirements of solid-state transmitters. Also, the bandwidth of shortened vertical antennas is very narrow. This severely limits the capability to maintain transmitter loading over even a small frequency range.

Impedance matching can be accomplished by means of L networks or impedance-matching transformers, but the narrow bandwidth limitation remains. A more elegant solution to the impedance matching and narrow bandwidth problem is to install an automatic tuner at the antenna base. Such a device matches the antenna and coaxial line automatically, and permits operation over a wide frequency range.

The tools are now available to tailor a mobile antenna design to produce maximum radiation efficiency. Mathematical modeling with a personal computer reveals that loading coil Q factor and ground loss resistance greatly influence the optimum loading coil position in a short vertical antenna. It also shows that longer antennas, higher coil Q, and higher operating frequencies produce higher radiation efficiencies.

End effect has not been included in any of the equations to assure that the loading coil will be slightly larger than necessary. Pruning the antenna to resonance should be done by removing coil turns, rather than by shorting turns or shortening the whip section excessively. Shortening the whip reduces radiation efficiency, by both shortening the antenna and moving the optimum coil position. Shorting turns in the loading coil degrades the Q of the coil.

Shortened Dipoles

Mathematical modeling techniques can be applied to shortened dipoles by using zero ground loss resistance

and by doubling the computed values of radiation resistance and feed-point impedance. Radiation efficiency, however, does not double. Rather, it remains unchanged, because a second loading coil is required in the other leg of the dipole. The addition of the second coil offsets the gain in efficiency that occurs when the feed-point impedance and radiation resistance are doubled. There is a gain in radiation efficiency over a vertical antenna worked against ground, though, because the dipole configuration allows ground loss resistance to be eliminated from the calculations.

CONTINUOUSLY LOADED ANTENNAS

The design of high-Q air core inductors for RF work is complicated by the number of parameters that must be optimized simultaneously. One of these factors affecting coil Q adversely is radiation from a discrete loading coil. Therefore, the possibility of cutting down other losses while incorporating the coil radiation into that from the rest of the antenna system is an attractive one.

The general approach has been to use a coil made from heavy wire (#14 or larger), with length-to-diameter ratios as high as 21. British experimenters have reported good results with 8-foot overall lengths on the 1.8- and 3.5-MHz bands. The idea of making the entire antenna out of one section of coil has also been tried with some success. This technique is referred to as linear loading. Further information on linear-loaded antennas can be found in Chapter 6.

While going to extremes trying to find a perfect loading arrangement may not improve antenna performance very much, a poor system with lossy coils and high-resistance connections must be avoided if a reasonable signal is to be radiated.

MATCHING TO THE TRANSMITTER

Most modern transmitters require a 50- Ω output load, and because the feed-point impedance of a mobile whip is quite low, a matching network is usually necessary. Although calculations are helpful in the initial design, considerable experimenting is often necessary in final tune-up. This is particularly true for the lower bands, where the antenna is electrically short compared with a quarter-wave whip. The reason is that the loading coil is required to tune out a very large capacitive reactance, and even small changes in component values result in large reactance variations. Since the feed-point resistance is low to begin with, the problem is even more aggravated.

You can transform the low resistance of the whip to a value suitable for a 50- Ω system with an RF transformer or with a shunt-feed arrangement, such as an L network. The latter may only require a shunt coil or shunt capacitor at the base of the whip, since the net series capacitive or inductive reactance of the antenna and its loading coil may be used as part of the network. The following example illustrates the calculations involved.

Assume that a center-loaded whip antenna, 8.5 feet in overall length, is to be used on 7.2 MHz. From Table 1, earlier in this chapter, we see that the feed-point resistance of the antenna will be approximately 19 Ω , and from Fig 5 that the capacitance of the whip, as seen at its base, is approximately 24 pF. Since the antenna is to be center loaded, the capacitance value of the section above the coil will be cut approximately in half, to 12 pF. From this, it may be calculated that a center-loading inductor of 40.7 μ H is required to resonate the antenna, that is, to cancel out the capacitive reactance. (This figure agrees with the approximate value of 40 μ H shown in Table 1. The resulting feed-point impedance would then be $19 + j0 \Omega$ —a good match, if one happens to have a supply of 19- Ω coax.)

Solution: The antenna can be matched to a 52- Ω line such as RG-8 by tuning it either above or below reso-

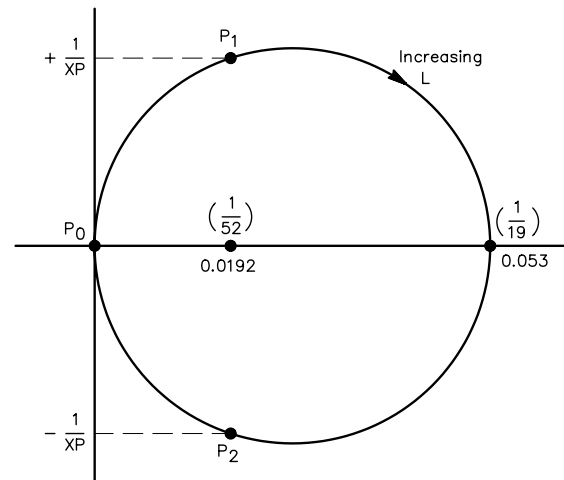


Fig 19—Admittance diagram of the RLC circuit consisting of the whip capacitance, radiation resistance and loading coil discussed in text. The horizontal axis represents conductance, and the vertical axis susceptance. The point P_0 is the input admittance with no whip loading inductance. Points P_1 and P_2 are described in the text. The conductance equals the reciprocal of the resistance, if no reactive components are present. For a series RX circuit, the conductance is given by

$$G = \frac{R}{R^2 + X^2}$$

and the susceptance is given by

$$B = \frac{-X}{R^2 + X^2}$$

Consequently, a parallel equivalent GB circuit of the series RX one can be found which makes computations easier. This is because conductances and susceptances add in parallel the same way resistances and reactances add in series.

nance and then canceling out the undesired component with an appropriate shunt element, capacitive or inductive. The way in which the impedance is transformed up can be seen by plotting the admittance of the series RLC circuit made up of the loading coil, antenna capacitance, and feed-point resistance. Such a plot is shown in **Fig 19** for a constant feed-point resistance of $19\ \Omega$. There are two points of interest, P1 and P2, where the input conductance is 19.2 millisiemens, corresponding to $52\ \Omega$. The undesired susceptance is shown as $1/X_p$ and $-1/X_p$, which must be canceled with a shunt element of the opposite sign, but with the same magnitude. The value of the canceling shunt reactance, X_p , may be found from the formula:

$$X_p = \frac{R_f Z_0}{\sqrt{R_f (Z_0 - R_f)}} \quad (\text{Eq 21})$$

where X_p is the reactance in Ω , R_f is the feed-point resistance, and Z_0 is the feed-line impedance. For $Z_0 = 52\ \Omega$ and $R_f = 19\ \Omega$, $X_p = \pm 39.5\ \Omega$. A coil or good quality mica capacitor may be used as the shunt element. With the tune-up procedure described later, the value is not critical, and a fixed-value component may be used.

To arrive at point P1, the value of the center loading-coil inductance would be less than that required for resonance. The feed-point impedance would then appear capacitive, and an inductive shunt matching element would then be required. To arrive at point P2, the center loading coil should be more inductive than required for resonance, and the shunt element would need to be capacitive.

The value of the center loading coil required for the shunt-matched and resonated condition may be deter-

mined from the equation:

$$L = \frac{10^6}{4\pi^2 f^2 C} \pm \frac{X_s}{2\pi f} \quad (\text{Eq 22})$$

where addition is performed if a capacitive shunt is to be used, or subtraction performed if the shunt is inductive, and where L is in μH , f is the frequency in MHz, C is the capacitance of the antenna section being matched in pF, and

$$X_s = \sqrt{R_f (Z_0 - R_f)} \quad (\text{Eq 23})$$

For the example given, where $Z_0 = 52\ \Omega$, $R_f = 19\ \Omega$, $f = 7.2\ \text{MHz}$, and $C = 12\ \text{pF}$, X_s is found to be $25.0\ \Omega$. The required antenna loading inductance is either $40.2\ \mu\text{H}$ or $41.3\ \mu\text{H}$, depending on the type of shunt. Various matching possibilities for this example are shown in **Fig 20**. At A, the antenna is shown as tuned to resonance with L_L , a $40.7\ \mu\text{H}$ coil, but with no provisions included for matching the resulting $19\text{-}\Omega$ impedance to the $50\text{-}\Omega$ line. At B, L_L has been reduced to $40.2\ \mu\text{H}$ to make the antenna appear net capacitive, and L_M , having a reactance of $39.5\ \Omega$, is added in shunt to cancel the capacitive reactance and transform the feed-point impedance to $50\ \Omega$. The arrangement at C is similar to that at B except that L_L has been increased to $41.3\ \mu\text{H}$, and C_M (a shunt capacitor having a negative reactance of $39.5\ \Omega$) is added, which also results in a $52\text{-}\Omega$ nonreactive termination for the feed line.

The values determined for the loading coil in the above example point out an important consideration concerning the matching of short antennas—relatively small changes in values of the loading components will have a greatly magnified effect on the matching requirements. A change of less than 3% in the loading coil inductance value necessitates a completely different matching network! Likewise, calculations show that a 3% change in antenna capacitance will give similar results, and the value of the precautions mentioned earlier becomes clear. The sensitivity of the circuit with regard to frequency variations is also quite critical, and an excursion around practically the entire circle in **Fig 19** may represent only 600 kHz, centered around 7.2 MHz, for the above example. This is why tuning up a mobile antenna can be very frustrating unless a systematic procedure is followed.

Tune-Up

Assume that inductive shunt matching is to be used with the antenna in the previous example, **Fig 20B**, where $39.5\ \Omega$ is needed for L_M . This means that at 7.2 MHz, a coil of $0.87\ \mu\text{H}$ will be needed across the whip feed-point terminal to ground. With a $40\text{-}\mu\text{H}$ loading coil in place, the adjustable whip section above the loading coil should be set for minimum height. Signals in the receiver will sound weak and the whip should be lengthened a bit at a time until signals start to peak. Turn the transmitter on and check the SWR at a few frequencies to find where a

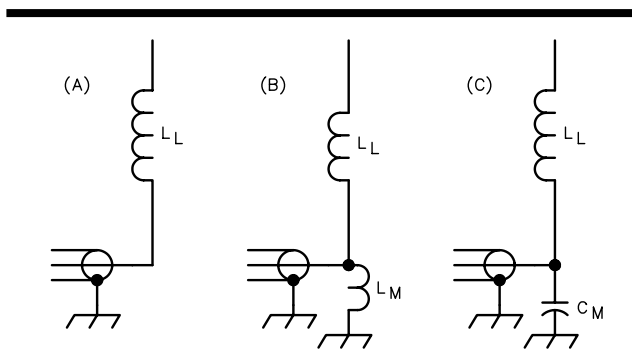


Fig 20—At A, a whip antenna that is resonated with a center loading coil. At B and C, the value of the loading coil has been altered slightly to make the feed-point impedance appear reactive, and a matching component is added in shunt to cancel the reactance. This provides an impedance transformation to match the Z_0 of the feed line. An equally acceptable procedure, rather than altering the loading coil inductance, is to adjust the length of the top section above the loading coil for the best match, as described in the tune-up section of the text.

minimum occurs. If it is below the desired frequency, shorten the whip slightly and check again. It should be moved approximately $\frac{1}{4}$ inch at a time until the SWR is minimum at the center of the desired range. If the frequency where the minimum SWR occurs is above the desired frequency, repeat the procedure above, but lengthen the whip only slightly.

If a shunt capacitance is to be used, as in Fig 20C, a value of 560 pF would correspond to the required -39.5Ω of reactance at 7.2 MHz. With a capacitive shunt, start with the whip in its longest position and shorten it until signals peak up.

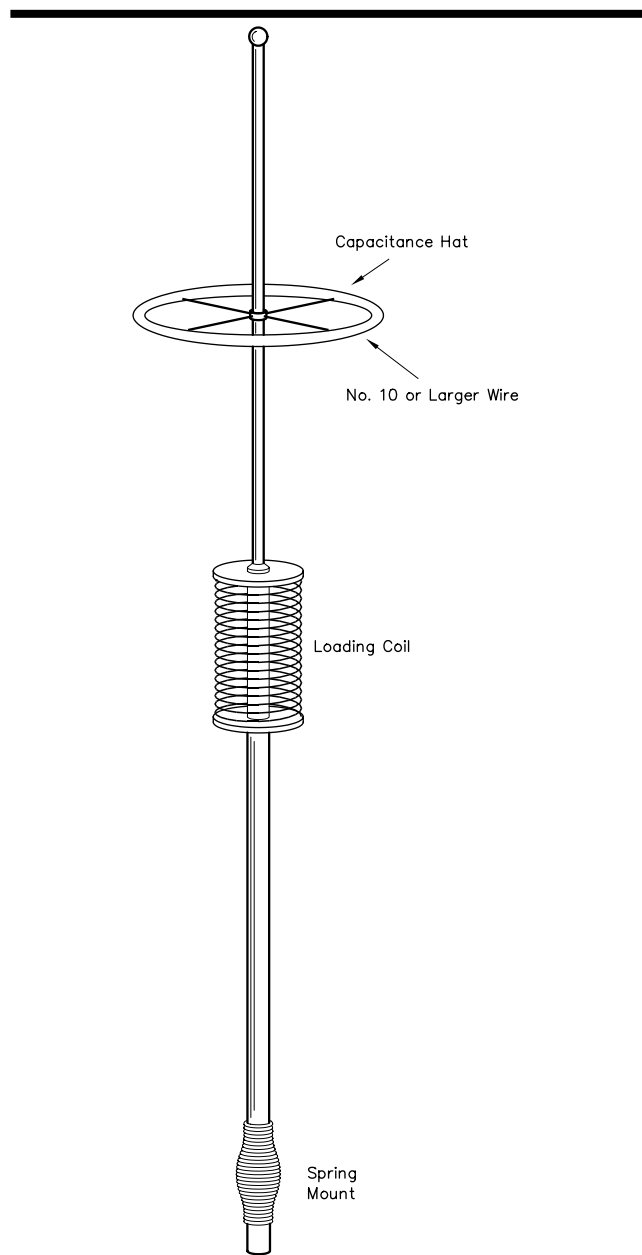


Fig 21—A capacitance hat can be used to improve the performance of base- or center-loaded whips. A solid metal disc can be used in place of the skeleton disc shown here.

TOP-LOADING CAPACITANCE

Because the loss resistance varies with the inductance of the loading coil, the resistance can be reduced by removing turns from the coil. This must be compensated by adding capacitance to the portion of the mobile antenna that is *above* the loading coil (**Fig 21**). *Capacitance hats*, as they are called, can consist of a single stiff wire, two wires or more, or a disc made up of several wires like the spokes of a wheel. A solid metal disc could also be used, but is less practical for mobile work. The larger the capacitance hat (physically), the greater is the capacitance. The greater the capacitance, the less is the inductance required for resonance at a given frequency.

Capacitance-hat loading is applicable in either base-loaded or center-loaded systems. Since more inductance is required for center-loaded whips to make them resonant at a given frequency, capacitance hats are particularly useful in improving their efficiency.

TAPPED-COIL MATCHING NETWORK

Some of the drawbacks of the L-network can be eliminated by the use of the tapped-coil arrangement shown in **Fig 22**. Tune-up still remains critical, however, although somewhat more straightforward than for an L-network.

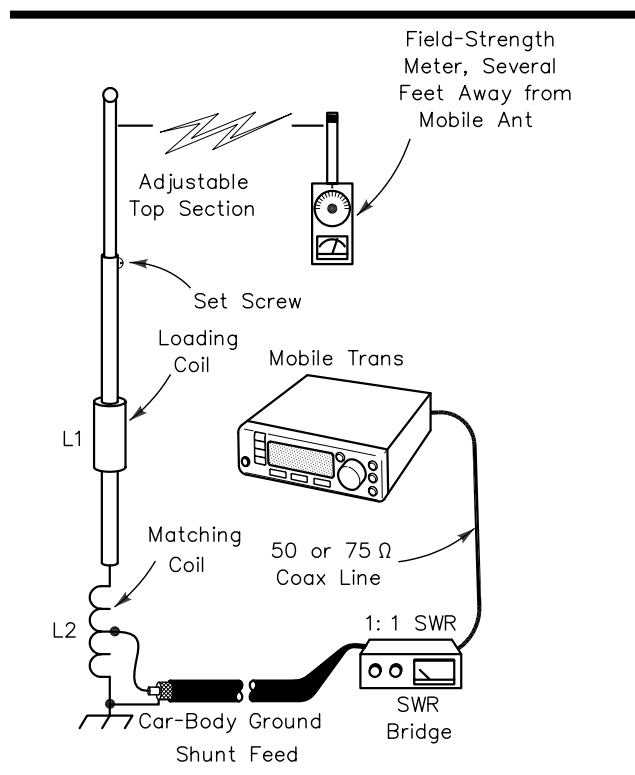


Fig 22—A mobile antenna using shunt-feed matching. Overall antenna resonance is determined by the combination of L1 and L2. Antenna resonance is set by pruning the turns of L1, or adjusting the top section of the whip, while observing the field-strength meter or SWR indicator. Then adjust the tap on L2 for the lowest SWR.

Coil L2 can be inside the car body, at the base of the antenna, or at the base of the whip. As L2 helps determine the resonance of the antenna, L1 should be tuned to resonance in the desired part of the band with L2 in the circuit. The top section of the whip can be telescoped until a field-strength maximum is found. The tap on L2 is then adjusted for the lowest reflected power. Repeat these two adjustments until no further increase in field strength can be obtained; this point should coincide with the lowest SWR. The number of turns needed for L2 will have to be determined experimentally.

MOBILE IMPEDANCE-MATCHING COIL

Bob Hawk, KØYEH, designed this shunt-coil L-network system for HF mobile antennas and dubbed it the KØYEH Dollar Special. Its primary purpose is to provide a very efficient match to 50-Ω coax line, and not to base-load the antenna. The antenna itself should already be resonated for the band of operation, preferably using a center loading inductor for efficiency. KØYEH used a Hustler antenna and resonator on his car. See Fig 23.

The Dollar Special is a great performer, fun to build, and costs only about a dollar for parts. If you have a junk box, you probably already have just about everything you'll need. With the matcher properly installed and

adjusted, you will be able to get on any of the HF bands (3.5 through 29.7 MHz) for which your antenna is designed, with a 1:1 SWR.

The matching unit is shown in Fig 24. It adapts easily to passenger cars, pickup trucks, vans, trailers and RVs, as long as there is a metal body for a ground. Body mounts are better than bumper mounts for a number of reasons. The matcher can, however, be bumper mounted, and will still perform reasonably well in this configuration.

A 3.5-MHz mobile whip, resonated as an electrical quarter-wave antenna, typically presents a load impedance of about 8 Ω, and this represents a mismatch of more than 6 to 1! Similar mismatches (but of lesser magnitudes as frequency is increased) occur on the higher bands as well.

The matching coil is easy and efficient to use after initial tune-up. After finding the best coil tap using the alligator clip, you should mark the tap position with fin-



Fig 23—Bob Hawk showing off his mobile antenna, which uses the KØYEH Dollar Special matching unit.

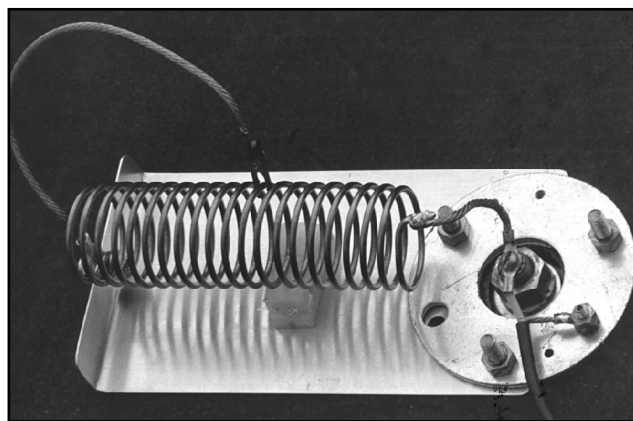


Fig 24—The assembled Dollar Special, ready for mounting.

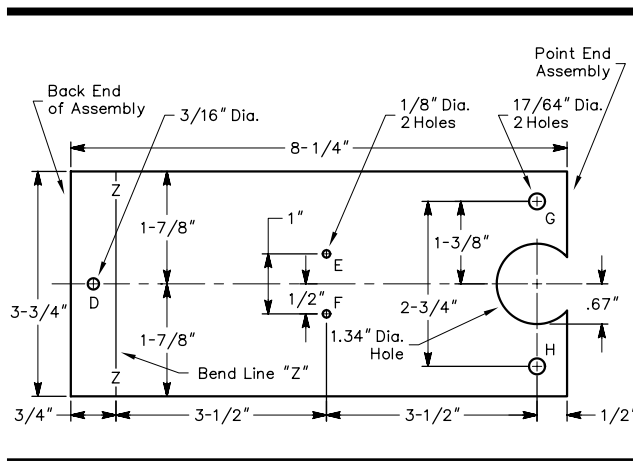


Fig 25—Drilling template for the base plate of the Dollar Special.

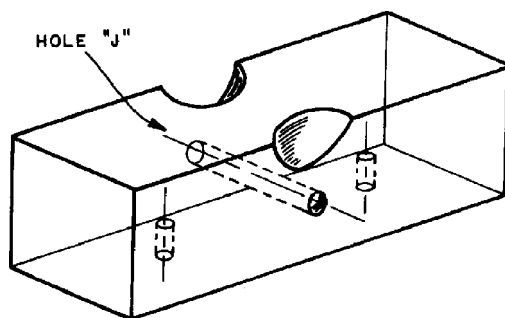


Fig 26—Insulated standoff (to support the coil). Mount on the base at holes E and F with two small (no. 5) sheet-metal screws. Trim the top center, as shown, to about $\frac{1}{8}$ to $\frac{1}{4}$ inch wide. The insulation block is about $\frac{1}{2}$ inch square \times $1\frac{3}{4}$ -inch. Drill a $\frac{1}{8}$ -inch hole at J (for fishing line) to tie to the bottom of one coil turn.

Table 4

Materials Needed to Construct the Dollar Special

- 1) Aluminum or brass sheet $3\frac{3}{4}$ inch wide, $7\frac{3}{4}$ inch long, and about 0.040 to 0.050 inch thick.
- 2) One $9\frac{1}{2}$ foot length of #10 solid copper wire.
- 3) Flexible braid about $\frac{5}{16}$ to $\frac{3}{8}$ inch wide: one length $7\frac{1}{2}$ inch long with a terminal for a no. 10 metal bolt on one end and a no. 30c Mueller clip (small copper alligator clip) soldered to the other end. The second piece of braid should be $3\frac{3}{8}$ inch long with a terminal for a no. 8 screw soldered to one end.
- 4) One piece of dielectric (insulating) material about $\frac{1}{2}$ to $\frac{5}{8}$ inch square and about 2 inch long. This can be plastic such as nylon, Teflon, polyethylene or phenolic, or dry wood (if wood, preferably painted or boiled in paraffin).
- 5) One no. 10-32 \times $\frac{3}{4}$ inch bolt, three star washers, two flat washers, and one lock washer.
- 6) Two no. 5 sheet-metal screws, $\frac{3}{8}$ -inch long, to mount the dielectric standoff at points X and Y.

gernail polish. Band changing may then be done easily, usually within a couple of minutes (depending on the length of time you need to change resonators).

Construction

Fig 25 shows a drilling template for the matching-coil assembly, and **Fig 26** shows details of the insulation standoff block. **Table 4** contains a list of materials needed for the Dollar Special. Carefully lay out the reference lines on the base plate, using a needle-point scribe and a ruler. Mark and drill all holes. The large 1.34-inch diameter hole may be cut out with a nibbling tool or a chassis punch, or you can drill several holes in the area and file

them out. After drilling and cutting all holes, make a 90° bend at bend-line Z.

To form the loading coil, find a piece of $1\frac{1}{4}$ -inch diameter tubing or pipe that is at least a foot long. Use it as a form and wind the #10 copper wire tightly around it. About $20\frac{1}{2}$ turns make up the coil. After winding, carefully spread the coil turns as evenly as possible so that the coil is 5 inches long with 20 turns. On one end of the coil, fashion a loop to fit snugly around the $\frac{3}{16}$ -inch bolt. (This bolt will be attached at point D, shown at the left in **Fig 25**.)

Bend the extra $\frac{1}{2}$ turn at the feed-point end of the coil at a 45° angle (about $\frac{1}{2}$ inch from the end of the 20th turn) and cut off the excess. Attach the end of the $2\frac{3}{8}$ inch length of braid at this point and solder. Wrapping the joint with fine solid copper wire (about #24) before soldering makes the soldering job easier.

Fabricate the standoff insulator as shown in **Fig 26**. With a file or knife, remove material at the top center, as shown, to avoid sharp edges against the coil tie-down material. Next mount the dielectric standoff to the base at points E and F using two no. 5 screws. In mounting the dielectric piece, make sure that hole J is parallel to the base plate and to the axis of the mounted coil.

Secure the ground end of the coil and the terminal end of the 7-inch length of braid at hole D with the $\frac{3}{16}$ -inch bolt assembly. Connect the one bottom turn of the coil to the standoff with a 2- or 3-foot piece of cord or string (fishing line works well) through hole J.

Your Dollar Special should now be complete and ready for mounting. The secret of the outstanding performance of any mobile antenna is good grounding. Be sure to observe the precautions given in the next section about removing paint from the vehicle body.

Mounting the Matcher

The Dollar Special is easily mounted. If you have a standard (preferably heavy duty) swivel mount on your vehicle, remove two of the (usually 3) bolts from the mount and slip the base of the matcher underneath the heavy ring plate (approximately 4-inch diameter). Connect the "hot" (feed-point) end of the coil, with attached terminal, to the same feed-point connector as the center conductor of the coax. Make sure the shield of the coax is grounded to the large mounting ring with a short length of the shield braid (2 inches long or less).

Make sure the hole in the matcher base (about 1.34 inches) is properly centered so it does not touch and short out the center bolt assembly of the antenna. It is a good idea to make sure you have at least about $\frac{1}{8}$ to $\frac{3}{16}$ inch of clearance here.

Remove the antenna mount completely and remove all the paint and primer from at least a 1-inch diameter area around each of the bolt holes on the inner side of the mount. It is essential to obtain the best possible ground to the vehicle body. Star washers should be used between

all contacting surfaces, and the hardware must be tightened well.

If you do not have a standard mount, make the appropriate connections to the antenna you are using based on these instructions. Mounting may take a little creativity, but the Dollar Special can be made to work with virtually any kind of mobile antenna.

Tune-Up

Place an SWR meter in the transmission line at the output of the transceiver. To avoid possible damage to the final amplifier and to prevent any unnecessary interference, tune-up should be done with the SWR meter at maximum sensitivity and the RF drive adjustments at no more than necessary to get an accurate SWR indication. Because 7 MHz is one of the most popular mobile bands, it is desirable to begin the tune-up procedure there. (Adjustment of each of the other bands is similar.)

First, move the alligator clip on the matching coil to the eighth turn from the feed-point end of the coil. Make a few spot SWR checks and determine where the SWR is lowest. If the SWR improves as you move toward the top of the band (7.3 MHz), you'll need to lengthen the resonator whip a small amount or use more inductance in your center loading coil. Conversely, if you find the SWR best at the bottom of the band, you will need to shorten the whip or use less center-loading inductance. You will also need to move the alligator clip on the Dollar Special coil (check the SWR while you do this) a turn or half-turn at a time until you eventually find the coil-tap position that yields the best match.

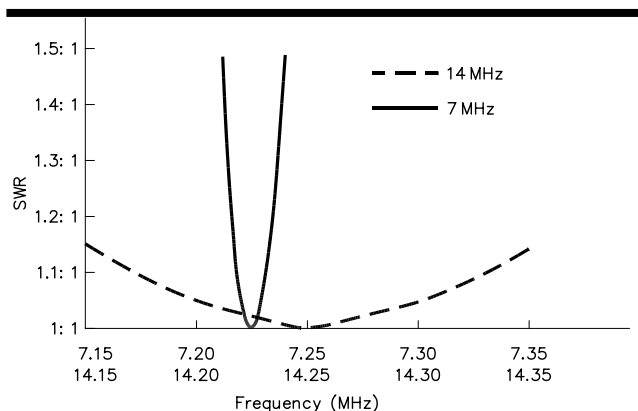


Fig 27—Typical SWR curves for the 7- and 14-MHz amateur bands. At 14 MHz, with adjustment centered on 14.25 MHz, the entire voice band is covered with an SWR of less than 1.2 to 1. Operation is similar at 21 and 28 MHz. At 7 MHz, the bandwidth is narrower, which is even more true for 3.5 MHz. A match may be obtained after significant frequency shifts in these bands by adjusting the antenna resonator.

After you have completed the tuning, the SWR should be at (or near) 1:1 at the desired frequency. On the 7-MHz band you should be able to move 10 to 15 kHz either way from this frequency with less than a 1.5:1 SWR. On 14 MHz and higher bands, you should be able to work the entire SSB subband with less than a 1.5:1 SWR. (These figures will vary somewhat depending on the antenna that you are using, but these numbers are typical for a Hustler antenna.) Measured SWR curves are shown in **Fig 27**.

Once you have found the best tap position on the matching coil for 7 MHz, mark it with red enamel or fingernail polish. This single tap position on the matching coil should be usable across the entire 7-MHz band. Frequency excursions of more than 15 or 20 kHz from the center of the desired frequency range will require changing the length of the whip top section accordingly.

The other bands are tuned in a similar manner. Approximate tap positions on the matching coil for the other bands (counting from the feed-point end of the coil) are as follows.

- 3.5 MHz—15 turns
- 7 MHz—8 turns
- 14 MHz—4½ turns
- 21 MHz—3 turns
- 28 MHz—2 turns

Most commercially made masts (Hustler, for example) are 4.5 feet long, and are made of approximately ½-inch OD tubing with ⅜-inch × 24 threaded fittings. If you are fortunate enough to find the material and have the capability, make a 1½ foot extension to add to the top of your mast, or else use a 6-foot mast. Your reward will be significantly improved operation on the 3.5-through 21-MHz bands.

TWO-BAND HF ANTENNA WITH AUTOMATIC BAND SWITCHING

A popular HF mobile antenna is a center-loaded whip consisting of a loading coil mounted 2 to 4 feet from the base, with a whip atop the coil. A shorting-tap wire is provided to short out turns at the bottom end of the coil, bringing the antenna to resonance. Another popular scheme uses a commercial resonator, consisting of a coil and a short top section, mounted on the short mast.

It is obvious that to change bands with these HF antennas, the operator must stop the car, get out, and change the coil tap or resonator. Further, if a matching arrangement is used in the trunk of the vehicle at the antenna mount (such as a shunt L or shunt C), the matching reactance must also be changed. The antenna described in this section was developed by William T. Schrader, K2TNO, to provide instant band changing.

One approach to instant band changing is to install a pair of relays, one to switch the loading-coil tap and one to switch the matching reactance. (Of course, this is

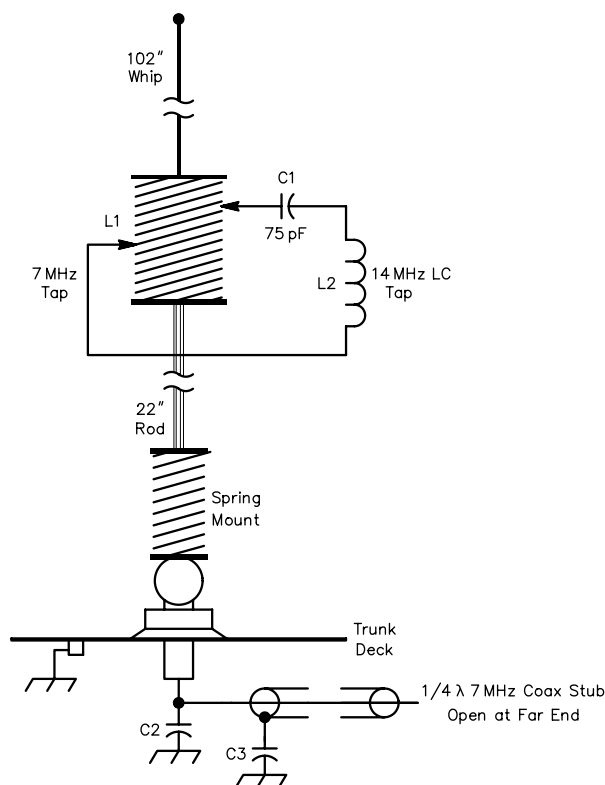


Fig 28—Details of the 7- and 14-MHz mobile antenna.

C1—Ceramic doorknob capacitor. See text.

C2—14 MHz matching. See text for determining value. May be made up of two or three parallel-connected 1000-V silver mica capacitors to obtain the required value.

C3—7 MHz matching, parallel-connected 1000-V silver mica capacitors or air variable. See text.

L1—Multiband center loading coil for mobile antenna.

L2—8 1/2 turn coil (B & W #3046), 1 1/4 inch diameter, 6 turns per inch.

not practical with an antenna resonator.) In addition to the problem of running relay lines through the passenger compartment, this approach is a poor one because the coil-tap changing relay would need to be at the coil, adding weight and wind load to an already cumbersome antenna. Furthermore, that relay would need to be sealed, as it would be exposed to the weather.

The solution here allows automatic band changing, depending upon only the frequency of the signal applied to the antenna. The antenna described provides gratifying results; it shows an SWR of less than 1.2:1 at both the 7- and 14-MHz design frequencies. The chosen method employs two resonant circuits, one that switches the matching capacitance in and out, and one that either shorts or opens turns of the coil, depending upon the excitation frequency. See **Fig 28**.

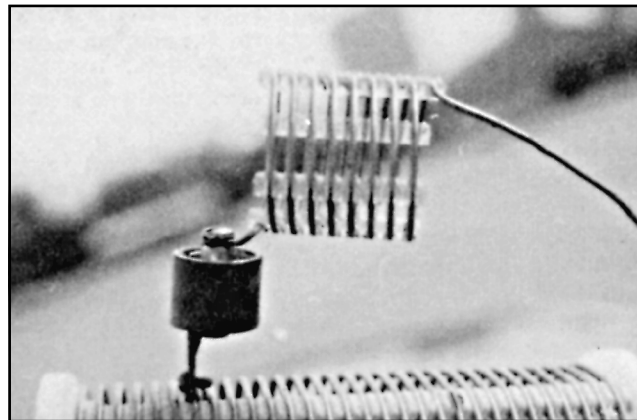


Fig 29—Close-up of the mounting arrangement of the 14-MHz LC network on the main tuning coil. The antenna was pulled to a nearly horizontal position and the camera tilted slightly for this photograph.)

Coil-Tap Switching

A series LC circuit looks electrically like a dead short at its resonant frequency. Below that frequency it presents a capacitive reactance; above resonance it looks inductive. A series resonant network, L2-C1, is resonant at the 14-MHz design frequency. One end of C1 is connected to the 14-MHz tap point on the coil, and the other end is connected to the bottom of the coil. On 14 MHz, the network looks like a short circuit and shorts out the unwanted turns at the bottom end of the coil. At 7 MHz the network is not a short, and therefore opens the bottom turns (but adds some reactance to the antenna).

A coil-tapping clip is soldered to the stud at one end of C1. The other end of C1 is connected to L2. A dip meter is used to prune L2 until the L2-C1 network is resonant somewhere in the 14-MHz CW band. The design of the plastic supports on L2 limits pruning of the coil to 1/4-turn increments. One lead of L2 should be cut close to the plastic and the short pigtail attached with a machine screw to the capacitor stud. The far end of L2 should have a long pigtail (about 5 to 6 inches) to secure the lower end of the network to the bottom of the antenna loading coil, L1. While resonating the network, the long pigtail can be bent around to clip to the top of the capacitor to form a parallel-resonant circuit.

Any doorknob capacitor between about 25 and 100 pF could be used for C1. The lower the value of C, the larger the coil inductance will need to be. A 1000-V silver mica capacitor would also work, but the doorknob is preferred because of the mechanical stability it provides.

The LC network should be mounted to the main coil, with the lower coil pigtail extended down roughly parallel to the main coil. Some turns adjustment will be required, so this pigtail should not be tight. The mounting details are visible in **Fig 29**.

Tuning the Antenna

Once the LC network is attached, the antenna must be tuned for the 7- and 14-MHz bands. This job *requires* the use of an impedance-measuring device such as an R-X noise bridge (home-built or commercial, either is fine) or an SWR analyzer. As with many antenna projects, you're just wasting your time if you try to do the job with an SWR meter alone. Prepare a length of coax feed line that is an electrical half wavelength at the 7-MHz design frequency. Do not attempt to use the vehicle coax feed line unless you want to do a lot of Smith Chart calculations.

Once the special feed line is attached, install the impedance bridge and begin the tuning as follows. The antenna must first be resonated to each band by adjusting the taps on L1, first for 7 and then for 14 MHz. Mark these two tap locations on the coil. Then using the steps that follow, perform tuning for the 14-MHz design frequency.

- 1) Move the 7-MHz tap wire up the coil to a new position that leaves about 60% of the original turns unshorted.
- 2) Listen at 14 MHz and adjust the impedance bridge for a null. The reactance dial should show capacitive reactance. Move the LC-network tap point down the coil about $\frac{1}{4}$ turn at a time until the bridge indicates pure resistance.
- 3) Switch to 7 MHz and follow the same procedure. On this band, move the shorting wire about $\frac{1}{2}$ turn at a time. Do not be surprised if it takes some hunting to find resonance; tuning is very critical on 7 MHz.
- 4) The two adjustments interact; repeat steps 2 and 3 of this section for both bands until the measured impedance is purely resistive at both design frequencies.
- 5) Remove the impedance bridge and install an SWR meter. Determine the SWR on both bands. The minimum SWR should be about 1.5:1 on 14 MHz and about 2.2:1 on 7 MHz. Shift the VFO frequency about 10 kHz above and below the design frequencies on both bands to verify that the minimum SWR occurs at the design frequencies. Do not expect the minimum SWR to be 1:1, because the antenna is not yet matched to the line. Alternate bands and adjust the two taps slightly for minimum SWR at the desired frequencies for both bands.
- 6) Record the SWR and tap points for both bands. This completes the adjustments for the resonating work.

Designing the Matching Networks

Since the feed-point impedance is not 52 Ω on either band, a matching network is needed for each. Matching can be done easily with an L network, as described earlier in this chapter and in Chapter 25. Schrader's network consists of a shunt capacitor from the antenna feed point to ground and a compensating increase in the coil inductance of L1, obtained by moving the tap slightly. The value of the matching capacitor is calculated by knowing R_A , the antenna feed-point resistance

at resonance, Z_0 , the impedance of the coax feed line, and f , the operating frequency in kHz.

- 1) Calculate the antenna feed-point resistance from the relationship $SWR = Z_0 / R_0$. Do this calculation for both bands. For the antenna Schrader constructed, values of R_0 were 33.3 Ω on 14 MHz and 21.4 Ω on 7 MHz.
- 2) Calculate the value for C2, the 14-MHz matching capacitor. This is the value obtained for C_M from

$$C_M = \frac{\sqrt{R_A (Z_0 - R_A)}}{2 \pi f Z_0 R_A} \quad (\text{Eq 23})$$

where

C_M is the matching capacitance in pF

R_0 and Z_0 are in Ω

f is in MHz.

Using Schrader's value of R_0 as an example, the capacitance is calculated as follows.

$$C_M = \frac{\sqrt{33.3 (52 - 33.3)}}{2 \pi \times 14.06 \times 52 \times 33.3} \times 10^6 = 163 \text{ pF}$$

This is the value for C2. A practical value is 160 pF.

- 3) From Eq 24, calculate the total matching capacitance required for 7 MHz. Again, using Schrader's value,

$$C_M = \frac{\sqrt{21.4 (52 - 21.4)}}{2 \pi \times 7.06 \times 52 \times 21.4} \times 10^6 = 518 \text{ pF}$$

- 4) Because C2 is present in the matching circuit at both 7 and 14 MHz, the value of C3 is not the C_M value just calculated. Calculate the value of C3 from

$$C3 = C_M - C2 \quad (\text{Eq 24})$$

where C_M is the value calculated in step 3 of this section.

In this example, $C3 = 518 - 163 = 355 \text{ pF}$.

Final Tuning of the Antenna

Install C2 from the antenna feed point to ground. Now readjust the tap point of the 14-MHz LC network to add just enough additional inductance to give a 50- Ω feed-point resistance. The tap point will be moved down (more turns in use) as the match is approached.

- 1) Attach the SWR meter and apply RF at 14 MHz (10 W or so). Note that the SWR is higher than it was before C2 was added.
- 2) Move the tap point down the coil about $\frac{1}{8}$ turn at a time. Eventually the SWR will begin to fall, and there will be a point where it approaches 1:1. For the antenna in the photos, almost a full additional coil turn was necessary on 14 MHz.
- 3) Verify (by shifting the VFO) that the minimum SWR occurs at the 14-MHz design frequency. Adjust the tap point until this condition is met. Note: If the SWR never falls to nearly 1:1, either C_M was miscalculated, the SWR was not measured correctly, the antenna was not

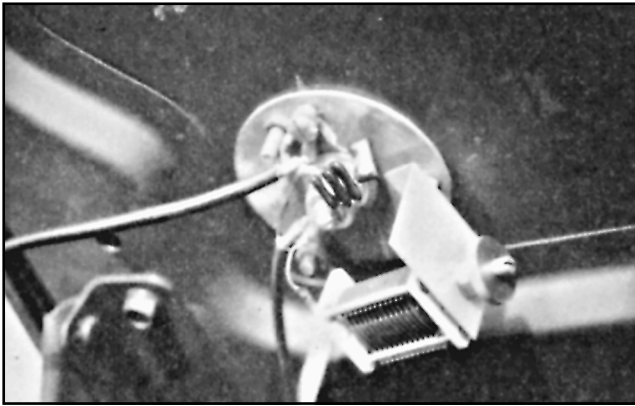


Fig 30—Details of the matching network located at the base of the antenna inside the vehicle. The mica capacitors are visible at the center. The coaxial stub used to switch them in and out of the circuit comes in from the left, and the feed line exits toward the bottom of the photo.

resonant, or the measuring coax feed line was not actually $\frac{1}{2}$ wavelength long on 7 MHz.

- 4) Add C3 in parallel with C2. Repeat steps 2 and 3 of this section at 7 MHz, moving the 7-MHz tap wire.
- 5) Recheck 14 and 7 MHz. Both bands should now show a low SWR (less than 1.2:1) at the design frequencies. Note: The grounded end of C3 must be lifted when you recheck 14 MHz and then reconnected for 7 MHz.

Now the antenna is resonant and properly matched on both bands, but C3 must be manually grounded and ungrounded to change bands. This problem may be solved as described below.

Matching Capacitor Switching

A length of coaxial cable (any impedance) that is exactly one-quarter wavelength long at a given frequency and is open-circuited at its far end will be resonant at that frequency. At this frequency, the input end of the coax appears as a dead short. If a signal of twice the frequency is applied, the line is $\frac{1}{2} \lambda$ long at that frequency, and the input terminals of the line are not shorted, but rather present a very high impedance (an open circuit, in theory). This property of quarter- and half-wavelength transmission lines can be used as a switch in this antenna, because the two frequencies in use are harmonically related.

Cut a length of RG-58 to resonate at the 7-MHz design frequency (about 22 feet), and leave the far end open. High RF voltages exist at this end, so it is a good idea to insulate it. Strip back the braid about $\frac{3}{16}$ inch and tape the end of the cable. This length of coax acts as an automatic switch to either ground or lift the low side of C3.

Connect one lead of C3 to the antenna feed point, and the other end to the center conductor of the coax stub, as shown in the diagram of Fig 28. Ground the braid of the coax at the base of the antenna. This circuit grounds

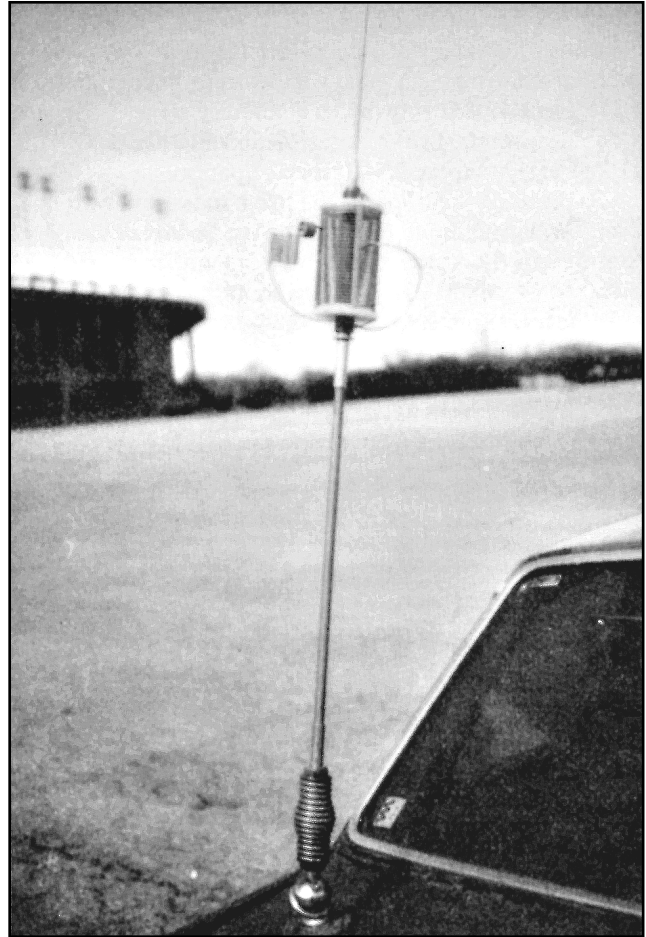


Fig 31—This photo shows the antenna mounted on the trunk of a car. The structure is somewhat cumbersome, so it is guyed appropriately.

Table 5

Coil Tap Positions for the Two-Band Mobile Antenna

<i>Unshorted Turns¹</i>		<i>Resonant Frequency (MHz)²</i>	
<i>14-MHz LC</i>	<i>7-MHz Tap</i>	<i>14-MHz Band</i>	<i>7-MHz Band</i>
$6\frac{1}{4}$	$11\frac{1}{2}$	14.190	7.267
	$11\frac{3}{4}$	14.170	7.144
	12	14.160	7.104
	$12\frac{1}{4}$	—	7.034
$6\frac{1}{2}$	12	14.085	7.207
	$12\frac{1}{4}$	14.070	7.080
	$12\frac{1}{2}$	14.020	7.005

¹Turns in use (measured from the top of the coil).

²Frequency at which SWR is 1:1.

the low end of the capacitor on 7.060 MHz, but opens it on 14.060 MHz automatically, depending on the frequency of the signal applied to it. Details of the matching network are shown in Fig 30.

Coil the coax stub and place it out of the way (in the trunk or wherever is convenient). Coiling does not affect stub tuning at all.

Operation of the Antenna

With antenna adjustments completed, remove the $\frac{1}{2}$ -wavelength feed line and reinstall the regular feed line. The antenna should now be operable on either band with a very low SWR. Because of the high Q of the open-wire coil and the antenna, bandwidth is limited on 7 MHz. An antenna tuner can be used to allow wide frequency excursions. If only a small segment of the 7-MHz band is to be used, no tuner is necessary.

The L2-C1 network should be positioned behind the main coil for minimum wind buffeting. As its attachment point is dictated by the electrical requirements, the network can be rotated behind the coil by installing a washer on the $\frac{3}{8}$ -inch \times 24 stud where the bottom of the coil is attached to the lower mast. The antenna is shown installed on a vehicle in **Fig 31**.

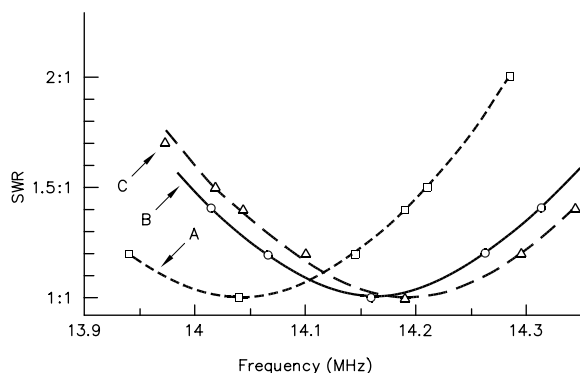


Fig 32—SWR curves for the antenna in the 14-MHz band. The 7-MHz tap was 12 turns from the top. Curves are shown for the 14-MHz LC tap positioned at $6\frac{1}{2}$ turns (A) and at $6\frac{1}{4}$ turns (B). In the last case, moving the 7-MHz tap to $11\frac{1}{2}$ turns altered the resonant frequency as shown at C.

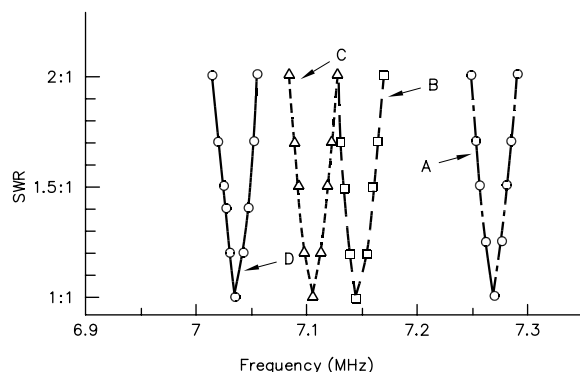


Fig 33—SWR curves for the antenna in the 7-MHz band. The 14-MHz LC tap was $6\frac{1}{4}$ turns from the top. The 7-MHz tap for curve A was set at $11\frac{1}{2}$ turns, $11\frac{3}{4}$ turns for B, 12 turns for C, and $12\frac{1}{4}$ turns for D.

Orientation of the tap wire and the LC bottom tap wire have a large effect on tuning. Be sure to orient these leads during tuning in the same way that you will when using the antenna.

SWR measurements have been made with various tap positions of both the 14-MHz LC trap and the 7-MHz tap wire. The results are summarized in **Table 5**. With the matching and switching system installed as described, the antenna showed an SWR of 1:1 at the transmitter on both bands. The 2:1 SWR bandwidth was about 40 kHz on 7 MHz, and over 350 kHz on 14 MHz.

Table 5 includes typical coil-tap settings for changing the resonant frequency on both bands. Exact tap positions will depend upon the geometry of the antenna, its position on the vehicle and the arrangement of the leads themselves. The table also shows how the two band adjustments interact. For example, with the 14-MHz LC tap at $6\frac{1}{4}$ turns, changing the 7-MHz tap from $11\frac{1}{2}$ to 12 turns moved the 7-MHz resonance point from 7.267 to 7.104 MHz. There was also a 30-kHz change in the 14-MHz resonance point, from 14.190 to 14.160 MHz. The inverse effect was even more pronounced. With 12 turns in use for the 7-MHz tap, moving the 14-MHz LC tap from $6\frac{1}{4}$ to $6\frac{1}{2}$ turns altered the 14-MHz frequency from 14.160 to 14.085 MHz. Simultaneously the 7-MHz resonant frequency shifted from 7.104 to 7.207 MHz. Thus, both settings interact strongly.

Since the bandwidth on 14 MHz is nearly sufficient to cover the entire amateur band without adjustment, the settings of the 14-MHz LC network are not very critical.

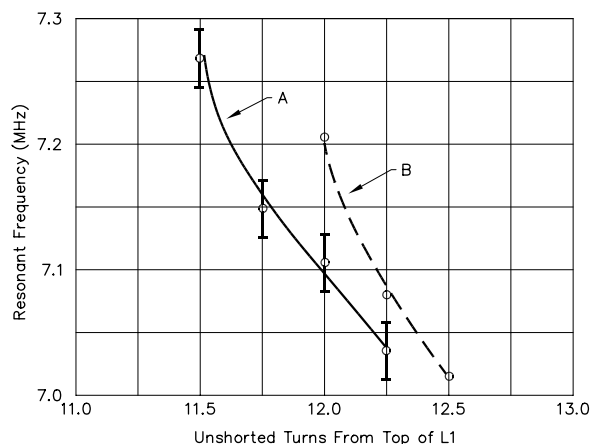


Fig 34—Effect of tap positions on resonant frequency in the 7 MHz band. The 14-MHz LC tap was set at $6\frac{1}{4}$ turns from the top. At A, each circled dot shows the resonant frequency at which the SWR is 1:1. Bars about each point show the frequency limits at which the SWR is 2:1. The measurements were repeated with the 14-MHz LC tap set at $6\frac{1}{2}$ turns, yielding the circled points on curve B.

However, as Table 5 shows, slight readjustments of either tap will have marked effects upon 7-MHz performance.

Typical SWR curves for the two bands are shown in Figs 32 and 33. **Fig 32** shows that moving the 14-MHz LC tap point from $6\frac{1}{2}$ to $6\frac{1}{4}$ turns raised the resonant frequency from 14.040 to 14.168 MHz. The 7-MHz tap was set at 12 turns for these measurements. When the 7-MHz tap was moved to $11\frac{1}{2}$ turns, the 14-MHz resonant frequency was raised to 14.190 MHz. The 14-MHz LC tap was kept constant for the measurements shown in **Fig 33**, and the difference in resonant frequency that results from moving the 7-MHz tap is shown.

The matching network, using C2/C3, is quite broadband. Once the feed-point matching capacitors (C_M) and the retuned coil were adjusted, the minimum SWR was 1:1 at all tap settings on both bands. Thus, the matching arrangement does not require adjustment. If a compromise setting is chosen for the 14-MHz LC tap position to allow both CW and SSB operation on that band, only adjustment of the 7-MHz tap will be required during routine operation. To this end, the plots shown in **Fig 34** were obtained. The curves show the 7-MHz resonant frequency as a function of tap position. Also included is a plot showing the effect at 7 MHz of altering the 14-MHz LC tap point.

Other Considerations

There is no reason why the strategy described here could not be applied to any two bands, as long as the desired operating frequencies are harmonically related. Other likely candidates would be 3.5-MHz CW/7-MHz CW using a 3.5-MHz coil, 14 MHz/28 MHz using a 14-MHz coil, and 7-MHz SSB/14-MHz SSB. A combination that would probably not work is 3.8-MHz SSB/7-MHz SSB, but it might be worth a try.

The antenna performs very well on the design frequencies. It is too big for routine city use, but it sure makes a great open-highway antenna.

A MOBILE J ANTENNA FOR 144 MHz

The J antenna is a mechanically modified version of the Zepp (Zeppelin) antenna. It consists of a half-wave-length radiator fed by a quarter-wave matching stub. This antenna exhibits an omnidirectional pattern with little high-angle radiation, but does not require the ground plane that $\frac{1}{4}$ -wave and $\frac{5}{8}$ -wave antennas do to work properly. The material in this section was prepared by Domenic Mallozzi, N1DM, and Allan White, W1EYI.

Fig 35 shows two common configurations of the J antenna. **Fig 35A** shows the shorted-stub version that is usually fed with 200- to 600- Ω open-wire line. Some have attempted to feed this antenna directly with coax without a balun, and this usually leads to less than optimum results. Among the problems with such a configuration are a lack of reproducibility and heavy coupling with nearby objects. To eliminate these problems, many amateurs have used a 4:1 half-wave balun between the feed point and a coaxial feed line. This simple addition results in an antenna that can be easily reproduced and that does not interact so heavily with surrounding objects. The bottom of the stub may be grounded (for mechanical or other reasons) without impairing the performance of the antenna.

The open-stub-fed J antenna shown in **Fig 35B** can be connected directly to low-impedance coax lines with good results. The lack of a movable balun (which allows some impedance adjustment) may make this antenna a bit more difficult to adjust for minimum SWR, however.

The Length Factor

Dr. John S. Belrose, VE2CV, noted in *The Canadian Amateur* that the diameter of the radiating element is important to two characteristics of the antenna—its bandwidth and its physical length. (See Bibliography at

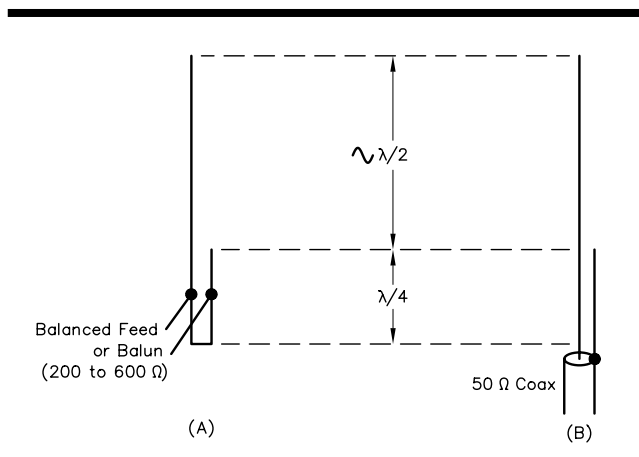


Fig 35—Two configurations of the J antenna.



Fig 36—The mount for the mobile J is made from stainless-steel angle stock and secured to the bumper with stainless-steel hardware. Note the $\frac{1}{2}$ -inch pipe plug and a PL-259 (with a copper disc soldered in its unthreaded end). These protect the mount and connector threads when the antenna is not in use.



Fig 37—The J antenna, ready for use. Note the bakelite insulator and the method of feed. Tie wraps are used to attach the balun to the mounting block and to hold the coax to the support pipe. Clamps made of flashing copper are used to connect the balun to the J antenna just above the insulating block. The ends of the balun should be weatherproofed.

the end of this chapter.) As the element diameter is increased, the usable bandwidth increases, while the physical length of the radiating element decreases with respect to the free-space half-wavelength. The increased diameter makes the end effect more pronounced, and also slows the velocity of propagation on the element. These two effects are related to resonant antenna lengths by a factor, “k.” This factor is expressed as a decimal fraction giving the equivalent velocity of propagation on the antenna wire as a function of the ratio of the element diameter to a wavelength. The k factor is discussed at length in Chapter 2.

The length of the radiating element is given by

$$\ell = \frac{5904 \times k}{f} \quad (\text{Eq 25})$$

where

ℓ = length in inches
 f = frequency in MHz
 k = k factor.

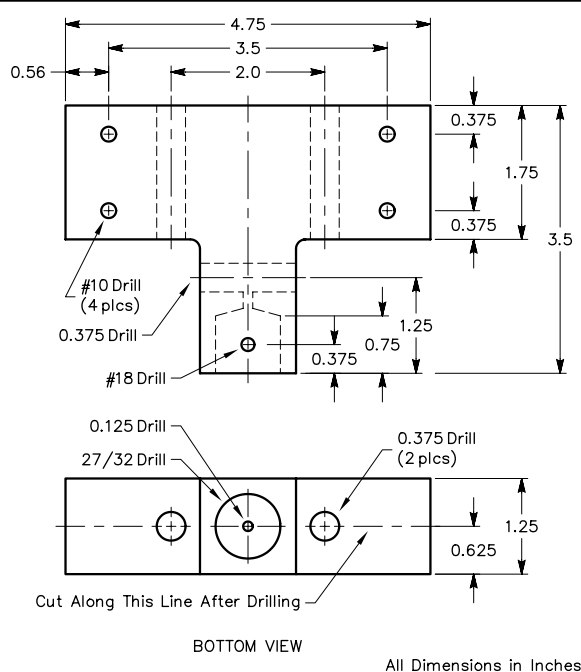


Fig 38—Details of the insulated mounting block. The material is bakelite.

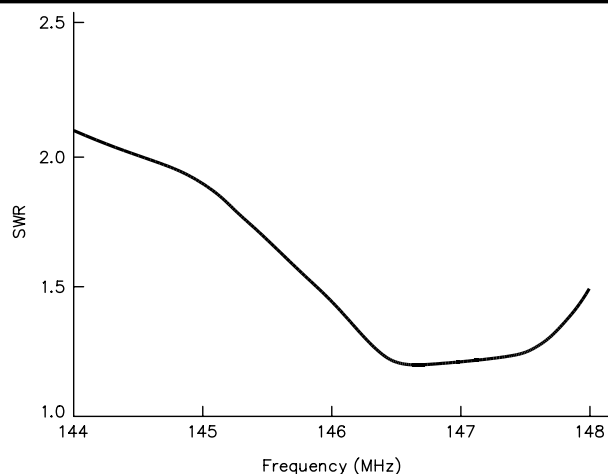


Fig 39—Measured SWR of the mobile J antenna.

The k factor can have a significant effect. For example, if you use a $\frac{5}{8}$ -inch diameter piece of tubing for the radiator at 144 MHz, the k value is 0.907 (9.3% shorter than a free-space half wavelength).

The J antenna gives excellent results for both mobile and portable work. The mobile described here is similar to an antenna described by W. B. Freely, K6HMS, in April 1977 *QST*. This design uses mechanical components that are easier to obtain. As necessary with all mobile antennas, significant attention has been paid to a strong, reliable, mechanical design. It has survived not

only three New England winters, but also two summers of 370-mile weekend commutes. During this time, it has maintained consistent electrical performance with no noticeable deterioration.

The mechanical mount to the bumper is a 2×2 -inch stainless steel angle iron, 10 inches long. It is secured to the bumper with stainless steel hardware, as shown in **Fig 36**. A stainless steel $\frac{1}{2}$ -inch pipe coupling is welded to the left side of the bracket, and an SO-239 connector is mounted at the right side of the bracket. The bracket is mounted to the bumper so a vertical pipe inserted in the coupling will allow the hatchback of the vehicle to be opened with the antenna installed, **Fig 37**.

A $\frac{1}{2}$ -inch galvanized iron pipe supports the antenna so the radiating portion of the J is above the vehicle roof line. This pipe goes into a bakelite insulator block, visible in **Fig 37**. The insulator block also holds the bottom of the stub. This block was first drilled and then split with a band saw, as shown in **Fig 38**. After splitting, the two portions are weatherproofed with varnish and rejoined with 10-32 stainless hardware. The corners of the insulator are cut to clear the L sections at the shorted end of the stub.

The quarter-wave matching section is made of $\frac{1}{4}$ -inch type L copper tubing ($\frac{5}{16}$ inch ID, $\frac{3}{8}$ inch OD). The short at the bottom of the stub is made from two copper L-shaped sections and a short length of $\frac{1}{4}$ -inch tubing. Drill a $\frac{1}{8}$ -inch hole in the bottom of this piece of tubing to drain any water that may enter or condense in the stub.

A $\frac{5}{16}$ -inch diameter brass rod, $1\frac{1}{2}$ to 2 inches long, is partially threaded with a $\frac{5}{16} \times 24$ thread to accept a Larsen whip connector. This rod is then sweated into one of the legs of the quarter-wave matching section. A 40-inch whip is then inserted into the Larsen connector.

The antenna is fed with 50- Ω coaxial line and a coaxial 4:1 half-wave balun. This balun is described at the end of Chapter 26. As with any VHF antenna, use high-quality coax for the balun. Seal all open cable ends and the rear of the SO-239 connector on the mount with RTV sealant.

Adjustment is not complicated. Set the whip so that its tip is 41 inches above the open end of the stub, and adjust the balun position for lowest SWR. Then adjust the height of the whip for the lowest SWR at the center frequency you desire. **Fig 39** shows the measured SWR of the antenna after adjustments are completed.

THE SUPER-J MARITIME ANTENNA

This 144-MHz vertical antenna doesn't have stringent grounding requirements and can be made from easy to find parts. The material in this section was prepared by Steve Cerwin, WA5FRF, who developed the Super-J for use on his boat.

Antennas for maritime use must overcome difficulties that other kinds of mobile antennas normally do not encounter. For instance, the transom of a boat is the

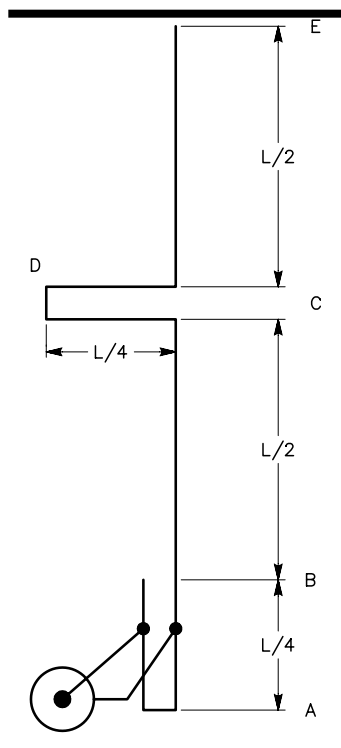


Fig 40—Schematic representation of the Super-J maritime antenna. The radiating section is two half waves in phase.

logical place to mount an antenna. But the transoms of many boats are composed mostly of fiberglass, and they ride some distance out of the water—from several inches to a few feet, depending on the size of the vessel. Because the next best thing to a ground plane (the water surface) is more than an appreciable fraction of a wavelength away at 144 MHz, none of the popular gain-producing antenna designs requiring a counterpoise are suitable. Also, since a water surface does a good job of assuming the earth's lowest mean elevation (at least on a calm day), anything that can be done to get the radiating part of the antenna up in the air is helpful.

One answer is the venerable J-pole, with an extra

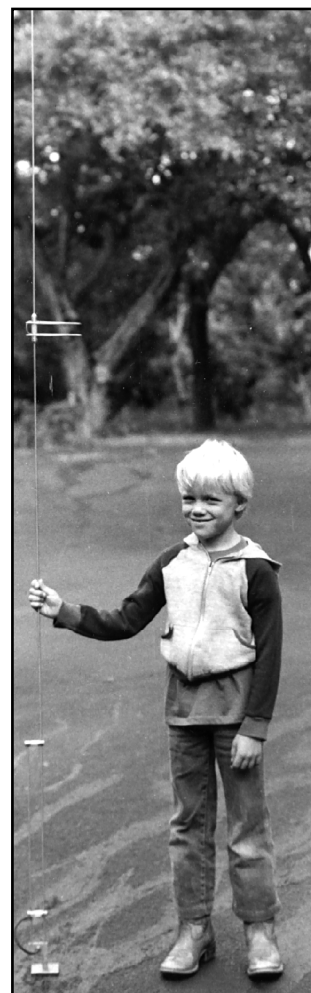


Fig 41—Andy and the assembled Super-J antenna.

in-phase half-wave section added on top—the Super-J antenna. The two vertical half waves fed in phase give outstanding omnidirectional performance for a portable antenna. Also, the J-pole feed arrangement provides the desired insensitivity to height above ground (or water) plus added overall antenna height. Best of all, a $\frac{1}{4}$ -wave CB whip provides enough material to build the whole driven element of the antenna, with a few inches to spare. The antenna has enough bandwidth to cover the entire 144-MHz band, and affords a measure of lightning protection by being a grounded design.

Antenna Operation

The antenna is represented schematically in **Fig 40**. The classic J-pole antenna is the lower portion shown between points A and C. The half-wave section between points B and C does most of the radiating. The added half-wave section of the Super-J version is shown between points C and E. The side-by-side quarter-wave elements between points A and B comprise the J feed arrangement.

At first glance, counterproductive currents in the J section between points A and B may seem a waste of element material, but it is through this arrangement that the antenna is able to perform well in the absence of a good ground. The two halves of the J feed arrangement, side by side, provide a loading mechanism regardless of whether or not a ground plane is present.

The radiation resistance of any antenna fluctuates as a function of height above ground, but the magnitude of this effect is small compared to the wildly changing impedance encountered when the distance from a ground plane ele-

ment to its counterpoise is varied. Also, the J section adds $\frac{1}{4}$ wavelength of antenna height, reducing the effect of ground height variations even further. Reducing ground-height sensitivity is particularly useful in maritime operation on those days when the water is rough.

The gain afforded by doubling the aperture of a J-pole with the extra half-wave section can be realized only if the added section is excited in phase with the half-wave element B-C. This is accomplished in the Super-J in a conventional manner, through the use of the quarter-wave phasing stub shown between C and D.

Construction and Adjustment

The completed Super-J is shown in **Fig 41**. Details of the individual parts are given in **Fig 42**. The driven element can be liberated from a quarter-wave CB whip antenna and cut to the dimensions shown. All other metal stock can be obtained from metal supply houses or machine shops. Metal may even be scrounged for little

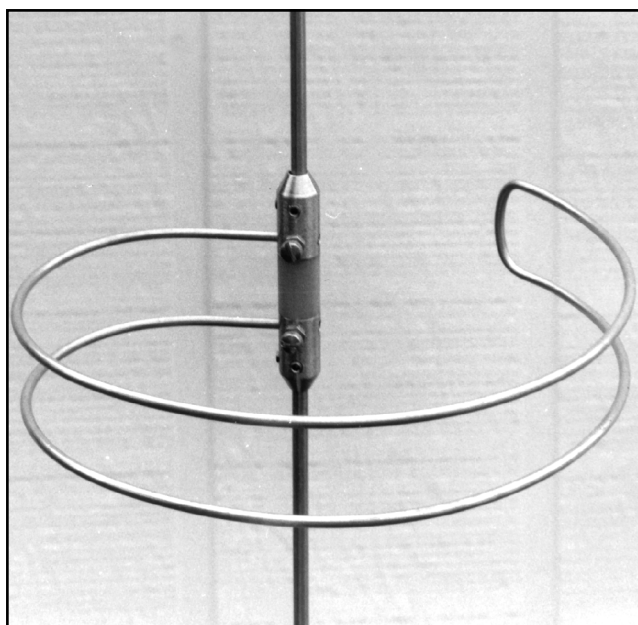


Fig 43—A close-up look at the $\frac{1}{4}$ - λ phasing section of the Super-J. The insulator fitting is made of stainless-steel end caps and fiberglass rod.

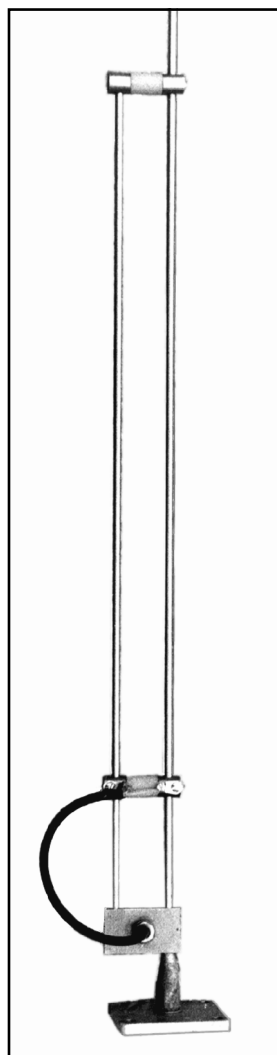


Fig 44—The bottom shorting bar and base mounting plate assembly.

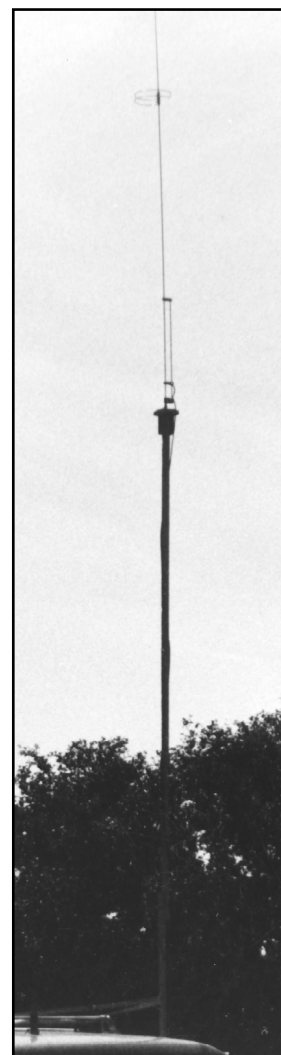


Fig 45—The Super-J in portable use at a field site.

or nothing as scraps or remnants, as were the parts for the antenna shown here.

The center insulator and the two J stub spacers are made of $\frac{1}{2}$ -inch fiberglass and stainless steel stock, and the end caps are bonded to the insulator sections with epoxy. If you don't have access to a lathe to make the end caps, a simpler one-piece insulator design of wood or fiberglass could be used. However, keep in mind that good electrical connections must be maintained at all joints, and strength is a consideration for the center insulator.

The quarter-wave phasing stub is made of $\frac{1}{8}$ -inch stainless steel tubing, **Fig 43**. The line comprising this stub is bent in a semicircular arc to narrow the vertical profile and to keep the weight distribution balanced. This makes for an attractive appearance and keeps the antenna from leaning to one side.

The bottom shorting bar and base mounting plate are made of $\frac{1}{4}$ -inch stainless steel plate, shown in **Fig 44**. The J stub is made of $\frac{3}{16}$ -inch stainless-steel rod stock. The RF connector may be mounted on the shorting bar as shown, and connected to the adjustable slider with a short section of coaxial cable. RTV sealant should be used at the cable ends to keep out moisture. The all-stainless construction looks nice and weathers well in maritime mobile applications.

The antenna should work well over the whole 144-MHz band if cut to the dimensions shown. The only tuning required is adjustment of the sliding feed point for minimum SWR in the center of the band segment you use most. Setting the slider $2\frac{13}{16}$ inch above the top of the shorting bar gave the best match for this antenna and may be used for a starting point. Four turns of coax made into a coil at the feed point or a ferrite-sleeve balun act as a common-mode choke balun to ensure satisfactory performance.

Performance

Initial tests of the Super-J were performed in portable use and were satisfactory, if not exciting. **Fig 45** shows the Super-J mounted on a wooden mast at a portable site. Simplex

Fig 46—This 144-MHz antenna uses a combination of top and center loading. It offers low construction cost and improved efficiency over continuously loaded rubber-duddy antennas.

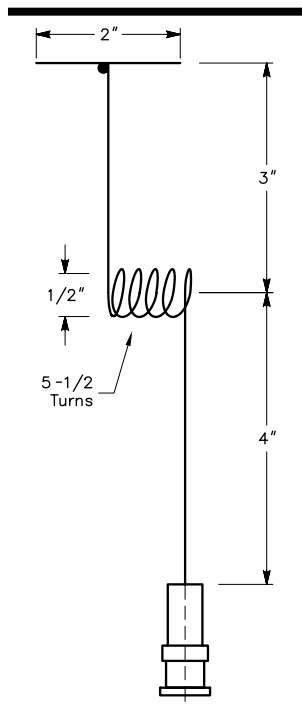
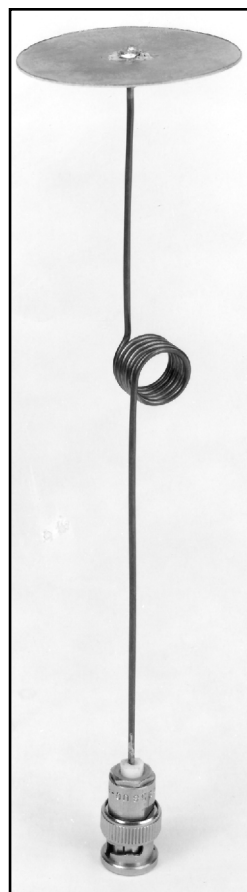


Fig 47—Dimensions for the top-loaded 144-MHz antenna. See text regarding coil length.

communication with a station 40 miles away with a 10-W mobile rig was full quieting both ways. Stations were worked through distant repeaters that were thought inaccessible from this location.

Comparative tests between the Super-J and a commercial $\frac{5}{8}$ -wave antenna mounted on the car showed the Super-J to give superior performance, even when the Super-J was lowered to the same height as the car

roof. The mast shown in **Fig 45** was made from two 8-foot lengths of 1×2 -inch pine. (The two mast sections and the Super-J can be easily transported in most vehicles.)

The Super-J offers a gain of about 6 dB over a quarter-wave whip and around 3 dB over a $\frac{5}{8}$ -wave antenna. Actual performance, especially under less-than-ideal or variable ground conditions, is substantially better than other vertical antennas operated under the same conditions. The freedom from ground-plane radials proves to be a real benefit in maritime mobile operation, especially for those passengers in the back of the boat with sensitive ribs!

A TOP-LOADED 144-MHz MOBILE ANTENNA

Earlier in this chapter, the merits of various loading schemes for shortened whip antennas were discussed. Quite naturally, one might be considering HF mobile operation for the application of those techniques. But the principles may be applied at any frequency. **Fig 46** shows a 144-MHz antenna that is both top and center loaded. This antenna is suitable for both mobile and portable operation, being intended for use on a handheld transceiver. This antenna was devised by Don Johnson, W6AAQ, and Bruce Brown, W6TWW.

A combination of top and center loading offers improved efficiency over continuously loaded antennas such as the "stubby" pictured at the beginning of this chapter. This antenna also offers low construction cost. The only materials needed are a length of stiff wire and a scrap of circuit-board material, in addition to the appropriate connector.

Construction

The entire whip section with above-center loading coil is made of one continuous length of material. An 18-inch length of brazing rod or #14 Copperweld wire is suitable.

In the antenna pictured in Fig 46, the top loading disk was cut from a scrap of circuit-board material, but flashing copper or sheet brass stock could be used instead. Aluminum is not recommended.

The dimensions of the antenna are given in Fig 47. First wind the center loading coil. Use a 1/2-inch bolt, wood dowel, or other cylindrical object for a coil form. Begin winding at a point 3 inches from one end of the wire, and wrap the wire tightly around the coil form. Wind 5 1/2 turns, with just enough space between turns so they don't touch.

Remove the coil from the form. Next, determine the length necessary to insert the wire into the connector you'll be using. Cut the long end of the wire to this length plus 4 inches, measured from the center of the coil. Solder the wire to the center pin and assemble the connector. A tight-fitting sleeve made of Teflon or Plexiglas rod may be used to support and insulate the antenna wire inside the shell. An alternative is to fill the shell with epoxy cement, and allow the cement to set while the wire is held centered in the shell.

The top loading disk may be circular, cut with a hole saw. A circular disk is not required, however—it may be

of any shape. Just remember that with a larger disk, less coil inductance will be required, and vice versa. Drill a hole at the center of the disk for mounting it to the wire. For a more rugged antenna, reinforce the hole with a brass eyelet. Solder the disk in place at the top of the antenna, and construction is completed.

Tune-Up

Adjustment consists of spreading the coil turns for the correct amount of inductance. Do this at the center frequency of the range you'll normally be using. Optimum inductance is determined with the aid of a field strength meter at a distance of 10 or 15 feet.

Attach the antenna to a handheld transceiver operating on low power, and take a field-strength reading. With the transmitter turned off, spread the coil turns slightly, and then take another reading. By experiment, spread or compress the coil turns for the maximum field-strength reading. Very little adjustment should be required. There is one precaution, however. You must keep your body, arms, legs, and head in the same relative position for each field-strength measurement. It is suggested that the transceiver be placed on a nonmetal table and operated at arm's length for these checks.

Once the maximum field-strength reading is obtained, adjustments are completed. With this antenna in operation, you'll likely find it possible to access repeaters that are difficult to reach with other shortened antennas. W6AAQ reports that in distant areas his antenna even outperforms a $5/8\lambda$ vertical.

VHF QUARTER-WAVELENGTH VERTICAL

Ideally, a VHF vertical antenna should be installed over a perfectly flat reflector to assure uniform omnidirectional radiation. This suggests that the center of the automobile roof is the best place to mount it for mobile use. Alternatively, the flat portion of the trunk deck can be used, but will result in a directional pattern because of car-body obstruction.

Fig 48 illustrates how a Millen high-voltage connector can be used as a roof mount for a VHF whip. The hole in the roof can be made over the dome light, thus providing accessibility through the upholstery. RG-59 and the $1/4$ -wave matching section, L (Fig 48C), can be routed between the car roof and the ceiling upholstery and brought into the trunk compartment, or down to the dashboard of the car. Instead of a Millen connector, some operators install an SO-239 coax connector on the roof for mounting the whip. The method is similar to that shown in Fig 48.

It has been established that in general, $1/4\lambda$ vertical antennas for mobile repeater work are not as effective as $5/8\lambda$ verticals are. With a $5/8\lambda$ antenna, more of the transmitted signal is directed at a low wave angle, toward the horizon, offering a gain of about 1 dB over the $1/4\lambda$ vertical. However, in areas where the repeater is located

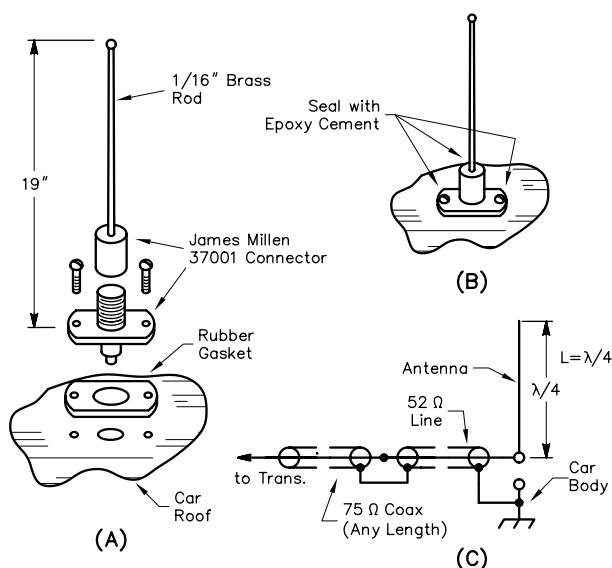


Fig 48—At A and B, an illustration of how a quarter-wavelength vertical antenna can be mounted on a car roof. The whip section should be soldered into the cap portion of the connector and then screwed into the base socket. This arrangement allows for the removal of the antenna when desired. Epoxy cement should be used at the two mounting screws to prevent the entry of moisture through the screw holes. Diagram C is discussed in the text.

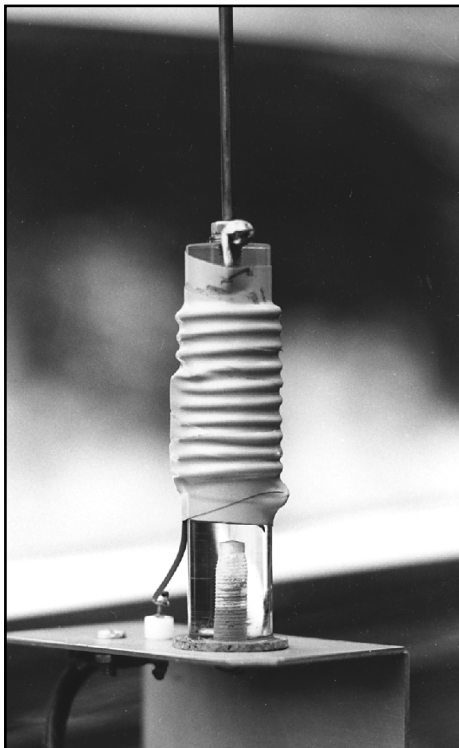
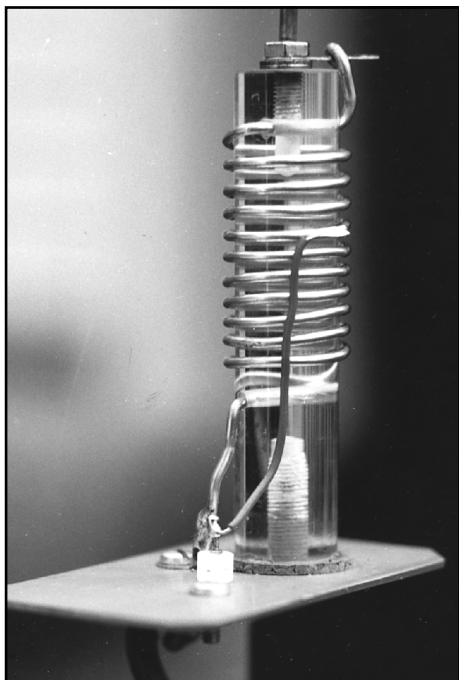


Fig 49—At top, a photograph of the $\frac{5}{8}\lambda$ vertical base section. The matching coil is affixed to an aluminum bracket that screws onto the inner lip of the car trunk. Above, the completed assembly. The coil has been wrapped with vinyl electrical tape to keep out dirt and moisture.

Fig 50—Structural details for the 2-meter $\frac{5}{8}\lambda$ antenna are provided at A. The mounting bracket is shown at B and the equivalent circuit is given at C.

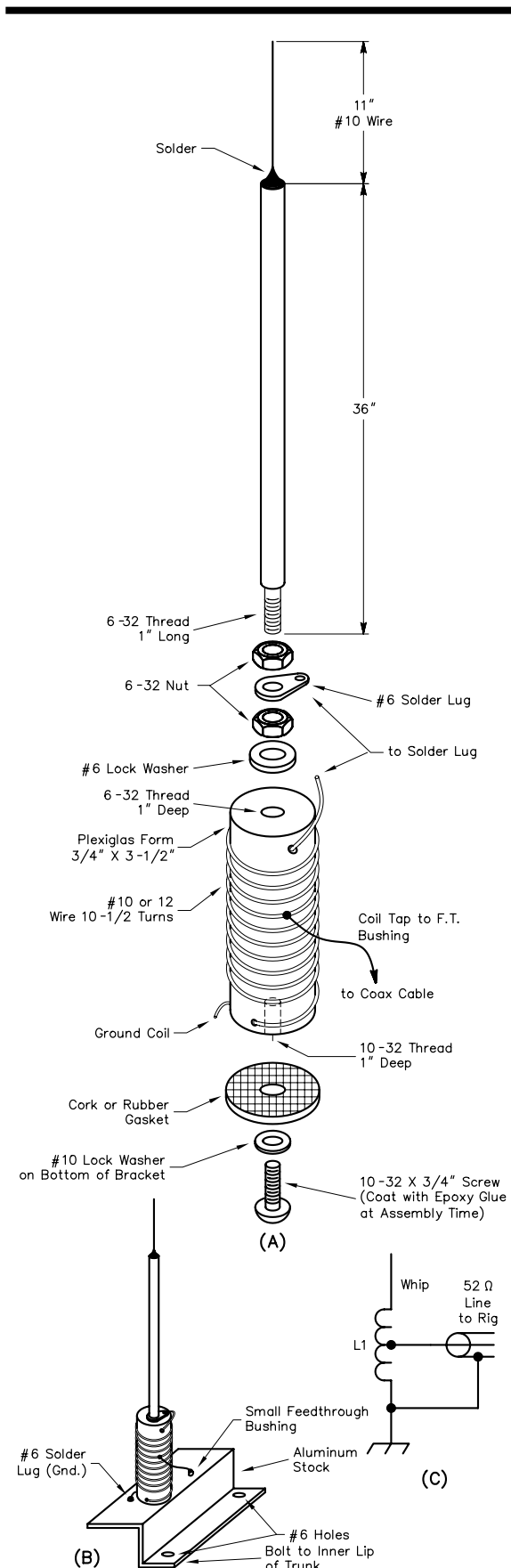




Fig 51—The 220-MHz $\frac{5}{8}$ - λ mobile antenna. The coil turns are spaced over a distance of 1 inch, and the bottom end of the coil is soldered to the coax connector.

nearby on a very high hill or a mountain top, the $\frac{1}{4}$ - λ antenna will usually offer more reliable performance than a $\frac{5}{8}$ - λ antenna. This is because there is more power in the lobe of the $\frac{1}{4}$ - λ vertical at higher angles.

144-MHz $\frac{5}{8}$ -WAVELENGTH VERTICAL

Perhaps the most popular antenna for 144-MHz FM mobile and fixed-station use is the $\frac{5}{8}$ -wavelength vertical. As compared to a $\frac{1}{4}$ -wavelength vertical, it has 1 dB of gain.

This antenna is suitable for mobile or fixed-station use because it is small, omnidirectional, and can be used with radials or a solid-plane ground (such as a car body). If radials are used, they need be only $\frac{1}{4}$ wavelength long.

Construction

The antenna shown here is made from low-cost materials. **Fig 49** shows the base coil and aluminum mounting plate. The coil form is a piece of low-loss solid rod, such as Plexiglas or phenolic. The dimensions for this and other parts of the antenna are given in **Fig 50**. A length of brazing rod is used as the whip section.

The whip should be 47 inches long. However, brazing rod comes in standard 36-inch lengths, so if used, it is necessary to solder an 11-inch extension to the top of the whip. A piece of #10 copper wire will suffice. Alternatively, a stainless-steel rod can be purchased to make a 47-inch whip. Shops that sell CB antennas should have such rods for replacement purposes on base-loaded antennas. The limitation one can expect with brazing rod is the relative fragility of the material, especially when the threads are cut for screwing the rod into the base coil form. Excessive stress can cause the rod to break where it enters the form. The problem is complicated somewhat in this design because a spring is not used at the antenna mounting point. Builders of this antenna can find all kinds

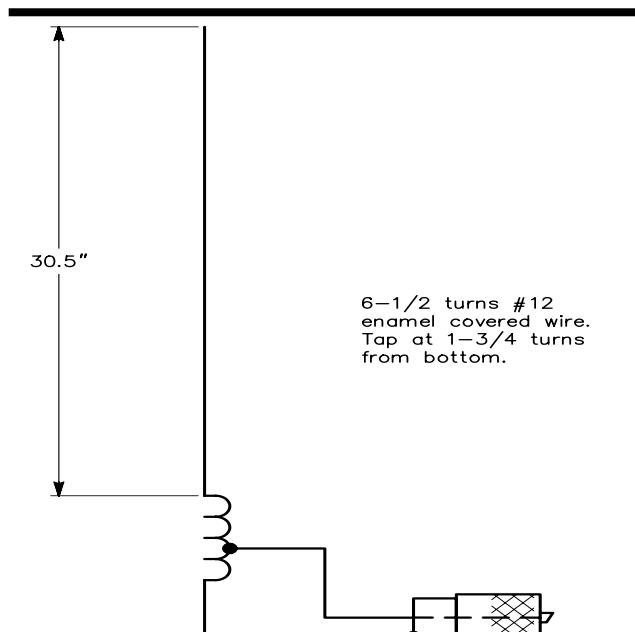


Fig 52—Diagram of the 220-MHz mobile antenna.

of solutions to the problems just outlined by changing the physical design and using different materials when constructing the antenna. The main purpose of this description is to provide dimensions and tune-up information.

The aluminum mounting bracket must be shaped to fit the car with which it will be used. The bracket can be used to effect a no-holes mount with respect to the exterior portion of the car body. The inner lip of the vehicle trunk (or hood) can be the point where the bracket is attached by means of no. 6 or no. 8 sheet-metal screws. The remainder of the bracket is bent so that when the trunk lid or car hood is raised and lowered, there is no contact between the bracket and the moving part. Details of the mounting unit are given in **Fig 50B**. A 14-gauge metal (or thicker) is recommended for rigidity.

Wind $10\frac{1}{2}$ turns of #10 or #12 copper wire on the $\frac{3}{4}$ -inch diameter coil form. The tap on L1 is placed approximately four turns below the whip end. A secure solder joint is imperative.

Tune-Up

After the antenna has been mounted on the vehicle, connect an SWR indicator in the 50- Ω transmission line. Key the 144-MHz transmitter and experiment with the coil tap placement. If the whip section is 47 inches long, an SWR of 1:1 can be obtained when the tap is at the right location. As an alternative method of adjustment, place the tap at four turns from the top of L1, make the whip 50 inches long, and trim the whip length until an SWR of 1:1 occurs. Keep the antenna well away from other objects during tune-up, as they may detune the antenna and yield false adjustments for a match.

A 5/8-WAVELENGTH 220-MHz MOBILE ANTENNA

The antenna shown in **Figs 51** and **52** was developed to fill the gap between a homemade $1/4\lambda$ mobile antenna and a commercially made $5/8\lambda$ model. While antennas can be made by modifying CB models, that presents the problem of cost in acquiring the original antenna. The major cost in this setup is the whip portion. This can be any tempered rod that will spring easily.

Construction

The base insulator portion is made of $1/2$ -inch Plexiglas rod. A few minutes' work on a lathe is sufficient to shape and drill the rod. (The innovative builder can use an electric drill and a file for the lathe work.) The bottom $1/2$ inch of the rod is turned down to a diameter of $3/8$ inch. This portion will now fit into a PL-259 UHF connector. A $1/8$ -inch diameter hole is drilled through the center of the rod. This hole will hold the wires that make the connec-

tions between the center conductor of the connector and the coil tap. The connection between the whip and the top of the coil is also run through this opening. A stud is force-fitted into the top of the Plexiglas rod. This allows for removal of the whip from the insulator.

The coil should be initially wound on a form slightly smaller than the base insulator. When the coil is transferred to the Plexiglas rod, it will keep its shape and will not readily move. After the tap point has been determined, a longitudinal hole is drilled into the center of the rod. A #22 wire can then be inserted through the center of the insulator into the connector. This method is also used to attach the whip to the top of the coil. After the whip has been fully assembled, a coating of epoxy cement is applied. This seals the entire assembly and provides some additional strength. During a full winter's use there was no sign of cracking or other mechanical failure. The adjustment procedure is the same as for the 144-MHz version described previously.

HF Antennas For Sailboats

This material was contributed by Rudy Severns, N6LF. Many of the antenna ideas appearing earlier in this chapter can be applied to sailboats. However, the presence of the mast and the rigging, plus the prevalence of non-conducting fiberglass hulls complicates the issue. There are many possibilities for antennas aboard sailboats. This includes both permanently installed antennas and antennas that can be hoisted for temporary use at anchor:

1. **Permanent**

Commercial or home-brew automobile-type verticals
Backstay verticals and slopers
Shunt feed of uninsulated rigging

2. **Temporary**

Sloping dipoles
Inverted V's
Yagis

You should remember some basic facts of life on a sailboat:

- 1) On most boats the spars, standing rigging and some running rigging will be conductors. Stainless steel wire is usually used for the rigging and aluminum for the spars.
- 2) Topping lifts, running backstays and jackstays all may be made of conducting materials and may often change position while the boat is underway. This changes the configuration of the rigging and may affect radiation patterns and feed-point impedances.
- 3) Shipboard antennas will always be close to the mast and rigging, in terms of electrical wavelength. Some antennas may in fact be part of the rigging.
- 4) The feed-point impedance and radiation pattern can be strongly influenced by the presence of the rigging.
- 5) Because of the close proximity, the rigging is an integral part of the antenna and should be viewed as such.
- 6) The behavior of a given antenna will depend of the details of the rigging on a particular vessel. The performance of a given antenna can vary widely on different boats, due to differences in dimensions and arrangement of the rigging.
- 7) Even though you may be floating on a sea of salt water, grounding still requires careful attention!

ANTENNA MODELING

Because of the strong interaction between the rigging and the antenna, accurate prediction of radiation patterns and a reasonable guess at expected feed-point impedance requires that you model both the antenna and the rigging. Unless you do accurately model the system, considerable cut-and-try may be needed. This can be expensive when it has to be done in 1×19 stainless steel wire with \$300 swaged insulator fittings!

In fact, when your antenna is going to be part of standing rigging, it's a very good idea to try your designs out at the dock. You could temporarily use Copperweld wire and inexpensive insulators in place of the stainless rigging wire and the expensive insulators. This approach can save a good deal of money and aggravation. A wide variety of modeling programs are available and can be very helpful in designing a new antenna but they have to be used with some caution:

- 1) The rigging will have many small intersection angles and radically different conductor diameters, this can cause problems for *NEC* and *MININEC* programs.
- 2) You must usually taper the segment lengths near the junctions. This is done automatically in programs like *ELNEC* and *EZNEC*.
- 3) It is usually necessary to use one wire size for the mast, spars and rigging. Some improvement in accuracy can be obtained by modeling the mast as a cage of 3 or 4 wires.

The predicted radiation patterns will be quite good but the feed-point impedance predictions should be viewed as preliminary. Some final adjustment will usually be required. Because of the wide variation between boats, even those of the same class, each new installation is unique and should be analyzed separately.

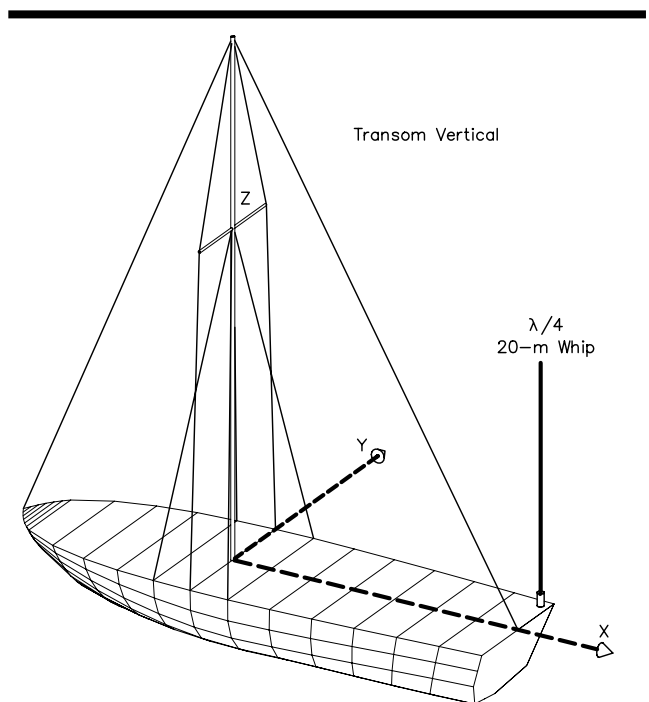


Fig 53—An example of a 20-meter $\lambda/4$ whip mounted on the transom. A local ground system must also be provided, as described in the section on grounding.

A SAFETY NOTE

Ungrounded rigging endpoints near deck level can have high RF potentials on them when you transmit. For example, the shrouds on a fiberglass boat connect to chainplates that are bolted to the hull, but are not grounded. These can inflict painful RF burns on the unwary, even while operating at low power! As a general rule all rigging, spars and lifelines near deck level should be grounded. This also makes good sense for lightning protection. For a backstay antenna with its feed point near deck level, a sleeve of heavy wall PVC pipe can be placed over the lower end of the stay as a protective shield.

TRANSOM AND MASTHEAD MOUNTED VERTICALS

A very common antenna for boats is a vertical, either a short mobile antenna or a full $\lambda/4$, placed on the transom, as shown in Fig 53. Note that in this example the antenna is mounted off to one side—it could also be

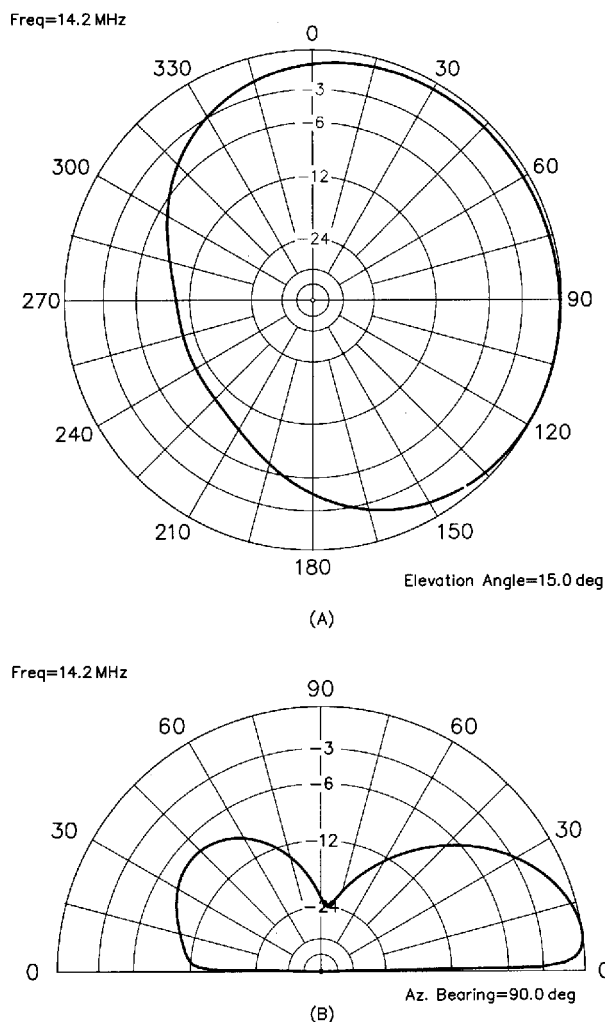


Fig 54—Typical radiation pattern for the $\lambda/4$ transom mounted whip in Fig 53.

mounted in the center of the transom. The 20-meter radiation pattern for this antenna as shown in Fig 54. Unlike a free standing vertical, this antenna doesn't have an omnidirectional pattern. It is asymmetrical, with a front-to-back ratio of about 13 dB. Further, the angle for maximum gain is offset in the direction the antenna is placed on the transom.

This is a very good example of the profound effect the rigging can have on any antenna used on board a sailboat. Not only is the pattern affected but the feed-point impedance will be reduced from a nominal 36Ω to 25 to 30Ω .

The directive gain can be useful—if you point the boat in the right direction! Usually, however, a more uniform omnidirectional pattern is more desirable. It is tempting to suggest putting the vertical at the masthead, perhaps using a 6-foot loaded automobile whip, with the mast and rigging acting as a ground plane. Fig 55 shows such a system. Unfortunately, this usually doesn't work very well because the overall height of the mast and antenna will very likely be $> 5/8 \lambda$. This will result in high-angle lobes, as shown in Fig 56. Depending on the mast height, this idea may work reasonably well on 40 or 80 meters, but

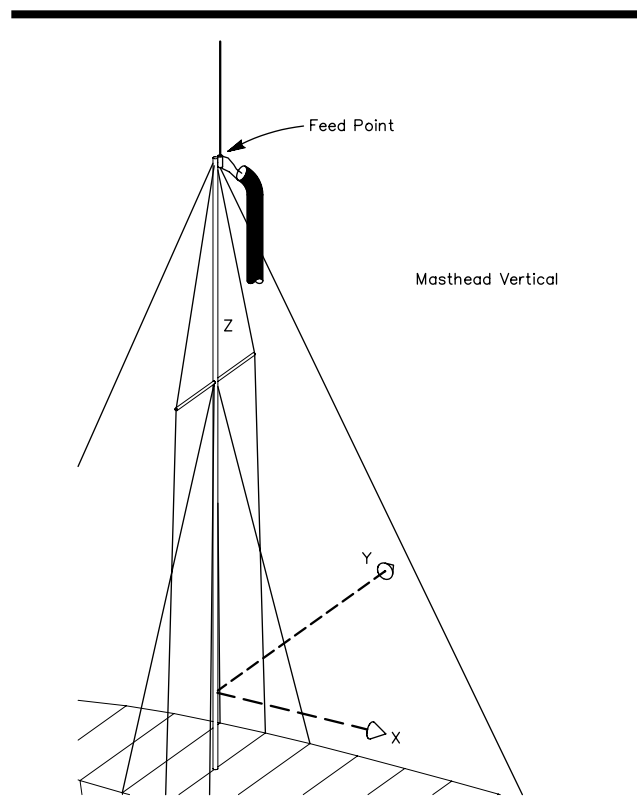


Fig 55—A whip mounted at the masthead. The feed line is fed back down the mast either inside or outside. The base of the mast and the rigging is assumed to be properly grounded.

Freq=14.2 MHz

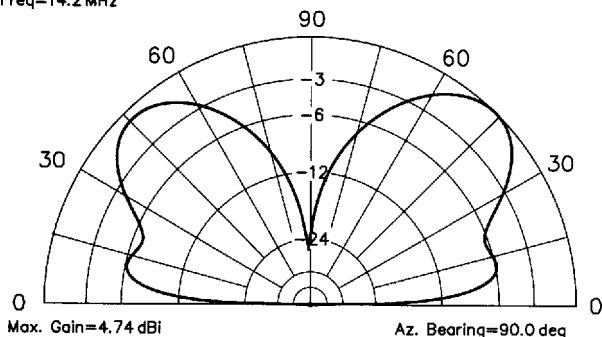


Fig 56—Typical radiation pattern for a masthead-mounted vertical. The multiple vertical lobes are due to the fact the antenna is higher than $\lambda/2$.

you will still be faced with severe mechanical stress due to magnified motion at the masthead in rough sea. The masthead is usually reserved to VHF antennas, with their own radial ground plane.

THE BACKSTAY VERTICAL

A portion of the backstay can be insulated and used as a vertical as shown in **Fig 57**. The length of the insulated section will be $\lambda/4$ on the lowest band of interest. Typically, due to the loading effect of the rest of the rigging, the resonant length of the insulated section will be shorter than the classic $234/f$ (MHz) relation, although it can in some case actually be longer. Either modeling or trial adjustment can be used to determine the actual length needed. On a typical 35 to 40-foot sailboat, the lowest band for $\lambda/4$ resonance will be 40 meters due to the limited length of the backstay. Examples of the radiation patterns on several bands for such an antenna are given

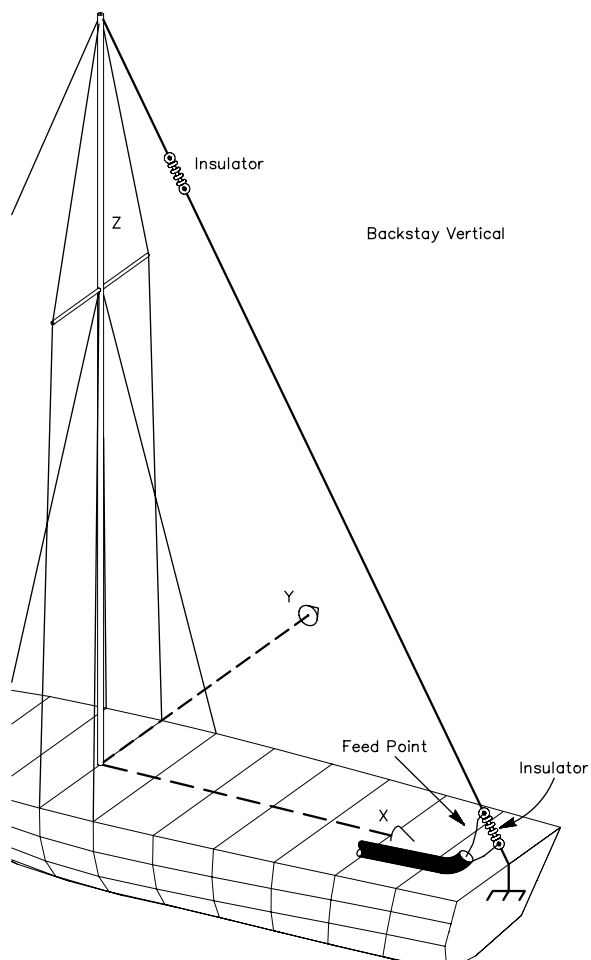
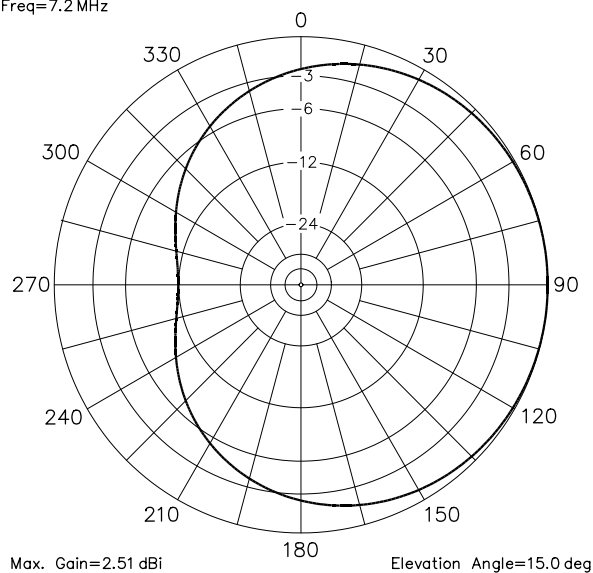


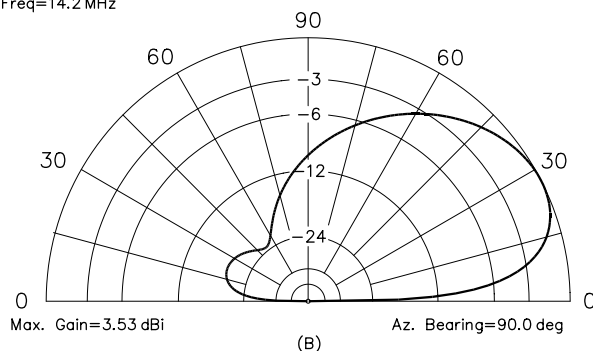
Fig 57—An example of a backstay vertical. A local ground point must be established on the transom next to the base of the backstay.

Freq=7.2 MHz



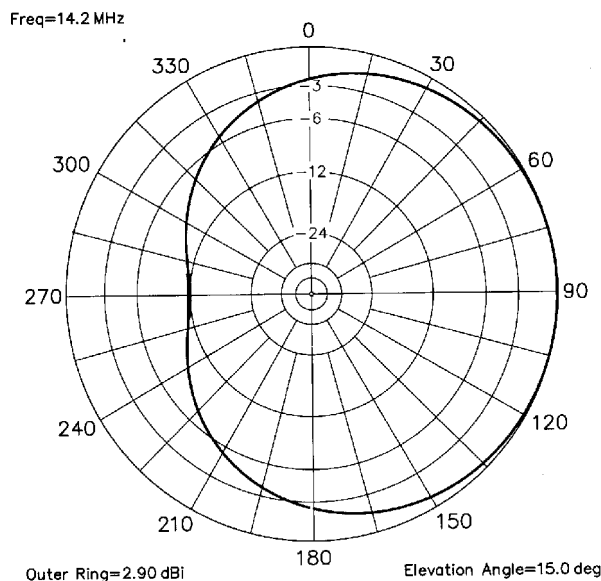
(A)

Freq=14.2 MHz

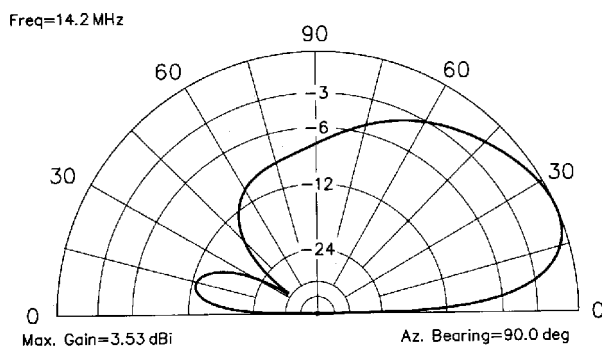


(B)

Fig 58—Typical radiation patterns on 40 meters for the backstay vertical in Fig 57.

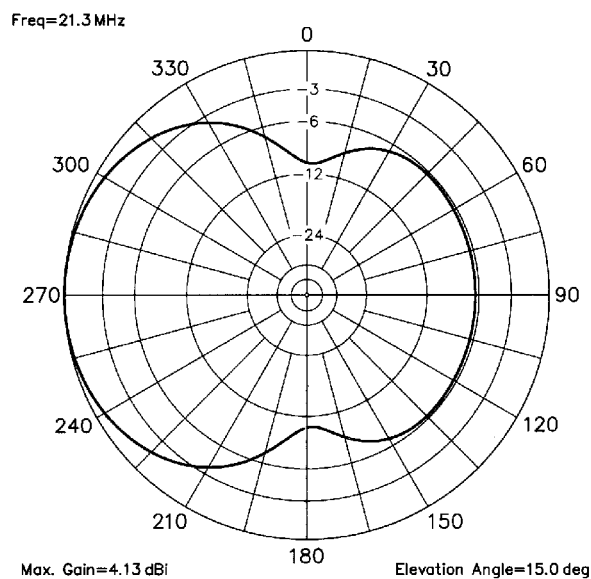


(A)

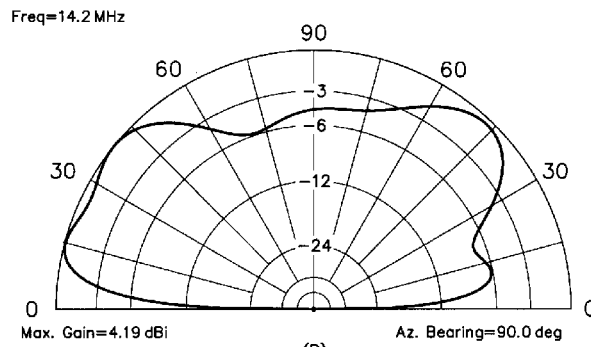


(B)

Fig 59—Typical radiation patterns on 20 meters for the backstay vertical in Fig 57.



(A)



(B)

Fig 60—Typical radiation patterns on 15 meters for the backstay vertical in Fig 57.

in **Figs 58 through 60**.

The pattern is again quite directional due to the presence of the mast and rigging. On 15 meters, where the antenna is approximately $\frac{3}{4}\lambda$, higher angle lobes appear. On 40 and 15 meters, the feed point is near a current maximum and is in the range of 30 to 50 Ω . On 20 meters, however, the feed point is a very high impedance because the antenna is near $\lambda/2$ resonance. One way to get around this problem for multiband use is to make the antenna longer than $\lambda/4$ on the lowest band. If the lowest band is 40 meters then on 20 meters the feed-point impedance will be much lower. This antenna is non-resonant on any of the bands but can be conveniently fed with a tuner because the feed-point impedances are within the range of commonly available commercial tuners. Tuners specifically intended for marine applications frequently can

accommodate very high input impedances, but they tend to be quite expensive.

The sensitivity of the radiation pattern to small details of the mast and rigging is illustrated in **Fig 61**. This is the same antenna as shown in Fig 57 with the exception that the forestay is assumed to be ungrounded. In this particular example, ungrounding the forestay drastically increases the front-to-back ratio. With slightly different dimensions, however, the pattern could have changed in other ways.

High-quality insulators for rigging wire can be quite expensive and represent a potential weak point—if they fail the mast may come down. It is not absolutely necessary to use two insulators in a backstay vertical. As shown in **Fig 62**, the upper insulator may be omitted. The radiation patterns are shown in **Figs 63 and 64**. In this case the

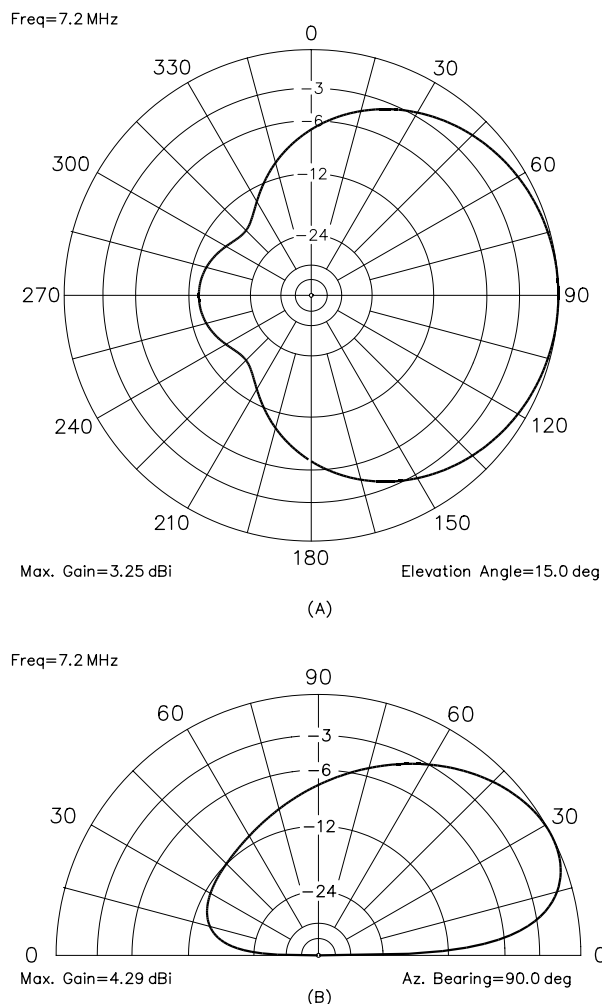


Fig 61—The effect of ungrounding the forestay on the radiation pattern. This is for 40-meter operation.

pattern is actually more symmetrical than it was with an upper insulator—but this may not hold true for other rigging dimensions. The feed point does not have to be at the bottom of the backstay. As indicated in Fig 62, the feed point can be moved up into the backstay to achieve a better match or a more desirable feed-point impedance variation with frequency. In that case, the center of the coaxial feed line is connected to the upper section and the shield to the lower section. The cable is then taped to the lower portion of the backstay.

If single-band operation is all you want, even the lower insulator can be omitted by using shunt feed. A gamma match would be quite effective for this purpose, as discussed in Chapter 6 when driving a grounded tower.

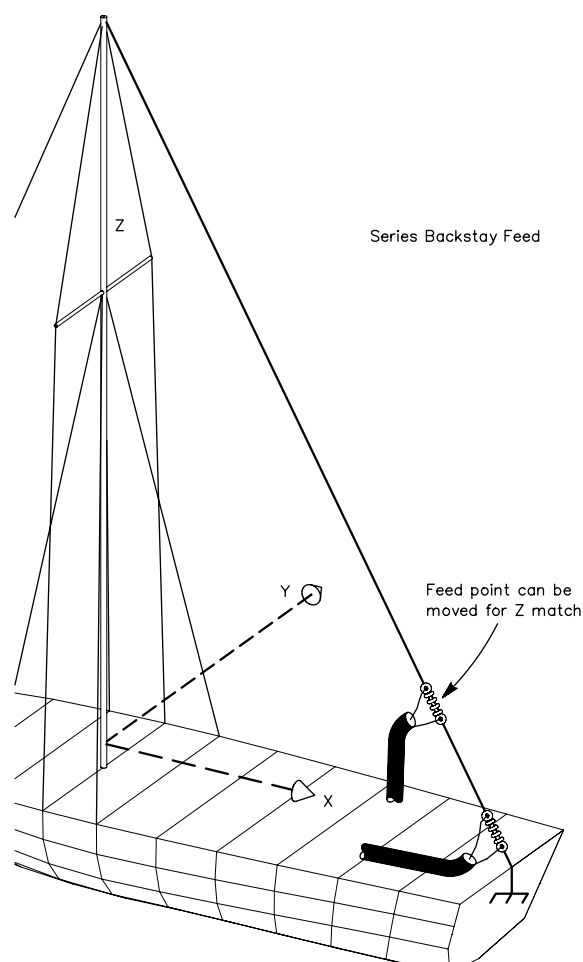


Fig 62—Feeding the backstay without an insulator at the top. The feed point may be moved along the antenna to find a point with a better match on a particular band or to provide a better range of impedances for the tuner to match. The coaxial feed line is taped to the lower portion of the backstay. Again, a good local ground is needed at the base of the backstay.

A 40-METER BACKSTAY HALF SLOPER

A half-sloper antenna can be incorporated into the backstay, as shown in Fig 65. This will behave very much the same as the slopers described in Chapter 6. The advantage of this antenna for a sailboat installation is that you don't need to create a good ground connection at the stern, as you would have to do for a transom-mounted vertical or the backstay vertical just described. This may be more convenient. The mast, shrouds and stays must still be grounded for the half-sloper but the arrangement is somewhat simpler.

TEMPORARY ANTENNAS

Not everyone needs permanent antennas. A variety

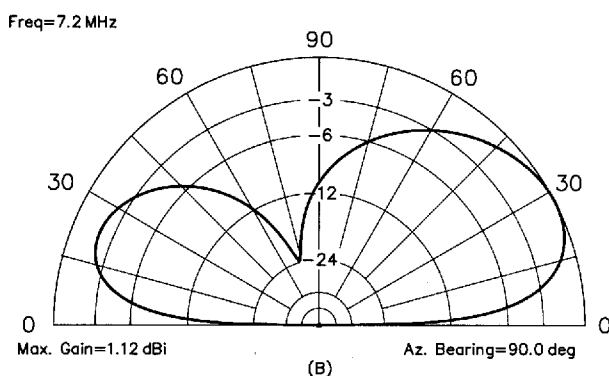
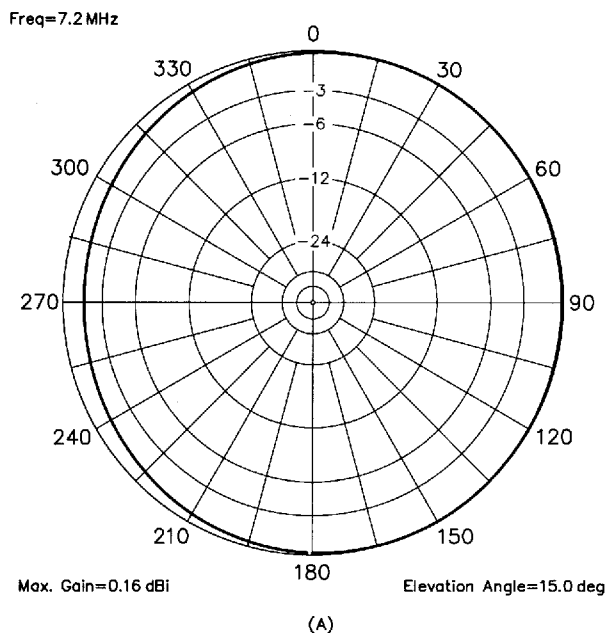


Fig 63—Typical 40-meter radiation pattern in Fig 62.

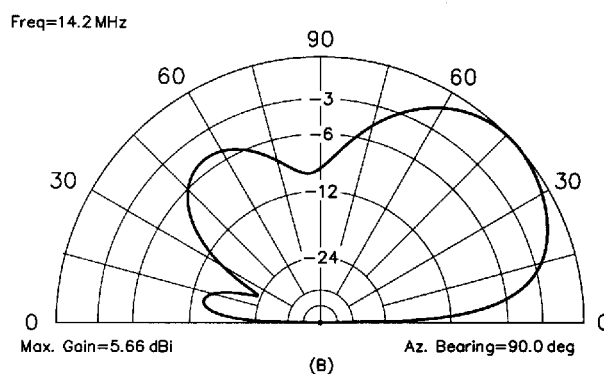
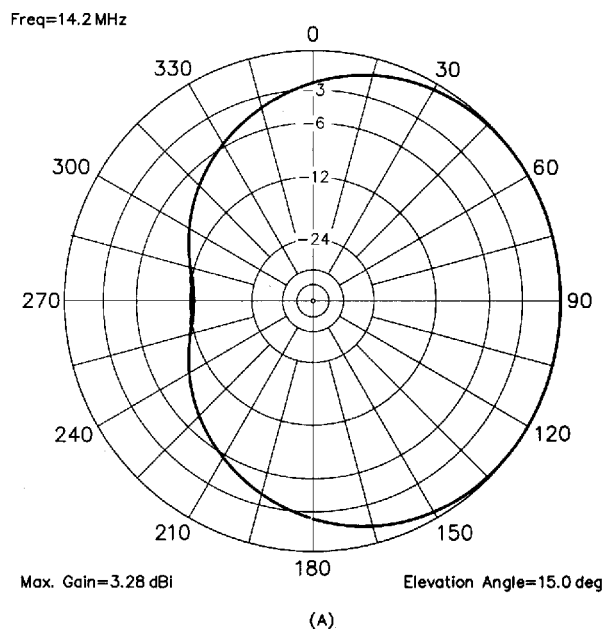


Fig 64—Typical 20-meter radiation pattern in Fig 62.

of temporary antennas can be arranged. A few of these are shown in **Figs 66** through **68**. Of all of these the rigid dipole (Fig 66) will provide the best operation and will have a pattern close to that expected from a freestanding dipole. The other two examples will be strongly affected by their close proximity to the rigging.

GROUNDING SYSTEMS

You may be sitting in the middle of a thousand miles of saltwater. This is great for propagation but you will still have to connect to that ground if you want to use a vertical. There are many possibilities, but the scheme shown in **Fig 69** is representative. First a bonding wire, or better yet a copper strap (it can be very thin!), is connected from bow-to-stern on each side, connecting the forestay, life-

line stanchions, chainplates, bow and stern pulpits and the backstay. Other bonding wires are run from the bow, stern and chainplates on both sides to a common connection at the base of the mast. The fore-and-aft bonding can be attached to the engine and to the keel bolts. The question arises: "What about electrolysis between the keel and propeller if you bond them together?" This has to be dealt with on a case-by-case basis. If your protective zincs are depleting more rapidly after you install a bonding scheme, change it by disconnecting something, the engine-shaft-propeller, for example.

Grounding will vary in every installation and has to be customized to each vessel. However, just as on shore, the better the ground system, the better the performance of the vertical!

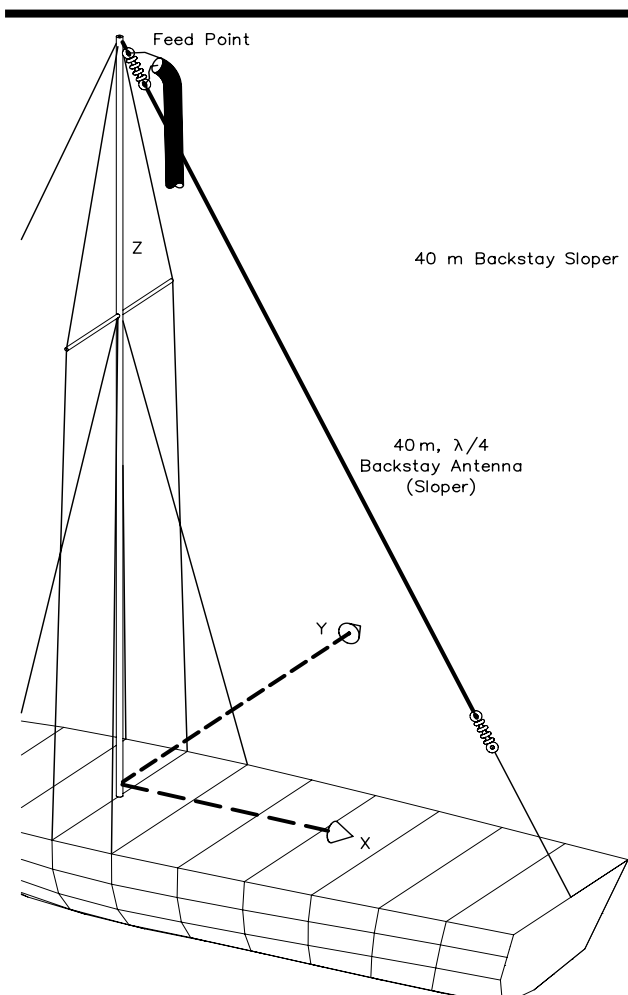


Fig 65—A 40-meter half-sloper fed at the masthead.

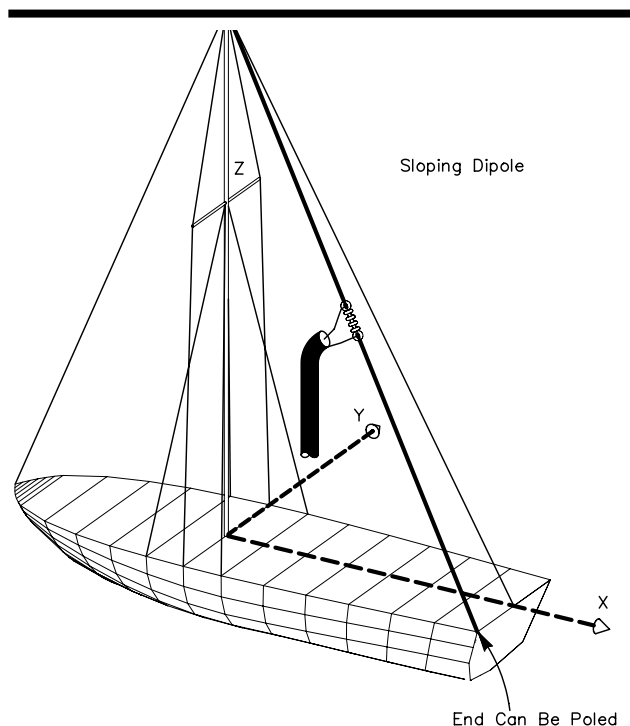


Fig 67—One end of dipole can be attached to the main halyard and pulled up to the masthead. The bottom end of the dipole should be poled out away from the rigging as much as possible to reduce the impact of the rigging on the impedance.

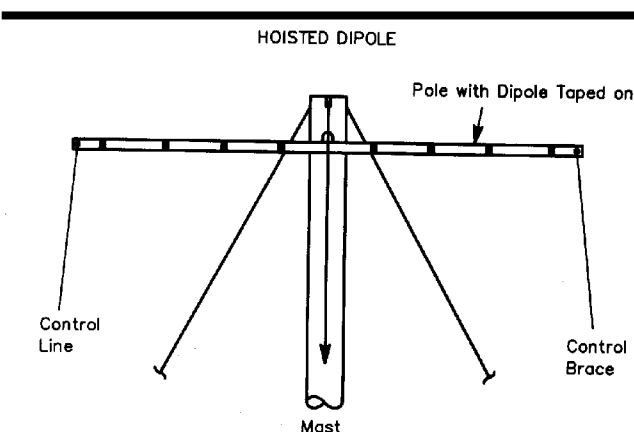


Fig 66—A dipole can be taped to a wood or bamboo pole and hoisted to the masthead with the main halyard while at anchor. It is possible to make this a multiband dipole.

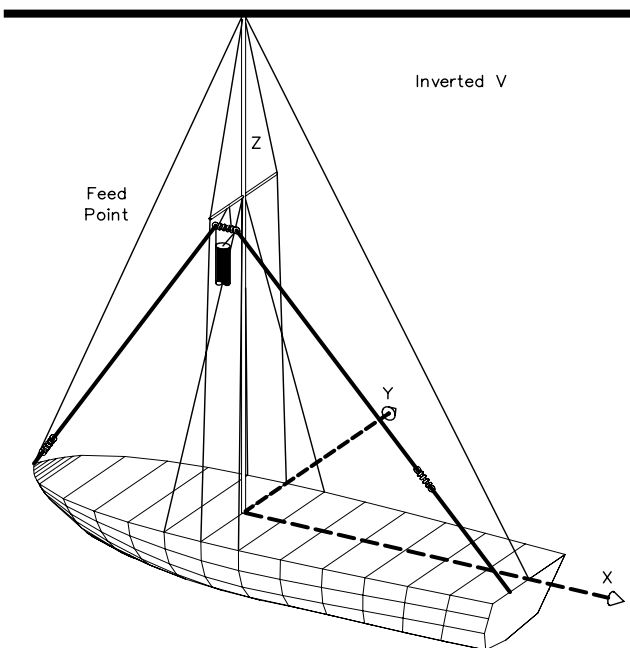


Fig 68—The flag halyard can be used to hoist the center of an inverted V to the spreaders, or alternatively, the main halyard can be used to hoist the center of the antenna to the masthead. Interaction between the rigging and the antenna will be very pronounced and the length of the antenna will have to be adjusted on a cut-and-try basis.

Antennas for Power Boats

Powerboaters are not usually faced with the problems and opportunities created by the mast and rigging on a sailboat. A powerboat may have a small mast, but usually not on the same scale as a sailboat. Antennas for power boats have much more in common with automotive mobile operation, but with some important exceptions:

- 1) In an automobile, the body is usually metal and it provides a groundplane or counterpoise for a whip antenna. Most modern powerboats, however, have fiberglass hulls. These are basically insulators, and will not work as counterpoises. (On the other hand, metal-hulled power boats can provide nearly ideal grounding!)
- 2) A height restriction on automotive mobile whips is imposed by clearance limits on highway overpasses and also by the need to sustain wind speeds of up to 80 miles per hour on the highway.
- 3) In general, powerboats can have much taller antennas that can be lowered for the occasional low bridge.
- 4) The motion on a powerboat, especially in rough seas, can be quite severe. This places additional mechanical strain on the antennas.
- 5) On both powerboats and sailboats, operation in a salt-water marine environment is common. This means that a careful choice of materials must be made for the antennas to prevent corrosion and premature failure.

The problem of a ground plane for vertical antennas can be handled in much the same manner as shown in **Fig 69** for sailboats. Since there will most likely not be a large keel structure to connect to and provide a large surface area, additional copper foil can be added inside the hull to increase the counterpoise area. Because of the small area of the propeller, it may be better not to connect to the engine, but to rely instead on increasing the area of the counterpoise and operate it as a true counterpoise—that is, isolated from ground. Sometimes a number of radial wires are used for a vertical, much like that for a ground-plane antenna. This is not a very good idea

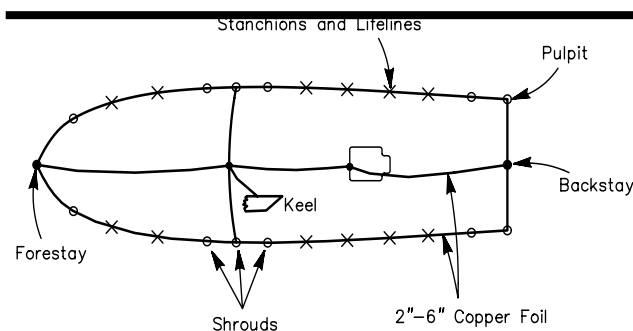


Fig 69—A typical sailboat grounding scheme.

unless the “wires” are actually wide copper-foil strips that can lower the Q substantially.

The problem is the high voltage present at the ends of normal ground-plane antenna radials. For a boat these radials are likely to be in close proximity to the cabin, which in turn contains both people and electronic equipment. The high potential at the ends of the radials is both a safety hazard and can result in RF coupling back into the equipment, including ham gear, navigational instruments and entertainment devices. The cook is not likely to be happy if he or she gets an RF burn after touching the galley stove! Decoupling the counterpoise from the transmission line, as discussed in Chapter 6, can be very helpful to keep RF out of other equipment.

One way to avoid many of the problems associated with grounding is to use a rigid dipole antenna. On 20 meters and higher, a rigid dipole made up from aluminum tubing, fiberglass poles or some combination of these, can be effective. As shown in **Fig 70A** the halves of the dipole can be slanted upward like rabbit ears to reduce the wingspan and increase the feed-point impedance for a better match to common coax lines. On the lower bands a pair of mobile whips can be used, as shown in **Fig 70B**. Home-brew coils could also be used.

For short-range communication, a relatively low dipole over saltwater can be effective. However, if long-range communication is needed, then a well-designed vertical, operating over seawater, will work much better. For these to work, of course, you must solve the ground problems associated with a vertical.

It is not uncommon for large powerboats to have a two or three-element multiband Yagi installed on a short

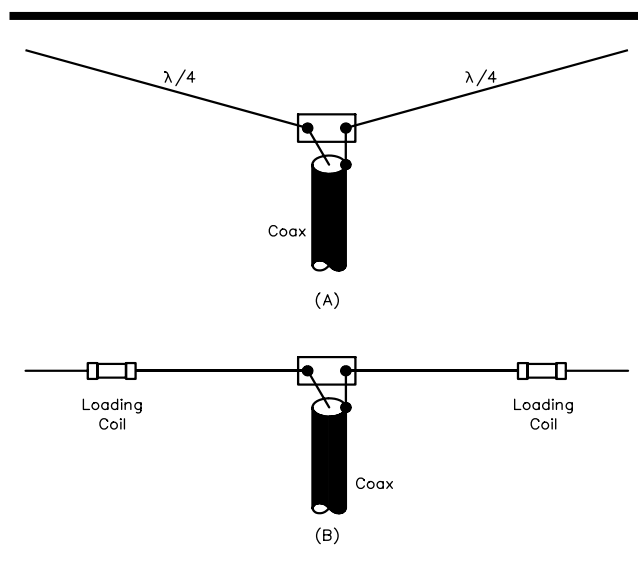


Fig 70—At A, a rigid dipole made from aluminum tubing, fiberglass poles or a combination of these. At B, a pair of mobile whips used as a dipole.

mast. While these can be effective, if they are not mounted high ($> \lambda/2$) they may be disappointing for longer-range communication. Over saltwater, vertical polarization is very effective for longer distances. A simpler, but well-designed, vertical system on a boat may outperform a low Yagi.

The combination of a good ground system and one of the high-quality, motor-tuned multiband mobile whips now available commercially can also be very effective.

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