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Chapter 21

Mobile and Maritime HF Antennas

Mobile antennas are designed for use while in motion. At the mention of mobile antennas, most amateurs think of a whip antenna mounted on an automobile or other vehicle. While it is true that most mobile antennas are vertical whips, mobile antennas can also be found in other places. For example, antennas intended for use aboard a boat or ship are usually called *marine* or *maritime antennas*. Whip antennas are common in maritime service, but wire antennas installed on masts are also common.

Few amateurs construct their own antennas for HF mobile and maritime use, since safety requirements dictate very sound mechanical construction. (A short directory table of mobile antenna manufacturers is included on the CD-ROM provided with this book.) Even if commercially made antennas are installed, most require some adjustment to optimize the particular installation and type of operation desired. The information in this chapter will provide a better understanding of the requirements for designing and choosing HF mobile antennas and using them effectively.

The chapter begins with a discussion of mobile antenna fundamentals at HF, updated from previous editions by Alan Applegate, KØBG. The following sections explain the more important attributes of the most popular designs and how to get the best from them. This will include mounting, impedance matching, and other important issues to all types of mobile antennas. Several examples of mobile antenna installation are provided. Information on constructing a capacitive hat-loaded whip and an adjustable "screwdriver" HF mobile antenna is included on the CD-ROM accompanying this book.

The second half of the chapter covers maritime HF antennas for sail and power boats and was updated by Rudy Severns, N6LF for this edition. The text discusses important issues regarding placement and safety of the maritime HF system. Several examples of common installation practices are given, based on antenna designs presented elsewhere in this book.

21.1 HF MOBILE ANTENNA FUNDAMENTALS

High frequency mobile antennas come in every imaginable configuration of efficiency, overall length, quality, design, sturdiness, ease of mounting, and selling price. The design, mounting method employed, and most importantly where the antenna is mounted, all have an effect on maximum efficiency — the holy grail of HF mobile operation. The right combination of strengths and weaknesses depends on how you expect to use the antenna.

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 perspective, perhaps the optimum band for HF-mobile operation is 7 MHz. The popularity of regional mobile nets on 7 MHz is perhaps the best indication of how effective mobile communication can be on that band.

If you intend to chase DX, 20 meters and above are perhaps the best choices as antennas for those bands offer the best efficiency for a given physical size. For local communication, 28 MHz is also useful as a full-size whip without

Fig 21.1 — A simple HF mobile whip can be mounted on almost any vehicle. (*NØAX photo*)

loading coils is not too large for convenient use and is easy to build. In fact, a slightly shortened CB whip works very well.

On the HF bands, the physical size of full-size whips becomes a problem and some form of electrical loading is usually employed to shorten the antenna. Commonly used loading techniques consist of placing a coil at the base of the whip (base loading), or at the center of the whip (center loading). **Figure 21.1** shows a typical mobile whip installation. These and other techniques for reducing the physical size of antennas are discussed in this chapter.

For typical antenna lengths used in mobile operation, the difficulty in constructing suitable loading coils increases as the frequency of operation is lowered. Radiation resistance of the antenna decreases as the antenna becomes electrically shorter, which is the same as lowering the frequency of operation for a fixed-length antenna. In addition, the required inductance to resonate the antenna gets larger. The result is that the fraction of the applied power lost as heating in ohmic losses increases and the antenna becomes less efficient.

Designing short HF mobile antennas requires a careful balance of loading coil Q, loading coil position in the antenna, ground loss resistance, and 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, first presented this approach in *The ARRL Antenna Compendium Volume 1*. (See the Bibliography following the sections on mobile antennas.)

21.1.1 THE EQUIVALENT CIRCUIT OF A TYPICAL MOBILE ANTENNA

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 36 Ω. 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.

When the frequency of operation is lowered below the antenna's resonant frequency, the antenna looks like a series RC circuit, as shown in **Figure 21.2**. For the average 8-foot whip, the capacitive reactance may range from about –150 Ω at 21 MHz to as high as –8000 Ω at 1.8 MHz, while the radiation resistance R_R, varies from about 15 Ω at 21 MHz to as low as 0.1 Ω at 1.8 MHz.

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

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

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

Since the radiation resistance is low, considerable current must flow in the circuit if any appreciable power is to be

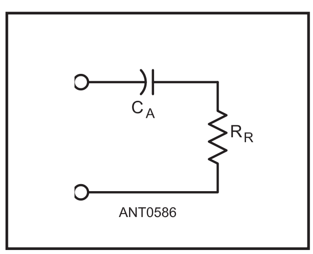


Fig 21.2 — At frequencies below resonance, the whip antenna will show capacitive reactance as well as resistance. R_R is the radiation resistance, and C_A represents the antenna capacitance.

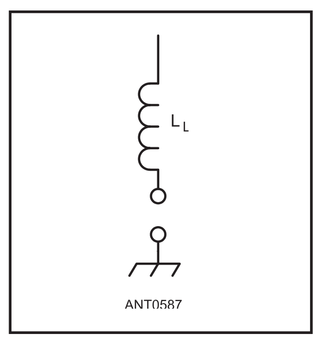


Fig 21.3 — The capacitive reactance at frequencies below the resonant frequency of the whip can be canceled by adding an equivalent inductive reactance in the form of a loading coil in series with the antenna.

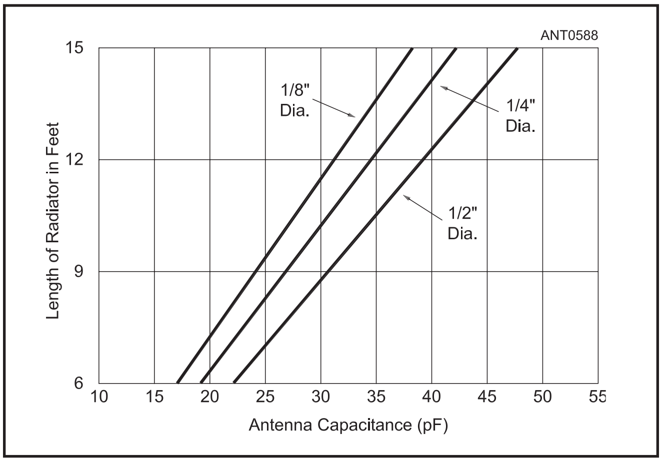


Fig 21.4 — Graph showing the approximate capacitance of short vertical antennas for various diameters and lengths. These values should be approximately halved for a center-loaded antenna.

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) in series, as shown in **Figure 21.3**, thus tuning the system to resonance.

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

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

where

C_A = capacitance of antenna in pF

ℓ = antenna height in feet

D = diameter of radiator in inches

f = operating frequency in MHz

Figure 21.4 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 starting point for the final experimental adjustment that must always be made.

21.1.2 LOADING A SHORT MOBILE ANTENNA

To minimize loading coil loss, the coil should have a high ratio of reactance-to-resistance (that is, a high unloaded Q). A loading coil for use at 4 MHz, 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 may show a Q of 300 or more at 4 MHz, with a resistance of 12 Ω or less.

The coil could then be placed at the base of the antenna in series with the feed line and the antenna to tune out the unwanted capacitive reactance, as shown in Figure 21.3. 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 more efficient designs than simple base loading are possible. While many ideas have been tried with varying degrees of success, only a few have been generally accepted and incorporated into actual antenna 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:

$$E = \frac{120\,\pi\,I\,\ell}{d\,\lambda} \tag{3}$$

where

I = the antenna current in amperes

λ = 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 **Figure 21.5**. 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 length would decrease. In Figure 21.5 the antenna is represented by a series of LC circuits in which C1 is greater than C2, which is greater than C3, and so on. L1 is less than L2, 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

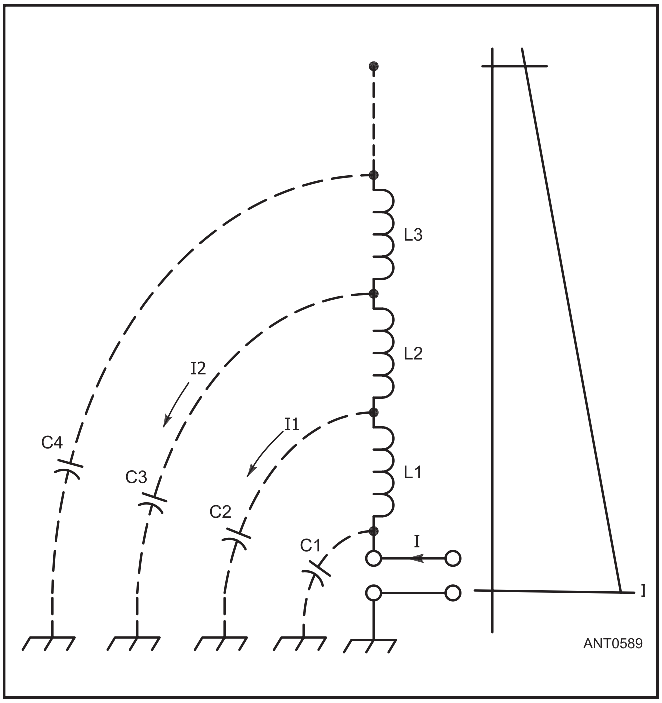


Fig 21.5 — A circuit approximation of a simple whip over a perfectly conducting ground plane. The shunt capacitance per unit length gets smaller as the height increases, and the series inductance per unit length gets larger. Consequently, most of the antenna current returns to the ground plane near the base of the antenna, giving the current distribution shown at the right.

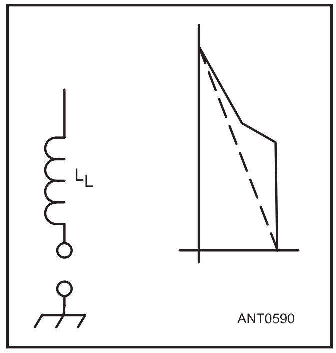


Fig 21.6 — Improved current distribution resulting from center loading.

make the current more uniform in order to increase field strength. One would be to increase the capacitance of the top of the antenna to ground throughthe use of *top loading* or a *capacitance hat*, as discussed in the chapter on **Single Band MF and HF Antennas**. 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 **Figure 21.6**, rather than at the base. If the coil is resonant (or nearly so) at the frequency of operation with the capacitance to ground of the section above the coil, the current distribution is improved as also shown in Figure 21.6. The result with either top loading and center loading is that the radiation resistance is increased, offsetting the effect of losses and making matching easier.

Table 21.1 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

Table 21.1
Approximate Values for 8-foot Mobile Whip

f(MHz)	*Loading L (µH)*	*R_C(Q50) (Ω)*	*R_C(Q300) (Ω)*	*R_R (Ω)*	*Feed R* (Ω)*	*Matching L (µH)*
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 21.2
Suggested Loading Coil Dimensions

Req'd L (µH)	*Turns*	*Wire Size*	*Dia. (Inches)*	*Length (Inches)*
700	190	22	3	10
345	135	18	3	10
150	100	16	2.5	10
77	75	14	2.5	10
77	29	12	5	4.25
40	28	16	2.5	2
40	34	12	2.5	4.25
20	17	16	2.5	1.25
20	22	12	2.5	2.75
8.6	16	14	2	2
8.6	15	12	2.5	3
4.5	10	14	2	1.25
4.5	12	12	2.5	4
2.5	8	12	2	2
2.5	8	6	2.375	4.5
1.25	6	12	1.75	2
1.25	6	6	2.375	4.5

of reducing the coil resistance to a minimum, especially on the three lower frequency bands. **Table 21.2** shows suggested loading-coil dimensions for the inductance values given in Table 21.1.

21.1.3 RADIATION RESISTANCE OF A SHORT MOBILE ANTENNA

The determination of radiation efficiency requires the knowledge of resistive power losses and radiation losses. Radiation loss — the power radiated by the antenna as electromagnetic energy — is expressed in terms of radiation resistance. Radiation resistance is defined as the resistance that would dissipate the same amount of power as is radiated by the antenna. The variables used in the equations that follow are defined once in the text and are summarized in **Table 21.3**. Radiation resistance of vertical antennas shorter than 45 electrical degrees (⅛ wavelength) is approximately:

$$R_R = h^2/312 \qquad (4)$$

where

R_R = radiation resistance in Ω
h = antenna length in electrical degrees.

Antenna height in electrical degrees is expressed by:

$$H = \frac{\ell}{984} \times f(\text{MHz}) \times 360 \qquad (5)$$

where

ℓ = antenna length in feet
f (MHz) = operating frequency in MHz.

Table 21.3
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

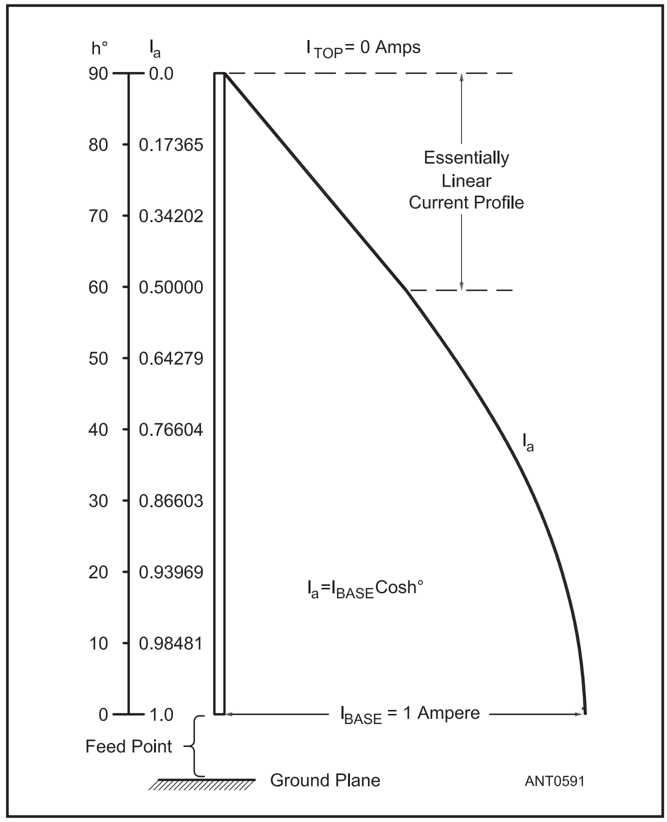


Fig 21.7 — Relative current distribution on a vertical antenna of height h = 90 electrical degrees.

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 **Figure 21.7**. The current distribution on an antenna 90° long electrically (¼ wavelength) varies with the cosine of the length in electrical degrees. The current distribution over 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 **Figure 21.8**. The radiation resistance is given by:

$$R_R = KA^2 \qquad (6)$$

where

K = a constant (to be derived shortly)
A = area of the triangular current distribution in degree-amperes.

Degree-ampere area is a product of current and electrical

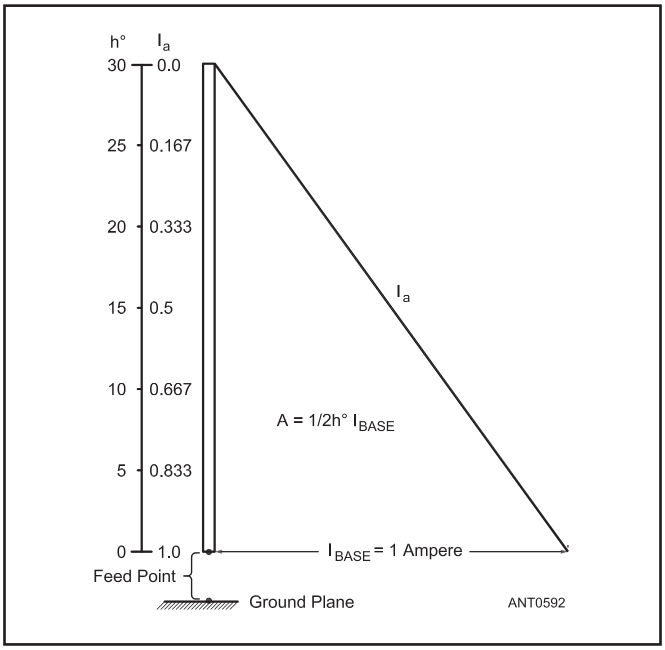


Fig 21.8 — Relative current distribution on a base-loaded vertical antenna of height H = 30 electrical degrees (linearized). The base loading coil is not shown here.

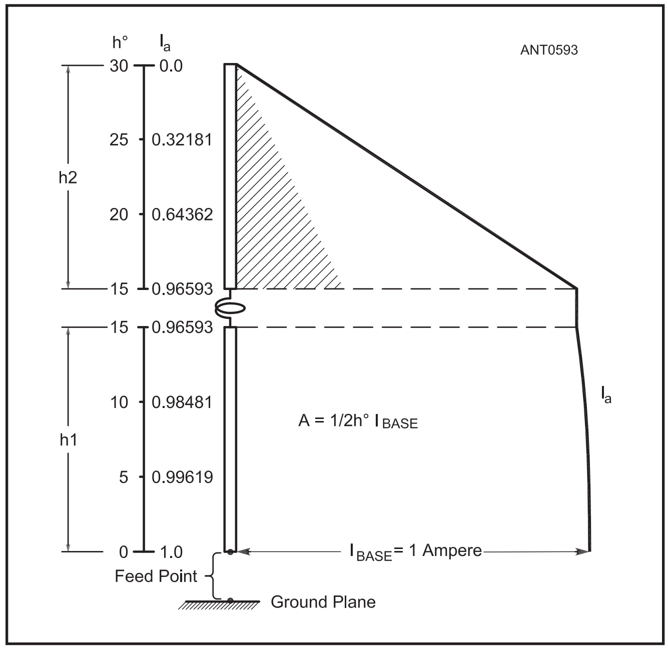


Fig 21.9 — Relative current distribution on a center-loaded antenna with base and top sections each equal to 15 electrical degrees in length. The cross-hatched area shows the current distribution that would exist in the top 15° of a 90°-high vertical fed with 1 ampere at the base.

length, calculated for a triangular current distribution as

$$A = \tfrac{1}{2}\,h \times I_{BASE} \qquad (7)$$

It is referred to as "area" because it is the area between a plot of current and the electrical length axis, as shown in Figures 21.7 and 21.8. More current flowing over a longer electrical distance in degrees results in a higher degree-ampere area and more power being radiated.

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

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

By substituting the values from Figure 21.8 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

$$R_R = 0.0128 \times A^2 \qquad (9)$$

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 than Eq 4.

21.1.4 OPTIMUM LOADING COIL INDUCTANCE AND PLACEMENT

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 is to be realized. (See the program *MOBILE.EXE*, which may be downloaded from **www.arrl.org/antenna-book-reference**.)

When the loading coil is moved up the antenna (away from the feed point), the current distribution is modified as shown in **Figure 21.9**. 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? Because the loading coil is a lumped constant, disregarding losses and radiation from the coil, it maintains 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. This is easily verified by measuring RF current 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 an antenna that is a full 90° long. 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

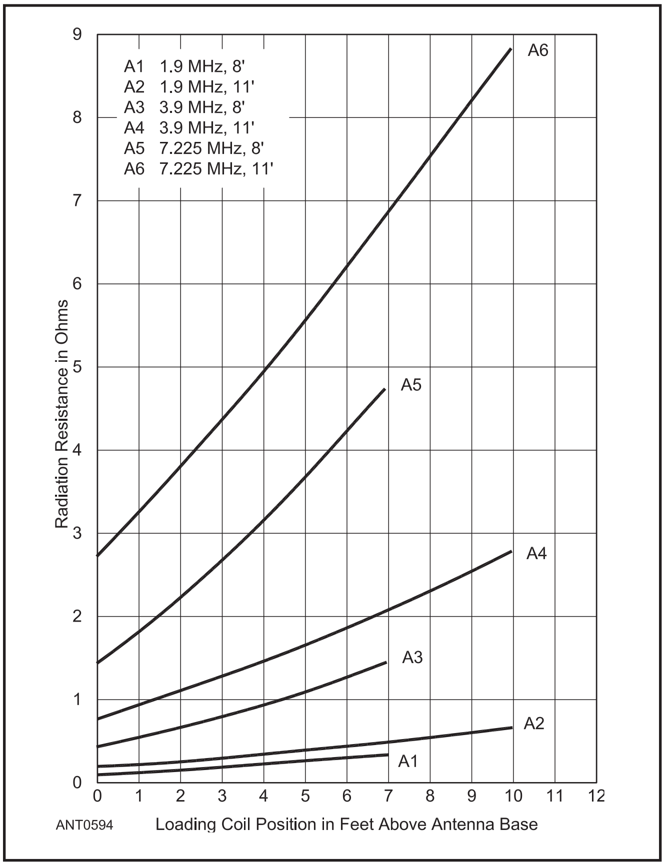


Fig 21.10 — Radiation resistance plotted as a function of loading coil position.

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 Figure 21.9 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 Figure 21.9.

The degree-ampere area of Figure 21.9 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:

$$A = \tfrac{1}{2}\,[h_1(1 + \cos h_1) + h_2 (\cos h_1)] \qquad (10)$$

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 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 in **Figure 21.10**. 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 Figure 21.10 the curves reveal that the radiation resistance increases 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 the reason will become apparent shortly.

Required Loading Coil 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 as in Figure 21.8, the loading coil reactance required to resonate the antenna is given by

$$X_L = -j\, K_m \cot h \qquad (11)$$

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

$$K_m = 60\; [\; (\,\ln (2H/a) - 1\;] \qquad (12)$$

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 Figure 21.9. The loading coil reactance required to resonate the antenna when the coil is away from the base is given by

$$X_L = j\, K_{m2} (\cot h_2) - j\, K_{m1} (\tan h_1) \qquad (13)$$

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 Figure 21.10 have been calculated and plotted in **Figure 21.11**. These curves show the influence of the loading coil position on the reactance required for resonance. The curves in Figure 21.11 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 is needed, and because optimum Q is attained when the loading coil diameter is twice the loading coil length, the coil would grow very quickly to an impractical size above the center of the antenna. 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 consuming 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

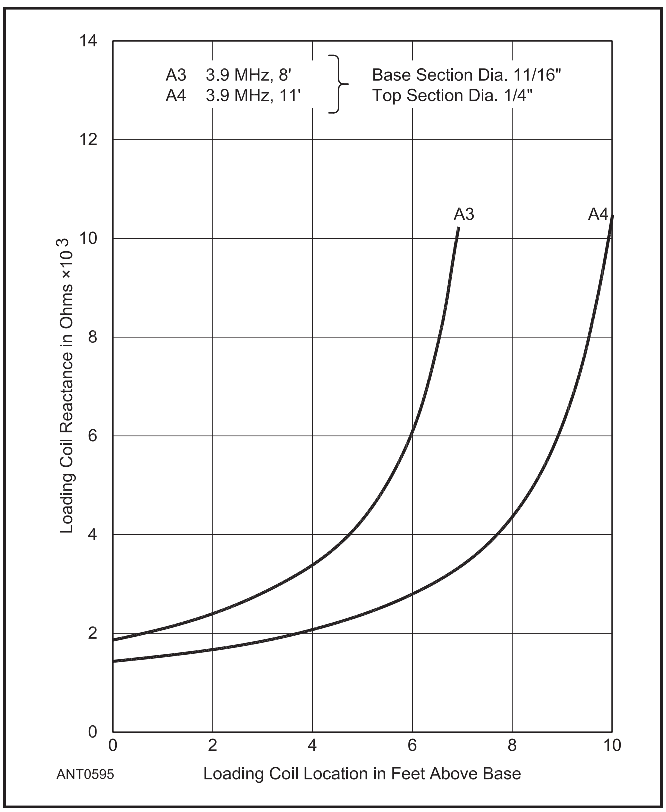


Fig 21.11 — Loading coil reactance required for resonance, plotted as a function of coil height above the antenna base. The resonant frequency is 3.9 MHz.

$$R_C = \frac{X_L}{Q} \tag{14}$$

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 produces a Q between 150 and 160 at 3.8 MHz.

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. (See the section "HF Mobile Antenna Types.") Despite general proscriptions against shorting turns, these systems are often more efficient than antennas with small, relatively low-Q, fixed loading coils.

21.1.5 RADIATION EFFICIENCY

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

$$E = \frac{P_R}{P_I} \times 100\% \tag{15}$$

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:

$$E = \frac{I^2 R_R \times 100}{I^2 R_R + I^2 R_G + \left(I \cos h_1\right)^2 R_C} \qquad (16)$$

where
I = antenna base current in amperes
R_G = ground loss resistance in Ω
R_C = coil loss resistance in Ω
R_R = radiation 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

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

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

Ground Loss

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

$$R_T = R_R + R_G + R_C\,(\cos^2 h_1) \qquad (18)$$

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

$$R_G = R_T - R_R - R_C \cos^2 h_1 \qquad (19)$$

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. It is only feasible to control the first two variables. 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 that also 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 2.5 Ω. 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 4 Ω. 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 6 Ω.

The same antenna therefore sees three different ground

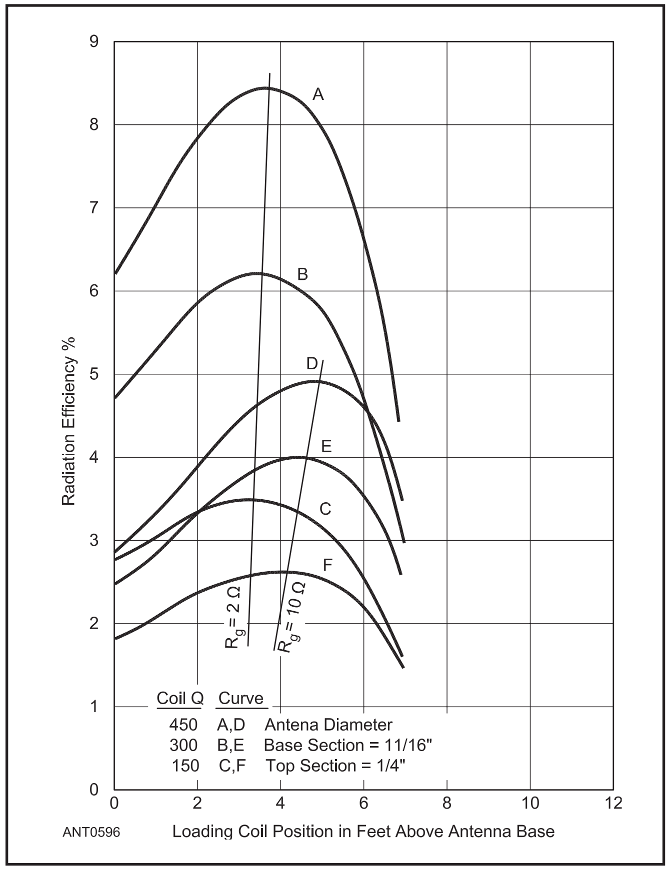


Fig 21.12 — Radiation efficiency of 8-foot antennas at 3.9 MHz.

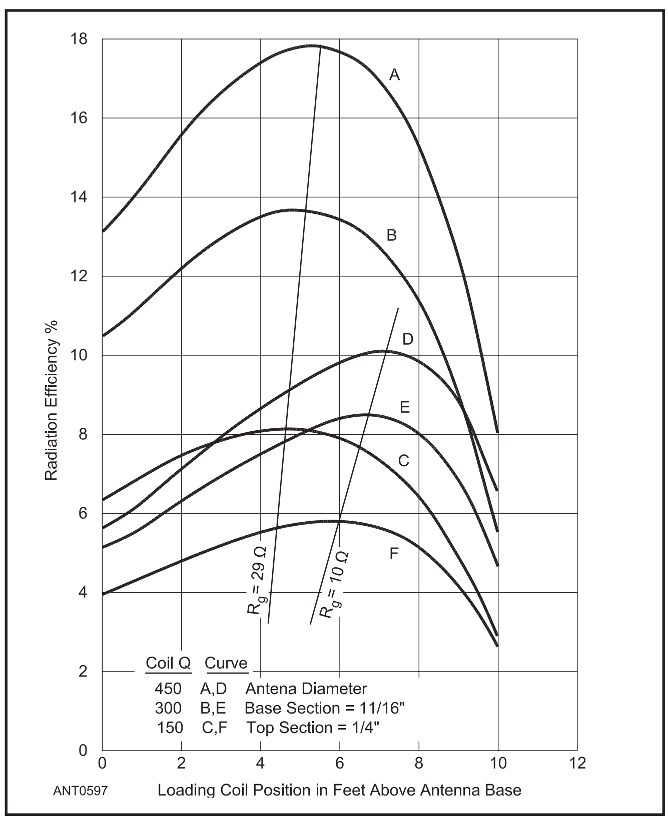


Fig 21.13 — Radiation efficiency of 11-foot antennas at 3.9 MHz.

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 was used to calculate the radiation efficiency curves depicted in **Figures 21.12** through **21.15**. These curves were calculated for 80 and 40 meter 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 ½-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) radiation efficiency increases at high frequencies,

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 peak 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 Figure 21.11. 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 Figure 21.10.

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 that resulted from insertion of a base section of larger diameter than the whip when the coil is above the base.

The curves in Figures 21.12 through 21.15 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. **Figure 21.16** 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 Figures 21.12 through 21.15 show that radiation efficiencies can be quite low at 3.9 MHz compared to 7 MHz. They are lower yet at 1.8 MHz. To gain some perspective on what these low efficiencies mean in terms of

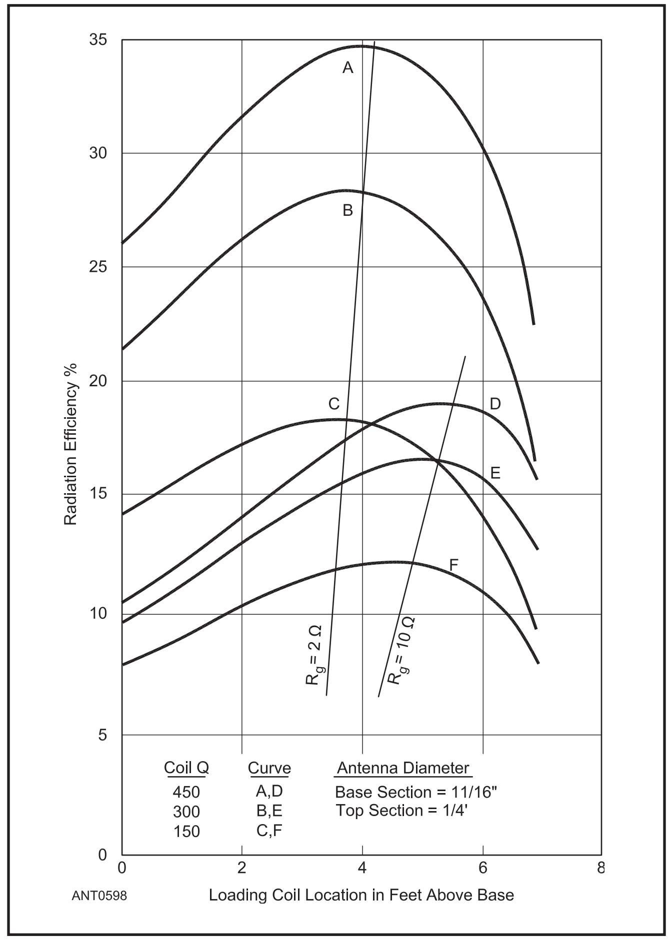


Fig 21.14 — Radiation efficiency of 8-foot antennas at 7.225 MHz.

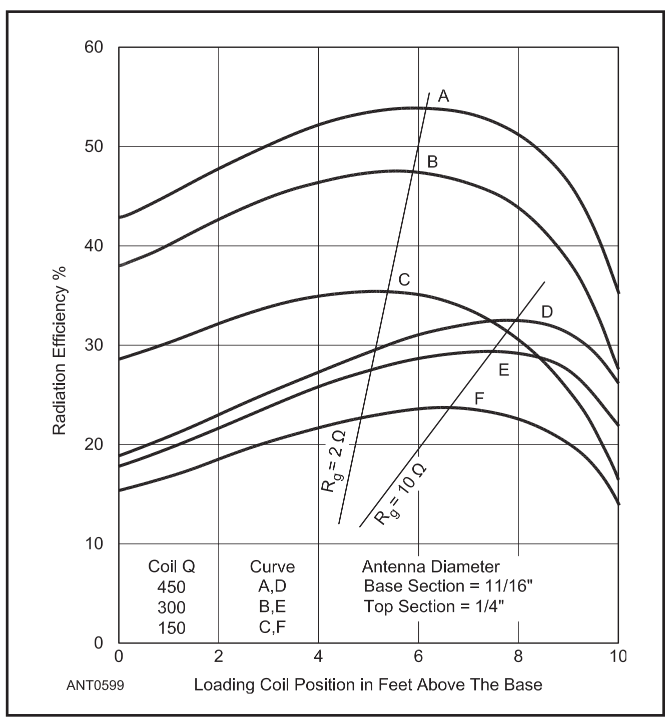


Fig 21.15 — Radiation efficiency of 11-foot antennas at 7.225 MHz.

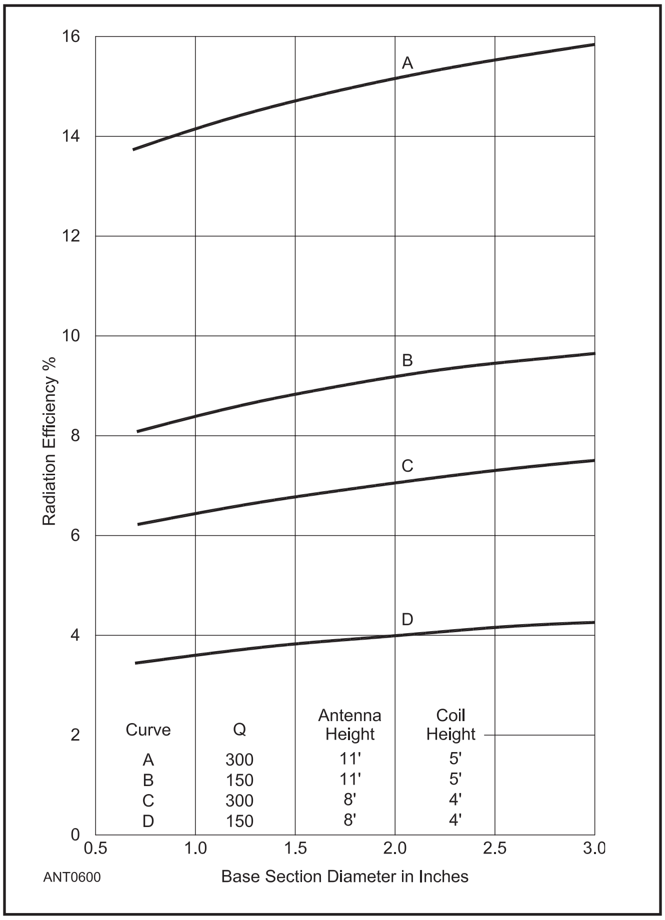


Fig 21.16 — Radiation efficiency plotted as a function of base section diameter. Frequency = 3.9 MHz, ground loss resistance = 2 Ω, and whip section = 1/4-inch diameter.

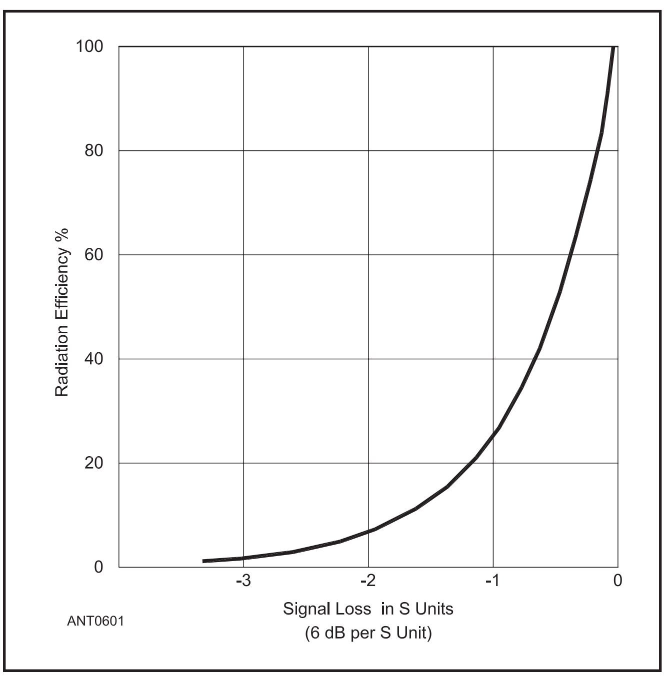


Fig 21.17 — Mobile antenna signal loss as a function of radiation efficiency, compared to a quarter-wave vertical antenna over perfect ground.

signal strength, **Figure 21.17** was calculated using the following equation:

$$dB = \log \frac{100}{E} \qquad (20)$$

where

dB = signal loss in decibels

E = efficiency in percent.

The curve in Figure 21.17 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. Additional improvement can be obtained by operating in an open area and over or near good ground, such as wetlands and fresh or saltwater.

21.1.6 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 an unloaded coil Q of 300 and a ground-loss resistance of 2 Ω has a base input impedance of about 13 Ω. This low impedance value causes a standing wave ratio of 4:1 in 50-Ω coax 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 band- width problem is to install an automatic tuner at the antenna base. Such a device matches the antenna and feed 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.

Matching to the Transmitter

Most modern transmitters require a 50-Ω 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 21.1 earlier in this chapter we see that the feed point resistance of the antenna will be approximately 19 Ω and from Figure 21.4 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 µH is required to resonate the antenna by canceling out the capacitive reactance. (This figure agrees with the approximate value of 40 µH shown in Table 21.1. The resulting feed point impedance would then be 19 + *j* 0 Ω.)

Solution: The antenna can be matched to a 52-Ω line such as RG-8 by tuning it either above or below resonance 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 **Figure 21.18** for a constant feed point resistance of 19 Ω. There are two points of interest, P1 and P2, where the input conductance is 19.2 millisiemens, corresponding to 52 Ω. 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:

$$X_P = \frac{R_f Z_0}{\sqrt{R_f\left(Z_0 - R_f\right)}} \tag{21}$$

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 Ω and R_f = 19 Ω, X_P = ±39.5 Ω. 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 determined from the equation:

$$L = \frac{10^6}{4\pi^2 f^2 C} \pm \frac{X_S}{2\pi f} \tag{22}$$

where addition is performed if a capacitive shunt is to be used and 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

$$X_S = \sqrt{R_f\left(Z_0 - R_f\right)} \tag{23}$$

For the example given, where Z_0 = 52 Ω, R_f = 19 Ω, f = 7.2 MHz , and C = 12 pF, X_S is found to be 25.0 Ω. The required antenna loading inductance is either 40.2 µH or

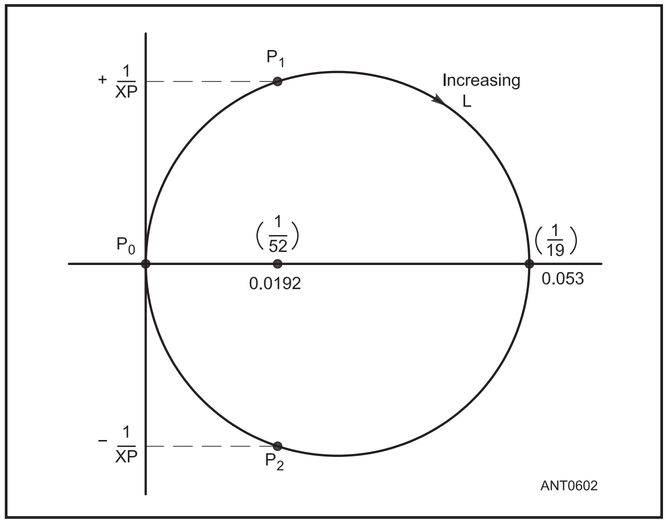


Fig 21.18 — Admittance diagram of the RLC circuit consisting of the whip capacitance, radiation resistance and loading coil discussed in text. The horizontal axis represents conductance, and the vertical axis susceptance. The point P_0 is the input admittance with no whip loading inductance. Points P_1 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 G-B circuit to the series RX circuit can be found that makes computations easier. This is because conductances and susceptances add in parallel the same way resistances and reactances add in series.

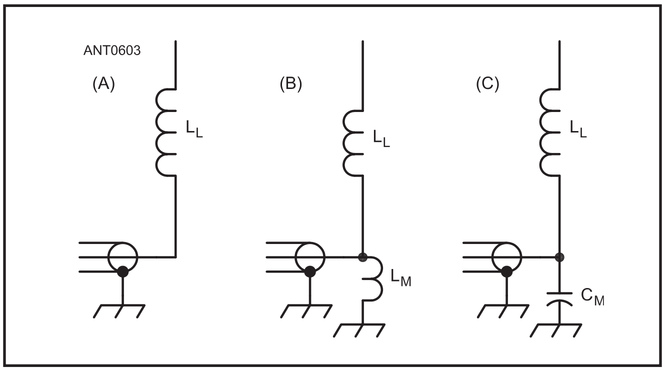


Fig 21.19 — At A, a whip antenna that is resonated with a center loading coil. At B and C, the value of the loading coil has been altered slightly to make the feed point impedance appear reactive, and a matching component is added in shunt to cancel the reactance. This provides an impedance transformation 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.

Shunt Coil Matching

The use of a shunt coil is the preferred matching methodology for two reasons. First, it provides a dc ground for the antenna which helps control static buildup. Second, once adjusted, no further adjustment is needed to cover all of the HF bands between 80 and 10 meters. Thus it is an ideal matching scenario for remotely-controlled (tuned) antennas. Capacitive matching, on the other hand, requires changing capacitance for every band, and sometimes within a band. It should be noted that any HF mobile antenna for bands at frequencies below 20 MHz that do not require matching to obtain a low SWR are less than optimal performers.

41.3 µH, depending on the type of shunt. Various matching possibilities for this example are shown in **Figure 21.19**. At A, the antenna is shown as tuned to resonance with L_L, a 40.7 µH coil, but with no provisions included for matching the resulting 19-Ω impedance to the 52-Ω line. At B, L_L has been reduced to 40.2 µH to make the antenna appear net capacitive, and L_M, having a reactance of 39.5 Ω, is added in shunt to cancel the capacitive reactance and transform the feed point impedance to 50 Ω. The arrangement at C is similar to that at B except that L_L has been increased to 41.3 µH, and C_M (a shunt capacitor having a negative reactance of 39.5 Ω) is added, which also results in a 52-Ω 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 Figure 21.18 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, Figure 21.19B, where 39.5 Ω is needed for L_M. This means that at 7.2 MHz, a coil of 0.87 µH will be needed across the whip feed point terminal to ground. With a 40-µH 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 minimum occurs. If it is below the desired frequency, shorten the whip slightly and check again. It should be moved approximately ¼ inch at a time until the SWR reaches a 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 Figure 21.19C, a value of 560 pF would correspond to the required –39.5 Ω 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.

21.2 HF MOBILE ANTENNA TYPES

21.2.1 THE SCREWDRIVER ANTENNA

No doubt the biggest change in HF mobile operation has been brought about by the screwdriver antenna. Originally conceived by Don Johnson, W6AAQ (SK), the basic design has become ubiquitous, available from many different manufacturers. They consist of a large, hollow lower mast, an extendable coil assembly, and a whip, typically 60 to 96 inches long.

The unused portion of the coil is stored in the mast of the antenna. Finger stock at the top of the mast makes contact with the coil. A dc motor, controlled remotely, drives a screw arrangement that extends or retracts the coil to tune lower or higher in frequency, respectively. That tuning can be done while in motion is an attractive feature, hence their popularity.

A decent quality, high-Q, screwdriver antenna is not inexpensive and can cost upward of $1000, although most are about half this amount. They're relatively heavy and require both a feed line (coax), and a motor control lead. Some varieties also use a reed switch to count the turns of the screw (see the "Mobile Antenna Controllers and Tuners" section).

Shortened versions of the screwdriver are available from several manufacturers and have become very popular. Their light weight, short length, and ease of mounting, account for their popularity. However, because of their short overall length and low-Q coils, they take a big hit in performance over their full-sized cousins, especially when mounted on lip mounts. They also require some special considerations when coupled to automatic antenna controllers, as covered later.

It should be noted that not all models use the same mounting scheme. Some use standard ⅜-24 bolts, and at least one uses a ¾-inch bolt. Some form of base insulator is also required in most cases.

If you wish to build your own screwdriver antenna, plans for doing so are included on the CD-ROM supplied with this *Antenna Book*.

21.2.2 MONOBAND ANTENNAS

There are several types of monoband antennas, including the "bug catcher", linear-loaded varieties, and the ever-popular Hustler series.

The bug catcher shown in **Figure 21.20** can be the most efficient of all of the mobile antenna types, if mounted correctly. (The name derives from the tendency of the coil to "catch bugs" while driving.) However, it has several drawbacks, not the least of which is wind-loading, especially when equipped with a capacitive top-hat, which is discussed later.

Bug catcher antennas, in which a large air-wound loading coil is used for center loading, are monoband by nature but can be made multiband. The usual practice is to make the coil large enough in reactance to resonant the antenna on 80 meters. Then a jumper wire is used to short coil turns to resonate the antenna on the higher bands. However, shorting turns reduces coil Q and lowers efficiency.

They tend to be heavier than other monoband antennas, requiring heavy-duty mounting and base springs — even guys to keep them stable at highway speeds.

Fig 21.20 — A "bug catcher" style antenna showing the large, air-wound center-loading coil in the center of the antenna with a capacitance-hat at the top. This antenna was designed and constructed by VE6AB.

Helical-Wound Antennas

These lightweight antennas are quite popular due to their low cost and reasonable performance. They look similar to the continuously loaded antennas covered below except they use a single, fixed-value loading coil.

The antenna itself is basically a fiberglass tube or rod with a small-gauge wire wound around it. Toward the top of the tube, the wire is close-wound in a loading coil and the antenna is topped off with a short, adjustable-length whip, commonly referred to as a *stinger*.

Due to their light weight, a mag-mount, angle, or trunk lip mount may be used with surprisingly good results considering their low Q, and relatively short length (≈7 feet). Changing bands requires changing the complete antenna, but most models have quick disconnects available making the task quicker and easier. As a general rule, they don't require impedance matching, as their overall losses bring the input impedance very close to 50 Ω.

Continuously-Loaded Antennas

There are several manufacturers of both monoband and multiband antennas that could be described as continuously-loaded. (Sometimes referred to as "linear-loaded," this is not the linear-loading technique used to shorten dipoles and beam antennas.) For these antennas, loading is done using multiple fixed-value inductors spaced over the length of the

Extending Bandwidth

Monoband antennas have a finite bandwidth. Depending on the band and installation parameters, the 2:1 bandwidth may be as little as 12 kHz on 80 meters to as much as 1 MHz or more on 10 meters. Since modern solid state transceivers start to reduce on their output at SWR above 2:1, it would be convenient to extend the bandwidth.

One way to do this is to use an internal (or external) auto-coupler (antenna tuner or ATU for short). The technique works well, as long as we don't try to match an antenna on a band it is not resonant on as this greatly increases the overall losses. However, few if any made-for-mobile transceivers have built in ATUs. Using an external unit will certainly suffice if you're willing to put up with the added complexity.

As we learned in the "HF Mobile Antenna Fundamentals" section, we can use a shunt element to match the antenna's input impedance to 50-Ω feed line. If we substitute a ¼-wave shorted coaxial stub for the fixed-value shunt element, we can effectively increase the bandwidth in the process. This is possible because the shorted stub's reactance swing is opposite that of the antenna's as we change frequencies — the ¼-wave stub's reactance will become more capacitive above resonance as the antenna's feed point reactance becomes more inductive.

Typically, the useable SWR bandwidth will increase from 30% to as much as 50%, again based on the frequency and installation parameters. The drawback is that we have to use a different stub for each band of operation.

antenna or winding a continuous coil with a large pitch (ratio of turn length to turn diameter) along the antenna.

The multiband versions use what is commonly called a "flying lead" connected at the base, which in turn connects to taps along the coil making up the body of the antenna to select the band.

Proponents incorrectly argue that the large length-to-diameter, up to 25 to 1, allows the coil to radiate, thus increasing efficiency. However, what little advantage this form of loading has, it is more than offset by the low coil Q, and short overall length (4 to 7 feet).

These antennas typically do not require matching but a few models exhibit input impedances of greater than 100 Ω and thus need to be matched.

Shortened Dipoles

A few amateurs opt to purchase two identical mobile antennas, and mount them in a V configuration. Knowing that ground loss is the dominate factor in determining antenna efficiency, they reason that replacing the ground loss with a second antenna is a viable solution. While they're correct that it increases radiation resistance as well as the feed point input impedance, efficiency remains largely the same because ground loss has been replaced with the second antenna's loss of about the same magnitude. Gain claims are often exaggerated, as well. A full-size, lossless dipole in free space has a maximum theoretical gain of 2.15 dBi — higher values assume the presence of ground reflections and antenna heights of ½ wavelength or more which are impractical at best for a mobile station.

Stainless Steel Whips

Almost without exception, most whips referred to as "CB whips" are made from 17-7 stainless steel wire. Their overall length is 102 inches but at one time 108- and 120-inch versions were available. They are made from wire about 0.220 to 0.250 inch in diameter that is straightened and ground down to an OD of 0.200 inch. Beginning at about 60 inches above the base, they're tapered down to 0.100 inch OD at the tip. The whip is finished off with a swaged-on ⅜-24 threaded brass base fitting and a small corona ball added at the tip.

Stainless steel isn't the best of RF conductors, especially on the lower HF bands. When compared to an aluminum conductor of the same size, the additional resistive losses may reduce the ERP (effective radiated power) by ≈3 dB on 160 meters, depending on the overall length of the whip in use.

The unfortunate truth is, there is no viable alternative with the strength and flexibility of 17-7 stainless steel! Whips can be copper plated (a costly step) but the improvement is minimal. Covering the whip with silver-plated copper braid is easy to do, but again, the ERP improvement versus the additional wind loading might not be worth the effort.

Corona Balls

The small corona balls supplied atop standard CB whips provide a slight amount of eye protection but their effect on reducing corona is questionable. What is corona and how does a corona ball prevent it?

As we learned in the **HF Mobile Antenna Fundamentals** section, the highest RF voltage occurs at the very top of the whip. Under the right weather conditions, it is possible to see the corona discharge from the end of a pointed whip even when running modest power levels. *Corona discharge* is caused by the small radius of the whip's tip creating large differences in voltage that exceed the breakdown voltage of air across small distances. This causes the air to ionize and conduct. The discharge then extends away from the antenna as "streamers" until voltage is reduced below the level of ionization. Static discharges from the pointed tip can also become a problem on receive.

The solution is to replace the pointed end with a smoother, larger surface. The corona ball's smooth, round surface creates reduces voltage changes with distance that cause corona discharge. The corona ball must be large enough to be effective — at least 0.5 inch in diameter and preferably 1 inch — and are available from several *QST* advertisers. Above 1 inch, wind loading becomes a problem.

Capacitance hats, or cap-hats or top-hats for short, are a method of increasing the efficiency of HF mobile antennas at the expense of complexity and higher wind loading. They increase efficiency by adding capacitance to that portion of the antenna above the loading coil, effectively increasing the overall electrical length.

They may consist of a single stiff wire, two or more wires, a disc made up of several more wires like the spokes of a wheel, a set of loops, or wire arranged as the spokes of a wheel as shown in **Figure 21.21**. The larger the hat (physically), the greater the capacitance and the greater the effective increase in electrical length. Since less inductance is then required to resonate the electrically longer antenna, coil Q losses will also decrease.

No matter where the hat is located, the added capacitance will be the same. However, if placed too close to the coil, the added capacitance will decrease efficiency rather than improve it. The most effective position is at the very top of the antenna. At a minimum, hats should be placed at least half their diameter above the coil (Figure 21.21 shows the hat in the center of the whip) and as far away from vehicle sheet metal as possible. These facts require robust antenna construction and mounting techniques but the increase in performance is worth the effort.

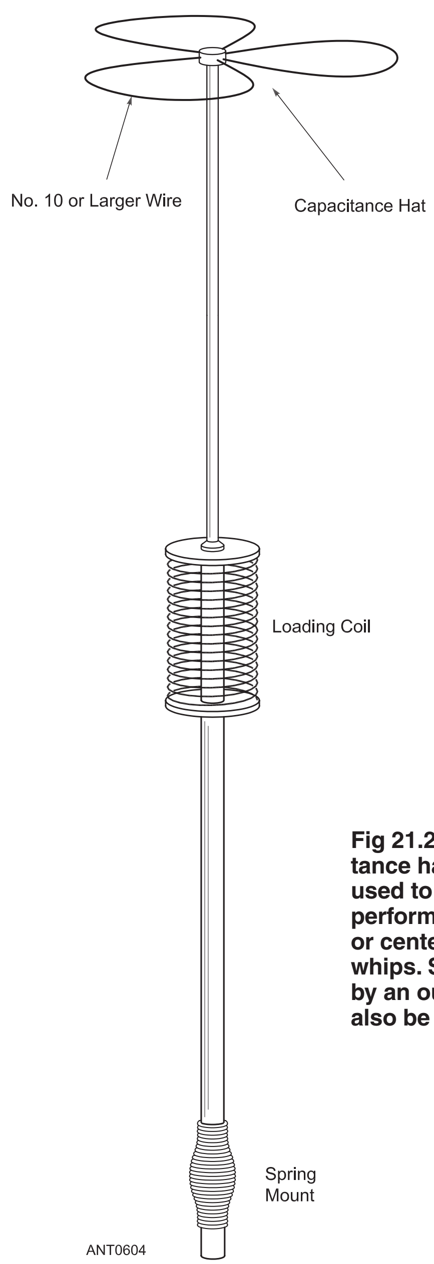


Fig 21.21 — A capacitance hat can be used to improve the performance of base- or center-loaded whips. Spokes joined by an outer ring can also be used.

Plans for a capacitive hat hub designed and made by Ken Muggli, KØHL are provided on the included CD-ROM including where to buy materials. The supporting whip in this case is a 102-inch CB whip that has been cut down to 60 inches.

As described and when mounted atop a Scorpion 680 screwdriver antenna, 80 through 17 meter operation is possible. Measured field strength improvement over an unloaded 102-inch whip is between 3 dB, and 6 dB, depending on the band.

21.2.3 ANTENNA MOUNTING

Antenna mounts come in so many different styles that it is difficult to decide which is best for any specific installation. Ball mounts, clip mounts, bracket mounts, stake pocket mounts, trailer hitch mounts, and even “mag” (magnet) mounts are popular. Which mount you pick and where you install it depends on many factors. Among them are weight, overall length, frequency of operation, the vehicle in question, and personal preferences.

Weight may be a few ounces for a UHF antenna to as much as 20 pounds for a full-sized, high Q, “bug catcher” antenna. The length may be a few inches for a UHF antenna, to as much as 13 feet or more for an HF one.

Some vehicles lend themselves to antenna mounting and some don’t. In general, pickup trucks make better antenna platforms than vans and SUVs. No doubt the biggest decision for many hams is whether or not to drill holes in body sheet metal.

Another often-overlooked requirement is deciding on which side of the vehicle the antenna should be mounted. For rear-mounted antennas, the driver’s side of the vehicle is preferred. This can be very important if you live in an area with low bridges and overhanging trees as there is typically more clearance toward the center of the street. Further, it is easier to see the antenna in the side mirrors if they are on the driver’s side. If you’ve chosen front mounting, common when pulling a trailer or RV, then it should be mounted to the right in order to avoid distraction or obstruction of your vision.

Whatever method you choose for mounting your antenna, it must be sturdy enough to hold the weight and withstand the wind loading imposed by the antenna without too much flexing. It should be attached in such a way to maximize what little ground plane a vehicle represents. The key phrase for mounting the antenna is: *It is the metal mass directly under the antenna, not what’s alongside, that counts the most!* Keep in mind, no matter what the antenna, permanent and secure mounting maximizes performance and safety.

HF Mobile Antenna Mounts

Figure 21.22 shows a typical center-loaded, remote-controlled, 80 through 10 meter screwdriver antenna, a Scorpion Antennas SA-680. This homebrew mount was made by Joe McEneaney, KG6PCI. The 18-pound antenna is supported by a steel mast welded to a frame extension. There is a stainless steel plate at the top of the mast, bolted to the top of the bed rail, that secures the antenna and reduces ground losses. A quick disconnect at the base of the antenna facilitates removal when desired.

Because of the difficulty in designing and finding someone to weld a special mount, most mobile operators opt for a commercial trailer hitch mount from one of the many *QST* advertisers. While secure, trailer hitch mounting schemes increase ground losses, and should be avoided if possible.

If you drive a pickup truck, mounts in the top of the bed rail or in the bed offer more efficient operation. A stake pocket mount like the Breedlove model shown in **Figure 21.23** is a good, no-holes choice. Its offset design allows it to extend from beneath most bed covers.

Figure 21.22 — A Scorpion 680 screwdriver antenna mounted on the truck of KG6PCI. *(Photo courtesy of Alan Applegate, KØBG and Ron Douglass, NI7J)*

3/8-Inch Threaded Mounts

Most monoband, a few screwdriver types, and some VHF antennas mount via a male or female ⅜-24 threaded stud. Ball mounts, clip and lip mounts, and mag mounts are frequently supplied with this type of threaded base. Mounts so equipped often require base insulators to isolate the antenna from the mounting hardware. Feed line connections may be simple wire lugs, an SO-239 connector, or a coaxial cable pigtail with or without a female RF connector installed.

The studs themselves are often stainless steel, but some are mild steel or brass. If the antenna in question is a heavy bug-catcher, a strong stud is in order. A replacement stud can be easily made from a 2-inch, class-8 bolt by cutting off and redressing the threaded portion. The resulting stud has over twice the tensile strength of the stainless steel version.

Fig 21.23 — Stake-pocket mounts are designed to fit into the square holes in the walls of a pickup truck's bed. An offset mount as shown in the photo will also clear most bed covers.

Ball Mounts

Ball mounts like the one shown in **Figure 21.24** aren't used much anymore as late-model automotive sheet metal isn't as strong as it once was or has been replaced by plastic or composite materials. Further, most hams don't have the necessary tools to fabricate heavy-duty insulators and large backing plates to overcome the thin sheet metal problem for the larger, heavier antennas. However, for ham-sticks and shortened CB whips, ball mounts are more than adequate, even on lighter sheet metal.

Fig 21.24 — A ball mount is attached to a vertical or nearly-vertical vehicle panel and can be adjusted so that the antenna is vertical. The spring shown in this photo may or may not be included with the mount. The length of the spring must be included in the antenna's total length.

Clip or Lip Mounts

Clip mounts are a mixed bag of tricks. Most are quite adaptable to any surface angle including those offered by trunk lids, rear hatches, and even side doors. For light-duty VHF and UHF antennas, they offer a convenient mounting method. If you're careful in closing the door or hatch they're attached to, they work quite well. Clearance between the mount and the vehicle body structure should be checked before purchase, however.

Typical clip mounts are secured by setscrews. The folded-over sheet metal of the car body to which the set screws make contact is often jagged and thus offers a less than secure electrical connection. Even modest and lightweight antennas tend to stress the connection. When the connection loosens, intermittent SWR and RFI problems are often the result. Therefore, as a general rule, clip mounts should be restricted to antennas weighing less than 2 pounds. (Larger antennas can be used if guyed or otherwise stabilized above the mount.)

All modern vehicles are dipped in a zinc compound before final assembly and painting. When exposed to air, zinc rapidly oxidizes but in this case the oxidation is a good thing! When a piece of road debris nicks the paint down to the zinc layer, it quickly oxidizes, and protects the base metal underneath. Do not remove this zinc coating to bare metal! This removes the protective coating, allowing the underlying steel to rust and creates an intermittent connection.

All lip mounts bring the coax cable into the trunk or passenger cabin through the weather seal potentially allowing water to enter. The problem is often exacerbated by the larger control cable most screwdriver antennas require. Take care to dress the cables and seals to direct water toward a drain hole or other exit.

Angle Brackets

Angle brackets come in a variety of sizes, shapes, angles, hole size, attachment style, strength, and colors. They're great for lightweight antennas like ham-sticks and VHF antennas, but shouldn't be used for heavier ones. There are special hood seam versions for some models of trucks and other vehicles. They require holes for attachment screws. Some mounts can be clamped on mirror arms or other tubes and struts.

Magnet "Mag" Mounts

Lots of folks use mag mounts with good success for both HF and VHF antennas. Models are available that can secure just about any size antenna. In fact, some VHF antennas come preassembled with mag mounts. Although they're meant for temporary mounting, it is common for them to be used as permanent mounts as a way to avoid drilling holes. Mag mounts have several drawbacks that tend to limit them to temporary installation.

Coax routing is always a problem if for no other reason than weather sealing. The magnet tends to collect road debris, primarily metallic brake dust that eventually gets under the magnet and rusts or scratches the vehicle's finish.

Regardless of the number or size of the magnets, the ultimate holding power relies on the metal surface. For example, some newer vehicles use steel-reinforced composite materials and although the magnets stick to the surface, the force with which they do so is less than on an all-steel surface. In these cases, mag mounts *should not* be used.

For larger antennas mounts are available with from three to five large magnets. These mounts tend to be very heavy and are difficult to install and remove. When used with large antennas, even large mag mounts should be securely tethered and/or guyed to keep them in place for very obvious reasons.

High ground loss and common-mode currents on the coax shield can be a problem when using mag mounts, as they rely on capacitive coupling to the vehicle body for RF return current. Installing a ground strap to the nearest chassis hard point is often recommended but does little to solve these problems.

21.2.4 MOBILE ANTENNA CONTROLLERS AND TUNERS

Screwdriver antennas have become very popular in part because their operating frequency can be changed while in motion. Most manufacturers offer some form of manual control box as an option. However, manual controllers require the operator to watch either an internal or external SWR indicator during tuning, which isn't safe while in motion. Fortunately, there is a solution — the automatic antenna controller.

There are two basic types with several variations, SWR sensing and turn counters. Both types require special attention with respect to RF on the antenna's control leads and we'll cover that issue, as well. Most have a built-in *park* feature which retracts the coil all the way into the mast. If you have garage or carport clearance issues, this is a nice feature.

Automatic Screwdriver Antenna Controllers

The West Mountain Radio TARGETuner (**www.westmountainradio.com**) shown in **Figure 21.25** is a typical example of an automatic controller that can retune an antenna based on SWR or based on frequency data from a radio. Frequency data directly from a radio's computer control port and the SWR level from a separate sensing unit. Commanding the radio to activate a TUNE function varies with the manufacturer and/or radio.

One clear advantage of most automatic controllers is that they store the previous operating frequency. Therefore, when you change frequency, the controller always moves the

Fig 21.25 — An SWR-sensing controller adjusts the length of the screwdriver coil for minimum SWR automatically.

antenna in the correct direction, saving wear and tear on the motor assembly. The controllers also have manual modes that allow an operator to adjust the screwdriver length for initial setup or fine-tuning.

Turn Counter Controllers

Most screwdriver antennas come equipped with a turns counter, usually in the form of a magnet attached to the drive assembly that closes a magnetic reed switch. As the motor turns, the switch opens and closes once or twice every 360°. The controller counts the closures and moves the antenna to a *predetermined* resonance point. **Figure 21.26**, an Ameritron SDC-104, is an example of this type of turns-counting controller. "Jog" buttons are included to touch up the SWR once the predetermined point is reached.

Like some SWR type controllers, turn counters are prone to RF currents on their control leads, so proper RF choking is essential.

Common-Mode Current Problems

In an ideal world, RF flows down the outer surface of the center conductor of coaxial cable and returns on the inner surface of the coax shield. In the real world, RF current will flow on the *outside* of the coax shield, completely independently of the currents inside. The skin effect electrically separates the inside and outside of the shield. This creates a "third wire" — the outside of the shield — that is often connected directly to one side of an antenna. For mobile antennas, the outside of the shield is usually connected to the vehicle body. In addition, if the coax is not itself shielded from the antenna's radiated field, the outside of the shield will pick up RF energy radiated by the antenna. This unbalanced RF current is called "common-mode current" as opposed to the balanced differential-mode currents inside the coax. The common-mode RF current can radiate a signal of its own, just like from any antenna carrying RF, and it can also cause RFI to your radio and to the vehicle's electronic systems.

In the case of HF mobile antennas, the magnitude of common-mode current on feed lines and other cables increases as ground impedance increases which also increases ground losses. As a result the coax and control cables running to clamp or lip-mount and mag-mount antennas will typically carry more common-mode current than body-mounted antennas.

Because of the potential for RFI from common-mode currents, it is prudent to add RF chokes to reduce common-mode currents in a mobile installation, even though there may be no direct indication of a problem. The best place to install a common-mode RF choke is near the base of the antenna where the feed line is connected and not inside the vehicle.

The most convenient way to create an RF choke is to use the "split bead" or "split core" ferrite cores. A mix 31, ¾-inch ID split bead may be utilized with great effect. Depending on the coax size, between five and seven turns of either RG-58 or RG-8X can be wound through that size bead as shown in **Figure 21.27A**. The impedance will be somewhat greater than 1.8 kΩ at 10 MHz which is adequate in most cases. If not, a second split bead can be used effectively doubling the impedance. Take care not to bend the coaxial cable too sharply in making the choke, particularly for foam-insulation cables, as the center conductor can be forced through the insulation over time, creating a short circuit. For more information on ferrite common-mode chokes, see the **Transmission Line System Techniques** chapter.

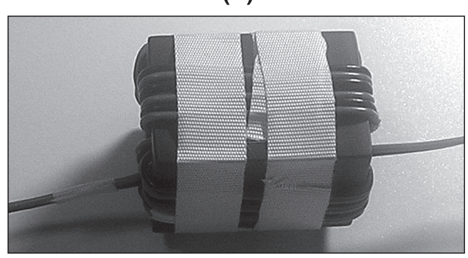
Control Lead RF Chokes

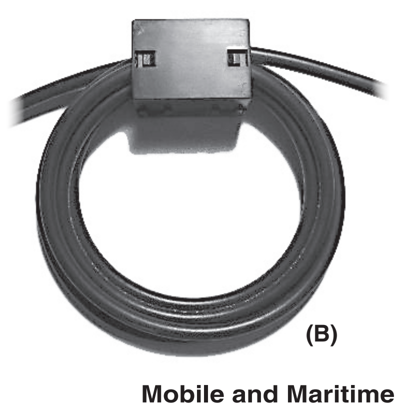
All screwdriver antennas have one thing in common: Their control motor and any reed switches are housed inside the antenna. Therefore, the control leads will be "hot" with RF during transmissions. This RF must be prevented from reaching the controller or erratic operation may result. This is especially important when utilizing short antennas on clip mounts with their inherent ground losses.

Figure 21.27A shows a motor lead choke utilizing a ¾-inch ID, mix 31 split bead. These specific split beads are available from a variety of *QST* advertisers. The one shown is

Fig 21.26 — A turns-counting controller keeps track of coil position by counting switch closures from a reed switch mounted on the antenna.

(A)





(B)

Fig 21.27 — At A, dc power leads are wound around a split ferrite bead to form an RF choke. B shows how coaxial cable can be wound on a split ferrite bead to form an RF choke on the outside of the cable shield. Wind coax loosely to avoid forcing the center conductor through the center insulation.

wound with 13 turns of #18, nylon insulated wire with an OD of 0.068 inches. Larger diameter wire will not allow enough turns to be wound on the core. It is important that the turns not be overlapped or twisted as this will reduce the choke's effective impedance. In this case, the choke presents approximately 10 kΩ of impedance at 10 MHz, an amount adequate in all but the most severe cases. It is important to wind as many non-overlapping turns on the core as possible.

21.3 BIBLIOGRAPHY FOR HF MOBILE ANTENNAS

Source material and more extended discussions of topics covered in this chapter can be found in the references given below and in the textbooks listed at the end of the **Antenna Fundamentals** chapter.

J. S. Belrose, "Short Antennas for Mobile Operation," *QST*, Sep 1953, pp 30-35.

J. M. Boyer, "Antenna-Transmission Line Analog," *Ham Radio*, April 1977, pp 52-58 and May 1977, pp 29-39.

B. F. Brown, "Tennamatic: An Auto-Tuning Mobile Antenna System," *73*, Jul 1979, p 132.

B. F. Brown, "Optimum Design of Short Coil-Loaded High-Frequency Mobile Antennas," *ARRL Antenna Compendium Volume 1* (Newington: ARRL, 1985), p 108.

C.W. Frazell and T.D. Allison, "Another Look at an Old Subject: The Bug Catcher," *QST*, Dec 1980, pp 30-32.

E. A. Laport, *Radio Antenna Engineering* (New York: McGraw-Hill Book Co., 1952), p 23.

C. E. Smith and E. M. Johnson, "Performance of Short Antennas," *Proceedings of the IRE*, Oct 1947.

F. E. Terman, *Radio Engineering Handbook*, 3rd edition (New York: McGraw-Hill Book Co., 1947), p 74.

21.4 HF ANTENNAS FOR SAIL AND POWER BOATS

21.4.1 PLANNING YOUR INSTALLATION

Many of the mobile antennas discussed earlier in this chapter can be applied to sailboats. (For readers who might not be fully conversant with nautical jargon, the Wikipedia's online glossary of nautical terms at **en.wikipedia.org/wiki/Glossary_of_nautical_terms** will help you keep port and starboard straight.) However, the presence of the mast and rigging, plus the prevalence of nonconducting fiberglass hulls complicates the issue:

- On most boats the spars, standing rigging and some running rigging will be conductors. Stainless steel wire is usually used for rigging and aluminum for spars.
- Topping lifts, running backstays, jackstays, etc may also be made from conducting materials on occasion and often change position while the boat is underway. This changes the configuration of the rigging and may affect radiation patterns and feed point impedances. For example, when tacking you may discover that the SWR on starboard tack is quite different from that on port tack. A conducting topping lift can do this as well as running backstays.
- The antennas on a boat will always be close (in terms of wavelength) to the mast and rigging. Some antennas may in fact be part of the rigging. This means very tight electrical coupling between the antenna and the rigging.
- The feed point impedance, SWR and radiation pattern can be strongly influenced by the presence of spars and rigging.
- The behavior of a given antenna will depend on 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.
- Even though you may be floating on a sea of saltwater, grounding still requires careful attention!
- The radio will typically be an HF transceiver with an output power of 100 W. This low power operation means you must pay careful attention to the efficiency of the "antenna system" and take into account the radiation pattern which will normally be asymmetric with significant signal reduction in some directions.

The First Step

An effective antenna system for a sailboat can require a good deal of effort and some expense. It may be necessary for example, to modify the rigging and do considerable work inside the hull to install a grounding system. For this reason it is important at the beginning to define your goals: Do you simply want to have a little fun at anchor on a summer vacation or are you planning to go blue water cruising and perhaps need to communicate back home from the middle of the Indian Ocean? Is the installation primarily for emergencies to summon assistance or will you want to have daily communications with other boats and shore stations? Or do you want all these plus lots of time for just DXing or chatting with friends back home?

You need to think about what bands you want to operate on. As we'll see shortly, multiband operation poses some problems. Your intended use for Amateur Radio will determine the time, effort and money you have to invest in the antenna system and it will also directly impact your final choice of antenna.

Note the use of the words "antenna system" above. This includes not only the antenna itself but the grounding system, the feed arrangements and very possibly an antenna tuner. All of these components interact and affect the final result.

Antenna Modeling

Because of the strong interaction between the rigging and the antenna, accurate prediction of radiation patterns and a reasonable guess at feed point impedances requires that you model both the antenna and the rigging with CAD software. Fortunately easy-to-use antenna modeling software is available at low cost or even free.[1,2] Unless you accurately model the system, considerable cut-and-try may be needed and even then you won't have any real idea of how your system is performing. Cut-and-try can be expensive when it has to be done in 1 × 19 stainless steel wire with $300 swaged insulator fittings!

Modeling allows you to try a number of different ideas and see which approach works best for your installation. While the software is very helpful, it has to be used with some caution:

1) You will need a reasonably accurate model using the physical dimensions of the spars and rigging unique to your boat. Take the time to carefully measure the dimensions and create a model that includes all the spars and conductive rigging.

2) The connections between the spars and rigging will have many small intersection angles and radically different conductor diameters — this can cause problems for *NEC* and *MININEC* programs. In general, sufficient accuracy can be obtained by using the same diameter for all the parts of the *NEC* model including the spars. Make all the conductors 0.25 inch which is typical for standing rigging.

3) Be careful to make the segment lengths at a junction the same for each wire connected to that junction.

4) For more information on antenna modeling, see the **Antenna Modeling** chapter.

From *NEC* modeling, you can expect the predicted radiation patterns to be close to reality but the feed point impedance predictions will be approximate. 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.

NEC modeling will be used for much of the following discussion.[3] The model uses the dimensions and rigging arrangements for a Crealock 37 sailboat. The author (N6LF) and his wife lived aboard this boat for many years and cruised off-shore extensively. Some of the ideas shown are taken directly from experience on this boat, other boats he has owned and boats belonging to fellow cruisers.

A Suggestion

When the antenna is going to be integrated into the standing rigging, it's a very good idea (after modeling) to try your designs out at the dock. For example, suppose you want to insulate part of your backstay and use it as your primary antenna. Temporarily you could replace the backstay with a stout Dacron line and use wire and inexpensive insulators for the initial tests to determine the antenna final dimensions. Then finalize the backstay in stainless wire and swaged insulators. This approach can save a lot of money and aggravation.

A Safety Note

Ungrounded rigging near deck level can have high RF potentials when you transmit. For example, the shrouds on a fiberglass boat connect to chainplates that are bolted to the hull, but may not be grounded. The lower ends of the shrouds can inflict painful RF burns on the unwary, even while operating at low power. This is not hypothetical! As a general rule all rigging, spars and lifelines near deck level should be grounded. This also makes good sense for lightning protection. For antennas with parts near deck level that can be touched, a sleeve of schedule 80 PVC pipe can be placed over the lower end as a protective shield. It's not uncommon to stand at the stern with a hand grasping the backstay. You don't want to be able to grasp the backstay above the insulator without an insulating shield over it! Many commercial verticals for marine use are insulated.

As shown in the chapter **Effects of Ground**, it is possible to determine in advance the potentials that may exist on a given system using the near-field calculations provided by most software combined with some simple calculations using a spreadsheet.

21.4.2 ANTENNA OPTIONS

There are a number of possibilities for antennas on a sailboat. One of the simplest is to install a separate vertical as shown in **Figure 21.28.** An alternative is to insulate a portion

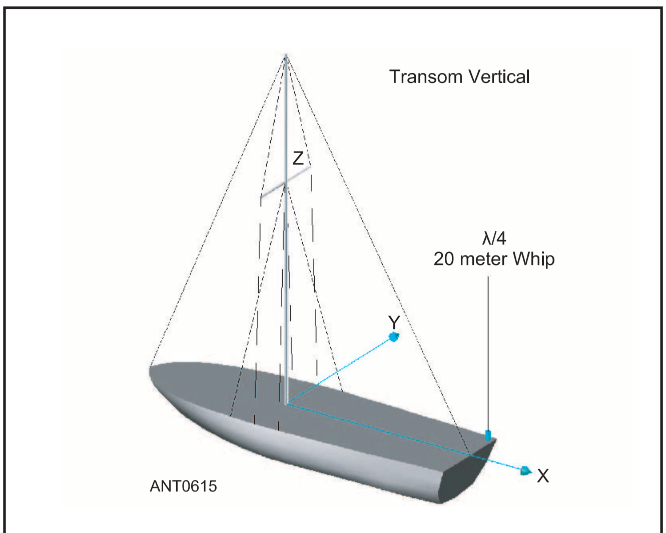


Fig 21.28 — An example of a 20 meter λ/4 whip mounted on the transom. A local ground system must also be provided, as described in the section on grounding.

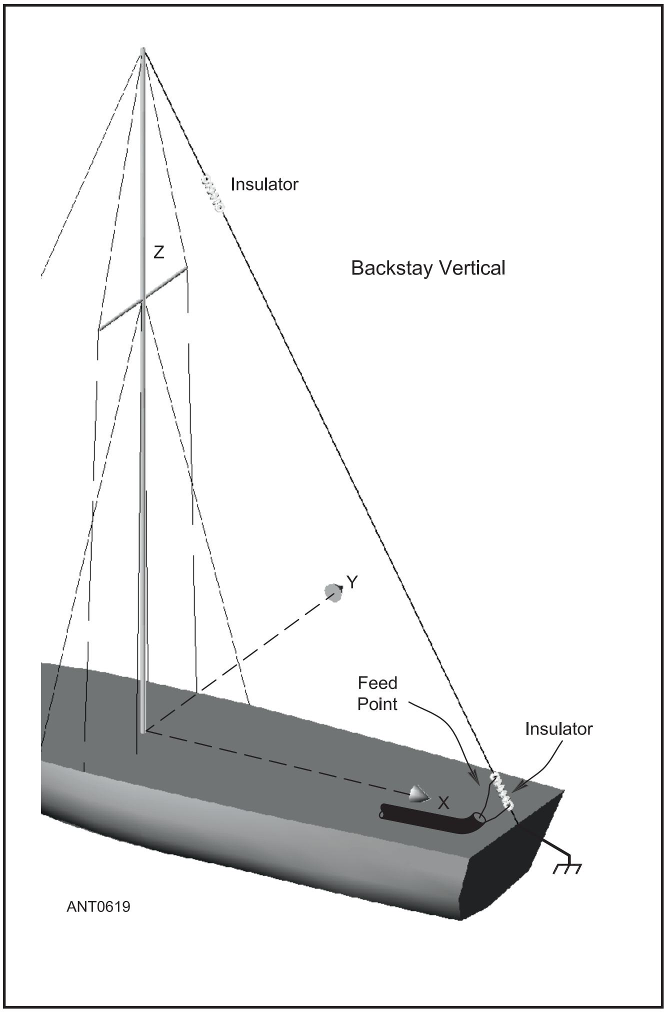


Fig 21.29 — An example of a backstay vertical fed at deck level. A local ground point must be established on the transom next to the base of the backstay.

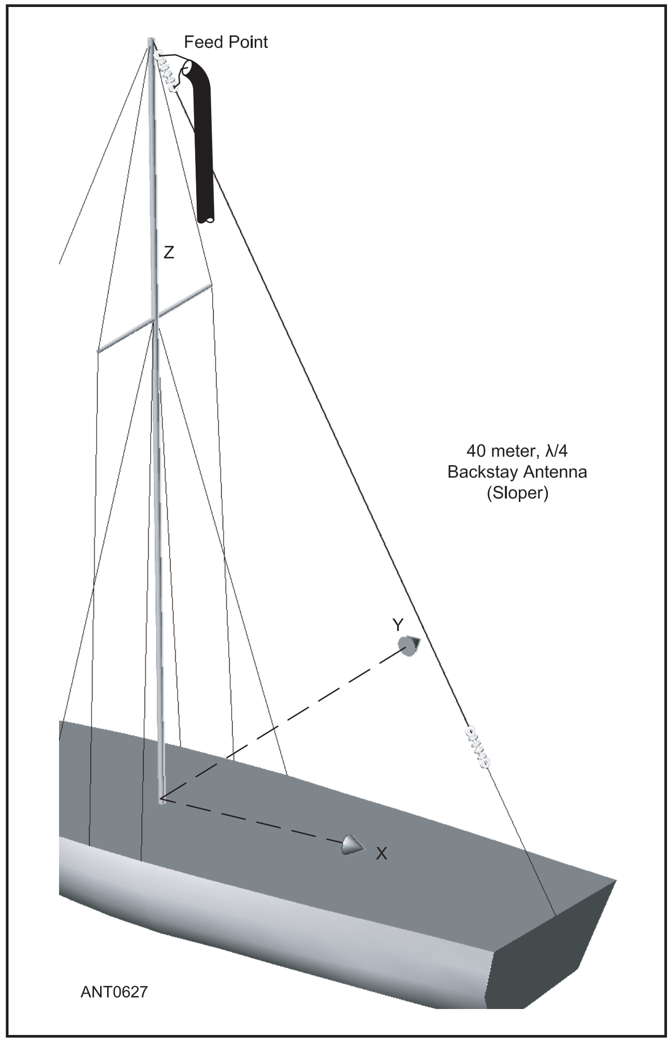


Fig 21.30 — An insulated stay 40 meter half-sloper fed at the masthead.

of the backstay and use that as a vertical as shown in **Figures 21.29** and **21.30**. The backstay vertical can be fed at deck level or at the masthead.

This is the same idea as the λ/4-sloper discussed in the chapter on **Single-Band MF and HF Antennas**. One problem with this antenna is that the lower end of the antenna is a very high potential point. You don't want the lower end of the sloper to be anywhere it could be reached from the deck. Another possibility is to place a self-supporting dipole at the masthead as shown in **Figure 21.31**.

These basic antennas can be applied in a number of ways:

1) For single-band operation you can make the vertical shown in Figure 21.28 λ/4 resonant or insulate a portion of the backstay that is λ/4 resonant (Figure 21.29 or 21.30). If the length of the backstay or the vertical is not long enough to reach resonance on the desired band you can use the loading techniques described earlier in this chapter for mobile antennas and there is also some useful information regarding loading in the chapter **Single-Band MF and HF Antennas**.

2) Another single-band option is the use of a self-supporting dipole at the masthead as shown in Figure 21.31. The antenna shown was fabricated from a pair of 12 foot fiberglass fly-fishing rod blanks (with a copper wire inside!) that were attached to ¾ inch by 6 foot aluminum tubes. Although it looks a bit ungainly this antenna survived several years of cruising and two 24 day passages in the north Pacific including the long beat back from Hawaii. The antenna was very effective for the 20 meter maritime nets. A 15 meter version of this antenna was installed on another boat for a passage from Australia back to the US via South Africa. With this masthead dipole they were able to work back to the US regularly from the Indian Ocean. One half of this antenna would make a good homebrew vertical on the transom.

3) For multiband operation it is possible to build or purchase multiband antennas, some of which are intended for mobile operation (see the **Multiband HF Antennas** chapter and material on mobile antennas earlier in this chapter). These come in many forms: multiple traps, replaceable upper sections, interchangeable loading coils for each band or motorized tuning of a loading coil. Unfortunately most

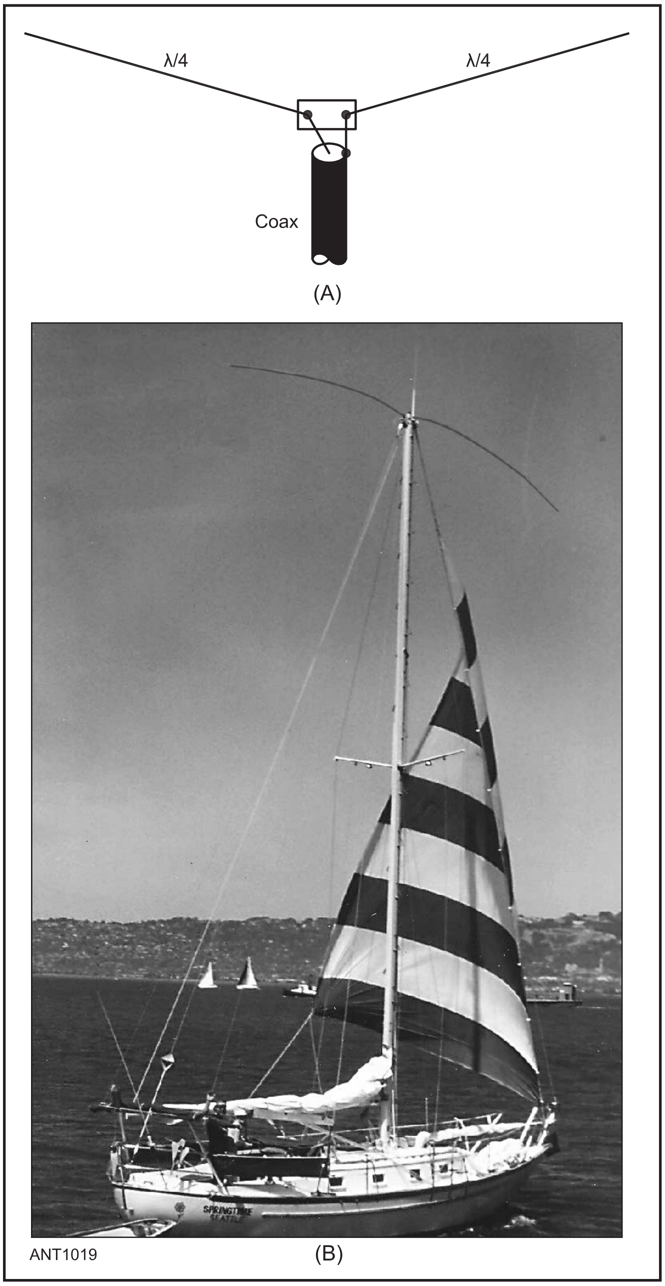


Fig 21.31 — A rigid dipole can be made from aluminum tubing, fiberglass poles or a combination of these and attached to the mast such as is visible in the photo at the top of the mast.

commercial products of this type are not intended for a marine environment. In addition, close proximity to the rigging can have a strong effect on multiband trap verticals, preventing them from being tuned properly.

4) Another option for multiband operation is the SteppIR family of self-adjusting verticals.[4] The antenna consists of a fiberglass tube, 18 feet or 34 feet long, inside of which is a variable length of conductive metal tape. The tape is motor driven so that its length can be adjusted to be resonant at any frequency from 40 or 20 meters (depending on the tube length) through 6 meters. It is even possible to purchase a tuning unit for operation on 80 meters. The antenna controller comes with pre-programmed length settings for the amateur bands but these can be custom adjusted to compensate for the interaction with the rigging. These antennas can be quite efficient and a tuner is not needed in most installations.

5) A common solution for multiband operation is to use a fixed length antenna, such as a vertical mounted on the transom or integrated into the backstay, combined with a tuner to provide a match to the transmitter.

6) It is also possible to use more than one antenna. For example, you could use an insulated backstay resonant on 40 meters combined with a shorter transom vertical for the higher bands.

21.4.3 ANTENNA TUNERS

Before examining some of these options in detail we need to talk a bit about tuners. Tuners are capable of providing a low SWR load for the transmitter over a wide range of HF frequencies and they can be very useful in an antenna system expanding the number of usable antenna configurations. But they have some limitations. There will be a limited range of impedances that the tuner can deal with. In general, very low and very high impedances lead to higher voltages and/or currents in the tuner components, which can lead to much lower tuner efficiency. The worst case is usually when the resistive component at the feed point is very low and the reactive component is high. This happens when antennas are used at frequencies below λ/4 resonance (see Table 21.1 for examples of feed point resistance as an 8 foot whip is excited at lower frequencies). As the antenna is made longer and approaches λ/2 resonance, the resistive part of Z_{in} can become very large, >1,000 Ω. From the point of view of tuner efficiency and the ability to provide a match, the antenna feed point impedance should be kept above 10 Ω and lower than 500 Ω if possible.

The tuner should be placed physically as close to the antenna feed point as possible. The best design is to have a good ground connection immediately adjacent to the feed point with the tuner right there. *Running an insulated wire from the feed point back through the boat to a tuner collocated with the transceiver is a very bad practice.* There is the danger of exposure to high potentials on the wire and the probability of RF coupling to the boat's wiring and other electronics. DO NOT DO THIS! If you have a good ground connection next to the feed point and another at the transmitter, it is possible to use a length of coaxial cable to bring the feed point to the tuner, allowing you to use a conventional manual tuner collocated with the transceiver. However, the coax is a transmission line and it will transform the feed point impedance to some new value that may or may not be better for the tuner. (See the **Transmission Lines** chapter for more on impedance transformation by feed lines.) In addition there can be very high voltages on the transmission line. The best general advice is to locate the tuner as close as possible to the antenna feed point!

Locating the tuner close to the feed point may have disadvantages however. Typically the tuner may need to be installed in a locker near the stern that may not be completely shielded from the weather so you have to use a weather-tight tuner. Also such a location makes it difficult to use a manual tuner since you may have to reach into the locker to adjust the tuner for a new band. Typically weather resistant automatic tuners are chosen for this application.

The chapter **Transmission Line System Techniques** has information on tuners you can build yourself and the ARRL has published a guide to tuners by Joel Hallas, W1ZR.[5]

21.4.4 THE EFFECT OF MAST AND RIGGING

A vertical can be placed on the transom as shown in Figure 21.28. (Note that the vertical is offset a short distance from the backstay to reduce coupling to the rigging slightly). This vertical could be a mobile whip, a fixed length commercial marine vertical or an insulated section of backstay. It turns out that the length of the antenna and whether it's part of the backstay or separate has only a modest effect on the radiation pattern so we will use 23 foot independent vertical that will give us a general idea what to expect from verticals of other lengths. **Figure 21.32** shows the radiation patterns for this antenna at 7.2, 14.2 and 21.25 MHz.

Unlike a vertical standing alone, this antenna doesn't have an omnidirectional pattern. It is asymmetrical, with pattern distortion of 8-10 dB depending on the band. Further, the pattern is offset in the direction the antenna is placed on the transom. With the backstay vertical that offset is absent. The pattern distortion shown in Figure 21.32 is very typical for a wide range of boats. The directive gain can be useful but only if you point the boat in the right direction! Otherwise you may have significant reduction in your signal.

Figure 21.33 shows Smith chart graphs for the feed point impedance at the base of a 23 foot vertical with and without the rig. Figures 21.32 and 21.33 are very good examples of the profound effect the mast and rigging can have on an antenna installed on a sailboat.

What if we chose a length other than 23 feet for either the vertical or an insulated backstay? Is there a better choice? **Figure 21.34** shows Z_{in} for various vertical lengths from 15 to 40 feet on 40, 20 and 15 meters. For a backstay vertical it would be common to set L=33 feet which gives a good match on 40 and 15 meters. Usually no tuner would be needed or at least the internal tuner found in most transceivers would have little difficulty matching those bands. However, L=33 feet is a very poor length for 20 meters — the impedance is very

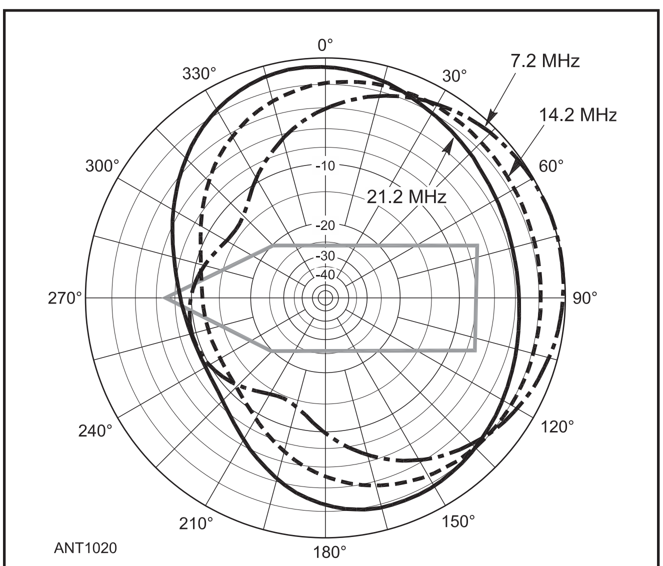


Fig 21.32 — Azimuth radiation pattern of a vertical at 15° elevation at 7.2, 14.2 and 21.2 MHz.

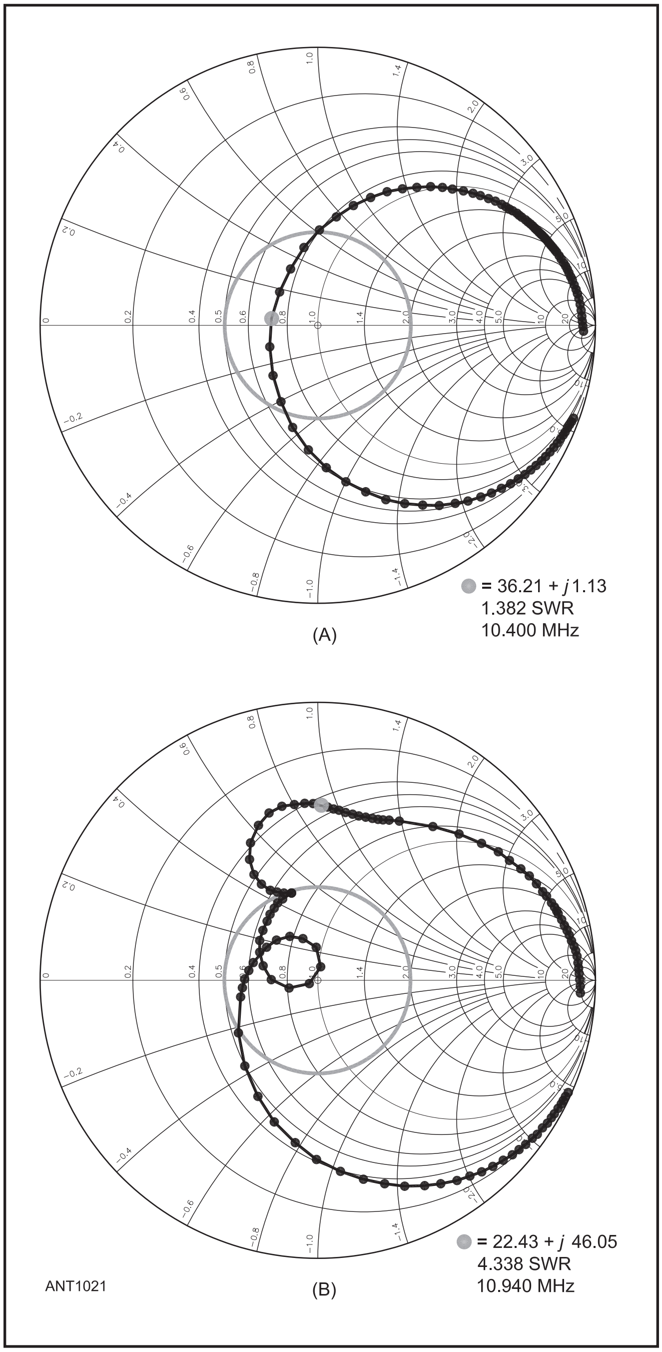


Fig 21.33 — Feed point impedance of a 23 foot free-standing vertical with the mast and rigging present. (Z_0 = 50 Ω)

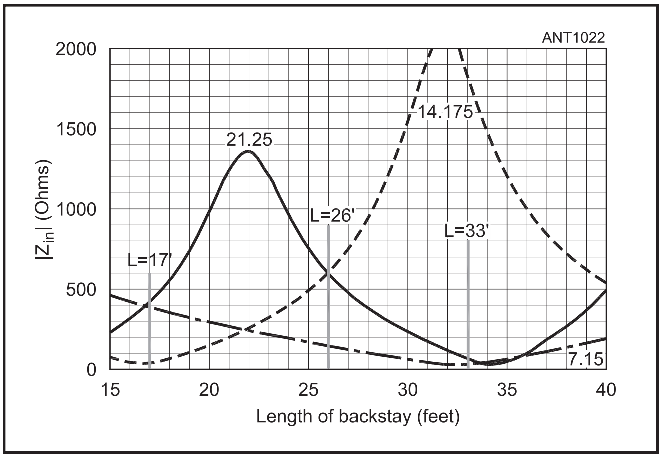


Fig 21.34 — Feed point impedance as a function of vertical length at 7.150, 14.175 and 21.250 MHz. (Z_0 = 50 Ω)

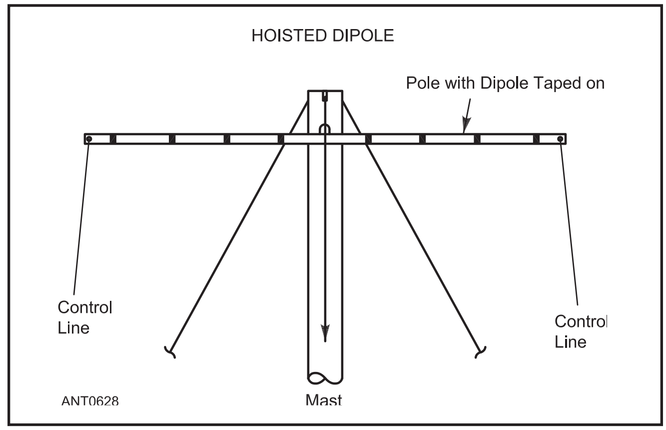


Fig 21.35 — A dipole can be taped to a wood or bamboo pole and hoisted to the masthead with the main halyard while at anchor. It is possible to make this a multiband dipole.

high and even the best tuner might have difficulty matching to that load. Instead of 33 feet you could set L=17 feet which will have Z_{in} = 11 –j384 Ω at 7.15 MHz, 36 + j8 Ω at 14.175 MHz and 220 + j451 Ω at 21.25 MHz. On 20 meters a tuner is not required and the impedances on 40 and 15 meters are reasonable for an automatic tuner.

Common lengths for commercial marine antennas intended for HF SSB service are 23 feet and 28 feet. From Figure 21.34 we can see these lengths have impedances that are a bit high (though not impossible) for many automatic tuners. A better choice would be 26 feet. However, this observation applies only to this particular example, on this boat! Other boats, with different rigging dimensions might be better (or worse) with a given vertical length. That is why it is a good idea to model each boat individually before choosing an antenna. Each installation will be unique!

The message here is that some lengths are better than others for verticals or insulated backstay antennas and these lengths may not be resonant on any of the bands. The choice of length will depend on the specifics of the boat, the desired operating bands and whether a tuner is used.

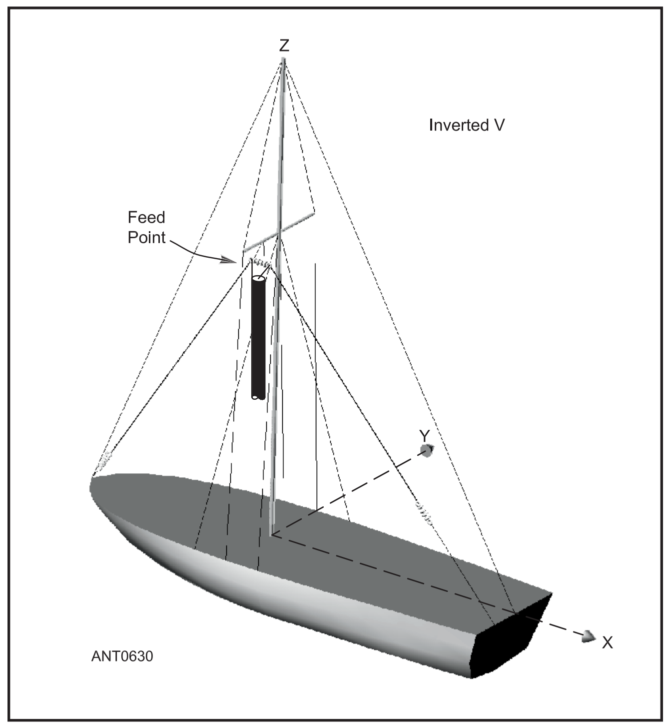


Fig 21.36 — The flag halyard can be used to hoist the center of an inverted V to the spreaders, or alternatively, the main halyard can be used to hoist the center of the antenna to the masthead. Interaction between the rigging and the antenna will be very pronounced and the length of the antenna will have to be adjusted on a cut-and-try basis.

21.4.5 TEMPORARY ANTENNAS

Not everyone needs permanent antennas. A variety of temporary antennas can be arranged. A few of these are shown in **Figures 21.35** through **21.37**. All of these options will be strongly affected by their close proximity to the rigging but by employing a tuner, they may work well for temporary operation. You can also try altering the wire lengths to get a better match.

21.4.6 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 **Figure 21.38** 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, lifeline 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 figure indicates the use of 2-4 inch wide copper strap for the connections. This is to provide low

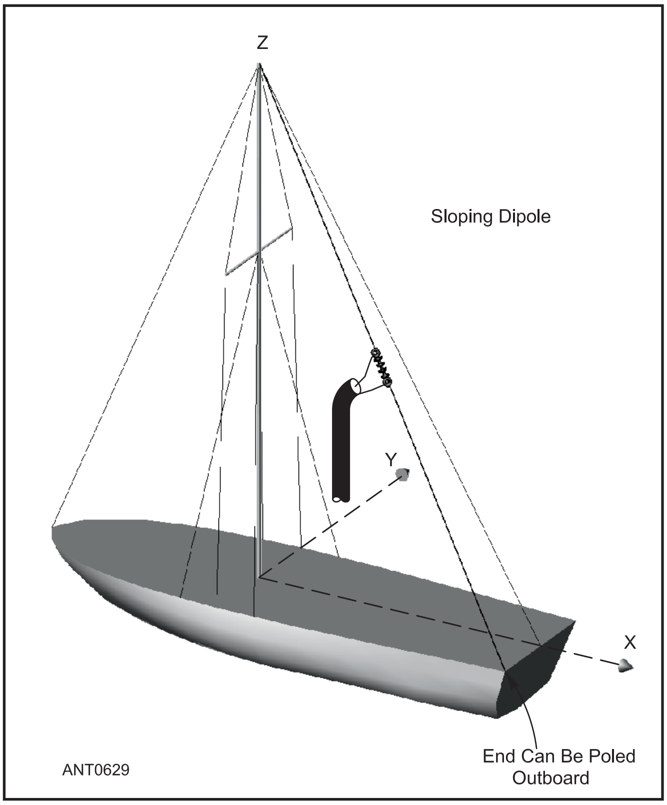


Fig 21.37 — One end of dipole can be attached to the main halyard and pulled up to the masthead. The bottom end of the dipole should be pulled out away from the rigging as much as possible to reduce the impact of the rigging on the impedance.

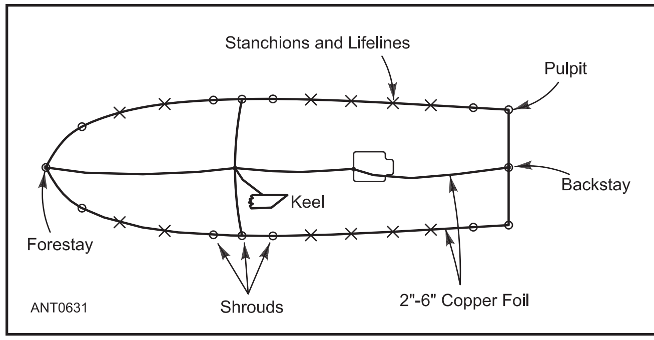


Fig 21.38 — A typical sailboat grounding scheme.

impedance grounding but that material may not always be readily available. It turns out that a pair of parallel wires (say #12) spaced a few inches apart will have an impedance similar to a wide copper strap and may be easier to install.

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 grounding system, 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!

21.4.7 ANTENNAS FOR POWER BOATS

Power boaters 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 ground plane for a whip antenna. Most modern powerboats, however, have fiberglass hulls. These are basically insulators and will not work as a counterpoise. (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. Hopefully your vessel will not experience these wind speeds!

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 saltwater marine environment is common. This means that a careful choice of materials must be made for the antennas to reduce corrosion and premature failure.

The problem of a ground plane for vertical antennas can be handled in much the same manner as shown in Figure 21.38 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 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 the chapter **Effects of Ground**, 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 as suggested in Figure 21.31. For short-range communication, a 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 have the ground system associated with a vertical. It is not uncommon for large powerboats to have a two or three-element multiband Yagi installed on a short 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.

21.5 BIBLIOGRAPHY FOR HF MARITIME ANTENNAS

Source material and more extended discussions of topics covered in this chapter can be found in the references given below, in the references listed at the end of the mobile antennas material, and in the textbooks listed at the end of the **Antenna Fundamentals** chapter.

1. *EZNEC* by Roy Lewallen, W7EL, **www.eznec.com**
2. *4NEC2* by Ari Voors, **www/qsl.net/4nec2/**
3. *EZNEC-Pro/4* (see reference 1)
4. SteppIR Antennas, **www.steppir.com**
5. Joel Hallas, W1ZR, *The ARRL Guide to Antenna Tuners* (Newington: ARRL, 2010).