Chapter 5

Loop Antennas

A loop antenna is a closed-circuit antenna—that is, one in which a conductor is formed into one or more turns so its two ends are close together. Loops can be divided into two general classes, those in which both the total conductor length and the maximum linear dimension of a turn are very small compared with the wavelength, and those in which both the conductor length and the loop dimensions begin to be comparable with the wavelength.

A "small" loop can be considered to be simply a rather large coil, and the current distribution in such a loop is the same as in a coil. That is, the current has the same phase and the same amplitude in every part of the loop. To meet this condition, the total length of conductor in the loop must not exceed about 0.1 λ. Small loops are discussed later in this chapter, and further in Chapter 14, Direction Finding Antennas.

A "large" loop is one in which the current is not the same either in amplitude or phase in every part of the loop. This change in current distribution gives rise to entirely different properties compared with a small loop.

Half-Wave Loops

The smallest size of "large" loop generally used is one having a conductor length of $^1/_2$ λ. The conductor is usually formed into a square, as shown in **Fig 1**, making each side $^1/_8$ λ long. When fed at the center of one side, the current flows in a closed loop as shown in Fig 1A. The current distribution is approximately the same as on a $^1/_2$ λ wire, and so is maximum at the center of the side opposite the terminals X-Y, and minimum at the terminals themselves. This current distribution causes the field strength to be maximum in the plane of the loop and in the direction looking from the low-current side to the high-current side. If the side opposite the terminals is opened at the center as shown in Fig 1B (strictly speaking, it is then no longer a loop because it is no longer a closed circuit), the direction of current flow remains unchanged but the maximum current flow occurs at the terminals. This reverses the direction of maximum radiation.

The radiation resistance at a current antinode (which is also the resistance at X-Y in Fig 1B) is on the order of 50 Ω. The impedance at the terminals in Fig 1A is a few thousand ohms. This can be reduced by using two identical loops side by side with a few inches spacing between them and applying power between terminal X on one loop and terminal Y on the other.

Unlike a $^1/_2$ λ dipole or a small loop, there is no direction in which the radiation from a loop of the type shown in Fig 1 is zero. There is appreciable radiation in the direction perpendicular to the plane of the loop, as well as to the "rear"—the opposite direction to the arrows shown. The front-to-back (F/B) ratio is approximately 4 to 6 dB. The small size and the shape of the directive pattern result in a loss of about 1 dB when the field strength in the optimum direction from such a

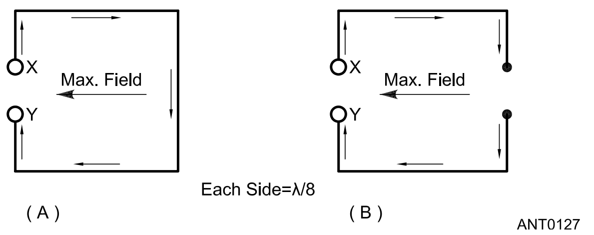

Fig 1—Half-wave loops, consisting of a single turn having a total length of $^1/_2$ λ.

loop is compared with the field from a $^1/_2$ λ dipole in its optimum direction.

The ratio of the forward radiation to the backward radiation can be increased, and the field strength likewise increased at the same time to give a gain of about 1 dB over a dipole, by using inductive reactances to "load" the sides joining the front and back of the loop. This is shown in **Fig 2**. The reactances, which should have a value of approximately 360 Ω, decrease the current in the sides in which they are inserted and increase it in the side having terminals. This increases the directivity and thus increases the efficiency of the loop as a radiator. Lossy coils can reduce this advantage greatly.

One-Wavelength Loops

Loops in which the conductor length is 1 λ have different characteristics than $^1/_2$-λ loops. Three forms of 1 λ loops are shown in **Fig 3**. At A and B the sides of the squares are equal to $^1/_4$ λ, the difference being in the point at which the terminals are inserted. At C the sides of the triangle are equal to $^1/_3$ λ. The relative direction of current flow is as shown in the drawings. This direction reverses halfway around the perimeter of the loop, as such reversals always occur at the junction of each $^1/_2$-λ section of wire.

The directional characteristics of loops of this type are opposite in sense to those of a small loop. That is, the radiation is maximum perpendicular to the plane of the loop and is minimum in either direction in the plane containing the loop. If the three loops shown in Fig 3 are mounted in a vertical plane with the terminals at the bottom, the radiation is horizontally polarized. When the terminals are moved to the center of one vertical side in Fig 3A, or to a side corner in B, the radiation is vertically polarized. If the terminals are moved to a side corner in C, the polarization will be diagonal, containing both vertical and horizontal components.

In contrast to straight-wire antennas, the electrical length of the circumference of a 1-λ loop is shorter than the actual length. For a loop made of bare #18 wire and operating at a frequency of 14 MHz, where the ratio of conductor length to wire diameter is large, the loop will be close to resonance when

$$\text{Length}_{\text{feet}} = \frac{1032}{f_{\text{MHz}}}$$

The radiation resistance of a resonant 1 λ loop is approximately 120 Ω, under these conditions. Since the loop dimensions are larger than those of a $^1/_2$-λ dipole, the radiation efficiency is high.

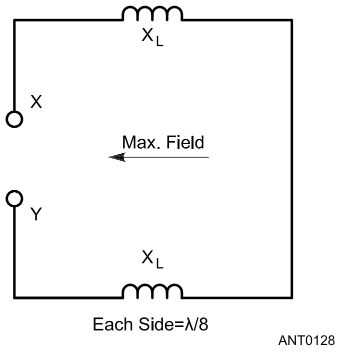

Fig 2—Inductive loading in the sides of a $^1/_2$-λ loop to increase the directivity and gain. Maximum radiation or response is in the plane of the loop, in the direction shown by the arrow.

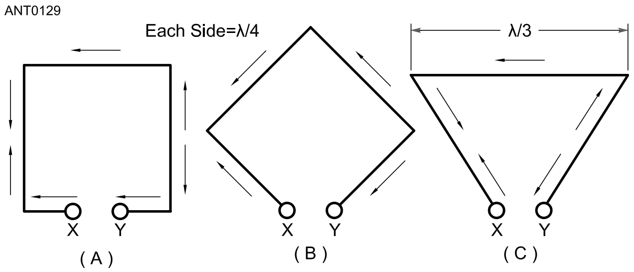

Fig 3—At A and B, loops having sides $^1/_4$ λ long, and at C having sides $^1/_3$ λ long (total conductor length 1 λ). The polarization depends on the orientation of the loop and on the position of the feed point (terminals X-Y) around the perimeter of the loop.

In the direction of maximum radiation (that is, broadside to the plane of the loop, regardless of the point at which it is fed) the 1-λ loop will show a small gain over a $^1/_2$-λ dipole. Theoretically, this gain is about 1 dB, and measurements have confirmed that it is of this order.

The 1-λ loop is more frequently used as an element of a directive antenna array (the quad and delta-loop antennas described in Chapter 12, Quad Arrays) than singly, although there is no reason why it cannot be used alone. In the quad and delta loop, it is nearly always driven so that the polarization is horizontal.

Small Loop Antennas

The electrically small loop antenna has existed in various forms for many years. Probably the most familiar form of this antenna is the ferrite *loopstick* found in portable AM broadcast-band receivers. Amateur applications of the small loop include direction finding, low-noise directional receiving antennas for 1.8 and 3.5 MHz, and small transmitting antennas. Because the design of transmitting and receiving loops requires some different considerations, the two situations are examined separately in this section. This information was written by Domenic M. Mallozzi, N1DM.

The Basic Loop

What is and what is not a small loop antenna? By definition, the loop is considered to be electrically small when its total conductor length is less than 0.1 λ—0.085 is the number used in this section. This size is based on the fact that the current around the perimeter of the loop must be in phase. When the winding conductor is more than about 0.085 λ long, this is no longer true. This constraint results in a very predictable figure-eight radiation pattern, shown in **Fig 4**.

The simplest loop is a 1-turn untuned loop with a load connected to a pair of terminals located in the center of one of the sides, as shown in **Fig 5**. How its pattern is developed is easily pictured if we look at some "snapshots" of the antenna relative to a signal source. **Fig 6** represents a loop from above, and shows the instantaneous radiated voltage wave. Note that points A and B of the loop are receiving the same instantaneous voltage. This means that no current will flow through the loop, because there is no current flow between points of equal potential. A similar analysis of **Fig 7**, with the loop turned 90° from the position represented in Fig 6, shows that this position of the loop provides maximum response. Of course, the voltage derived from the passing wave is small because of the small physical size of the loop. Fig 4 shows the ideal radiation pattern for a small loop.

The voltage across the loop terminals is given by

$$V = \frac{2\pi A N E \cos\theta}{\lambda} \qquad \text{(Eq 1)}$$

where

V = voltage across the loop terminals
A = area of loop in square meters
N = number of turns in the loop
E = RF field strength in volts per meter
θ = angle between the plane of the loop and the signal source (transmitting station)
λ = wavelength of operation in meters

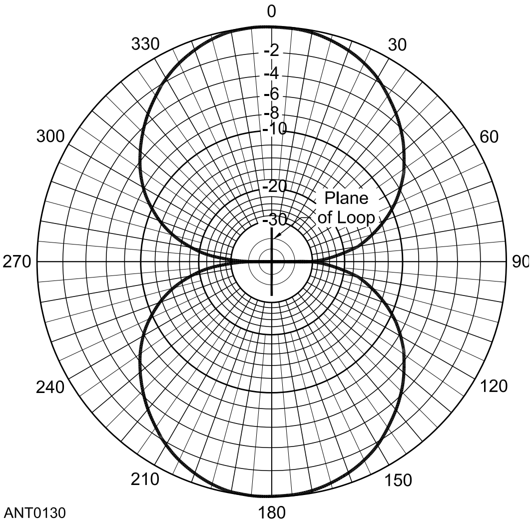

Fig 4—Calculated small loop antenna radiation pattern.

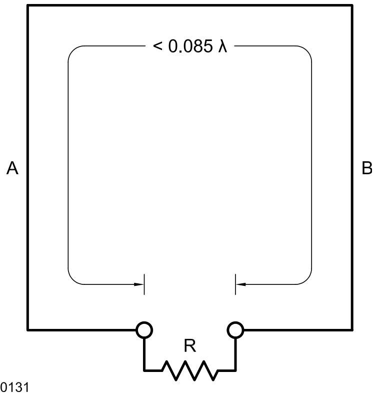

Fig 5—Simple untuned small loop antenna.

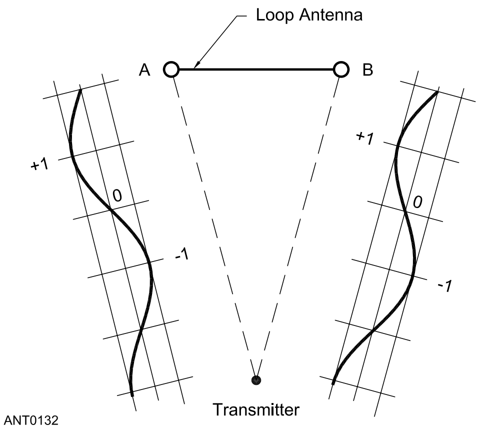

Fig 6—Example of orientation of loop antenna that does not respond to a signal source (null in pattern).

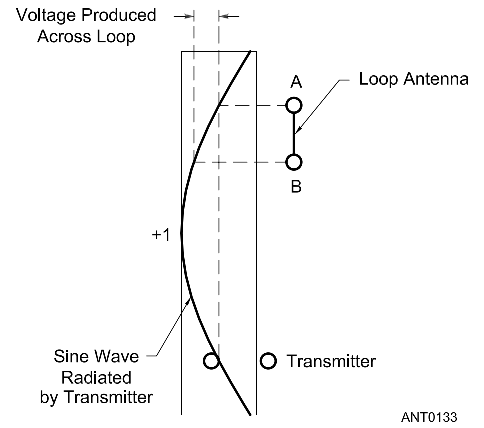

Fig 7—Example of orientation of loop antenna for maximum response.

This equation comes from a term called *effective height*. The effective height refers to the height (length) of a vertical piece of wire above ground that would deliver the same voltage to the receiver. The equation for effective height is

$$h = \frac{2\pi N A}{\lambda} \qquad \text{(Eq 2)}$$

where h is in meters and the other terms are as for Eq 1.

A few minutes with a calculator will show that, with the constraints previously stated, the loop antenna will have a very small effective height. This means it will deliver a relatively small voltage to the receiver, even with a large transmitted signal.

TUNED LOOPS

We can tune the loop by placing a capacitor across the antenna terminals. This causes a larger voltage to appear across the loop terminals because of the Q of the parallel resonant circuit that is formed.

The voltage across the loop terminals is now given by

$$V = \frac{2\pi A N E Q \cos\theta}{\lambda} \qquad \text{(Eq 3)}$$

where Q is the loaded Q of the tuned circuit, and the other terms are as defined above.

Most amateur loops are of the tuned variety. For this reason, all comments that follow are based on tuned-loop antennas, consisting of one or more turns. The tuned-loop antenna has some particular advantages. For example, it puts high selectivity up at the “front” of a receiving system, where it can significantly help factors such as dynamic range. Loaded Q values of 100 or greater are easy to obtain with careful loop construction.

Consider a situation where the inherent selectivity of the loop is helpful. Assume we have a loop with a Q of 100 at 1.805 MHz. We are working a DX station on 1.805 MHz and are suffering strong interference from a local station 10 kHz away. Switching from a dipole to a small loop will reduce the strength of the off-frequency signal by 6 dB (approximately one S unit). This, in effect, increases the dynamic range of the receiver. In fact, if the off-frequency station were further off frequency, the attenuation would be greater.

Another way the loop can help is by using the nulls in its pattern to null out on-frequency (or slightly off-frequency) interference. For example, say we are working a DX station to the north, and just 1 kHz away is another local station engaged in a contact. The local station is to our west. We can simply rotate our loop to put its null to the west, and now the DX station should be readable while the local will be knocked down by 60 or more dB. This obviously is quite a noticeable difference. Loop nulls are very sharp and are generally noticeable only on ground-wave signals (more on this later).

Of course, this method of nulling will be effective only if the interfering station and the station being worked are not in the same direction (or in exact opposite directions) from our location. If the two stations were on the same line from our location, both the station being worked and the undesired station would be nulled out. Luckily the nulls are very sharp, so as long as the stations are at least 10° off axis from each other, the loop null will be usable.

A similar use of the nulling capability is to eliminate local noise interference, such as that from a light dimmer in a neighbor’s house. Just put the null on the offending light dimmer, and the noise should disappear.

Now that we have seen some possible uses of the small loop, let us look at a bit of detail about its design. First, the loop forms an inductor having a very small ratio of winding length to diameter. The equations for finding inductance given in most radio handbooks assume that the inductor coil is longer than its diameter. However, F. W. Grover of the US National Bureau of Standards has provided equations for inductors of common cross-sectional shapes and small length-to-diameter ratios. (See the Bibliography at the end of this chapter.) Grover’s equations are shown in **Table 1**. Their use will yield relatively accurate numbers; results are easily worked out with a scientific calculator or home computer.

The value of a tuning capacitor for a loop is easy to calculate from the standard resonance equations. The only matter to consider before calculating this is the value of distributed capacitance of the loop winding. This capacitance shows up between adjacent turns of the coil because of their slight difference in potential. This causes each turn to appear as a charge plate. As with all other capacitances, the value of the distributed capacitance is based on the physical dimensions of the coil. An exact mathematical analysis of its value is a complex problem. A simple approximation is given by Medhurst (see Bibliography) as:

$$C = HD \qquad \text{(Eq 4)}$$

where

C = distributed capacitance in pF

H = a constant related to the length-to-diameter ratio of the coil (**Table 2** gives H values for length-to-diameter ratios used in loop antenna work.)

D = diameter of the winding in cm

Medhurst's work was with coils of round cross section. For loops of square cross section the distributed capacitance is given by Bramslev (see Bibliography) as

$$C = 60S \qquad \text{(Eq 5)}$$

where

C = the distributed capacitance in pF

S = the length of the side in meters

If you convert the length in this equation to centimeters, you will find Bramslev's equation gives results in the same order of magnitude as Medhurst's equation.

This distributed capacitance appears as if it were a capacitor across the loop terminals. Therefore, when determining the value of the tuning capacitor, the distributed capacitance must be subtracted from the total capacitance required to resonate the loop. The distributed capacitance also determines the highest frequency at which a particular loop can be used, because it is the minimum capacitance obtainable.

Electrostatically Shielded Loops

Over the years, many loop antennas have incorporated an electrostatic shield. This shield generally takes the form of a tube around the winding, made of a conductive but nonmagnetic material (such as copper or aluminum). Its purpose is to maintain loop balance with respect to ground, by forcing the capacitance between all portions of the loop and ground to be identical. This is illustrated in **Fig 8**. It is necessary to maintain electrical loop balance to eliminate what is referred to as the *antenna effect*. When the antenna becomes unbalanced it appears to act partially as a small vertical antenna. This vertical pattern gets superimposed on the ideal figure-eight pattern, distorting the pattern and filling in the nulls. The type of pattern that results is shown in **Fig 9**.

Adding the shield has the effect of somewhat reducing the pickup of the loop, but this loss is generally offset by the increase in null depth of the loops. Proper balance of the loop antenna requires that the load on the loop also be balanced. This is usually accomplished by use of a balun transformer or a balanced input preamplifier. One important point regarding the shield is that it cannot form a continuous electrical path around the loop perimeter, or it will appear as a shorted coil turn. Usually the insulated break is located opposite the feed point to maintain symmetry. Another point to be considered is that the shield should be of a much larger diameter than the loop winding, or it will lower the Q of the loop.

Various construction techniques have been used in

Table 1

Inductance Equations for Short Coils (Loop Antennas)

Triangle:

$$L\left(\mu H\right) = 0.006N^2\,s \left[\ln\left(\frac{1.1547\,sN}{\left(N+1\right)\ell}\right) + 0.65533 + \frac{0.1348\left(N+1\right)\ell}{sN}\right]$$

Square:

$$L\left(\mu H\right) = 0.008N^2\,s \left[\ln\left(\frac{1.4142sN}{\left(N+1\right)\ell}\right) + 0.37942 + \frac{0.3333\left(N+1\right)\ell}{sN}\right]$$

Hexagon:

$$L\left(\mu H\right) = 0.012N^2 s \left[\ln\left(\frac{2sN}{\left(N+1\right)\ell}\right) + 0.65533 + \frac{0.1348\left(N+1\right)\ell}{sN}\right]$$

Octagon:

$$L\left(\mu H\right) = 0.016N^2 \left[\ln\left(\frac{2.613sN}{\left(N+1\right)\ell}\right) + 0.75143 + \frac{0.07153\left(N+1\right)\ell}{sN}\right]$$

where

N = number of turns

s = side length in cm

ℓ = coil length in cm

Note: In the case of single-turn coils, the diameter of the conductor should be used for ℓ.

Table 2

Values of the Constant H for Distributed Capacitance

Length to Diameter Ratio	*H*
0.10	0.96
0.15	0.79
0.20	0.78
0.25	0.64
0.30	0.60
0.35	0.57
0.40	0.54
0.50	0.50
1.00	0.46

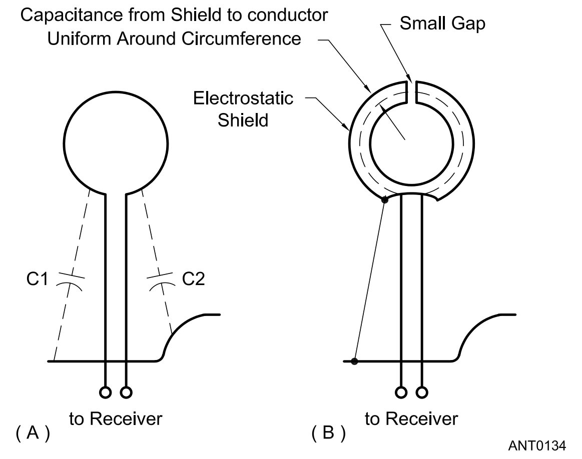

Fig 8—At A, the loop is unbalanced by capacitance to its surroundings. At B, the use of an electrostatic shield overcomes this effect.

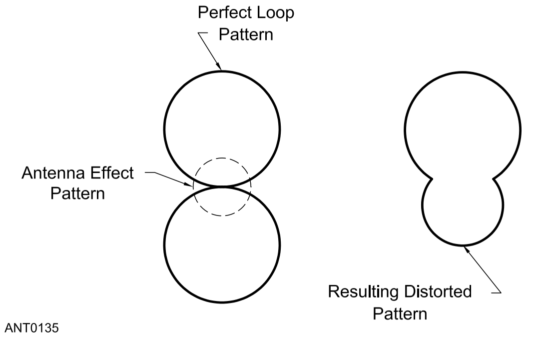

Fig 9—Distortion in loop pattern resulting from antenna effect.

making shielded loops. Genaille located his loop winding inside aluminum conduit, while True constructed an aluminum shield can around his winding. Others have used pieces of Hardline to form a loop, using the outer conductor as a shield. DeMaw used flexible coax with the shield broken at the center of the loop conductor in a multiturn loop for 1.8 MHz. Goldman uses another shielding method for broadcast receiver loops. His shield is in the form of a barrel made of hardware cloth, with the loop in its center. (See Bibliography for above references.) All these methods provide sufficient shielding to maintain the balance. It is possible, as Nelson shows, to construct an unshielded loop with good nulls (60 dB or better) by paying great care to symmetry.

LOOP Q

As previously mentioned, Q is an important consideration in loop performance because it determines both the loop bandwidth and its terminal voltage for a given field strength. The loaded Q of a loop is based on four major factors. These are (1) the intrinsic Q of the loop winding, (2) the effect of the load, (3) the effect of the electrostatic shield, and (4) the Q of the tuning capacitor.

The major factor is the Q of the winding of the loop itself. The ac resistance of the conductor caused by skin effect is the major consideration. The ac resistance for copper conductors may be determined from

$$R = \frac{0.996 \times 10^{-6}\ \sqrt{f}}{d} \qquad \text{(Eq 6)}$$

where

R = resistance in ohms per foot
f = frequency, Hz
d = conductor diameter, inches

The Q of the inductor is then easily determined by taking the reactance of the inductor and dividing it by the ac resistance. If you are using a multiturn loop and are a perfectionist, you might also want to include the loss from conductor proximity effect. This effect is described in detail later in this chapter, in the section on transmitting loops.

Improvement in Q can be obtained in some cases by the use of Litz wire (short for *Litzendraht*). Litz wire consists of strands of individual insulated wires that are woven into bundles in such a manner that each conductor occupies each location in the bundle with equal frequency. Litz wire results in improved Q over solid or stranded wire of equivalent size, up to about 3 MHz.

Also, the Q of the tuned circuit of the loop antenna is determined by the Q of the capacitors used to resonate it. In the case of air variables or dipped micas this is not usually a problem. But if variable-capacitance diodes are used to remotely tune the loop, pay particular attention to the manufacturer's specification for Q of the diode at the frequency of operation. The tuning diodes can have a significant effect on circuit Q.

Now we consider the effect of load impedance on loop Q. In the case of a directly coupled loop (as in Fig 5), the load is connected directly across the loop terminals, causing it to be treated as a parallel resistance in a parallel-tuned RLC circuit. Obviously, if the load is of a low value, the Q of the loop will be low. A simple way to correct this is to use a transformer to step up the load impedance that appears across the loop terminals. In fact, if we make this transformer a balun, it also allows us to use our unbalanced receivers with the loop and maintain loop symmetry. Another solution is to use what is referred to as an inductively coupled loop, such as DeMaw's four turn electrostatically shielded loop. A one-turn link is connected to the receiver. This turn is wound with the four-turn loop. In effect, this builds the transformer into the antenna.

Another solution to the problem of load impedance on loop Q is to use an active preamplifier with a high impedance balanced input and unbalanced output. This method also has the advantage of amplifying the low-level output voltage of the loop to where it can be used with a receiver of even mediocre sensitivity. In fact, the Q of the loop when used with a balanced preamplifier having high input impedance may be so high as to be unusable in certain applications. An example of this situation would occur where a loop is being used to receive a 5 kHz wide AM signal at a frequency where the bandwidth of the loop is only 1.5 kHz. In this case the detected audio might be very distorted. The solution to this is to put a Q-degrading resistor across the loop terminals.

FERRITE-CORE LOOP ANTENNAS

The ferrite-core loop antenna is a special case of the air-core receiving loops considered up to now. Because of its use in every AM broadcast-band portable radio, the ferrite-core loop is, by quantity, the most popular form of the loop antenna. But broadcast-band reception is far from its only use; it is commonly found in radio-direction-finding equipment and low-frequency-receiving systems (below 500 kHz) for time and frequency standard systems. In recent years, design information on these types of antennas has been a bit sparse in the amateur literature, so the next few paragraphs are devoted to providing some details.

Ferrite-loop antennas are characteristically very small compared to the frequency of use. For example, a 3.5-MHz version may be in the range of 15 to 30 cm long and about 1.25 cm in diameter. Earlier in this chapter, effective height was introduced as a measure of loop sensitivity. The effective height of an air-core loop antenna is given by Eq 2.

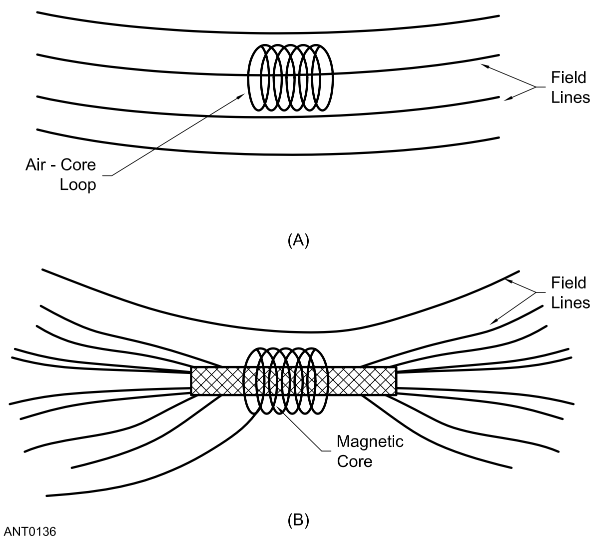

Fig 10—At A, an air-core loop has no effect on nearby field lines. B illustrates the effect of a ferrite core on nearby field lines. The field is altered by the reluctance of the ferrite material.

If an air-core loop is placed in a field, in essence it cuts the lines of flux without disturbing them (**Fig 10A**). On the other hand, when a ferrite (magnetic) core is placed in the field, the nearby field lines are redirected into the loop (Fig 10B). This is because the reluctance of the ferrite material is less than that of the surrounding air, so the nearby flux lines tend to flow through the loop rather than passing it by. (Reluctance is the magnetic analogy of resistance, while flux is analogous to current.) The reluctance is inversely proportional to the permeability of the rod core, μ_{rod}. (In some texts the rod permeability is referred to as effective permeability, μ_{eff}). This effect modifies the equation for effective height of a ferrite-core loop to

$$h = \frac{2 \pi N A \mu_{rod}}{\lambda} \qquad \text{(Eq 7)}$$

where

h = effective height (length) in meters
N = number of turns in the loop
A = area of loop in square meters
μ_{rod} = permeability of the ferrite rod
λ = wavelength of operation in meters

This obviously is a large increase in "collected" signal. If the rod permeability were 90, this would be the same as making the loop area 90 times larger with the same number of turns. For example, a 1.25-cm diameter ferrite-core loop would have an effective height equal to an air-core loop 22.5 cm in diameter (with the same number of turns).

By now you might have noticed we have been very careful to refer to rod permeability. There is a very important reason for this. The permeability that a rod of ferrite exhibits is a combination of the material permeability or μ, the shape of the rod, and the dimensions of the rod. In ferrite rods, μ is sometimes referred to as initial permeability, μ_i, or toroidal permeability, μ_{tor}. Because most amateur ferrite loops are in the form of rods, we will discuss only this shape.

The reason that μ_{rod} is different from μ is a very complex physics problem that is well beyond the scope of this book. For those interested in the details, books by Polydoroff and by Snelling cover this subject in considerable detail. (See Bibliography.) For our purposes a simple explanation will suffice. The rod is in fact not a perfect director of flux, as is illustrated in **Fig 11**. Note that some lines impinge on the sides of the core and also exit from the sides. These lines therefore would not pass through all the turns of the coil if it were wound from one end of the core to the other. These flux lines are referred to as *leakage flux*, or sometimes as flux leakage.

Leakage flux causes the flux density in the core to be nonuniform along its length. From Fig 11 it can be seen that the flux has a maximum at the geometric center of the length of the core, and decreases as the ends of the core are approached. This causes some noticeable effects. As a short coil is placed at different locations along a long core, its inductance will change. The maximum inductance exists when the coil is centered on the rod. The Q of a short coil on a long rod is greatest at the center. On the other hand, if you require a higher Q than this, it is recommended that you spread the coil turns along the whole length of the core, even though this will result in a lower value of inductance. (The inductance can be increased to the original value by adding turns.) **Fig 12** gives the relationship of rod permeability to material permeability for a variety of values.

The change in μ over the length of the rod results in an adjustment in the term μ_{rod} for its so called "free ends" (those not covered by the winding). This adjustment factor is given by

$$\mu' = \mu_{rod} \sqrt[3]{\frac{a}{b}} \qquad \text{(Eq 8)}$$

where

μ' = the corrected permeability
a = the length of the core
b = the length of the coil

This value of μ' should be used in place of μ_{rod} in Eq 7 to obtain the most accurate value of effective height.

All these variables make the calculation of ferrite loop antenna inductance somewhat less accurate than for the air-core version. The inductance of a ferrite loop is given by

$$L = \frac{4\pi N^2 A \mu_{rod} \times 10^{-4}}{\ell} \qquad \text{(Eq 9)}$$

where

L = inductance in μH
N = number of turns
A = cross-sectional area of the core in square mm
ℓ = magnetic length of core in mm

Experiments indicate that the winding diameter should be as close to that of the rod diameter as practical in order to maximize both inductance value and Q. By using all this information, we may determine the voltage at the loop terminals and its signal-to-noise ratio (SNR). The voltage may be determined from

$$V = \frac{2\pi A N \mu' Q E}{\lambda} \qquad \text{(Eq 10)}$$

where

V = output voltage across the loop terminals
A = loop area in square meters
N = number of turns in the loop winding
μ' = corrected rod permeability
Q = loaded Q of the loop
E = RF field strength in volts per meter
λ = wavelength of operation in meters

Lankford's equation for the sensitivity of the loop for a 10 dB SNR is

$$E = \frac{1.09 \times 10^{-10} \lambda \sqrt{f\ L\ b}}{A N \mu' \sqrt{Q}} \qquad \text{(Eq 11)}$$

where

f = operating frequency in Hz
L = loop inductance in henrys
b = receiver bandwidth in Hz

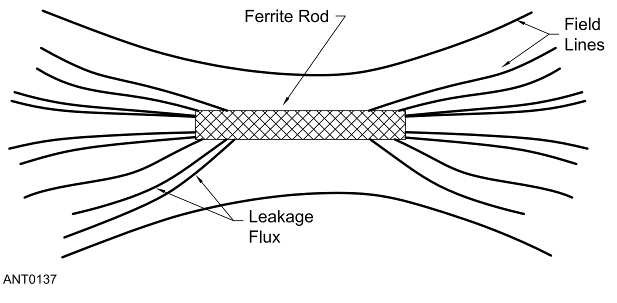

Fig 11—Example of magnetic field lines near a practical ferrite rod, showing leakage flux.

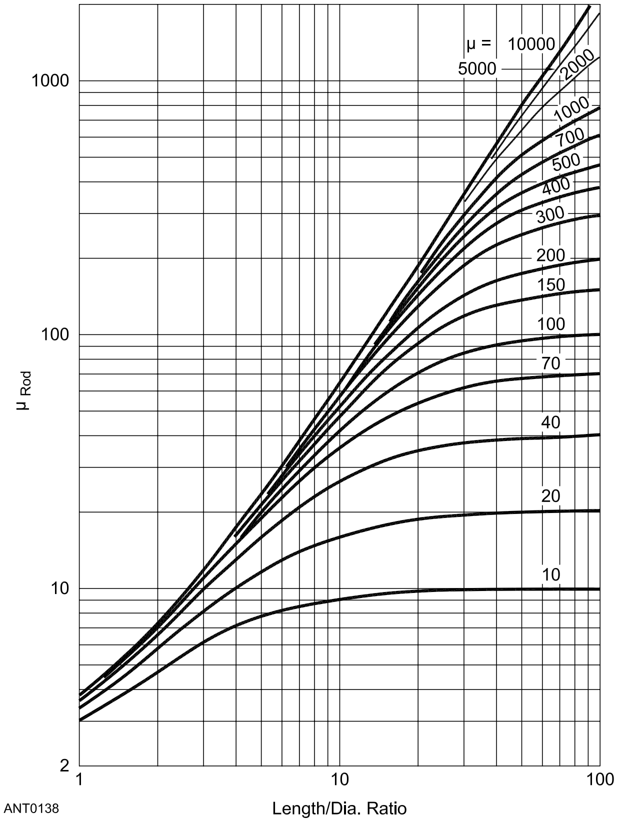

Fig 12—Rod permeability, μ_{rod}, versus material permeability, μ, for different rod length-to-diameter ratios.

Similarly, Belrose gives the SNR of a tuned loop antenna as

$$\mathrm{SNR} = \frac{66.3\,\mathrm{N\,A}\,\mu_{\mathrm{rod}}\,\mathrm{E}}{\sqrt{\mathrm{b}}}\sqrt{\frac{\mathrm{Qf}}{\mathrm{L}}} \qquad \text{(Eq 12)}$$

From this, if the field strength E, μ_{rod}, b, and A are fixed, then Q or N must increase (or L decrease) to yield a better SNR. Higher sensitivity can also be obtained (especially at frequencies below 500 kHz) by bunching ferrite cores together to increase the loop area over that which would be possible with a single rod. High sensitivity is important because loop antennas are not the most efficient collectors of signals, but they do offer improvement over other receiving antennas in terms of SNR. For this reason, you should attempt to maximize the SNR when using a small loop receiving antenna. In some cases there may be physical constraints that limit how large you can make a ferrite-core loop.

After working through Eq 11 or 12, you might find you still require some increase in antenna system gain to effectively use your loop. In these cases the addition of a low noise preamplifier may be quite valuable even on the lower frequency bands where they are not commonly used. Chapter 14 contains information on such preamplifiers.

The electrostatic shield discussed earlier with reference to air-core loops can be used effectively with ferrite-core loops. (Construction examples are presented in Chapter 14.) As in the air-core loop, a shield will reduce electrical noise and improve loop balance.

PROPAGATION EFFECTS ON NULL DEPTH

After building a balanced loop you may find it does not approach the theoretical performance in the null depth. This problem may result from propagation effects. Tilting the loop away from a vertical plane may improve performance under some propagation conditions, to account for the vertical angle of arrival. Basically, the loop performs as described above only when the signal is arriving perpendicular to the axis of rotation of the loop. At incidence angles other than perpendicular, the position and depth of the nulls deteriorate.

The problem can be even further influenced by the fact that if the loop is situated over less than perfectly conductive ground, the wave front will appear to tilt or bend. (This bending is not always detrimental; in the case of Beverage antennas, sites are chosen to take advantage of this effect.)

Another cause of apparent poor performance in the null depth can be from polarization error. If the polarization of the signal is not completely linear, the nulls will not be sharp. In fact, for circularly polarized signals, the loop might appear to have almost no nulls. Propagation effects are discussed further in Chapter 14.

SITING EFFECTS ON THE LOOP

The location of the loop has an influence on its performance that at times may become quite noticeable. For ideal performance the loop should be located outdoors and clear of any large conductors, such as metallic downspouts and towers. A VLF loop, when mounted this way, will show good sharp nulls spaced 180° apart if the loop is well balanced. This is because the major propagation mode at VLF is by ground wave. At frequencies in the HF region, a significant portion of the signals is propagated by sky wave, and nulls are often only partial.

Most hams locate their loop antennas near their operating position. If you choose to locate a small loop indoors, its performance may show nulls of less than the expected depth, and some skewing of the pattern. For precision direction finding there may be some errors associated with wiring, plumbing, and other metallic construction members in the building. Also, a strong local signal may be reradiated from the surrounding conductors so that it cannot be nulled with any positioning of the loop. There appears to be no known method of curing this type of problem. All this should not discourage you from locating a loop indoors; this information is presented here only to give you an idea of some pitfalls. Many hams have reported excellent results with indoor mounted loops, in spite of some of the problems.

Locating a receiving loop in the field of a transmitting antenna may cause a large voltage to appear at the receiver antenna terminals. This may be sufficient to destroy sensitive RF amplifier transistors or front-end protection diodes. This can be solved by disconnecting your loop from the receiver during transmit periods. This can obviously be done automatically with a relay that opens when the transmitter is activated.

LOOP ANTENNA ARRAYS

Arrays of loop antennas, both in combination with each other and with other antenna types, have been used for many years. The arrays are generally used to cure some "deficiency" in the basic loop for a particular application, such as a 180° ambiguity in the null direction, low sensitivity, and so forth.

A Sensing Element

For direction-finding applications the single loop suffers the problem of having two nulls that are 180° apart. This leads to an ambiguity of 180° when trying to find the direction to a transmitting station from a given location. A sensing element (often called a *sense antenna*) may be added to the loop, causing the overall antenna to have a cardioid pattern and only one null. The sensing element is a small vertical antenna whose height is equal to or greater than the loop effective height. This vertical is physically close to the loop, and when its omnidirectional pattern is adjusted so that its amplitude and phase are equal to one of the loop lobes, the patterns combine to form a cardioid. This antenna can be made quite compact by use of a ferrite loop to form a portable DF antenna for HF direction finding. Chapter 14 contains additional information and construction projects using sensing elements.

Arrays of Loops

A more advanced array that can develop more diverse patterns consists of two or more loops. Their outputs are combined through appropriate phasing lines and combiners to form a phased array. Two loops can also be formed into an array that can be rotated without physically turning the loops themselves. This method was developed by Bellini and Tosi in 1907 and performs this apparently contradictory feat by use of a special transformer called a *goniometer*. The goniometer is described in Chapter 14.

Aperiodic Arrays

The aperiodic loop array is a wide-band antenna. This type of array is useful over at least a decade of frequency, such as 2 to 20 MHz. Unlike most of the loops discussed up to now, the loop elements in an aperiodic array are untuned. Such arrays have been used commercially for many years. One loop used in such an array is shown in **Fig 13**. This loop is quite different from all the loops discussed so far in this chapter because its pattern is not the familiar figure eight. Rather, it is omnidirectional.

The antenna is omnidirectional because it is purposely unbalanced, and also because the isolating resistor causes the antenna to appear as two closely spaced short monopoles. The loop maintains the omnidirectional characteristics over a frequency range of at least four or five to one. These loops, when combined into end-fire or broadside phased arrays, can provide quite impressive performance. A commercially made end-fire array of this type consisting of four loops equally spaced along a 25-meter baseline can provide gains in excess of 5 dBi over a range of 2 to 30 MHz. Over a considerable portion of this frequency range, the array can maintain F/B ratios of 10 dB. Even though the commercial version is very expensive, an amateur version can be constructed using the information provided by Lambert. One interesting feature of this type of array is that, with the proper combination of hybrids and combiners, the antenna can simultaneously feed two receivers with signals from different directions, as shown in **Fig 14**. This antenna may be especially interesting to one wanting a directional receiving array for two or more adjacent amateur bands.

SMALL TRANSMITTING LOOP ANTENNAS

The electrically small transmitting-loop antenna involves some different design considerations compared to receiving loops. Unlike receiving loops, the size limitations of the antenna are not as clearly defined. For most purposes, any transmitting loop whose physical circumference is less than ¼ λ can be considered "small." In most cases, as a consequence of their relatively large size (when compared to a receiving loop), transmitting loops have a nonuniform current distribution along their circumference. This leads to some performance changes from a receiving loop.

The transmitting loop is a parallel-tuned circuit with a large inductor acting as the radiator. As with the receiving

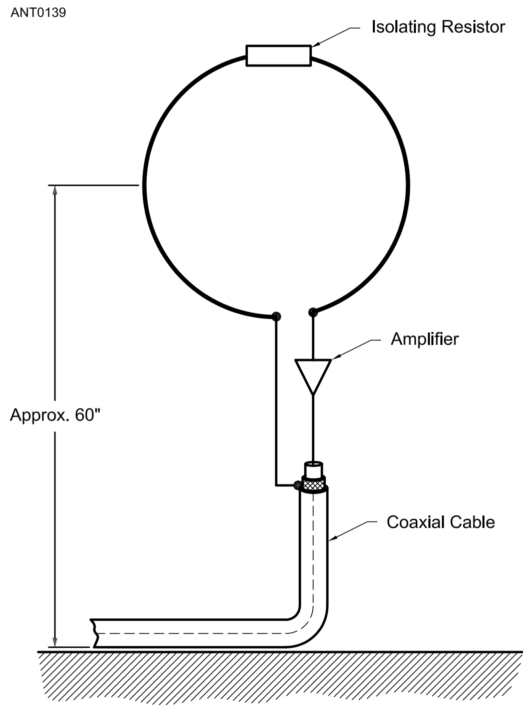

Fig 13—A single wide-band loop antenna used in an aperiodic array.

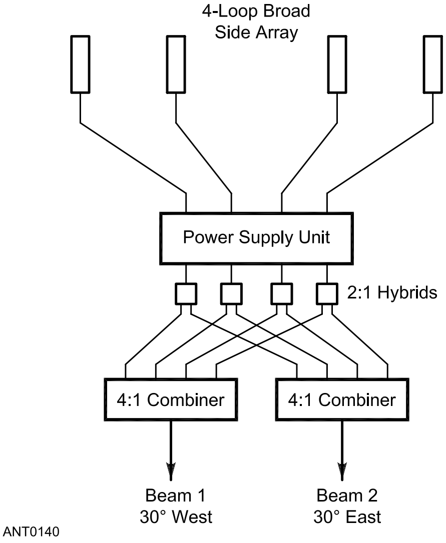

Fig 14—Block diagram of a four-loop broadside array with dual beams separated by 60° in azimuth.

Table 3
Transmitting Loop Equations

$$X_L = 2\pi f L \text{ ohms}$$

$$Q = \frac{f}{\Delta f} = \frac{X_L}{2(R_R + R_L)}$$

$$R_R = 3.12 \times 10^4 \left[\frac{NA}{\lambda^2}\right]^2 \text{ ohms}$$

$$V_C = \sqrt{P X_L Q}$$

$$I_L = \sqrt{\frac{PQ}{X_L}}$$

where

X_L = inductive reactance, ohms
f = frequency, Hz
Δf = bandwidth, Hz
R_R = radiation resistance, ohms
R_L = loss resistance, ohms (see text)
N = number of turns
A = area enclosed by loop, square meters
λ = wavelength at operating frequency, meters
V_C = voltage across capacitor
P = power, watts
I_L = resonant circulating current in loop

loop, the calculation of the transmitting-loop inductance may be carried out with the equations in Table 1. Avoid equations for long solenoids found in most texts. Other fundamental equations for transmitting loops are given in **Table 3**.

In the March 1968 *QST*, Lew McCoy, W1ICP, introduced the so-called "Army Loop" to radio amateurs. This was an amateur version of a loop designed for portable use in Southeast Asia by Patterson of the US Army and described in 1967. The Army Loop is diagrammed in **Fig 15A**, showing that this is a parallel tuned circuit fed by a tapped-capacitance impedance-matching network.

The Hart "high-efficiency" loop was introduced in the June 1986 *QST* by Ted Hart, W5QJR. It is shown schematically in Fig 15B and has the series-tuning capacitor separate from the matching network. The Hart matching network is basically a form of gamma match. Other designs have used a smaller loop connected to the transmission line to couple into the larger transmitting loop.

The approximate radiation resistance of a loop in ohms is given by

$$R_R = 3.12 \times 10^4 \left(\frac{NA}{\lambda^2}\right)^2 \qquad \text{(Eq 13)}$$

where

N = number of turns
A = area of loop in square meters
λ = wavelength of operation in meters

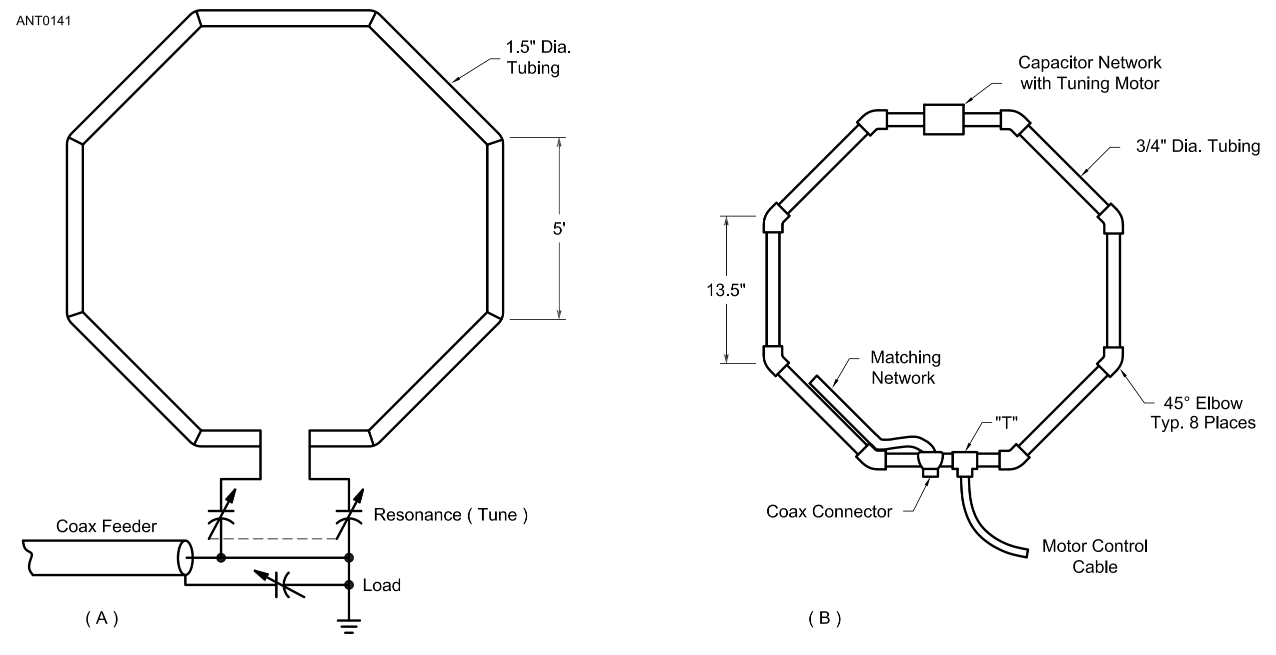

Fig 15—At A, a simplified diagram of the Army Loop. At B, the W5QJR loop, which is described in more detail later in this chapter.

The radiation resistance of a small transmitting loop is usually very small. For example, a 1-meter diameter, single-turn circular loop has a radius of 0.5 meters and an enclosed area of $\pi \times 0.5^2 = 0.785\ \text{m}^2$. Operated at 14.0 MHz, the free-space wavelength is 21.4 meters and this leads to a computed radiation resistance of only $3.12 \times 10^{-4} (0.785/21.4^2)^2 = 0.092\ \Omega$.

Unfortunately the loop also has losses, both ohmic and from skin effect. By using this information, the radiation efficiency of a loop can be calculated from

$$\eta = \frac{R_R}{R_R + R_L} \qquad \text{(Eq 14)}$$

where

η = antenna efficiency, %

R_R = radiation resistance, Ω

R_L = loss resistance, Ω, which includes the loop's conductor loss plus the loss in the series-tuning capacitor.

A simple ratio of R_R versus R_L shows the effects on the efficiency, as can be seen from **Fig 16**. The loss resistance is primarily the ac resistance of the conductor. This can be calculated from Eq 6. A transmitting loop generally requires the use of copper conductors of at least ¾ inch in diameter in order to obtain reasonable efficiency. Tubing is as useful as a solid conductor because high-frequency currents flow only along a very small depth of the surface of the conductor; the center of the conductor has almost no effect on current flow.

Note that the R_L term above also includes the effect of the tuning capacitor's loss. Normally, the unloaded Q of a capacitor can be considered to be so high that any loss in the tuning capacitor can be neglected. For example, a very high-quality tuning capacitor with no mechanical wiping contacts, such as a vacuum-variable or a transmitting butterfly capacitor, might have an unloaded Q of about 5000. This implies a series loss resistance of less than about 0.02 Ω for a capacitive reactance of 100 Ω. This relatively tiny loss resistance can become significant, however, when the radiation resistance of the loop is only on the order of 0.1 Ω! Practical details for curbing capacitor losses are covered later in this chapter.

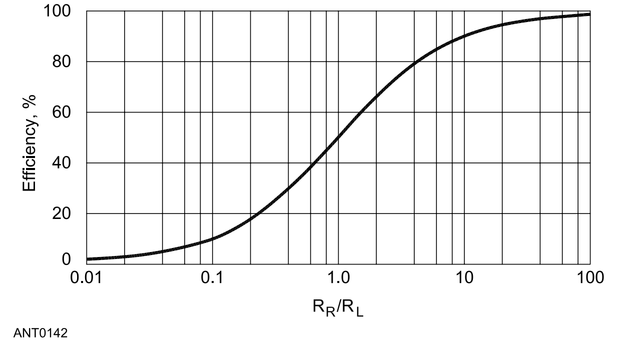

Fig 16—Effect of ratio of R_R/R_L on loop efficiency.

In the case of multiturn loops there is an additional loss related to a term called *proximity effect*. The proximity effect occurs in cases where the turns are closely spaced (such as being spaced one wire diameter apart). As these current-carrying conductors are brought close to each other, the current density around the circumference of each conductor gets redistributed. The result is that more current per square meter is flowing at the surfaces adjacent to other conductors. This means that the loss is higher than a simple skin-effect analysis would indicate, because the current is bunched so it flows through a smaller cross section of the conductor than if the other turns were not present.

As the efficiency of a loop approaches 90%, the proximity effect is less serious. But unfortunately, the less efficient the loop, the worse the effect. For example, an 8-turn transmitting loop with an efficiency of 10% (calculated by the skin-effect method) actually only has an efficiency of 3% because of the additional losses introduced by the proximity effect. If you are contemplating construction of a multiturn transmitting loop, you might want to consider spreading the conductors apart to reduce this effect. G. S. Smith includes graphs that detail this effect in his 1972 IEEE paper.

The components in a resonated transmitting loop are subject to both high currents and voltages as a result of the large circulating currents found in the high-Q tuned circuit formed by the antenna. This makes it important that any fixed capacitors have a high RF current rating, such as transmitting micas or the Centralab 850 series. Be aware that even a 100-W transmitter can develop currents in the tens of amperes, and voltages across the tuning capacitor in excess of 10,000 V. This consideration also applies to any conductors used to connect the loop to the capacitors. A piece of #14 wire may have more resistance than the rest of the loop conductor!

It is therefore best to use copper strips or the braid from a piece of large coax cable to make any connections. Make the best electrical connection possible, using soldered or welded joints. Using nuts and bolts should be avoided, because at RF these joints generally have high resistance, especially after being subjected to weathering.

An unfortunate consequence of having a small but high-efficiency transmitting loop is high loaded Q, and therefore limited bandwidth. This type of antenna may require retuning for frequency changes as little as 5 kHz. If you are using any wide-band mode such as AM or FM, this might cause fidelity problems and you might wish to sacrifice a little efficiency to obtain the required bandwidth.

A special case of the transmitting loop is that of the ferrite-loaded loop. This is a logical extension of the transmitting loop if we consider the improvement that a ferrite core makes in receiving loops. The use of ferrites in a transmitting loop is still under development. (See the Bibliography reference for DeVore and Bohley.)

PRACTICAL COMPACT TRANSMITTING LOOPS

The ideal small transmitting antenna would have performance equal to a large antenna. A small loop antenna can approach that performance except for a reduction in bandwidth, but that effect can be overcome by retuning. This section is adapted and updated from material written by Robert T. (Ted) Hart, W5QJR.

As pointed out above, small antennas are characterized by low radiation resistance. For a typical small antenna, such as a short dipole, loading coils are often added to achieve resonance. However, the loss inherent in the coils can result in an antenna with low efficiency. If instead of coils a large, low-loss capacitor is added to a low-loss conductor to achieve resonance, and if the antenna conductor is bent to connect the ends to the capacitor, a loop is formed.

Based on this concept, the small loop is capable of relatively high efficiency, compared to its coil-loaded cousin. In addition, the small loop, when mounted vertically, can radiate efficiently over the wide range of elevation angles required on the lower frequency bands. This is because it has both high-angle and low-angle response. See **Fig 17**, which shows the elevation response for a compact transmitting loop only 16.2 inches wide at 14.2 MHz. This loop is vertically polarized and its bottom is 8 feet above average ground, which has a conductivity of 5 mS/m and a dielectric constant of 13. For comparison, Fig 17 also shows the responses of three other reference antennas—the same small loop flipped sideways at a height of 30 feet to produce horizontal radiation, a full-sized ¼-λ ground plane antenna mounted 8 feet above average ground using two tuned radials, and finally a simple ½ λ flattop dipole mounted 30 feet above flat ground. The considerably smaller transmitting loop comes to within 3 dB of the larger ¼-λ vertical at a 10° elevation angle, and it is far stronger for high elevation angles because it does not have the null at high elevation angles that the ground plane has. Of course, this characteristic does make it more susceptible to strong signals received at high elevation angles. Incidentally, just in case you were wondering, adding more radials to the λ/4 ground plane doesn't materially improve its performance when mounted at an 8-foot height on 20 meters.

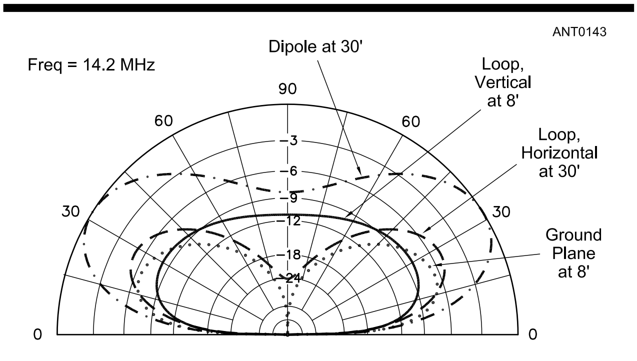

Fig 17—Elevation-plane plot at 14.2 MHz, showing response of an 8.5-foot circumference octagonal copper loop (width of 16.2 inches), compared to a full-sized λ/4 ground-plane vertical with two elevated λ/4 radials, the same small loop flipped horizontally at a height of 30 feet, and lastly, a λ/2 flattop dipole also at a height of 30 feet. Both the λ/4 ground-plane vertical and the vertically polarized loop are elevated 8 feet above typical ground, with σ = 5 mS/m and ε = 13. The low vertically polarized loop is surprisingly competitive, only down about 2.5 dB compared to the far larger ground plane at low elevation angles. Note that the vertical loop has both high-angle as well as low-angle radiation, and hence would be better at working close-in local stations than the ground-plane vertical, with its deep nulls at higher angles. The simple flattop dipole, however, is better than either vertical because of the poor ground reflection for a vertically polarized compared to a horizontally polarized signal.

The simple horizontal dipole in Fig 17 would be the clear winner in any shootout because its horizontally polarized radiation does not suffer as much attenuation at reflection from ground as does a vertically polarized wave. The case is not quite so clear-cut, however, for the small loop mounted horizontally at 30 feet. While it does have increased gain at medium elevation angles, it may not be worth the effort needed to mount it on a mast, considering the slight loss at low angles compared to its twin mounted vertically only 8 feet above ground.

A physically small antenna like the 16.2-inch-wide vertically polarized loop does put out an impressive signal compared to far larger competing antennas. Though somewhat ungainly, it is a substantially better performer than most mobile whips, for example. The main deficiency in a compact transmitting loop is its narrow bandwidth—it must be accurately tuned to the operating frequency. The use of a remote motor drive allows the loop to be tuned over a wide frequency range.

For example, for fixed-station use, two loops could be constructed to provide continuous frequency coverage from 3.5 to 30 MHz. A loop with an 8.5 foot circumference, 16 inches wide, could cover 10 through 30 MHz and a loop with a 20-foot circumference, 72 inches wide, could cover 3.5 to 10.1 MHz.

Table 4 presents summary data for various size loop antennas for the HF amateur bands. Through computer analysis, the optimum size conductor was determined to be 3/4-inch rigid copper water pipe, considering both performance and cost. Performance will be compromised, but only slightly, if 5/8-inch flexible copper tubing is used. This tubing can easily be bent to any desired shape, even a circle. The rigid 3/4-inch copper pipe is best used with 45° elbows to make an octagon.

The loop circumference should be between 1/4 and 1/8 λ at the operating frequency. It will become self-resonant above 1/4 λ, and efficiency drops rapidly below 1/8 λ. In the frequency ranges shown in Table 4, the high fre-

Table 4

Design Data for Loops

Loop Circumference = 8.5' (Width = 32.4"), Vertically Polarized

Frequency, MHz	10.1	14.2	21.2	29.0
Max Gain, dBi	–4.47	–1.42	+1.34	+2.97
Max Elevation Angle	40°	30°	22°	90°
Gain, dBi @10°	–8.40	–4.61	–0.87	+0.40
Total Capacitance, pF	145	70	29	13
Peak Capacitor kV	23	27	30	30

Loop Circumference = 8.5' (Width = 32.4"), Horizontally Polarized, @30'

Frequency, MHz	10.1	14.2	21.2	29.0
Max Gain, dBi	–3.06	+1.71	+5.43	+6.60
Max Elevation Angle	34°	28°	20°	16°
Gain, dBi @10°	–9.25	–3.11	+2.61	+5.34
Total Capacitance, pF	145	70	29	13
Peak Capacitor kV	23	27	30	30

Loop Circumference = 20' (Width = 6'), Vertically Polarized

Frequency, MHz	3.5	4.0	7.2	10.1
Max Gain, dBi	–7.40	–6.07	–1.69	–0.34
Max Elevation Angle	68°	60°	38°	30°
Gain, dBi @10°	–11.46	–10.12	–5.27	–3.33
Capacitance, pF	379	286	85	38
Peak Capacitor kV	22	24	26	30

Loop Circumference = 20' (Width = 6'), Horizontally Polarized, @30'

Frequency, MHz	3.5	4.0	7.2	10.1
Max Gain, dBi	–13.32	–10.60	–0.20	+3.20
Max Elevation Angle	42°	42°	38°	34°
Gain, dBi @10°	–21.62	–18.79	–7.51	–3.22
Capacitance, pF	379	286	85	38
Peak Capacitor kV	22	24	26	30

Loop Circumference = 38' (Width = 11.5'), Vertically Polarized

Frequency, MHz	3.5	4.0	7.2
Max Gain, dBi	–2.93	–2.20	–0.05
Max Elevation Angle	46°	42°	28°
Gain, dBi @10°	–6.48	–5.69	–2.80
Capacitance, pF	165	123	29
Peak Capacitor kV	26	27	33

Notes: These loops are octagonal in shape, constructed with ¾-inch copper water pipe and soldered 45° copper elbows. The gain figures assume a capacitor unloaded Q_C = 5000, typical for vacuum-variable type of tuning capacitor. The bottom of the loop is assumed to be 8 feet high for safety and the ground constants are "typical" at conductivity = 5 mS/m and dielectric constant = 13. Transmitter power is 1500 W. The voltage across the tuning capacitor for lower powers goes down with a multiplier of $\sqrt{\frac{P}{1500}}$. For example, at 100 W using the 38-foot-circumference loop at 7.2 MHz, the peak voltage would be $33 \text{ kV} \times \sqrt{\frac{100}{1500}} = 8.5 \text{ kV}$.

quency is tuned with a minimum capacitance of about 29 pF—including stray capacitance.

The low frequency listed in Table 4 is that where the loop response is down about 10 dB from that of a full-sized elevated ground plane at low elevation angles suitable for DX work. **Fig 18** shows an overlay at 3.5 MHz of the elevation responses for two loops: one with an 8.5-foot circumference and one with a 20-foot circumference, together with the response for a full-sized 80-meter ground plane elevated 8 feet off average ground with 2 tuned radials. The 20-foot circumference loop holds its own well compared to the full-sized ground plane.

Controlling Losses

Contrary to earlier reports, adding quarter-wave ground radials underneath a vertically polarized transmitting loop doesn't materially increase loop efficiency. The size of the conductor used for a transmitting loop, however, does directly affect several interrelated aspects of loop performance.

Data for Table 4 was computed for ¾-inch copper water pipe (nominal OD of 0.9 inch). Note that the efficiency is higher and the Q is lower for loops having a circumference near $^1/_4$ λ. Larger pipe size will reduce the loss resistance, but the Q increases. Therefore the bandwidth decreases, and the voltage across the tuning capacitor increases. The voltage across the tuning capacitor for high-power operation can become very impressive, as shown in Table 4. Rigid ¾-inch copper water pipe is a good electrical compromise and can also help make a small-diameter loop mechanically sturdy.

The equivalent electrical circuit for the loop is a parallel resonant circuit with a very high Q, and therefore a narrow bandwidth. The efficiency is a function of radiation resistance divided by the sum of the radiation plus loss resistances. The radiation resistance is much less than 1 Ω, so it is necessary to minimize the loss resistance, which is largely the skin-effect loss of the conductor, assuming that the tuning capacitor has very low loss. Poor construction techniques must be avoided. All joints in the loop must be brazed or soldered.

However, if the system loss is too low, for example by using even larger diameter tubing, the Q may become excessive and the bandwidth may become too narrow for practical use. These reasons dictate the need for a complete analysis to be performed before proceeding with the construction of a loop.

There is another source of additional loss in a completed loop antenna besides the conductor and capacitor losses. If the loop is mounted near lossy metallic conductors, the large magnetic field produced will induce currents into those conductors and be reflected as losses in the loop. Therefore the loop should be as far from other conductors as possible. If you use the loop inside a building constructed with large amounts of iron or near ferrous materials, you will simply have to live with the loss if the loop cannot otherwise be relocated.

The Tuning Capacitor

Fig 19 demonstrates the selection of loop size versus tuning capacitance for any desired operating frequency range for the HF amateur bands. This is for octagonal-shaped loops using ¾-inch copper water pipe with 45° copper elbows. For example, a capacitor that varies from 5 to 50 pF, used with a loop 10 feet in circumference, tunes from 13 to 27 MHz (represented by the left dark vertical bar). A 25 to 150-pF capacitor with a 13.5-foot loop circumference covers the 7 to 14.4-MHz range, represented by the right vertical bar.

Fig 20 illustrates how the 29-MHz elevation pattern becomes distorted and rather bulbous-looking for the 10-foot circumference loop, although the response at low elevation angles is still better than that of a full-sized ground-plane antenna.

Air Variable Capacitors

Special care must be taken with the tuning capacitor if an air-variable type is used. The use of a split-stator capacitor eliminates the resistance of wiper contacts, resistance that is inherent in a single-section capacitor. The ends of the loop are connected to the stators, and the rotor forms the variable coupling path between the stators. With this arrangement the value of capacitance is divided by two, but the voltage rating is doubled.

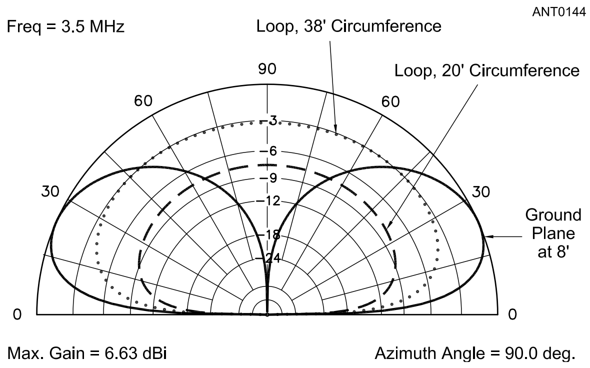

Fig 18—Elevation-plane response of three antennas at 3.5 MHz—a 20-foot circumference octagonal copper loop, a 38-foot circumference copper loop and a full-sized $\lambda/4$ ground plane with two elevated radials. The bottom of each antenna is mounted 8 feet above ground for safety. The 38-foot circumference loop (which has a "wingspan" of 11.5 feet) is fairly competitive with the much large ground-plane, being down only about 4 dB at low elevation angles. The 20-foot circumference loop is much more lossy, but with its top only about 14 feet off the ground is very much of a "stealth" antenna.

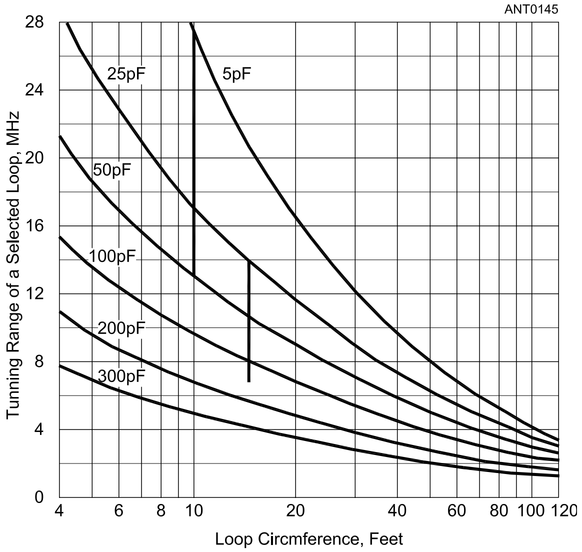

Fig 19—Frequency tuning range of an octagon-shaped loop using ¾-inch copper water pipe, for various values of tuning capacitance and loop circumference.

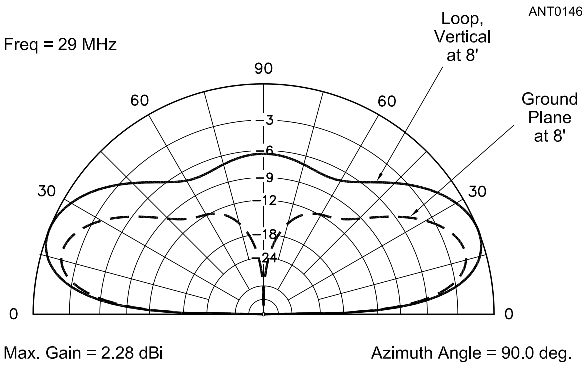

Fig 20—Elevation-plane plot for a 16.2-inch wingspan octagonal copper loop at 29 MHz, compared to a $\lambda/4$ ground-plane antenna with two resonant elevated radials. The gains at low angles are almost identical, but the loop exhibits more gain at medium and high elevation angles. Again, the bottom of each antenna is located 8 feet above ground for safety.

You must carefully select a variable capacitor for transmitting-loop application—that is, all contacts must be welded, and no mechanical wiping contacts are allowed. For example, if the spacers between plates are not welded to the plates, there will be loss at each joint, and thus degraded loop efficiency. (Earlier transmitting loops exhibited poor efficiency because capacitors with wiping contacts were used.)

There are several suitable types of capacitors for this application. A vacuum variable is an excellent choice, provided one is selected with an adequate voltage rating. Unfortunately, those capacitors are very expensive.

W5QJR used a specially modified air-variable capacitor in his designs. This had up to 340 pF maximum per section, with 1/4-inch spacing, resulting in 170 pF when both sections were in series as a butterfly capacitor. Another alternative is to obtain a large air variable, remove the aluminum plates, and replace them with copper or double-sided PC board material to reduce losses. Connect all plates together on the rotor and on the stators. Solder copper straps to the capacitor for soldering to the loop itself.

The spacing between plates in an air-variable capacitor determines the voltage-handling capability, rated at 75,000 V per inch. For other power ratings, multiply the spacing (and voltage) by the square root of the ratio of your power to 1000 W. For example, for 100 W, the ratio would be = 0.316.

Table 5
KD7S Loop-Tuning Capacitor Parts List for Nominal 50-pF Capacitor

Qty	*Description*
2	10-inch length of ¾-inch-ID type M copper water pipe
2	10-inch length of ½-inch-ID type M copper water pipe
1	3-inch length of ½-inch-ID type M copper water pipe
2	½-inch, 90° copper elbows
2	¾-inch, 90° copper elbows
2	10 × 22-inch piece of 0.005-inch-thick Teflon sheet plastic
1	12-inch length of #8-32 threaded brass rod
1	#8-32 brass shoulder nut
2	22 × 5½ × ¼-inch ABS plastic sheet (top and bottom covers)
3	1 × 5½ × ¼-inch ABS plastic sheet (end pieces and center) brace/guide
2	1 × 22 × ¼-inch ABS plastic sheet (side rails)
1	50 to 200-rpm gear-head dc motor
1	DPDT center-off toggle switch (up/down control)
2	SPDT microswitches (limit switches)
50 feet	3-conductor control cable
1	Enclosure for control switch

A Teflon-Insulated Trombone Variable Capacitor

Another type of variable capacitor discussed in the amateur literature for use with a compact transmitting loop is the so-called "trombone" type of capacitor. **Fig 21** shows a practical trombone capacitor created by Bill Jones, KD7S, for Nov 1994 *QST*. This capacitor uses downward pointing extensions of the two 3/4-inch OD main conductor copper pipes, with a Teflon-insulated trombone section made of 1/2-inch ID copper pipe. The trombone telescopes into the main pipes, driven by a lead screw and a 180-rpm gear-head motor. Like the butterfly air variable capacitor, the trombone works without lossy wiper contacts. Jones' capacitor varied from 12 pF (including strays) to almost 60 pF, making it suitable to tune his 3-foot circumference loop from 14 to 30 MHz at the 100-W level.

KD7S used 5-mil (0.005 inch) thick Teflon sheet as an insulator. Since Teflon is conservatively rated at more than 1 kV per mil of thickness, the voltage breakdown capability of this capacitor is well in excess of 5 kV. The parts list is given in **Table 5**.

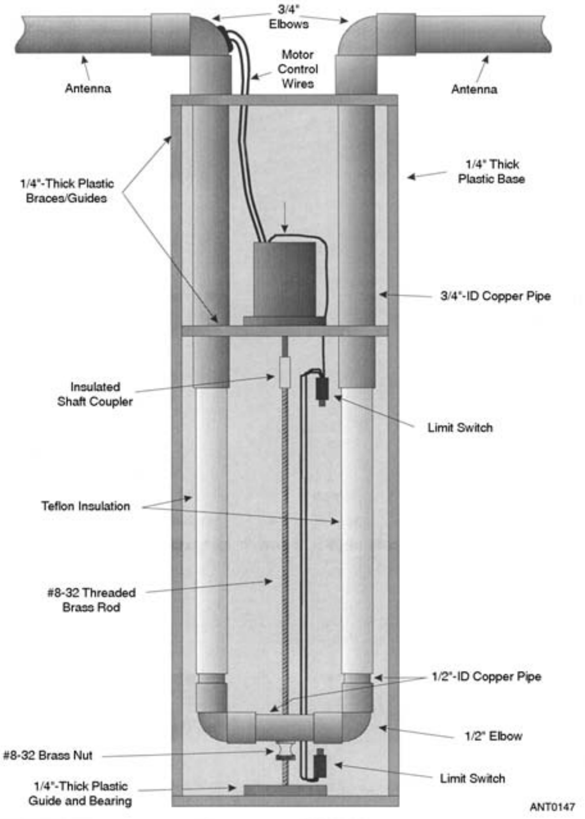

Fig 21—A practical trombone capacitor designed by Bill Jones, KD7S, for his compact transmitting loop. This capacitor has a tuning range from 12 to almost 60 pF, and can withstand at least 5 kV peak. The 10-inch ½-inch ID tubes are covered with Teflon-sheet insulation and slide into the ¾-inch ID copper pipes.

A short length of plastic tubing connects the threaded brass rod to the motor. The tubing acts as an insulator and a flexible coupling to smooth out minor shaft-alignment errors. The other end of the rod is threaded into a brass nut soldered to the crossbar holding the $^1/_2$-inch pipes together. Jones used a 12-V motor rated at 180 rpm, but it has sufficient torque to work with as little as 4 V applied. Instead of a sophisticated variable duty-cycle speed control circuit, he used an LM327 adjustable voltage regulator to vary the motor-control voltage from 4 to 12 V. Tuning speeds ranged from 11 seconds per inch at 12 V to 40 seconds per inch at 4 V. The higher speed is necessary to jump from band to band in a reasonable length of time. The lower speed makes it easy to fine-tune the capacitor to any desired frequency within a band.

When building the capacitor, keep in mind that the smaller tubes must telescope in and out of the larger tubes with silky smoothness. Any binding will cause erratic tuning. For the same reason, the #8-32 brass threaded rod must be straight and properly aligned with the brass nut. *Take your time with this part of the project.*

Perhaps the easiest way to form the insulator is to precut a length of Teflon sheet to the proper size. Place a lengthwise strip of double-sided tape on the tube to secure one end of the Teflon sheet. Begin wrapping the Teflon around the tube while keeping it as tight as possible. *Don't allow wrinkles or ridges to form.* Secure the other end with another piece of tape. Once both tubes are covered, ensure they are just short of being a snug fit inside the larger tubes. Confirm that the insulation completely overlaps the open end of the small tubes. If not, the capacitor is certain to arc internally with more than a few watts of power applied to it.

Route the motor wiring inside the antenna pipes to minimize the amount of metal within the field of the antenna. Bring the wires out next to the coaxial connector. A three-wire system allows the use of limit switches to restrict the movement of the trombone section. Be sure to solder together all metal parts of the capacitor. Use a small propane torch, a good quality flux and 50/50 solid solder. Do not use acid-core solder! Clean all parts to be joined with steel wool prior to coating them with flux.

A Cookie-Sheet and Picture-Frame-Glass Variable Capacitor

In Vol 2 of *The ARRL Antenna Compendium* series, Richard Plasencia, W0RPV, described a clever high-voltage variable capacitor he constructed using readily available materials. See **Fig 22**, which shows Plasencia's homebrew high-voltage variable capacitor, along with the coil and other parts used in his homemade antenna coupler. This capacitor could be varied from 16 to 542 pF and tested at a breakdown of 12,000 V.

The capacitor sits on four PVC pillars and consists of two $4^1/_2 \times 4^1/_2$-inch aluminum plates separated by a piece of window glass that is $8^1/_2 \times 5^1/_2$ inches in size. The lower plate is epoxied to the glass. The upper plate is free to move in a wooden track epoxied to the upper surface of the glass. The motor is reversible and moves the upper capacitor plate by rotating a threaded rod in a wing nut pinned to a tab on the capacitor plate. The four pillars are cut from PVC pipe to insulate the capacitor from the chassis and to elevate it into alignment with the motor shaft.

W0RPV used a piece of 0.063-inch thick single-weight glass that exhibited a dielectric constant of 8. He removed the glass from a dime-store picture frame. In time-honored ham fashion, he improvised his wooden tracks for the upper capacitor plate from a single wooden paint stirrer, and for the capacitor plates, he used aluminum cookie sheets.

The wooden track for the upper plate is made by splitting the wooden paint stirrer with a knife into one narrow and one wide strip. The narrow strip is cemented on top and overhangs the movable plate, creating a slotted track. Since the wood is supported by the glass plate, its insulating qualities are of no importance.

The principle of operation is simple. The reversible motor turns a threaded $^1/_4$-inch rod with a pitch of 20 threads to the inch. This rod engages a wing nut attached to the movable capacitor plate. Although W0RPV grounded his capacitor's movable plate with a braid, an insulator similar to that used in the trombone capacitor above should be used to isolate the lead-screw mechanism. Several pieces of braid made from RG-8 coax shield should be used to connect to the ends of the compact transmitting loop conductors to form low-loss connections.

W0RPV used a 90-rpm motor from a surplus vending machine. It moved his variable capacitor plate $4^1/_2$ inches, taking about a minute to travel from one end to the other. Since he wished to eliminate the complexity and dubious reliability of limit switches when used outdoors, he monitored the motor's dc current through two 3 Ω, 2W resistors

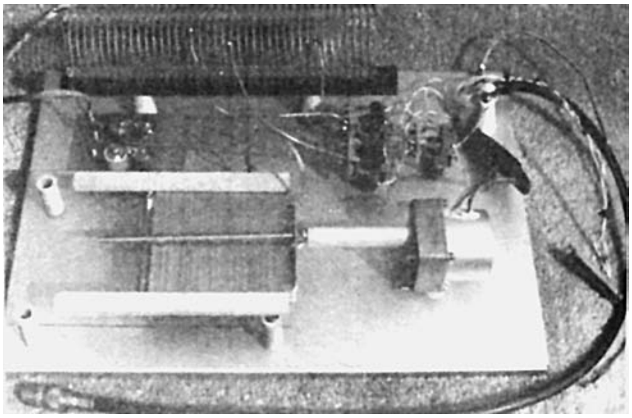

Fig 22—The picture-frame-glass variable capacitor design of Richard Plasencia, W0RPV. Two aluminum plates separated by a piece of glass scavenged from a picture frame create a variable capacitor that can withstand 12,000 V, with a variable range from 16 to 542 pF.

placed in series with each lead of the motor and shunted by red LEDs at the control box. When the motor stalled by jamming up against the PVC limit stop or against the inside of the plastic mounting box, the increased motor current caused one or the other of the LEDs to light up.

TYPICAL LOOP CONSTRUCTION

After you select the electrical design for your loop application, you must consider how to mount it and how to feed it. If you wish to cover only the upper HF bands of 20 through 10 meters, you will probably choose a loop that has a circumference of about 8.5 feet. You can make a reasonably sturdy loop using 1-inch diameter PVC pipe and 5/8-inch flexible copper tubing bent into the shape of a circle. Robert Capon, WA3ULH, did this for a QRP-level transmitting loop described in May 1994 *QST*. **Fig 23** shows a picture of his loop, with PVC H-frame stand.

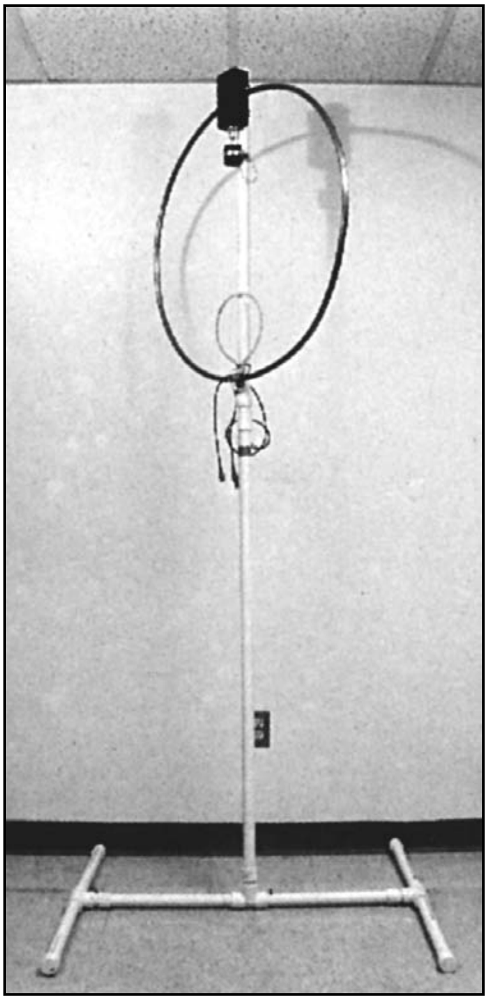

Fig 23—Photo of compact transmitting loop designed by Robert Capon, WA3ULH. This uses a 1-inch PVC H-frame to support the loop made of flexible 5/8-inch copper tubing. The small coupling loop made of RG-8 coax braid couples the loop to the coax feed line. The tuning capacitor and drive motor are at the top of the loop, shown here in the ARRL Laboratory during testing.

This loop design used a 20-inch long coupling loop made of RG-8 coax to magnetically couple into the transmitting loop rather than the gamma-match arrangement used by W5QJR in his loop designs. The coupling loop was fastened to the PVC pipe frame using 2-inch long #8 bolts that also held the main loop to the mast.

A more rugged loop can be constructed using rigid 3/4-inch copper water pipe, as shown in the W5QJR design in **Fig 24**. While a round loop is theoretically a bit more efficient, an octagonal shape is much easier to construct. The values presented in Table 4 are for octagons.

For a given loop circumference, divide the circumference by 8 and cut eight equal-length pieces of 3/4 inch copper water pipe. Join the pieces with 45° elbows to form the octagon. With the loop lying on the ground on scraps of 2 × 4 lumber, braze or solder all joints.

W5QJR made a box from clear plastic to house his air-variable capacitor and drive motor at the top of the loop. The side of the box that mounts to the loop and the capacitor should be at least ¼-inch thick, preferably 3/8-inch. The remainder of the box can be 1/8-inch plastic sheet. He mounted the loop to the plastic using 1/4-inch bolts (two on either side of center) after cutting out a section of pipe 2 inches wide in the center. On the motor side of the capacitor, he cut the pipe and installed a copper T for the motor wiring.

W5QJR's next step was to solder copper straps to the loop ends and to the capacitor stators, then he remounted the loop to the plastic. If you insert wood dowels, the pipe will remain round when you tighten the bolts. Next he installed the motor drive cable through the loop and connected it to the motor. Antenna rotator cable is a good choice for this cable. He completed the plastic box using short pieces of aluminum angle and small sheet-metal screws to join the pieces.

The loop was then ready to raise to the vertical position. Remember, no metal is allowed near the loop. W5QJR made a pole of 2 × 4-inch lumber with 1 × 4-inch boards on either side to form an I section. He held the boards together with 1/4-inch bolts, 2 feet apart and tied rope guys to the top. This made an excellent mast up to 50 feet high. The pole height should be one foot greater than the loop diameter, to allow room for cutting grass or weeds at the bottom of the loop. W5QJR installed a pulley at the top so that his loop could be raised, supported by rope. He supported the bottom of the loop by tying it to the pole and tied guy ropes to the sides of the loop to keep it from rotating in the wind. By moving the anchor points, he could rotate his loop in the azimuth plane.

W5QJR used a gamma-matching arrangement made of flexible 1/4-inch copper tubing to couple the loop to the transmission line. In the center of one leg, he cut the pipe and installed a copper T. Adjacent to the T, he installed a mount for the coax connector. He made the mount from copper strap, which can be obtained by splitting a short piece of pipe and hammering it flat.

While the loop was in the vertical position he cut a piece of 1/4-inch flexible copper tubing the length of one

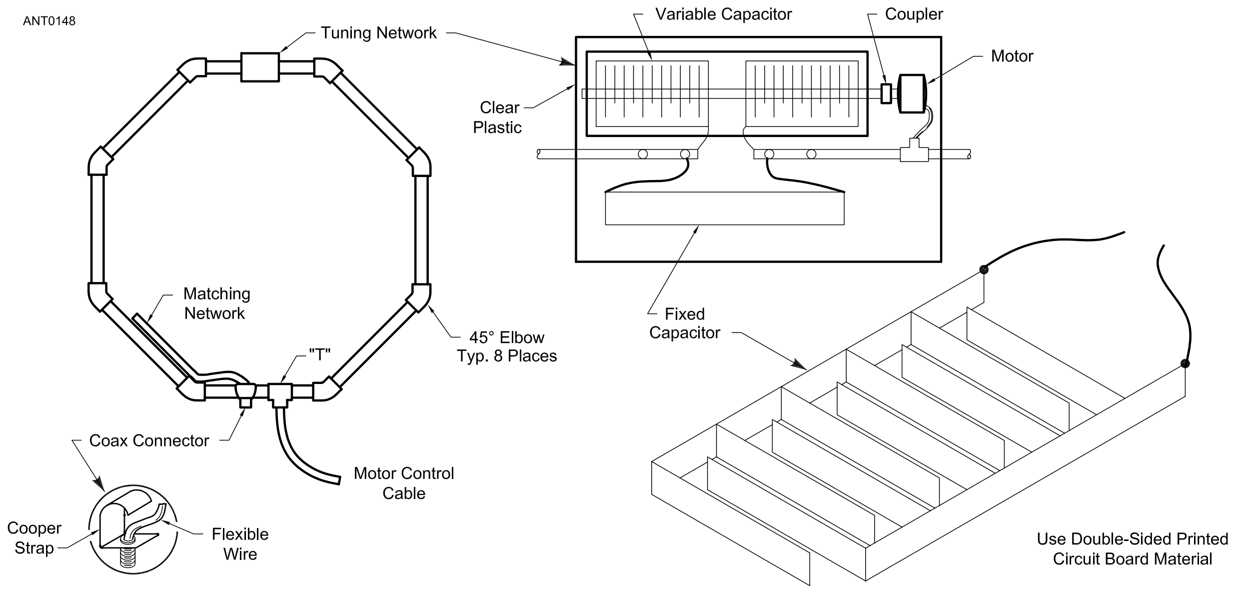

Fig 24—Octagonal loop construction details. Table 4 gives loop design data for various frequency ranges.

of the straight sides of the loop. He then flattened one end and soldered a piece of flexible wire to the other. He wrapped the tubing with electrical tape for insulation and connected the flexible wire to the coax connector. He then installed the tubing against the inside of the loop, held temporarily in place with tape. He soldered the flat part to the loop, ending up with a form of gamma match, but without reactive components. This simple feed provided better than 1.7:1 SWR over a 2:1 frequency range. For safety, he installed a good ground rod under the loop and connected it to the strap for the coax connector, using large flexible wire.

TUNE-UP PROCEDURE

The resonant frequency of the loop can be readily found by setting the receiver to a desired frequency and rotating the capacitor (by remote control) until signals peak. The peak will be very sharp because of the high Q of the loop.

Turn on the transmitter in the tune mode and adjust either the transmitter frequency or the loop capacitor for maximum signal on a field-strength meter, or for maximum forward signal on an SWR bridge. Adjust the matching network for minimum SWR by bending the matching line. Normally a small hump in the 1/4-inch tubing line, as shown in Fig 24, will give the desired results. For a loop that covers two or more bands, adjust the feed to give equally low SWR at each end of the tubing range. The SWR will be very low in the center of the tuning range but will rise at each end.

If there is metal near the loop, the additional loss will reduce the Q and therefore the impedance of the loop. In those cases it will be necessary to increase the length of the matching line and tap higher up on the loop to obtain a 50-Ω match.

PERFORMANCE COMPARISON

As previously indicated, a compact transmitting loop can provide performance approaching full-size dipoles and verticals. To illustrate one case, a loop 100 feet in circumference would be 30 feet high for 1.8 MHz. However, a good dipole would be 240 feet (1/2 λ) in length and at least 120 feet high (1/4 λ). A 1/4-λ vertical would be 120 feet tall with a large number of radials on the ground, each 120 feet in length. The smaller loop could replace both of those antennas with only a moderate degradation in performance and a requirement for a high-voltage variable capacitor.

On the higher frequencies, the same ratios apply, but full-size antennas are less dramatic. However, very few city dwellers can erect good verticals even on 7 MHz with a full-size counterpoise. Even on 14 MHz a loop about 3 feet high can work the world.

Other than trading small size for narrow bandwidth and a high-voltage capacitor, the compact transmitting loop is an excellent antenna and should find use where large antennas are not practical.

The Loop Skywire

Are you looking for a multiband HF antenna that is easy to construct, costs nearly nothing and yet works well? You might want to try this one. The *Loop Skywire* antenna is a full-sized horizontal loop. Early proponents suggested that the antenna could be fed with coaxial cable with little concern for losses, but later analysis proved that this was a bit of wishful thinking—the relatively low values for SWR across multiple bands indicate that cable losses were part and parcel of performance. The best way to feed this versatile antenna is with open-wire ladder line, with an antenna tuner in the shack to present the transmitter with a low value of SWR.

THE DESIGN

The Loop Skywire is shown in **Fig 25**. The antenna has one wavelength of wire in its perimeter at the design or fundamental frequency. If you choose to calculate L_{total} in feet, the following equation should be used:

$$L_{total} = \frac{1005}{f}$$

where f equals the frequency in MHz.

Given any length of wire, the maximum possible area the antenna can enclose is with the wire in the shape of a circle. Since it takes an infinite number of supports to hang a circular loop, the square loop (four supports) is the most practical. Further reducing the area enclosed by the wire loop (fewer supports) brings the antenna closer to the properties of the folded dipole, and both harmonic-impedance and feed-line voltage problems can result. Loop geometries other than a square are thus possible, but remember the two fundamental requirements for the Loop Skywire—its horizontal position and maximum enclosed area.

There is another great advantage to this antenna system. It can be operated as a vertical antenna with top-hat loading on other bands as well. This is accomplished by simply keeping the feed line run from the antenna to the shack as vertical as possible and clear of objects. Both feed-line conductors are then tied together, and the antenna is fed against a good ground.

CONSTRUCTION

Antenna construction is simple. Although the loop can be made for any band or frequency of operation, the following two Loop Skywires are good performers. The 10-MHz band can also be operated on both.

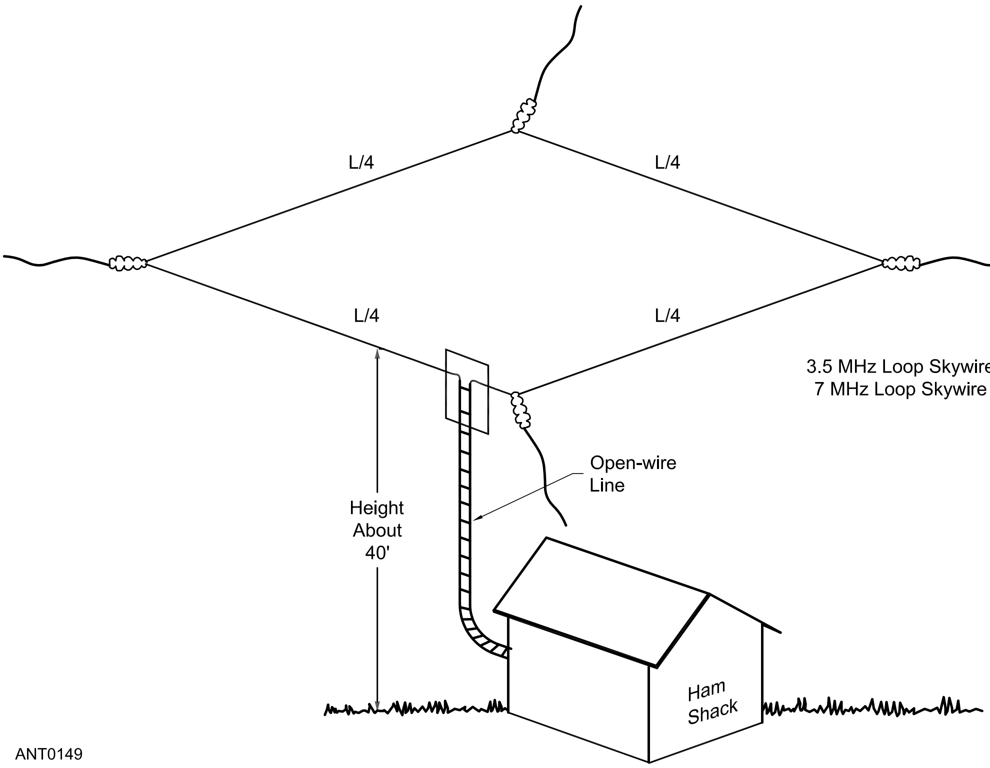

Fig 25—A complete view of the Loop Skywire. The square loop is erected horizontal to the earth.

3.5-MHz Loop Skywire
(3.5-28 MHz loop and 1.8-MHz vertical)
Total loop perimeter: 272 feet
Square side length: 68 feet

7-MHz Loop Skywire
(7-28 MHz loop and 3.5-MHz vertical)
Total loop perimeter: 142 feet
Square side length: 35.5 feet

The actual total length can vary from the above by a few feet, as the length is not at all critical. Do not worry about tuning and pruning the loop to resonance. No signal difference will be detected on the other end when that method is used.

Bare #14 copper wire is used in the loop. **Fig 26** shows the placement of the insulators at the loop corners. Two common methods are used to attach the insulators. Either lock or tie the insulator in place with a loop wire tie, as shown in Fig 26A, or leave the insulator free to "float" or slide along the wire, Fig 26B. Most loop users float at least two insulators. This allows pulling the slack out of the loop once it is in the air, and eliminates the need to have all the supports exactly placed for proper tension in each leg. Floating two opposite corners is recommended.

Fig 27A shows the azimuth-plane performance on 7.2 MHz of a 142-foot long, 7-MHz Loop Skywire, 40 feet high at an elevation angle of 10°, compared to a regular flattop ½-λ dipole at a height of 30 feet. The loop comes into its own at higher frequencies. Fig 27B shows the response at 14.2 MHz, compared again to a ½–λ 14.2-MHz

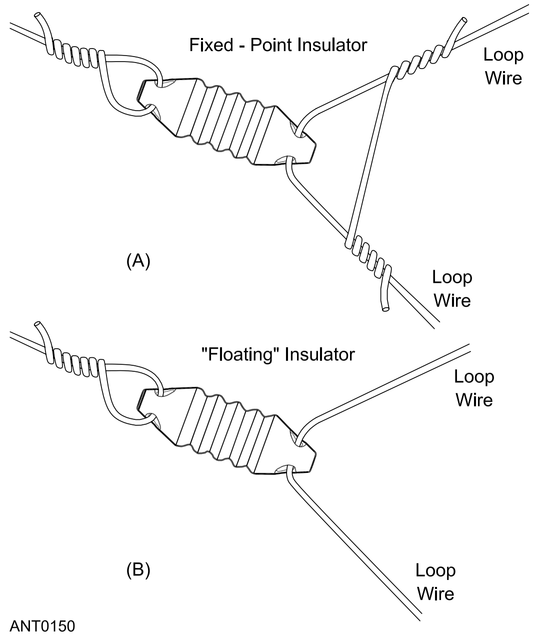

Fig 26—Two methods of installing the insulators at the loop corners.

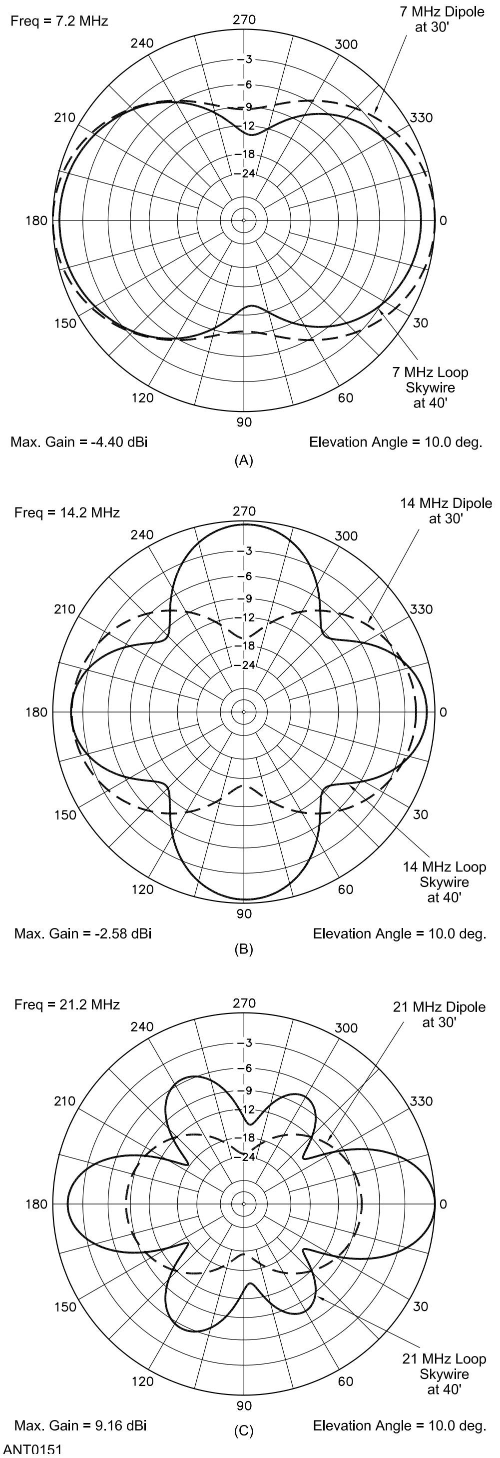

Fig 27—At A, azimuth-plane response of 142-foot long, 7-MHz Loop Skywire, 40 feet in the air at 7.2 MHz, compared with ½-λ dipole 30 feet in the air. At B, response of same Loop Skywire at 14.2 MHz, compared with ½-λ 14.2-MHz dipole 30 feet in the air. Now the loop has some advantage in certain directions. At C, response of the same Loop Skywire at 21.2 MHz compared to a 21.2-MHz dipole at 30 feet. Here, the Loop Skywire has more gain in almost all directions than the simple dipole. All azimuth-plane patterns were made at 10° elevation.

dipole at a height of 30 feet. Now the loop has several lobes that are stronger than the dipole. Fig 27C shows the response at 21.2 MHz, compared to a dipole. Now the loop has superior gain compared to the $^{1}/_{2}$-λ dipole at almost any azimuth. In its favored direction on 21.2 MHz, the loop is 8 dB stronger than the dipole.

The feed point can be positioned anywhere along the loop that you wish. However, most users feed the Skywire at a corner. **Fig 28** depicts a method of doing this, using a piece of plexiglass to provide insulation as well as strain relief for the open-wire ladder line. It is advantageous to keep the feed-point mechanicals away from the corner support. Feeding a foot or so from one corner allows the feed line to exit more freely. This method keeps the feed line free from the loop support.

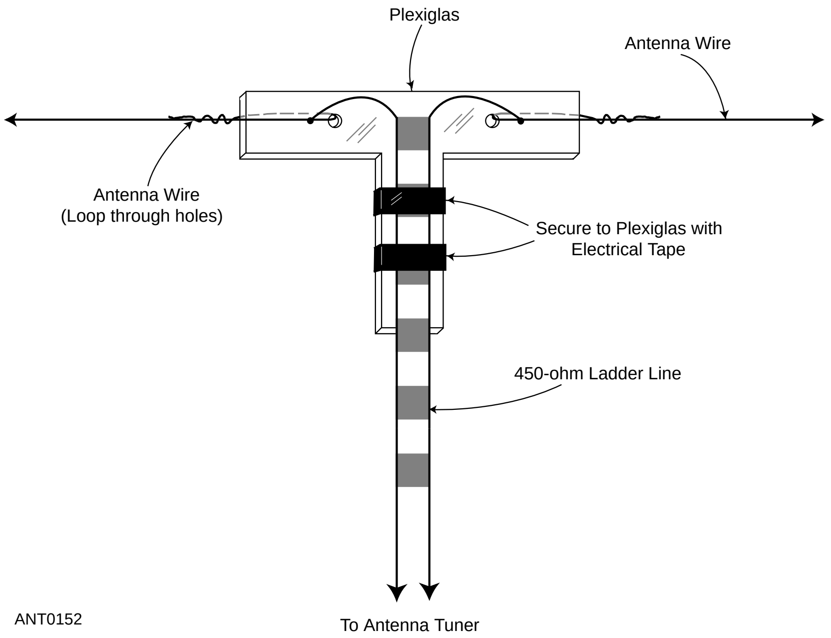

Fig 28—Most users feed the Skywire at a corner. A high-impedance weather-resistant insulator should be used for the feed-point insulator.

Generally a minimum of four supports is required. If trees are used for supports, then at least two of the ropes or guys used to support the insulators should be counterweighted and allowed to move freely. The feedline corner is almost always tied down, however. Very little tension is needed to support the loop (far less than that for a dipole). Thus, counterweights are light. Several such loops have been constructed with bungie cords tied to three of the four insulators. This eliminates the need for counterweighting.

Recommended height for the antenna is 40 feet or more. The higher the better, especially if you wish to use the loop in the vertical mode. However, successful local and DX operation has been reported in several cases with the antenna at 20 feet. **Fig 29** shows the feed arrangement for using the Loop Skywire as a top-loaded vertical fed against ground on the lower bands.

Because the loop is high in the air and has considerable electrical exposure to the elements, proper methods should be employed to eliminate the chance of induced or direct lightning hazard to the shack and operator. Some users simply completely disconnect the antenna from the antenna tuner and rig and shack during periods of possible lightning activity.

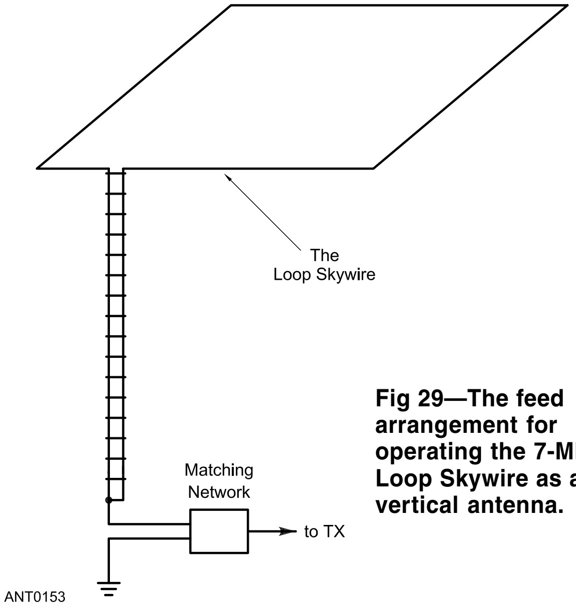

Fig 29—The feed arrangement for operating the 7-MHz Loop Skywire as a vertical antenna.

7-MHz Loop

An effective but simple 7MHz antenna that has a theoretical gain of approximately 1 dB over a dipole is a full-wave, closed vertical loop. Such a loop need not be square, as illustrated in **Fig 30A**. It can be trapezoidal, rectangular, circular, or some distorted configuration in between those shapes. For best results, however, you should attempt to make the loop as square as possible. The more rectangular the shape, the greater the cancellation of energy in the system, and the less effective it will be. In the limiting case, the antenna loses its identity as a loop and becomes a folded dipole.

You can feed the loop in the center of one of the vertical sides if you want vertical polarization. For horizontal polarization, you feed either of the horizontal sides at the center. Since optimum directivity occurs at right angles to the plane of the loop (or in more simple terms, broadside to the loop), you should hang the loop to radiate the maximum amount in some favored direction.

Fig 31A shows the azimuthal response at a takeoff angle of 15°, a typical angle for 40-meter DX, for vertical and horizontal feed systems over ground with “average” conductivity and dielectric constant. Fig 31A includes, for reference, the response of a flattop dipole 50 feet high. For DX work on 40 meters, the vertically polarized loop can perform as well as or substantially better than either a horizontally polarized loop or a flattop dipole, particularly in the azimuthal nulls of the dipole.

For the low elevation angles that favor DX work, the optimal feed point is at the center of one of the vertical wires. Feeding the loop at one of the corners at the bottom gives a

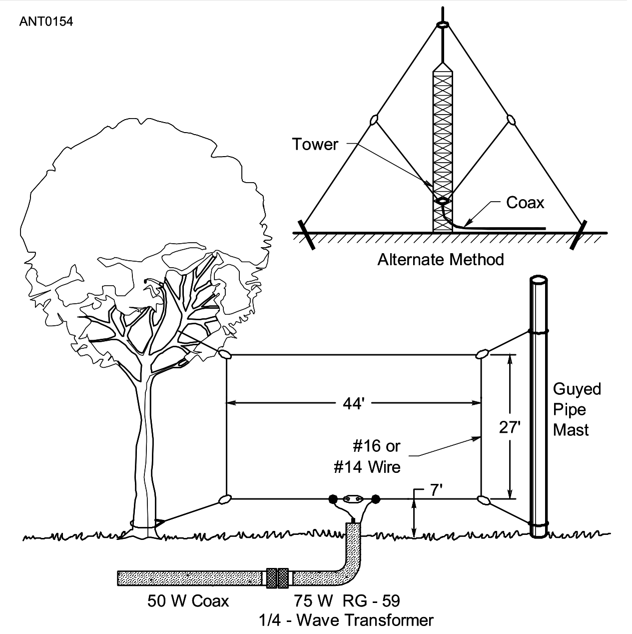

Fig 30—At A, details of the rectangular full-wave loop. The dimensions given are for operation at 7.05 MHz. The height above ground was 7 feet in this instance, although improved performance should result if the builder can install the loop higher above ground without sacrificing length on the vertical sides. At B, illustration how a single supporting structure can be used to hold the loop in a diamond-shaped configuration. Feeding the diamond at the lower tip provides radiation in the horizontal plane. Feeding the system at either side will result in vertical polarization of the radiated signal.

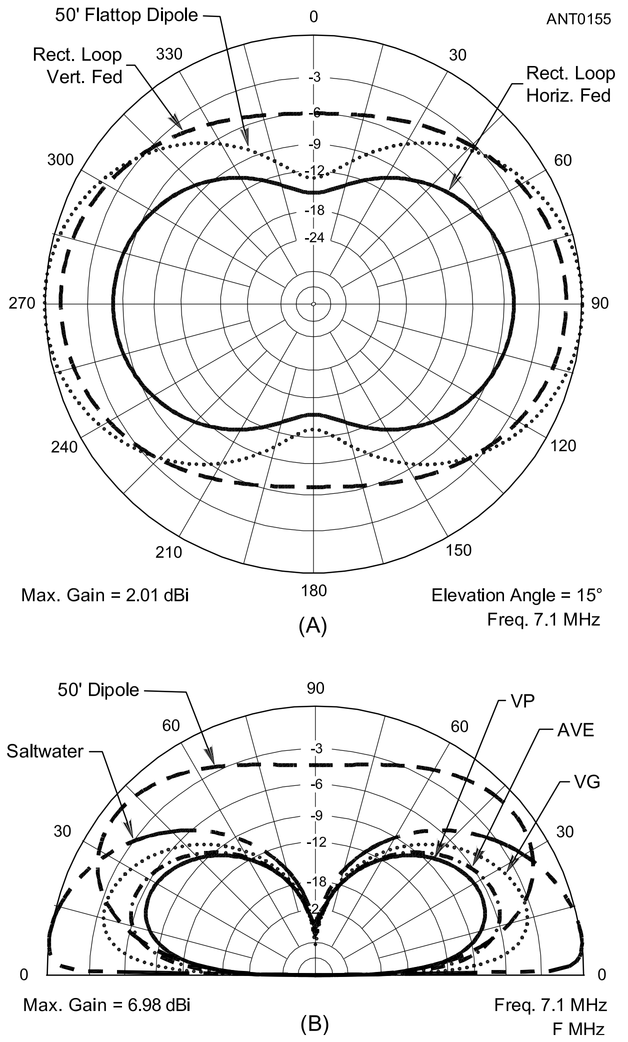

Fig 31—At A, azimuthal plane responses for the vertically and horizontally polarized 7-MHz loop, compared to a flattop 50-foot high dipole, all at a takeoff angle of 15° for DX work. The solid line is for feeding the loop horizontally at the bottom; the dashed line is for feeding the loop vertically at a side, and the dotted line is for a simple flattop horizontal dipole at 50 feet in height. For DX work, the vertically polarized loop is an excellent performer.

compromise result for both local and DX work. The actual impedance is roughly the same at each point: bottom horizontal center, corner or vertical side center.

Fig 31B demonstrates how the gain for vertical polarization changes over different type of grounds: saltwater, very poor ground (conductivity = 1 mS/m, dielectric constant = 5) very good (conductivity = 30 mS/m, dielectric constant = 20) and average ground (conductivity = 5 mS/m, dielectric constant = 13). Again, for reference a 50-foot high flattop dipole's elevation response is included. As has been mentioned previously in other chapters, a seaside location is a wonderful environment for verticals!

Just how you erect such a loop will depend on what is available in your backyard. Trees are always handy for supporting loop antennas. A disadvantage to the rectangular loop shown in Fig 30A is that two 34-foot high supports are needed, although in many instances your house may be high enough to serve as one of these supports. If you have a tower higher than about 50 feet, Fig 30B demonstrates how you can use it to support a diamond-shaped loop for 40 meters. The elevation and azimuthal responses are almost the same for either loop configuration, rectangular- or diamond-shaped.

The overall length of the wire used in a loop is determined in feet from the formula 1005/f (MHz). Hence, for operation at 7.125 MHz the overall wire length will be 141 feet. The matching transformer, an electrical $^1/_4$ λ of 75Ω coax cable, can be computed by dividing 246 by the operating frequency in MHz, then multiplying that number by the velocity factor of the cable being used. Thus, for operation at 7.125 MHz, 246/7.125 MHz = 34.53 feet. If coax with solid polyethylene insulation is used, a velocity factor of 0.66 must be employed. Foam-polyethylene coax has a velocity factor of 0.80. Assuming RG-59 is used, the length of the matching transformer becomes 34.53 (feet) × 0.66 = 22.79 feet, or 22 feet, $9^1/_2$ inches.

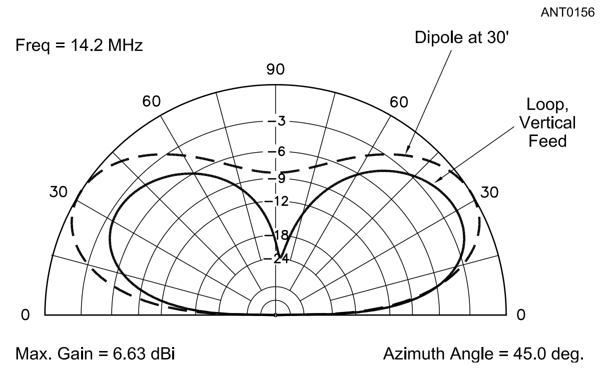

Fig 32—Elevation-plane response of 7-MHz loop used on 14.2 MHz. This is for a feed point at the center of one of the two vertical wires. The dashed line is the response of a flattop 20-meter dipole at 30 feet in height for comparison.

This same loop antenna in Fig 30A fed vertically may be used on the 14 and 21MHz bands, although its pattern will not be as good as that on its fundamental frequency and you will have to use an open-wire transmission line to feed the loop for multiband use. **Fig 32** shows the response at the peak lobe of the loop, at a 45° angle to the plane of the loop, compared to the peak response for a simple halfwave 20-meter dipole, 30 feet high. The gain from a simple flattop dipole, mounted at 30 feet, will be superior to the loop operated on a harmonic frequency.

A Receiving Loop for 1.8 MHz

You can use a small shielded-loop antenna to improve reception under certain conditions, especially at the lower amateur frequencies. This is particularly true when high levels of man-made noise are prevalent, when the second-harmonic energy from a nearby broadcast station falls in the 1.8MHz band, or when interference exists from some other amateur station in the immediate area. A properly constructed and tuned small loop will exhibit approximately 30 dB of front-to-side response, the minimum response being at right angles to the plane of the loop. Therefore, noise and interference can be reduced significantly or completely nulled out, by rotating the loop so that it is sideways to the interference-causing source.

Generally speaking, small shielded loops are far less responsive to man-made noise than are the larger antennas used for transmitting and receiving. But a trade-off in performance must be accepted when using the loop, for the strength of received signals will be 10 or 15 dB less than when using a full-size resonant antenna. This condition is not a handicap on 1.8 or 3.5 MHz, provided the station receiver has normal sensitivity and overall gain. Because a front-to-side ratio of 30 dB may be expected, a shielded loop can be used to eliminate a variety of receiving problems if made rotatable, as shown in **Fig 33**.

To obtain the sharp bidirectional pattern of a small loop, the overall length of the conductor must not exceed 0.1 λ. The loop of **Fig 34** has a conductor length of 20 feet. At 1.81 MHz, 20 feet is 0.037 λ. With this style of loop, 0.037 λ is about the maximum practical dimension if you want to tune the element to resonance. This limitation results from the distributed capacitance between the shield and inner conductor of the loop. RG-59 was used for the loop element in this example. The capacitance per foot for this cable is 21 pF, resulting in a total distributed

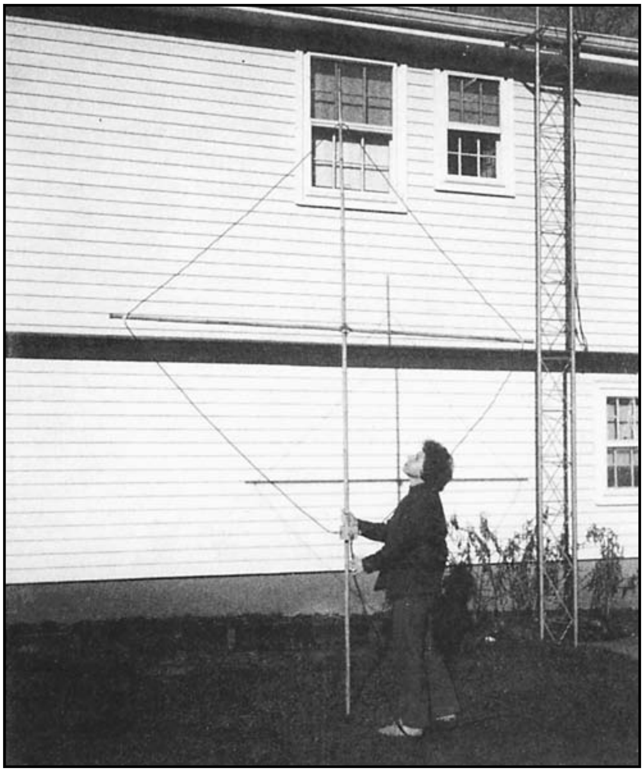

Fig 33—Jean DeMaw, W1CKK, tests the 1.8-MHz shielded loop. Bamboo cross arms are used to support the antenna.

capacitance of 420 pF. An additional 100 pF was needed to resonate the loop at 1.810 MHz.

Therefore, the approximate inductance of the loop is 15 µH. The effect of the capacitance becomes less pronounced at the higher end of the HF spectrum, provided the same percentage of a wavelength is used in computing the conductor length. The ratio between the distributed capacitance and the lumped capacitance used at the feed point becomes greater at resonance. These facts should be contemplated when scaling the loop to those bands above 1.8 MHz.

There will not be a major difference in the construction requirements of the loop if coaxial cables other than RG-59 are used. The line impedance is not significant with respect to the loop element. Various types of coaxial line exhibit different amounts of capacitance per foot, however, thereby requiring more or less capacitance across the feed point to establish resonance.

Shielded loops are not affected noticeably by nearby objects, and therefore they can be installed indoors or out after being tuned to resonance. Moving them from one place to another does not significantly affect the tuning.

You can see in the model shown in Fig 33 that a supporting structure was fashioned from bamboo poles. The X frame is held together at the center with two U bolts. The loop element is taped to the cross-arms to form a square. You could likely use metal cross arms without seriously degrading the antenna performance. Alternatively, wood can be used for the supporting frame.

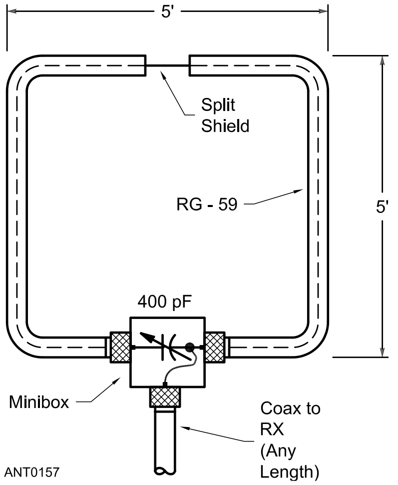

Fig 34—Schematic diagram of the loop antenna. The dimensions are not critical provided overall length of the loop element does not exceed approximately 0.1 λ. Small loops which are one half or less the size of this one will prove useful where limited space is a consideration.

A Minibox was used at the feed point of the loop to hold the resonating variable capacitor. In this model a 50 to 400-pF compression trimmer was used to establish resonance. You must weatherproof the box for outdoor installations.

Remove the shield braid of the loop coax for one inch directly opposite the feed point. You should treat the exposed areas with a sealing compound once this is done.

In operation this receiving loop has proven very effective for nulling out second-harmonic energy from local broadcast stations. During DX and contest operations on 1.8 MHz it helped prevent receiver overloading from nearby 1.8-MHz stations that share the band. The marked reduction in response to noise has made the loop a valuable station accessory when receiving weak signals. It is not used all of the time, but is available when needed by connecting it to the receiver through an antenna selector switch. Reception of European stations with the loop has been possible from New England at times when other antennas were totally ineffective because of noise.

It was also discovered that the effects of approaching storms (with attendant atmospheric noise) could be nullified considerably by rotating the loop away from the storm front. It should be said that the loop does not exhibit meaningful directivity when receiving sky-wave signals. The directivity characteristics relate primarily to ground-wave signals. This is a bonus feature in disguise, for when nulling out local noise or interference, one is still able to copy sky-wave signals from all compass points!

For receiving applications it is not necessary to match the feed line to the loop, though doing so may enhance the performance somewhat. If no attempt is made to obtain an SWR of 1, the builder can use 50 or 75-Ω coax for a feeder, and no difference in performance will be observed. The Q of this loop is sufficiently low to allow the operator to peak it for resonance at 1.9 MHz and use it across the entire 1.8MHz band. The degradation in performance at 1.8 and 2 MHz will be so slight that it will be difficult to discern.

An Indoor Stealth Loop

Ted Phelps, W8TP, wrote an article in *The ARRL Antenna Compendium, Vol 7* describing his attic-mounted wire loop antenna, fed with an automatic antenna tuner. Here is a shortened version of that article.

If you drive down my street in Whitechapel Village in Newark, DE, trying to find my ham location by looking for my antenna, you wouldn't find it. Even if you pulled up in front of my condo, you wouldn't notice any telltale signs, because my multiband antenna is completely hidden. It's in the attic of my two-bedroom condominium in a small retirement community completed in 1999.

Before the move, I had given considerable thought to what type of antenna I might use, if any. I already knew that permanent outdoor types were out of the question, due to restrictive real estate and condo association rules. So I planned a clause for any sales contract I might sign, specifically mentioning amateur radio and my desire to set up a station in my new living quarters. I decided I would not move where my lifelong hobby would be severely restricted or prohibited.

That meant that to be reasonably sure I could continue enjoying Amateur Radio as before, I would have to install an indoor antenna that could perform as well as a typical outdoor system. What kind? In Ohio, I had tried a horizontally polarized attic dipole made with #14 wire. It didn't work very well—it was just too low to the ground.

I learned about a high-tech method of remote antenna tuning using an antenna coupler which contains a microprocessor. I found this kind of automatic tuner available from two American manufacturers and within a reasonable price range. Although our move was still a few months ahead, I purchased a model SG-230 antenna coupler made by SGC Inc, Bellevue, WA, for use in Delaware.

Fig 35 shows the final dimensions of my hidden loop, which is a single-turn rectangular loop, erected in a north-south vertical plane and made from nearly 78 feet of #6 stranded, aircraft primary wire in a PVC jacket, held taut at the lower corners and supported by a pulley and guy rope at each upper corner. Because it's vertically polarized, it supports low-angle radiation reasonably well. By the way, if you're wondering why I used such a relatively large-gauge wire as #6 for the loop antenna, it was readily available from my son-in-law!

Fig 36 shows my completed condo unit. Note the doghouse dormer on the roof about 12 feet above ground at the attic floor. This is the level of my hidden loop's base leg.

In constructing my system I had to overcome RFI problems on my own premises. Each condo unit has its own electronic security panel on an upper shelf in a closet. As soon as I applied moderate power to my radio and loop, the Fire Alarm sounded and firefighters came to my door! The burglar/intrusion signal was triggered a couple of times, too. Working with a security installation technician, I found that *there was no ground wire connected to my security panel.* "We don't bother with that," said the tech, and then, reacting to my surprise, connected a #14 ground between the security panel and the house water-pipe ground. I then installed a ferrite bead on each lead entering the security panel. I also placed ferrite beads on keyer-paddle leads, GFCI electrical outlets, etc. Those

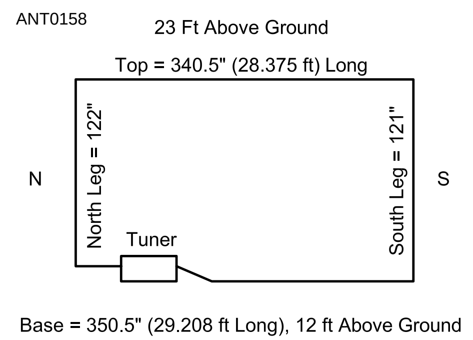

Fig 35—Diagram showing layout of W8TP's indoor hidden loop antenna.

Fig 36—Can you see W8TP's antenna in this photograph? Of course you can't—it's hidden from view inside his attic!

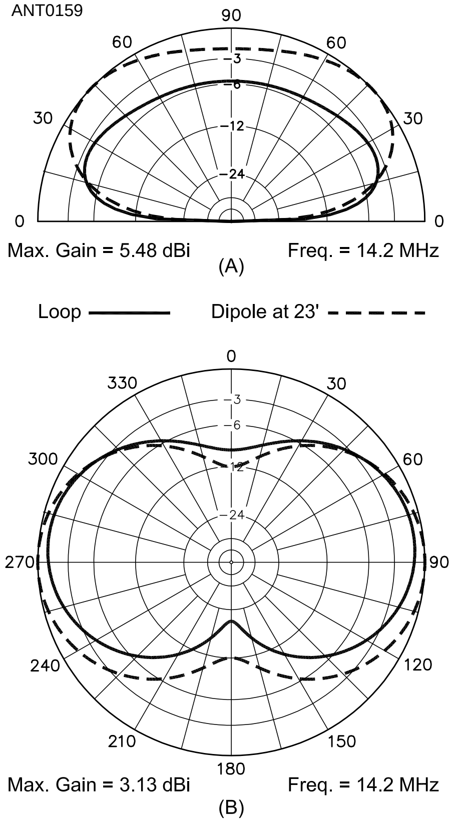

Fig 37—At A, computed elevation pattern at 14.2 MHz for W8TP's hidden loop (solid line), compared to a 20-meter dipole (dashed line) at a height of 23 feet. At B, a comparison of the azimuth patterns at a 20°-elevation angle for W8TP's loop (solid line) and the same 20-meter dipole (dashed line). The loop has a slightly asymmetrical response because it is fed at a corner, but its performance is competitive to an outdoor dipole. In fact, it has superior low-angle performance, typical of a vertically polarized antenna compared to a low horizontal antenna.

measures seem to have eliminated my RFI problems.

When we moved into our condo, I took the obvious precaution of not using a linear amplifier. I took extra care to establish a single-point ground for my station equipment by connecting all equipment grounds to the cover plate of the dedicated metallic outlet box behind the operating position, and thence to a separate ground rod in our front yard. I use a 1-kW RL Drake low-pass filter in the transceiver-antenna feed line.

Is this indoor antenna system safe? I believe so. In the attic it is not at all close to our living space. It is fixed firmly in place and unlike most amateur antennas it is *out of the weather*! I therefore do not use a quick-grounding system for times when a thunderstorm approaches.

Fig 37 shows the computed elevation and azimuth patterns on 20 meters. The tuner is able to hold the SWR down low enough so that my JRC-245 transceiver can operate through its internal antenna tuner.

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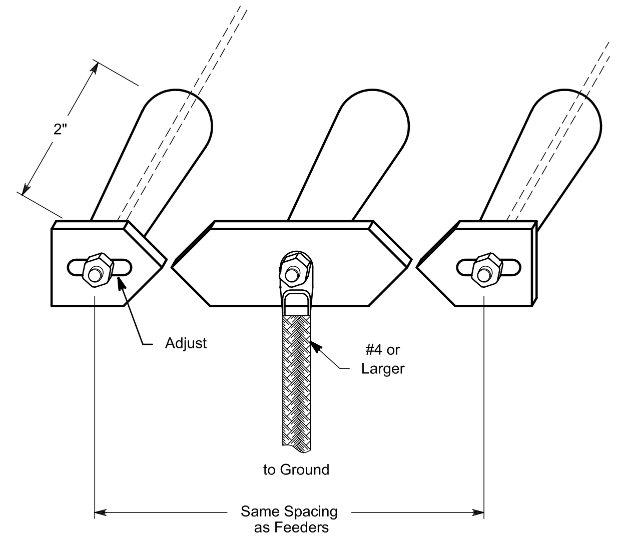

Fig 43—A simple lightning arrester for open-wire line made from three standoff or feedthrough insulators and sections of 1/8 × 1/2-inch brass or copper strap. It should be installed in the line at the point where the line enters the station. The heavy ground lead should be as short and as direct as possible. The gap setting should be adjusted to the minimum width that will prohibit arcing when the transmitter is operated.

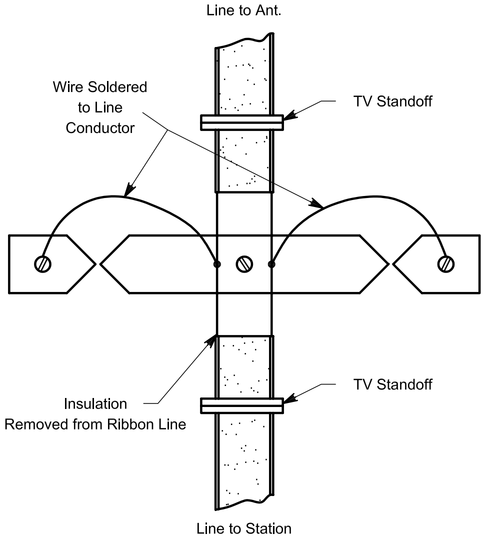

Fig 44—The lightning arrester of Fig 39 may be used with 300-Ω ribbon line in the manner shown here. The TV standoffs support the line an inch or so away from the grounded center member of the arrester

The construction of a homemade arrester for open-wire line is shown in **Fig 43**. This type of arrester can be adapted to ribbon line an inch or so away from the center member of the arrester, as shown in **Fig 44**. Sufficient insulation should be removed from the line where it crosses the arrester to permit soldering the arrester connecting leads.

Lightning Grounds

Lightning-ground connecting leads should be of conductor size equivalent to at least #10 wire. The #8 aluminum wire used for TV-antenna grounds is satisfactory. Copper braid 3/4-inch wide (Belden 8662-10) is also suitable. The conductor should run in a straight line to the grounding point. The ground connection may be made to a water pipe system (if the pipe is not plastic), the grounded metal frame of a building, or to one or more 5/8-inch ground rods driven to a depth of at least 8 feet. More detailed information on lightning protection is contained in Chapter 1, Safety.

A central grounding panel for coax cables coming into the house is highly recommended. See **Fig 45** for a photo of the homemade grounding panel installed by Chuck Hutchinson, K8CH, at his Michigan home. The coax cables screwed into dual-female feed-through UHF connectors. K8CH installed this aluminum panel under the outside grill for a duct that provided combustion air to an unused fireplace. He used ground strap to connect to ground rods located under the panel. See the ARRL book *Simple and Fun Antennas* for more information about ground panels.

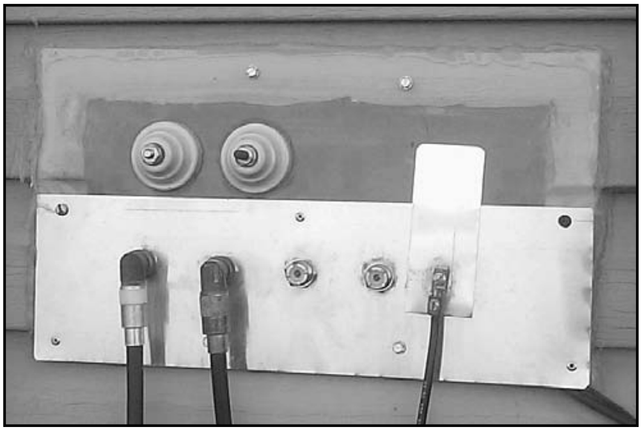

Fig 45—K8CH's coax entry panel mounted on exterior wall (later covered by grill that provides combustion to an unused fireplace). The ground braid goes to a ground rod located beneath the panel. (Photo courtesy: *Simple and Fun Antennas for Hams*)

Before a lightning storm approaches, a prudent ham will disconnect all feed lines, rotor lines and control lines inside the shack to prevent damage to sensitive electronics. When lightning is crashing about outside, you certainly don't want that lightning inside your shack!