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## 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  $0.1 \lambda$ . Small loops are discussed later in this chapter, and further in Chapter 14.

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 as compared with a small loop.

### Half-Wave Loops

The smallest size of “large” loop generally used is one having a conductor length of  $\frac{1}{2} \lambda$ . The conductor is usually formed into a square, as shown in Fig 1, making each side  $\frac{1}{8} \lambda$  long. When fed at the center of one side, the current flows in a closed loop as shown at A. The current distribution is approximately the same as on a  $\frac{1}{2}\text{-}\lambda$  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 at B (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  $50 \Omega$ . The impedance at the terminals in A 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  $\frac{1}{2}\text{-}\lambda$  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 of the order of 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 loop is compared with the field from a  $\frac{1}{2}\text{-}\lambda$  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

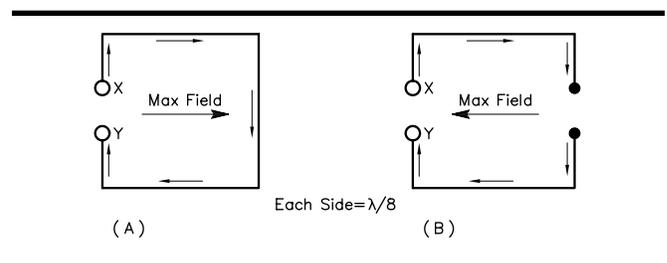


Fig 1—Half-wave loops, consisting of a single turn having a total length of  $\frac{1}{2} \lambda$ .

and back of the loop. This is shown in **Fig 2**. The reactances, which should have a value of approximately  $360 \Omega$ , 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.

### One-Wavelength Loops

Loops in which the conductor length is  $1 \lambda$  have different characteristics than  $1/2\text{-}\lambda$  loops. Three forms of  $1\text{-}\lambda$  loops are shown in **Fig 3**. At A and B the sides of the squares are equal to  $1/4 \lambda$ , the difference being in the point at which the terminals are inserted. At C the sides of the triangle are equal to  $1/3 \lambda$ . 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  $1/2\text{-}\lambda$  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 any 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 A, 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  $1\text{-}\lambda$  loop is shorter than the actual length. For loops made of wire and operating at frequencies below 30 MHz or so, where the ratio of conductor length to wire diameter is large, the loop will be close to resonance when

$$\text{Length}_{\text{feet}} = \frac{1005}{f_{\text{MHz}}}$$

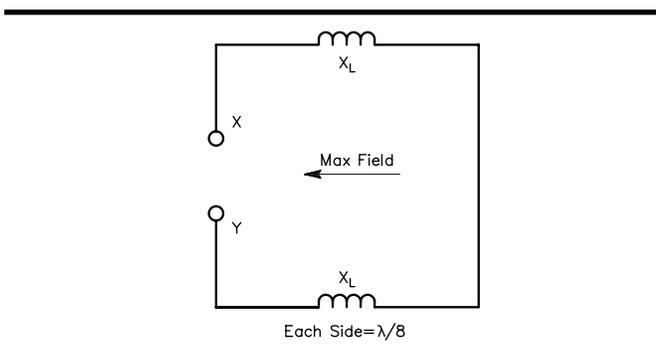
The radiation resistance of a resonant  $1\text{-}\lambda$  loop is approximately  $100 \Omega$ , when the ratio of conductor length to diameter is large. As the loop dimensions are comparable with those of a  $1/2\text{-}\lambda$  dipole, the radiation efficiency is high.

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  $1\text{-}\lambda$  loop will show a small gain over a  $1/2\text{-}\lambda$  dipole. Theoretically, this gain is about 2 dB, and measurements have confirmed that it is of this order.

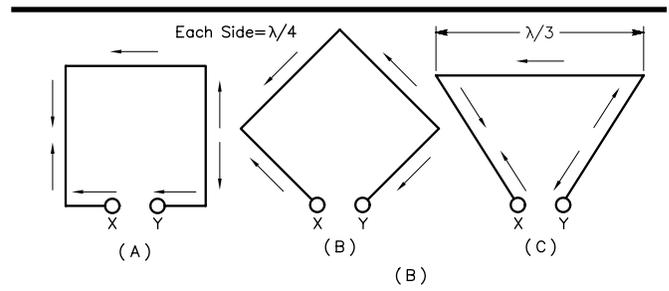
The  $1\text{-}\lambda$  loop is more frequently used as an element of a directive antenna array (the quad and delta-loop antennas described in Chapter 12) than singly, although there is no reason why it cannot be used alone. In the quad and delta loop, it is nearly always driven so that the polarization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



**Fig 2**—Inductive loading in the sides of a  $1/2\text{-}\lambda$  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.



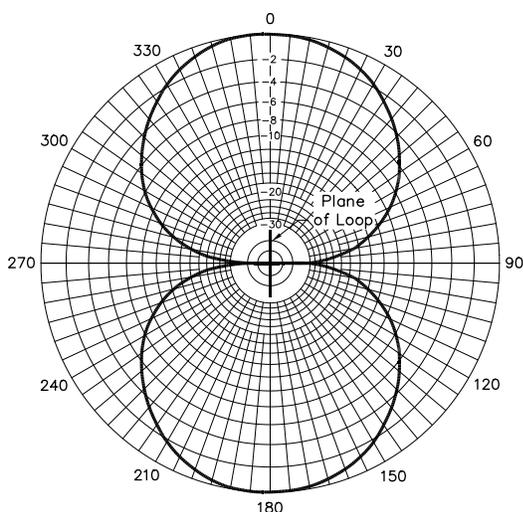
**Fig 3**—At A and B, loops having sides  $1/4 \lambda$  long, and at C having sides  $1/3 \lambda$  long (total conductor length  $1 \lambda$ ). The polarization depends on the orientation of the loop and on the position of the feed point (terminals X-Y) around the perimeter of the loop.

tennas 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.

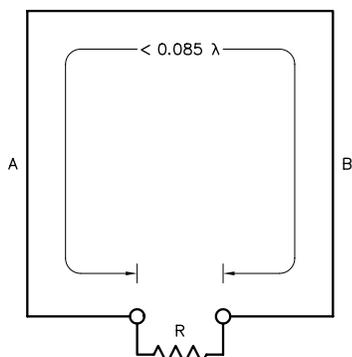
### The Basic Loop

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  $0.1 \lambda$ —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  $0.085 \lambda$ , 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, **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  $90^\circ$  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.



**Fig 4—Calculated small loop antenna radiation pattern.**



**Fig 5—Simple untuned small loop antenna.**

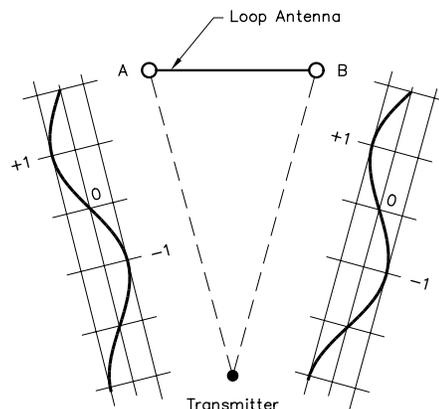
The voltage across the loop terminals is given by

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

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
- $\theta$  = angle between the plane of the loop and the signal source (transmitting station)
- $\lambda$  = wavelength of operation in meters

This equation comes from a term called ef-



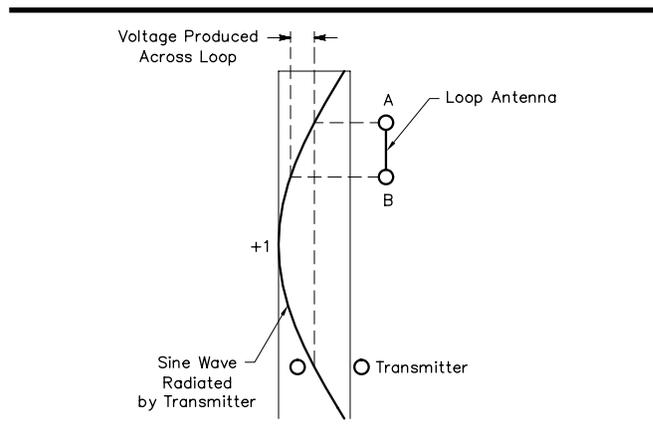
**Fig 6—Example of orientation of loop antenna that does not respond to a signal source (null in pattern).**

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

$$h = \frac{2\pi NA}{\lambda} \quad (\text{Eq 2})$$

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, with even a large signal.



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

## 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

$$V = \frac{2\pi ANEQ \cos\theta}{\lambda} \quad (\text{Eq 3})$$

where Q is the loaded Q of the tuned circuit, and 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

$$C = HD \tag{Eq 4}$$

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

**Table 1**  
**Inductance Equations for Short Coils (Loop Antennas)**

Triangle:

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

Square:

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

Hexagon:

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

Octagon:

$$L(\mu\text{H}) = 0.016N^2s \left[ \ln \left( \frac{2.613 \text{ sN}}{(N+1)\ell} \right) + 0.75143 + \frac{0.7153(N+1)\ell}{\text{sN}} \right]$$

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 λ.

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

$$C = 60S \tag{Eq 5}$$

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

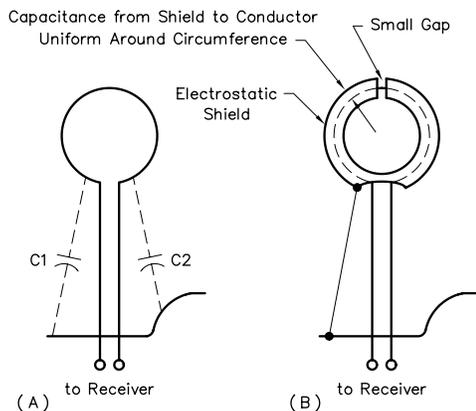
Over the years, many loop antennas have incorporated an electrostatic shield. This shield generally takes the form of a tube around the winding, made of a conductive but nonmagnetic material (such as copper or aluminum). Its purpose is to maintain loop balance with respect to ground, by forcing the capacitance 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. Two important points regarding the shield are 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 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.

**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.**

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

$$R = \frac{0.996 \times 10^{-6} \sqrt{f}}{d} \tag{Eq 6}$$

where

R = resistance in ohms per foot

f = frequency, Hz

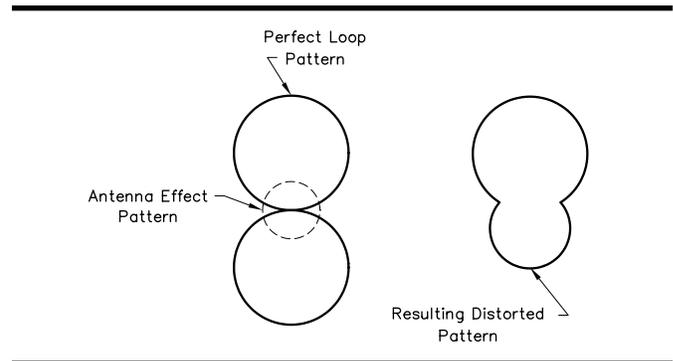
d = conductor diameter, inches

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 1-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.



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

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 locate 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.

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,  $\mu_{rod}$ . (In some texts the rod permeability is referred to as effective permeability,  $\mu_{eff}$ ). This effect modifies the equation for effective height of a ferrite-core loop to

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

where

h = effective height (length) in meters

N = number of turns in the loop

A = area of loop in square meters

$\mu_{rod}$  = permeability of the ferrite rod

$\lambda$  = wavelength of operation in meters

This obviously is a large increase in “collected” signal. If the rod permeability was 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

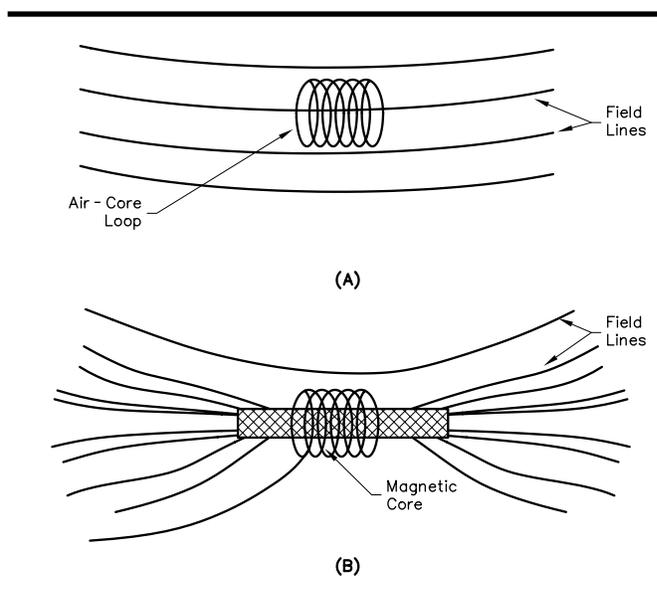


Fig 10—At A, an air-core loop has no effect on nearby field lines. B illustrates the effect of a ferrite core on nearby field lines. The field is altered by the reluctance of the ferrite material.

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  $\mu$ , the shape of the rod, and the dimensions of the rod. In ferrite rods,  $\mu$  is sometimes referred to as initial permeability,  $\mu_i$ , or toroidal permeability,  $\mu_{tor}$ . Because most amateur ferrite loops are in the form of rods, we will discuss only this shape.

The reason that  $\mu_{rod}$  is different from  $\mu$  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.

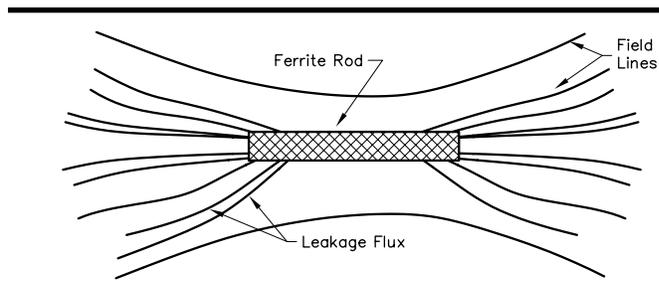
The change in  $\mu$  over the length of the rod results in an adjustment in the term  $\mu_{rod}$  for its so called “free ends” (those not covered by the winding). This adjustment factor is given by

$$\mu' = \mu_{rod} \sqrt[3]{\frac{a}{b}} \tag{Eq 8}$$

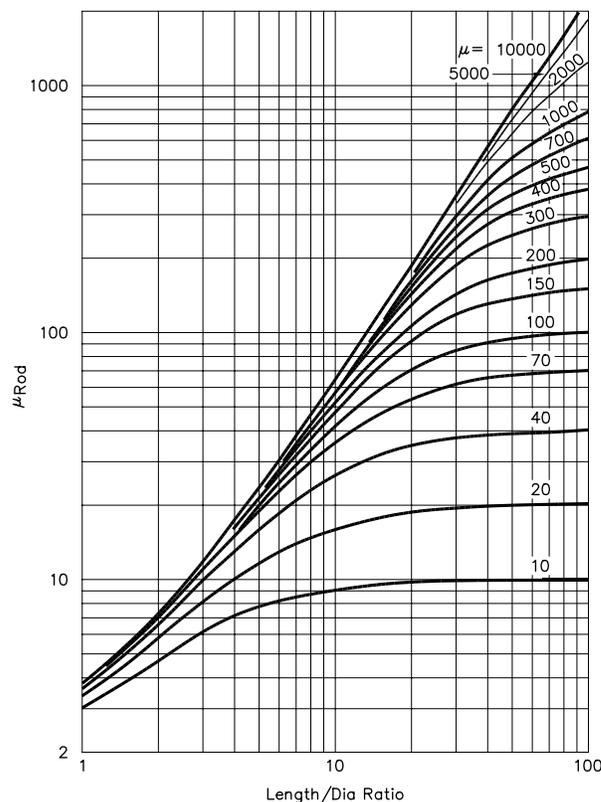
where

- $\mu'$  = the corrected permeability
- a = the length of the core
- b = the length of the coil

This value of  $\mu'$  should be used in place of  $\mu_{rod}$  in **Eq 7** to obtain the most accurate value of effective height.



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



**Fig 12—Rod permeability,  $\mu_{rod}$ , versus material permeability,  $\mu$ , for different rod length-to-diameter ratios.**

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

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

where

L = inductance in microhenries

N = number of turns

A = cross-sectional area of the core in square mm

$\ell$  = 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

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

where

V = output voltage across the loop terminals

A = loop area in square meters

N = number of turns in the loop winding

$\mu'$  = corrected rod permeability

Q = loaded Q of the loop

E = RF field strength in volts per meter

$\lambda$  = wavelength of operation in meters

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

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

where

f = operating frequency in Hz

L = loop inductance in henrys

b = receiver bandwidth in Hz

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

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

From this, if the field strength E,  $\mu_{\text{rod}}$ , 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 via ground wave. At frequencies in the HF region, a significant portion of the signals are propagated by sky wave, and nulls are often only partial.

For this reason 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 which 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 which 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 which 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 MHz 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 omni-directional.

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.

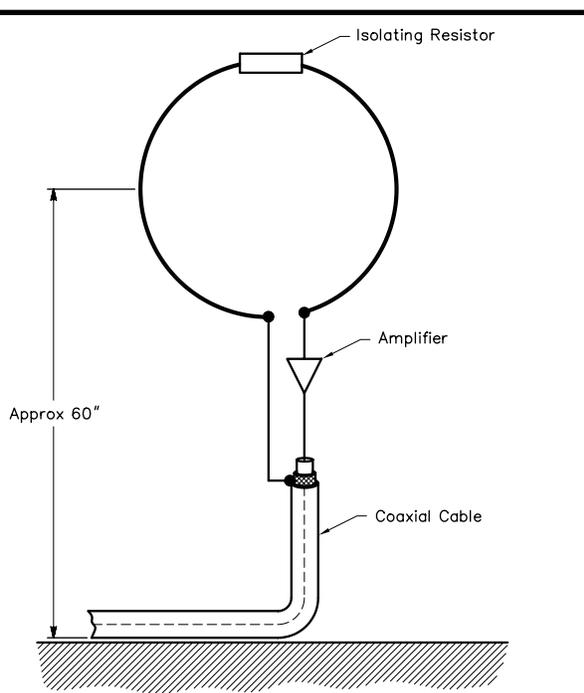


Fig 13—A single wide-band loop antenna used in an aperiodic array.

bands.

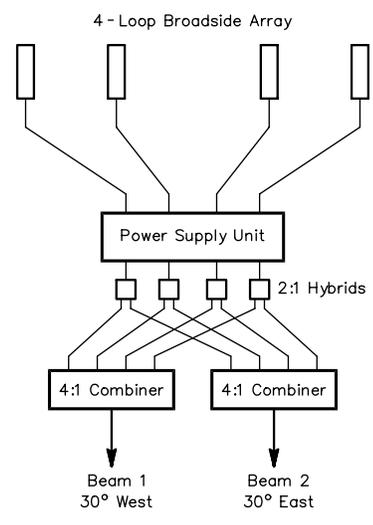


Fig 14—Block diagram of a four-loop broadside array with dual beams separated by 60° in azimuth.

## TRANSMITTING LOOP ANTENNAS

The electrically small transmitting loop antenna involves some different design considerations from 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 (not total conductor length) is less than  $\frac{1}{4} \lambda$  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 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 recent years, two types of transmitting loops have been predominant in the amateur literature: the “army loop” by Lew McCoy, W1ICP, and the “high efficiency” loop by Ted Hart, W5QJR. The army loop is a version of a loop designed for portable use in Southeast Asia by Patterson of the US Army. This loop is diagrammed in **Fig 15A**. It can be seen by examination that this loop appears as a parallel tuned

**Table 3**  
**Transmitting Loop Equations**

$$X_L = 2\pi fL \text{ ohms}$$

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

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

$$V_C = \sqrt{PX_L Q}$$

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

where

$X_L$  = inductive reactance, ohms

$f$  = frequency, Hz

$\Delta f$  = bandwidth, Hz

$R_R$  = radiation resistance, ohms

$R_L$  = loss resistance, ohms (see text)

$N$  = number of turns

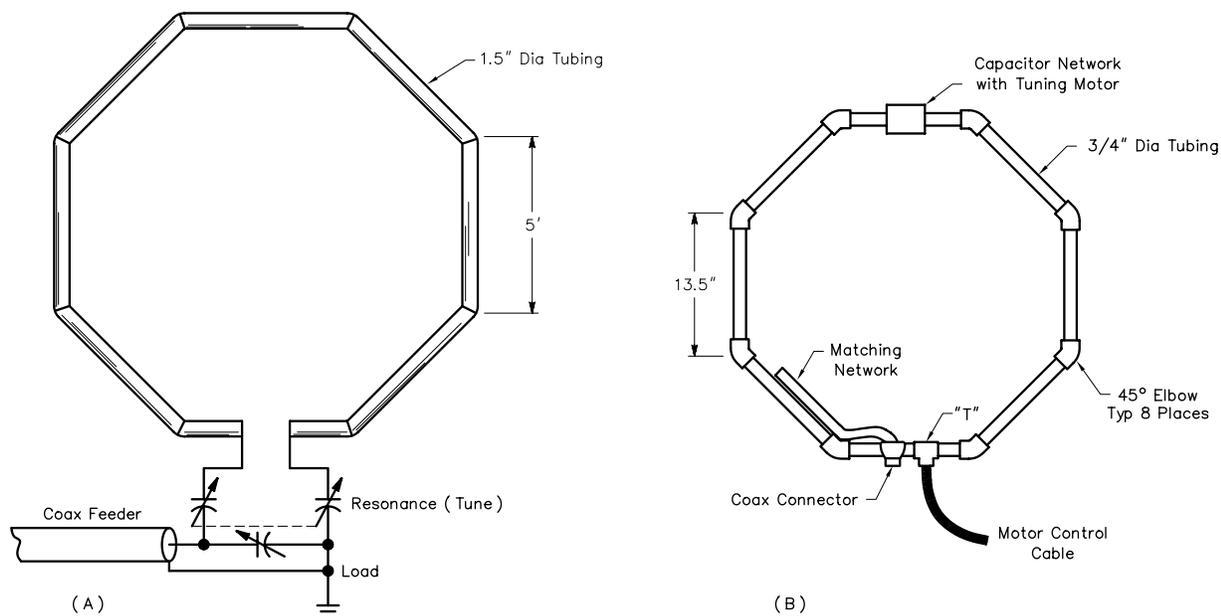
$A$  = area enclosed by loop, square meters

$\lambda$  = wavelength at operating frequency, meters

$V_C$  = voltage across capacitor

$P$  = power, watts

$I_L$  = resonant circulating current in loop



**Fig 15—A**, a simplified diagram of the army loop, **B**, the W5QJR Hart loop, which is described in more detail later in this chapter

circuit, fed by a tapped capacitance impedance-matching network. The Hart loop, shown in Fig 15B, has the tuning capacitor separate from the matching network. The matching network is basically a form of gamma match. (Additional data and construction details for the Hart loop are presented later in this chapter.) Here we cover some matters which are common to both antennas.

The radiation resistance of a loop in ohms is given by

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

where

$N$  = number of turns

$A$  = area of loop in square meters

$\lambda$  = wavelength of operation in meters

It is obvious that within the constraints given, the radiation resistance is very small. Unfortunately the loop has losses, both ohmic and from skin effect. By using this information, the radiation efficiency of a loop can be calculated from

$$\eta = \frac{R_R}{R_R + R_L} \times 100 \quad (\text{Eq 14})$$

where

$\eta$  = antenna efficiency, %

$R_R$  = radiation resistance,  $\Omega$

$R_L$  = loss resistance,  $\Omega$

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  $3/4$  inch in diameter in order to obtain efficiencies that are reasonable. 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.

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

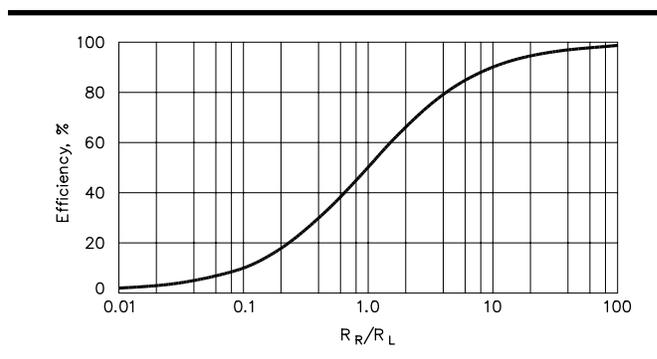


Fig 16—Effect of ratio of  $R_R/R_L$  on loop efficiency.

found in the high-Q tuned circuit formed by the antenna. This makes it important that the 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 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.)

## Small High Efficiency Loop Antennas for Transmitting

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 was written by Robert T. (Ted) Hart, W5QJR.

Small antennas are characterized by low radiation resistance. Typically, loading coils are added to small antennas to achieve resonance. However, the loss in the coils results in an antenna with low efficiency. If instead of coils a large 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 high efficiency. In addition, the small loop, when mounted vertically, has the unique characteristic of radiation at all elevation angles. Therefore it can replace both vertical and dipole antennas. Small size and high efficiency are advantages of using a properly designed and constructed loop on the lower frequency bands.

The only deficiency in a small loop antenna is narrow bandwidth; it must be tuned to the operating frequency. However, the use of a remote motor drive allows the loop to be tuned over a wide frequency range. For example, two loops could be constructed to provide continuous frequency coverage from 3.5 to 30 MHz.

### Loop Fundamentals

The small transmitting loop has been around since 1957 (see the Patterson [Bibliography](#) reference). Only recently has the small loop been developed into a practical antenna for amateurs. **Fig 17** presents data for various size loop antennas for the HF amateur bands. Through computer analysis, it has been determined that the optimum size conductor is  $3/4$ -inch copper pipe, considering both performance and cost.

The loop circumference should be between  $1/4$  and  $1/8 \lambda$  at the operating frequency. It will become self-resonant above  $1/4 \lambda$ , and efficiency drops rapidly below  $1/8 \lambda$ . In the frequency ranges shown in Fig 17, the high frequency is for 5 pF of tuning capacitance, and the low frequency is that at which the loop efficiency is down from 100% by 10 dB.

Where smaller loops are needed, the efficiency can be increased by increasing the pipe size or by adding radials to form a ground screen under the loop (data are given in Fig 17). The effect of radials is to double the antenna area because of the loop image. The length of each radial need be only twice the

<b>Loop No. 1</b>						
Frequency range, MHz	7.6-29.4					
Loop circumference, feet	8.5					
Conductor dia, inches	0.9					
Radials	No					
Frequency, MHz	10.1	14.2	18.0	21.2	24.0	29.0
Efficiency, dB below 100%	-6.5	-3.1	-1.6	-1.0	-0.7	-0.4
Bandwidth, kHz	5.5	9.9	18.2	30.2	46.0	91.4
Q	1552	1212	835	591	439	267
Tuning capacitance, pF	102.6	48.0	26.8	17.1	11.6	5.4
Capacitor voltage, kV P-P	38.21	40.03	37.40	34.16	31.32	26.86
Capacitor spacing, inches	0.255	0.267	0.249	0.228	0.209	0.179
Radiation resistance, ohms	0.009	0.034	0.088	0.170	0.279	0.594
Loss resistance, ohms	0.030	0.035	0.040	0.043	0.046	0.051
<hr/>						
<b>Loop No. 2</b>						
Frequency range, MHz	3.6-16.4					
Loop circumference, feet	20					
Conductor dia, inches	0.9					
Radials	No					
Frequency, MHz	4.0	7.2	10.1	14.2		
Efficiency, dB below 100%	-8.9	-2.7	-1.0	-0.3		
Bandwidth, kHz	3.3	8.4	22.1	73.8		
Q	1356	965	515	217		
Tuning capacitance, pF	310.5	86.1	36.8	11.6		
Capacitor voltage, kV P-P	38.28	43.33	37.48	28.83		
Capacitor spacing, inches	0.255	0.289	0.250	0.192		
Radiation resistance, ohms	0.007	0.069	0.268	1.047		
Loss resistance, ohms	0.044	0.059	0.070	0.083		
<hr/>						
<b>Loop No. 3</b>						
Frequency range, MHz	2.1-10.0					
Loop circumference, feet	38					
Conductor dia, inches	0.9					
Radials	No					
Frequency, MHz	3.5	4.0	7.2			
Efficiency, dB below 100%	-4.1	-3.0	-0.5			
Bandwidth, kHz	4.2	5.6	33.2			
Q	1014	880	265			
Tuning capacitance, pF	192.3	142.4	29.9			
Capacitor voltage, kV P-P	45.63	45.43	33.47			
Capacitor spacing, inches	0.304	0.303	0.223			
Radiation resistance, ohms	0.050	0.086	0.902			
Loss resistance, ohms	0.079	0.084	0.113			
<hr/>						
<b>Loop No. 4</b>						
Frequency range, MHz	0.9-4.1					
Loop circumference, feet	100					
Conductor dia, inches	0.9					
Radials	No					
Frequency, MHz	1.8	2.0	3.5	4.0		
Efficiency, dB below 100%	-2.7	-2.1	-0.4	-0.2		
Bandwidth, kHz	3.4	4.4	27.7	45.9		
Q	663	565	156	108		
Tuning capacitance, pF	215.7	166.4	24.9	8.8		
Capacitor voltage, kV P-P	46.75	45.48	31.63	28.09		
Capacitor spacing, inches	0.312	0.303	0.211	0.187		
Radiation resistance, ohms	0.169	0.257	2.415	4.120		
Loss resistance, ohms	0.148	0.157	0.207	0.221		

Fig 17—Design data for loops to cover various frequency ranges. The information is calculated for an 8-sided loop, as shown in Fig 19. The capacitor specification data is based on 1000 W of transmitted power. See text for modifying these specifications for other power levels.

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<b>Loop No. 5</b>							
Frequency range, MHz	5.1-29.4						
Loop circumference, feet	8.5						
Conductor dia, inches	0.9						
Radials	Yes						
Frequency, MHz	7.2	10.1	14.2	18.0	21.2	24.0	29.0
Efficiency, dB below 100%	-5.8	-2.7	-1.0	-0.5	-0.3	-0.2	-0.1
Bandwidth, kHz	4.9	9.2	24.4	55.7	102.4	164.6	344.1
Q	1248	925	490	272	174	123	71
Tuning capacitance, pF	209.7	102.6	48.0	26.8	17.1	11.6	5.4
Capacitor voltage, kV P-P	28.92	29.49	25.46	21.36	18.55	16.56	13.84
Capacitor spacing, inches	0.193	0.197	0.170	0.142	0.124	0.110	0.092
Radiation resistance, ohms	0.009	0.035	0.137	0.353	0.679	1.115	2.377
Loss resistance, ohms	0.025	0.030	0.035	0.040	0.043	0.046	0.051

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<b>Loop No. 6</b>							
Frequency range, MHz	2.4-16.4						
Loop circumference, feet	20						
Conductor dia, inches	0.9						
Radials	Yes						
Frequency, MHz	3.5	4.0	7.2	10.1	14.2		
Efficiency, dB below 100%	-5.7	-4.3	-0.8	-0.3	-0.1		
Bandwidth, kHz	3.7	4.6	21.9	74.5	278.7		
Q	1061	976	369	152	57		
Tuning capacitance, pF	409.8	310.5	86.1	36.8	11.6		
Capacitor voltage, kV P-P	31.68	32.48	26.80	20.40	14.83		
Capacitor spacing, inches	0.211	0.217	0.179	0.136	0.099		
Radiation resistance, ohms	0.015	0.026	0.277	1.072	4.187		
Loss resistance, ohms	0.041	0.044	0.059	0.070	0.083		

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<b>Loop No. 7</b>							
Frequency range, MHz	1.4-10.0						
Loop circumference, feet	38						
Conductor dia, inches	0.9						
Radials	Yes						
Frequency, MHz	1.8	2.0	3.5	4.0	7.2		
Efficiency, dB below 100%	-7.0	-5.8	-1.4	-1.0	-0.1		
Bandwidth, kHz	2.3	2.6	9.2	14.0	121.8		
Q	955	924	467	350	72		
Tuning capacitance, pF	783.7	630.9	192.3	142.4	29.9		
Capacitor voltage, kV P-P	31.74	32.92	30.97	28.64	17.48		
Capacitor spacing, inches	0.212	0.219	0.206	0.191	0.117		
Radiation resistance, ohms	0.014	0.021	0.201	0.344	3.607		
Loss resistance, ohms	0.056	0.059	0.079	0.084	0.113		

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<b>Loop No. 8</b>							
Frequency range, MHz	0.6-4.1						
Loop circumference, feet	100						
Conductor dia, inches	0.9						
Radials	Yes						
Frequency, MHz	1.8	2.0	3.5	4.0			
Efficiency, dB below 100%	-0.9	-0.6	-0.1	-0.1			
Bandwidth, kHz	8.7	12.5	104.2	176.4			
Q	255	197	41	28			
Tuning capacitance, pF	215.7	166.4	24.9	8.8			
Capacitor voltage, kV P-P	29.01	26.87	16.30	14.32			
Capacitor spacing, inches	0.193	0.179	0.109	0.095			
Radiation resistance, ohms	0.676	1.030	9.659	16.478			
Loss resistance, ohms	0.148	0.157	0.207	0.221			

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loop diameter. Quarter-wavelength radials should be used for loops mounted over poor ground to improve performance.

Data for Fig 17 was computed for  $3/4$ -inch copper water pipe (nominal OD of 0.9 inch). By comparing figures with radials (perfect screen assumed) and without, you will note that the effect of radials is greater for loops with a smaller circumference, for a given frequency. Also note the efficiency is higher and the Q is lower for loops having a circumference near  $1/4 \lambda$ . Larger pipe size will reduce the loss resistance, but the Q increases. Therefore the bandwidth decreases, and the voltage across the tuning capacitor increases.

Fig 18 allows the selection of loop size versus tuning capacitance for any desired operating frequency range for the HF amateur bands. 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 25-150 pF capacitor with a 13.5-foot loop covers the 7-14.4 MHz range, represented by the right vertical bar.

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 resistance. The radiation resistance is much less than  $1 \Omega$ , so it is necessary to minimize the loss resistance, which is largely the skin effect loss of the conductor. However, if the loss is too low, the Q will be excessive and the bandwidth will be 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.

### Additional Loss

There are two sources of additional loss in a completed loop antenna. First, if the loop is mounted near lossy metallic conductors, the large magnetic field will induce currents into those conductors and be reflected as loss 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 second source of loss is from poor construction, which can be avoided. All joints in the loop must be brazed or soldered. This also applies to the tuning capacitor. The use of a split-stator capacitor eliminates the resistance of wiper contacts, resistance that is inherent in a single-section capacitor. The

loop ends are connected to the stators, and the rotor forms the variable coupling path between stators. With this arrangement the value of capacitance is divided by two, but the voltage rating is doubled.

The capacitor must be selected 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 in each joint, and thus degraded loop efficiency. (Earlier transmitting loops exhibited poor efficiency because capacitors with wiping contacts were used.) There are two types of capacitors available 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. For this reason, a 170 pF-340 pF variable—per section, with  $1/4$ -inch spacing—has been designed for transmitting loops (available from W5QJR Antenna Products\*). Another alternative is to obtain a large air variable,

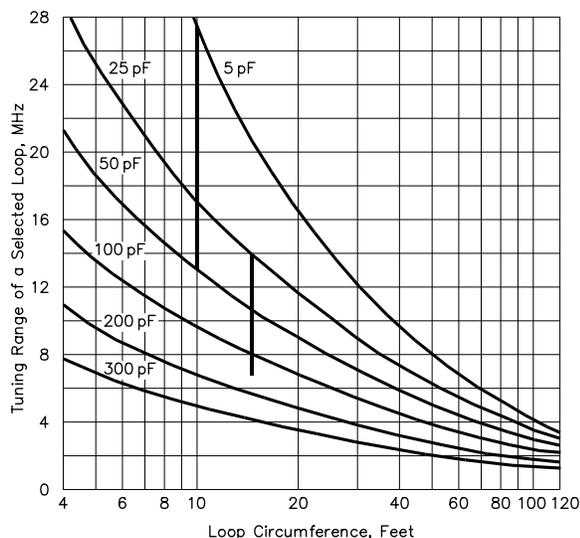


Fig 18—Frequency tuning range of an octagon-shaped loop using  $3/4$ -inch copper water pipe, for various values of tuning capacitance and loop circumference.

remove the aluminum plates, and replace them with copper or double-sided PC board material. 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 determines the voltage-handling capability, rated at 75,000 V per inch. Fig 17 includes the spacing required for each section of the split-stator capacitor for 1000 W RF power. 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  $\sqrt{100/1000} = 0.316$ .

### Remote Tuning

Because of the narrow bandwidth, the loop must be retuned each time the operating frequency is changed by more than a few kilohertz. A very high resolution motor and gear train is required. The use of a stepper motor with integral gear train provides an excellent drive. The preferred unit is available at this writing from Hurst Manufacturing Co.\*\* The controller is an integrated circuit that provides all the functions of speed control and direction of rotation. Add a variable resistor for speed control, control switches and a 12 V dc source, and you have a complete drive. (The 1988 cost of the motor and controller is about \$90.) For high RF power, it is advisable to add low-pass filters in the motor leads near the controller, to prevent RF from damaging the controller. Use 100- $\mu$ H RF chokes (Radio Shack), with 0.011- $\mu$ F disc capacitors from either side to ground.

### CONSTRUCTION

After you select the loop design for your application, construct it as shown in Fig 19. The efficiency of a small loop is related to area, and therefore a round loop would provide the maximum area for a given circumference. The octagon shape is much easier to construct, with only a small difference in area. The third choice would be a square. The values presented in Fig 17 are for an octagon.

For a given loop circumference, divide the circumference by 8 and cut eight equal-length pieces of 3/4-inch copper pipe. Join the pieces with 45° elbows to form the octagon. With the loop lying on the ground, braze or solder all joints. In the center of one leg, cut the pipe and install a copper T. Adjacent to the T, install a mount for the coax connector. Make the mount from copper strap, which can be

\*A variable capacitor designed specifically for transmitting loop use is available from W5QJR Antenna Products, PO Box 334, Melbourne, FL 32902. (Send SASE for information.)

\*\*Hurst Manufacturing Co, Princeton, IN 47670. Use motor no. 304-001 and controller no. 22001.

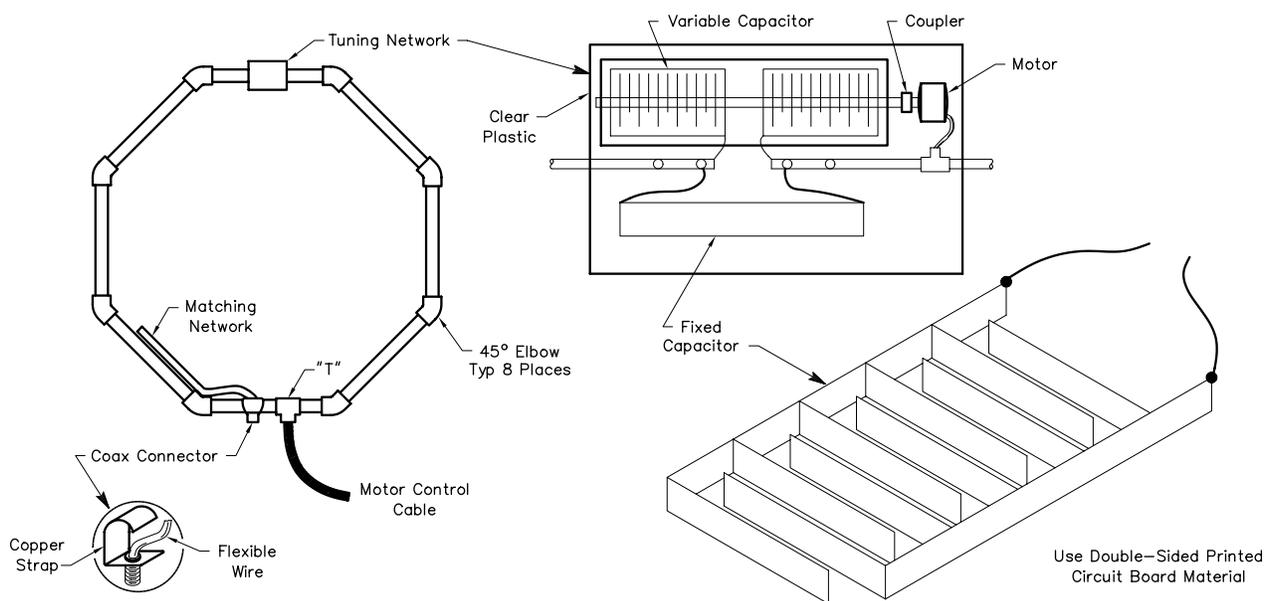


Fig 19—Loop construction details. Fig 17 gives loop design data for various frequency ranges.

obtained by splitting a short piece of pipe and hammering it flat.

Make a box from clear plastic to house the variable capacitor and the drive motor. The side of the box that mounts to the loop and the capacitor should be at least  $\frac{1}{4}$  inch thick, preferably  $\frac{3}{8}$  inch. The remainder of the box can be  $\frac{1}{8}$ -inch plastic sheet. Any good sign shop will cut the pieces to size for you. Mount the loop to the plastic using  $\frac{1}{4}$ -inch bolts (two on either side of center). Remove the bolts and cut out a section of pipe 2 inches wide in the center. On the motor side of the capacitor, cut the pipe and install a copper T for the motor wiring.

The next step is to solder copper straps to the loop ends and to the capacitor stators, then remount the loop to the plastic. If you insert wood dowels, the pipe will remain round when you tighten the bolts.

Now you can install the motor drive cable through the loop and connect it to the motor. Antenna rotator cable is a good choice for this cable. Complete the plastic box using short pieces of aluminum angle and small sheet-metal screws to join the pieces.

The loop is now ready to raise to the vertical position. Remember, no metal is allowed near the loop. Make a pole of  $2 \times 4$ -inch lumber with  $1 \times 4$ -inch boards on either side to form an I section. Hold the boards together with  $\frac{1}{4}$ -inch bolts, 2 feet apart. Tie rope guys to the top. This makes 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. By installing a pulley at the top, the loop can be raised and supported by rope. Support the bottom of the loop by tying it to the pole. Tie guy ropes to the sides of the loop to keep it from rotating in the wind. By moving the anchor points, the loop can be rotated in the azimuth plane.

With the loop in the vertical position, cut a piece of  $\frac{1}{4}$ -inch copper tubing the length of one of the sides of the loop. Flatten one end and solder a piece of flexible wire to the other. Wrap the tubing with electrical tape or cover with plastic tubing for insulation. Connect the flexible wire to the coax connector and install the tubing against the inside of the loop. Hold in place with tape. Solder the flat part to the loop. You have just constructed a form of gamma match, but without reactive components. This simple feed will provide better than 1.7:1 SWR over a 2:1 frequency range for the resonated loop. For safety, install a good ground rod under the loop and connect 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 (via remote control) until signals peak. The peak will be very sharp because of the high Q of the loop. Incidentally, the loop typically reduces electrostatic noise 26 dB compared to dipoles or verticals, thus allowing improved reception in noisy areas.

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  $\frac{1}{4}$ -inch tubing line, as shown in Fig 19, 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- $\Omega$  match.

### PERFORMANCE COMPARISON

As previously indicated, the loop will 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 ( $\frac{1}{2} \lambda$ ) in length and 120 feet high ( $\frac{1}{4} \lambda$ ). A  $\frac{1}{4}$ - $\lambda$  vertical would be 120 feet tall with a large number of radials, each 120 feet in length. The small loop would replace both of those antennas. Since very few hams have full-size antennas on 1.8 MHz, it is easy for a loop to emanate the “big signal on the band.”

On the higher frequencies, the same ratios apply, but the 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.

### Additional Comments

The loop should not be mounted horizontally except at great heights. The pattern for a horizontal loop will be horizontally polarized, but it will have a null overhead and be omnidirectional in the azimuth plane. The effect of the earth would be the same as on the pattern of a horizontal dipole at the same height.

It has taken a number of years to develop this small loop into a practical antenna for amateurs. Other than trading small size for narrow bandwidth, the loop is an excellent antenna and will find use where large antennas are not practical. It should be a useful antenna to a large number of amateurs.

## The Loop Skywire

Are you looking for a multiband HF antenna that is easy to construct, costs nearly nothing and works great? Try this one. This information is based on a November 1985 *QST* article by Dave Fischer, WØMHS.

There is one wire antenna that performs exceptionally well on the lower HF bands, but relatively few amateurs use it. This is a full-size horizontal loop. The Loop Skywire antenna is that type. It is fundamental and simple, easy to construct, costs nearly nothing, and eliminates the need for multiple antennas to cover the HF bands. It is made only of wire and coaxial cable, and often needs no Transmatch. It is an efficient antenna that is omnidirectional over real earth. It is noticeably less susceptible than dipoles and verticals to man-made and atmospheric noise. The antenna can also be used on harmonics of the fundamental frequency, and fits on almost every amateur's lot.

It is curious that many references to this antenna are brief pronouncements that it operates best as a high-angle radiator and is good for only short-distance contacts. Such statements, in effect, dismiss this antenna as useless for most amateur work. This is not the case! Those who use the Loop Skywire know that its performance far exceeds the short haul. DX is easy to work.

### THE DESIGN

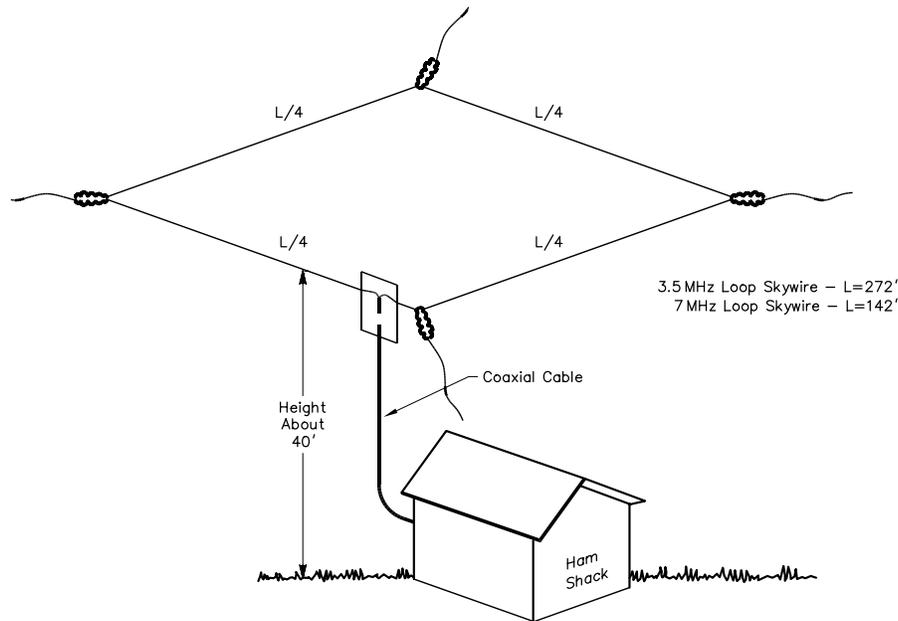
The Loop Skywire is shown in **Fig 20**. This antenna is a magnetic version of the open-wire, center-fed electric dipole that has performed extraordinarily well for many decades. Yet this one is less difficult to match and use. It is simply a loop antenna erected horizontal to the earth. Maximum enclosed area within the wire loop is the fundamental rule. The antenna has one wavelength of wire in its perimeter at the design or fundamental frequency. If you choose to calculate  $L_{\text{total}}$  in feet, the following equation should be used.

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

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.

A little-known fact in the amateur community is that loops can be fed simply at all harmonics of the design frequency. There is another great advantage to this antenna system. It can be operated as a vertical antenna with top-hat loading on all bands as well. This is accomplished by simply keeping the



**Fig 20—A complete view of the Loop Skywire. The square loop is erected horizontal to the earth.**

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 (via a shorted SO-239 jack, for example), 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 star performers. The 10-MHz band can also be operated on both.

*3.5-MHz Loop Skywire* (3.5-28 MHz loop and 1.8-MHz vertical)

Total loop perimeter: 272 feet

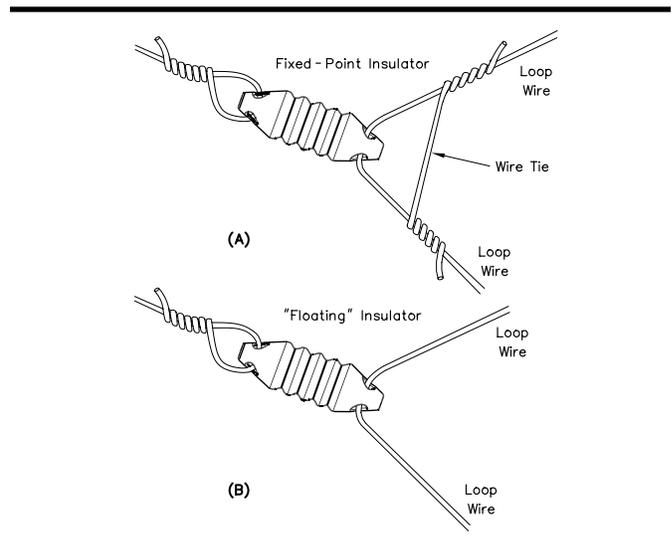
Square side length: 68 feet

*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.

Copper wire is usually used in the loop. Lamp or “zip” cord and Copperweld can also be used. Several loops have even been constructed successfully with steel wire, but soldering is difficult. **Fig 21** 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 21A, or leave the insulator free to “float” or slide along the



**Fig 21—Two methods of installing the insulators at the loop corners.**

wire, Fig 21B. 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. The feed point can be positioned anywhere along the loop that you wish. However, most users feed the Skywire at a corner. Fig 22 depicts a method of doing this. 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.

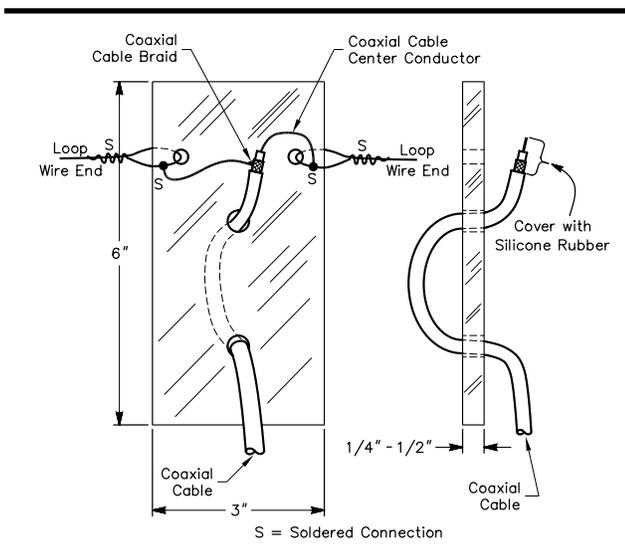
Generally a minimum of four supports is required. If trees are used for supports, then at least two of the ropes or guys used to support the insulators should be counterweighted and allowed to move freely. The feed-line corner is almost always tied down, however. Very little tension is needed to support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

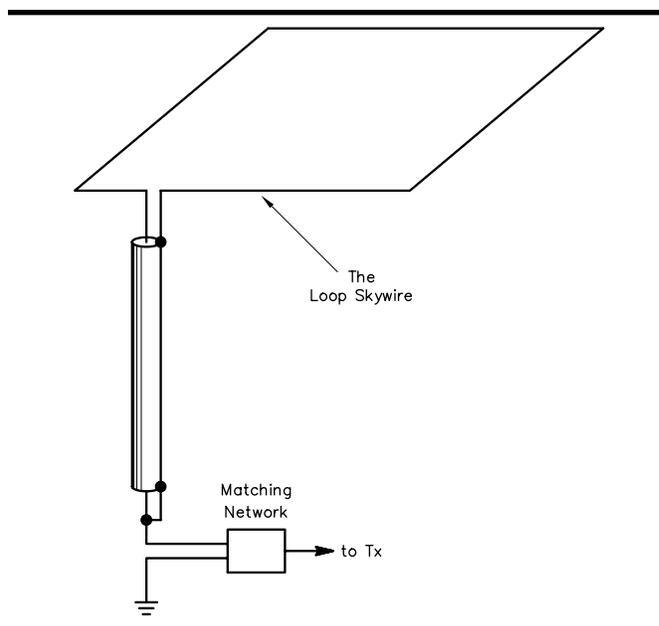
If you are preoccupied with SWR, the reading will depend on your operating frequency and the type of feed line used. Coaxial cable is sufficient. Open wire does not appear to make the loop perform any better or matching to it easier. Most users feed with RG-58, RG-59 or RG-62. RG-8 and RG-11 are generally too cumbersome to use. With full power and coaxial cable feeding these loops, feed-line problems have not been reported. The SWR from either of these loops is rarely over 3:1. If you are concerned about the SWR, use a Transmatch and eliminate all worries about power transfer and maximum signal strength. When constructing the loop, connect (solder) the coaxial feed line ends directly to the loop wire ends. Don't do anything else. Baluns or choke coils at the feed point are not to be used. They are unnecessary. Don't let anyone talk you into using them. The feed arrangement for operating the loop as a vertical antenna is shown in Fig 23.

The highest line SWR usually occurs at the second harmonic of the design frequency. The Loop Skywire is somewhat more broadband than corresponding dipoles, and the loop is efficient. Do not expect SWR curves that are "dummy load" flat!

Because the loop is high in the air and has considerable electrical exposure to the elements, proper



**Fig 22—Most users feed the Skywire at a corner. A high-impedance weather-resistant insulant should be used for the feed-point insulator. Cover the end of the coaxial cable with silicone rubber for protection from the weather and added electrical insulation. Dimensions shown are approximate.**



**Fig 23—The feed arrangement for operating the loop as a vertical antenna.**

methods should be employed to eliminate the chance of induced or direct lightning hazard to the shack and operator. Some users simply employ a three-connector (PL-259/PL-258/PL-259) weather-protected junction in the feed line outside the shack and completely disconnect the antenna from the rig and shack during periods of possible lightning activity.

Some skeptics have commented that the Loop Skywire is actually a vertical antenna in disguise. Yet when the loops have been used in on-the-air tests with both local and distant stations, the loop operating as a loop consistently “out-signals” the loop operating as a vertical.

## 7-MHz Loop

An effective but simple 7-MHz antenna that has a theoretical gain of approximately 2 dB over a dipole is a full-wave, closed vertical loop. Such a loop need not be square, as illustrated in **Fig 24**. It can be trapezoidal, rectangular, circular, or some distorted configuration in between those shapes. For best results, however, the builder 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.

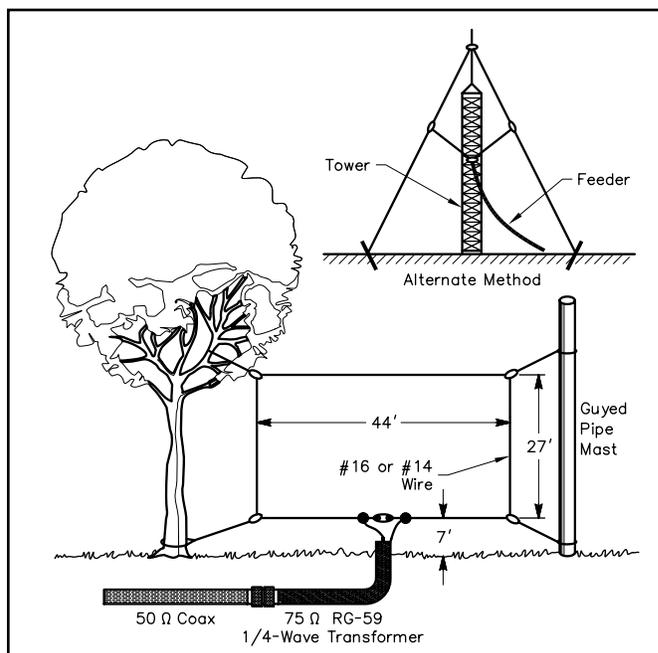
The loop can be fed in the center of one of the vertical sides if vertical polarization is desired. For horizontal polarization, it is necessary to feed either of the horizontal sides at the center.

Optimum directivity occurs at right angles to the plane of the loop, or in more simple terms, broad-side from the loop. One should try to hang the system from available supports which will enable the antenna to radiate the maximum amount in some favored direction.

Just how the wire is erected will depend on what is available in one’s yard. Trees are always handy for supporting antennas, and in many instances the house is high enough to be included in the lineup of solid objects from which to hang a radiator. If only one supporting structure is available it should be a simple matter to put up an A frame or pipe mast to use as a second support. (Also, tower owners see Fig 24 inset.)

The overall length of the wire used in a loop is determined in feet from the formula  $1005/f(\text{MHz})$ . Hence, for operation at 7.125 MHz the overall wire length will be 141 feet. The matching transformer, an electrical  $\frac{1}{4} \lambda$  of  $75 \Omega$  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,  $246/7.125 \text{ MHz} = 34.53$  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  $34.53 \text{ (feet)} \times 0.66 = 22.79$  feet, or 22 feet,  $9\frac{1}{2}$  inches.

This same loop antenna may be used on the 14 and 21-MHz bands, although its pattern will be somewhat different than on its fundamental frequency. Also, a slight mismatch will occur, but this



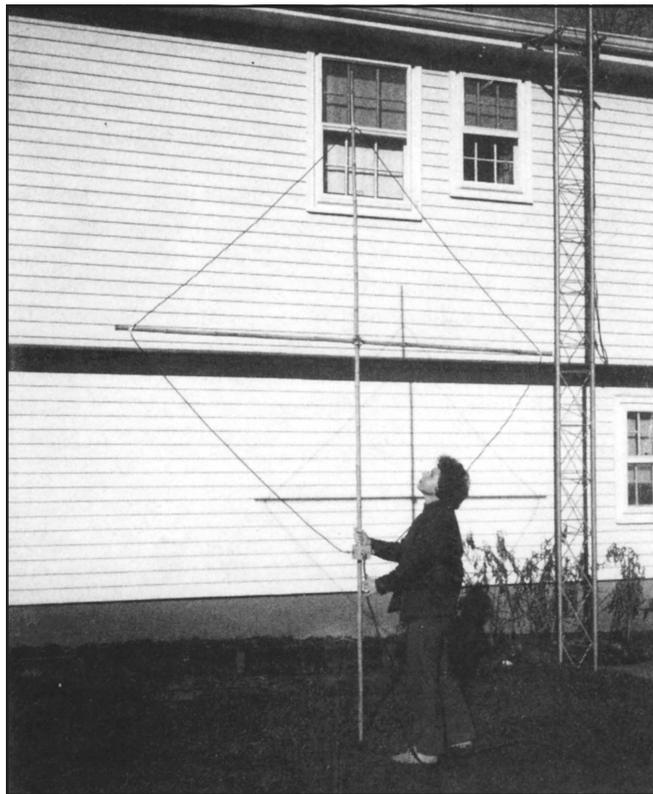
**Fig 24—Details of the full-wave loop. The dimensions given are for operation at 7.05 MHz. The height above ground was 7 feet in this instance, although improved performance should result if the builder can install the loop higher above ground without sacrificing length on the vertical sides. The inset illustrates 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.**

can be overcome by a simple matching network. When the loop is mounted in a vertical plane, it tends to favor low-angle signals. If a high-angle system is desired, say for 3.5 MHz, the full-wave loop can be mounted in a horizontal plane, 30 or more feet above ground. This arrangement will enhance sky-wave coverage on a short-haul basis.

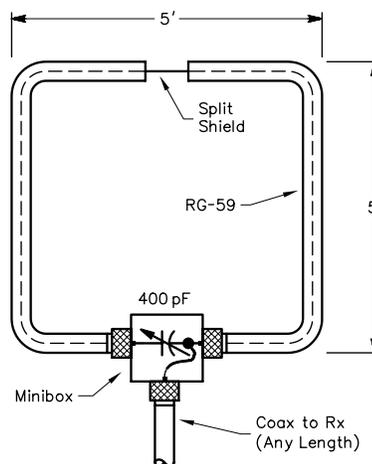
## A Receiving Loop for 1.8 MHz

Small shielded loop antennas can be used 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 1.8-MHz 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 25**.

To obtain the sharp bidirectional pattern of a small loop, the overall length of the conductor must not exceed  $0.1 \lambda$ . The loop of **Fig 26** has a conductor length of 20 feet. At 1.81 MHz, 20 feet is  $0.037 \lambda$ . With this style of loop,  $0.037 \lambda$  is about the maximum practical dimension if one is 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 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  $\mu$ H. The effect of the capacitance becomes less pronounced at the higher end of the HF spec-



**Fig 25**—Jean DeMaw, W1CKK, tests the 1.8-MHz shielded loop. Bamboo cross arms are used to support the antenna.



**Fig 26**—Schematic diagram of the loop antenna. The dimensions are not critical provided overall length of the loop element does not exceed approximately  $0.1 \lambda$ . Small loops which are one half or less the size of this one will prove useful where limited space is a consideration.

trum, 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.

In the model shown here it can be seen that a supporting structure was fashioned from bamboo poles. The X frame is held together at the center by means of two U bolts. The loop element is taped to the cross-arms to form a square. It is likely that one could use metal cross arms without seriously degrading the antenna performance. Alternatively, wood can be used for the supporting frame.

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

The shield braid of the loop coax is removed for a length of one inch directly opposite the feed point. The exposed areas should be treated with a sealing compound once this is done.

In operation this receiving loop has been very effective in nulling out second-harmonic energy from local broadcast stations. During DX and contest operation 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- $\Omega$  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 kHz and use it across the entire 1.8-MHz band. The degradation in performance at 1.8 and 2 MHz will be so slight that it will be difficult to discern.

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