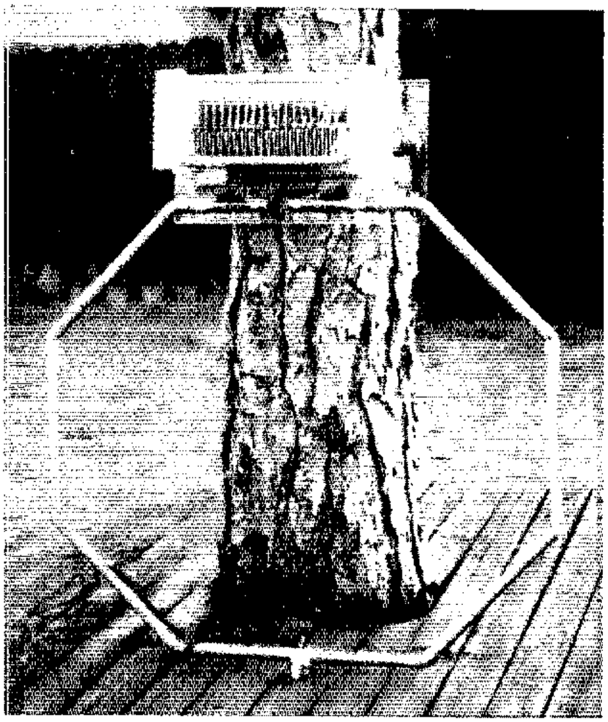
Small, High-Efficiency Loop Antennas



An alternative antenna for small spaces.

By Ted Hart, W5QJR
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The small loop antenna is akin to an uncut diamond. It has been around a long time, and has only recently been cut and polished to reveal a shining new gem. This antenna is small, operates well when mounted at ground level, and exhibits performance that competes with almost any HF antenna except a multi-element beam at a wavelength or more above ground. This article explains how the wrapper was taken off this antenna, and why.

History

The so-called "Army Loop" antenna was the first effective implementation of a small loop for transmitting.[1] It performed well, in spite of poor efficiency, but efforts to duplicate the design for amateur operation failed.[2] Antenna Research Associates developed the loop into an excellent small communications antenna and patented it in 1967, and Technology for Communications, International (TCI) also developed a version. Both companies have marketed the units at a price tag exceeding $13,000 including automatic tuner. My efforts have been directed to developing a small practical antenna that any ham can duplicate.

I was searching for a small antenna design to help hams with restricted space, and concluded that the loop was one feasible approach to achieve high efficiency in a small space. Small antennas are characterized by low radiation resistance, and the addition of a loading coil adds losses that result in poor efficiency. If a large capacitor is added to a small antenna to bring it into resonance, and the antenna conductor is bent to connect the two ends to the capacitor, a loop antenna is formed. If the losses in the conductor are small and there are no losses in the capacitor, a high-efficiency antenna can be achieved in a small space. The amount of losses that could be tolerated was unknown; therefore, I developed a set of equations to allow the various parameters to be calculated. Once that was done, the other problems were easily solved.

Small-Loop Definition

A small loop is defined as an antenna in the shape of a loop with a conductor length (circumference) less than one-third of a wavelength. It will produce a radiation pattern that compares to a doughnut (see Fig 1). If the doughnut is standing on the ground with its axis horizontal, there will be a null through its center (on its axis). A unique feature of the loop is the radiation polarization. First, consider the straight dipole. The polarization of the straight

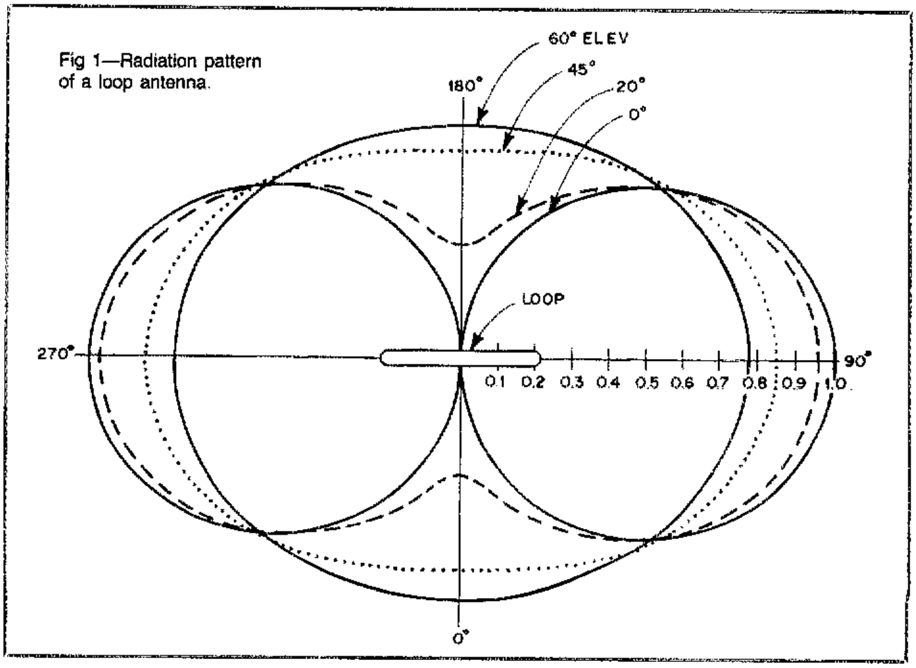

Fig 1—Radiation pattern of a loop antenna.

[1]Notes appear on page 36.

Table 1
Recommended Loop Antennas

Circumference (Feet)	*Frequency (MHz)*	*Efficiency (Below 100%) (−dB)*	*Tuning Capacitor (pF)*	*Bandwidth (kHz)*
8.5	29	0.4	9	109
	24	0.7	9	55
	21	1.0	23	36
	18	1.6	35	22
	14	3.1	60	12
	10	6.5	125	7
20	14	0.3	6	66
	10	1.0	29	20
	7	2.7	73	7
38	7.2	0.5	10	27
	4.0	3.0	102	5
	3.5	4.1	143	4
60	4.0	1.0	23	10
	3.5	1.5	47	7
	2.0	5.8	255	2
	1.8	7.0	328	2
100	2.0	2.1	88	4
	1.8	2.7	128	3

Notes
[1]All of the above use ¾-in copper tubing.
[2]Values of efficiency and bandwidth without radials.

dipole is taken to be the direction of the electric field, which is parallel to the axis of the dipole—no electric field or polarization exists in any other direction. If we bend the dipole into a circular loop having a single plane, the only polarization component radiated by the loop lies in the plane of the loop. However, in this plane the polarization component radiated from any given point on the loop is parallel to a line tangent to the loop at that point. Consequently, if the plane of the loop is oriented horizontally, the polarization will be horizontal everywhere—no vertical component exists because no polarization component exists outside the plane of the loop.

On the other hand, if the plane of the loop is oriented vertically, the tangent line at the point of 0° in elevation is vertical, yielding vertical polarization. At the point of 90° in elevation, the tangent line is horizontal, yielding horizontal polarization. However, at all points in the loop plane between 0° and 90° in elevation, the tangent line is at an angle between vertical and horizontal, yielding a linear polarization comprising both vertical and horizontal components. For example, at 30° elevation the polarization angle is 60°; at 45° elevation, the polarization is at 45°, and so on. The fact that it radiates at vertical and horizontal angles allows the benefits of both vertical *and* horizontal dipoles to be realized.

Mathematical Equations Used to Define the Loop

The equations I developed to define the loop follow.

Radiation resistance, R_R,

$$= 3.38 \times 10^{-8} (F^2A)^2 \qquad \text{(Eq 1)}$$

Loss resistance, R_L,

$$= 9.96 \times 10^{-4}\sqrt{F}\frac{S}{D} \qquad \text{(Eq 5)}$$

$$\text{Efficiency, } \eta, = \frac{R_R}{R_R + R_L} \qquad \text{(Eq 3)}$$

Inductance, L, $= 1.9 \times 10^{-8}$

$$S\left(7.353 \log_{10} \frac{96S}{\pi D} - 6.386\right) \qquad \text{(Eq 4)}$$

Inductive reactance, X_L,

$$= 2\pi FL \times 10^6 \qquad \text{(Eq 5)}$$

Tuning capacitor, CT,

$$= \frac{1}{2\pi FX_L \times 10^6} \qquad \text{(Eq 6)}$$

Quality factor, Q,

$$= \frac{F}{\Delta F} = \frac{X_L}{2(R_R + R_L)} \qquad \text{(Eq 7)}$$

$$\text{Bandwidth, } \Delta F, = \frac{F}{Q} \qquad \text{(Eq 8)}$$

Distributed capacitance, C_D, $= 0.82$ S

Capacitor voltage, V_C, $= \sqrt{PX_L Q}$ (Eq 9)

where
A = area of loop (sq ft)
S = length of conductor (ft)
F = operating frequency (MHz)
D = diameter of conductor (in)
P = transmitter power (W)

Efficiency

Efficiency is defined as the power radiated by the antenna divided by the power applied to the antenna. Power applied to the radiation resistance will radiate, while power applied to the loss resistance will be converted to heat. Radiation resistance is a function of the area of a loop. For a conductor of given length, a round loop will have more area, hence a higher radiation resistance than any other shape. When mechanical factors are considered, an octagon loop is the preferred shape. A loop will have a radiation resistance approaching 0.05 ohm; therefore, loss resistance must be kept low. A loop made of ¾-in-diameter copper pipe is a reasonable compromise if the circumference is greater than 1/8 wavelength. Loops with circumference less than that require larger conductors. Table 1 shows recommended loop sizes for various frequencies.

Frequency Range

The inductance of a loop can be calculated and the inductive reactance determined. The value of tuning capacitance that resonates the loop at a given frequency can then be calculated. I constructed several loops and measured them to find a value for the distributed capacitance. An equation was then empirically developed to define the distributed capacitance for any size of loop. Then, by subtracting distributed capacitance from tuning capacitance, we can determine the actual value of tuning capacitor required. With a large variable capacitor, a loop can be tuned to operate over a wide frequency range. The highest operating frequency of a small loop is determined by self-resonance, and the circumference must be less than ¼ wavelength. A 2:1 frequency range is reasonable for a loop—for example, a 14- to 30-MHz loop won second place in the ARRL Antenna Design Competition.[5]

Bandwidth

Here's the bad news—the loop is the equivalent of a high-Q tuned circuit, which means it has a narrow bandwidth. We can tune the loop over a wide frequency range, but the instantaneous bandwidth at the operating frequency will be low. At the lower design frequency of the recommended loops, the Q may be as high as 1000 and, therefore, the bandwidth is measured in kilohertz. This means you will need a remote motor drive on the tuning capacitor to shift frequencies. It's a low price to pay, and the only shortcoming of the loop antenna. You are simply trading bandwidth for size—you don't give up any other performance parameters.

The bandwidth can be calculated from the equations. After building your loop, it is im-

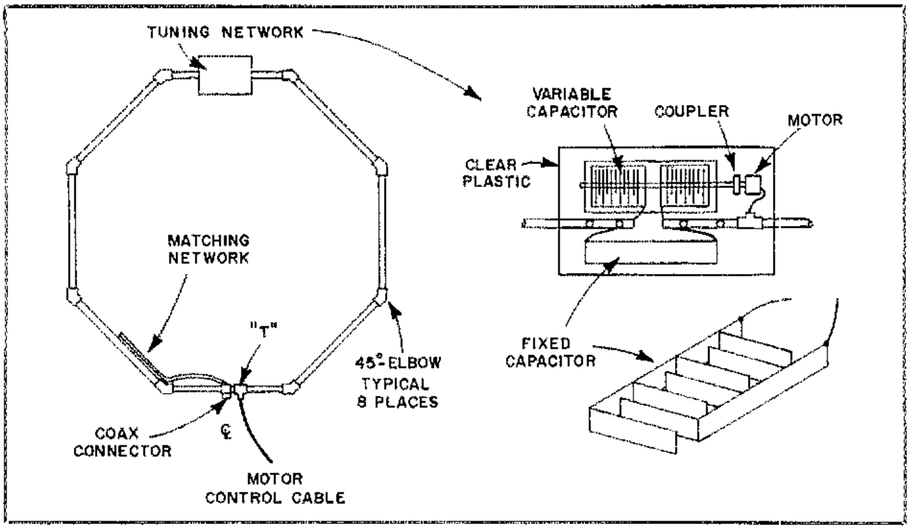

Fig 2—Construction details for the recommended loops.

portant to measure the actual bandwidth. Comparing the measured value to the calculated value will tell if you did a poor job of construction—it will be apparent. Any metal in close proximity to the loop will absorb radiation and reduce the efficiency. This will become apparent from the bandwidth measurement.

Choosing the Tuning Capacitor

A high-Q antenna also means a high voltage on the tuning capacitor. An air gap of one inch in air is good for about 75,000 V. A power input to the antenna of 500 W will produce voltages of up to 30,000 V, so you need a capacitor spacing of ½ inch (¼ in for 100 W). The ideal capacitor for this application is a high-voltage vacuum variable, if you can afford one. Using a conventional variable capacitor will make the antenna useless because of the losses in the wiper contacts. This was one dilemma I ran into during development of the antenna. Then, late one night, I realized that a split-stator capacitor has *no* wiper contacts. If you connect each side of the loop to the stators, the RF coupling is through the rotors—no wiper contacts—and the spacing is effectively doubled since the two sections of the capacitor are in series. Now you have an inexpensive capacitor with no wiper contacts. However, you will not get the low losses and high efficiency unless the plates are welded together. No mechanical contacts are allowed! This means that you cannot use a capacitor with mechanical spacers between the plates unless a conductor is welded to electronically bond the plates. A local welding shop can do the job for you. (Note: The amateur version of the "Army Loop" used wiper contacts in the tuning network—now you know why it didn't work.)

If you need a fixed capacitor to parallel the variable, make one of printed-circuit-board material. The value of capacitance can be determined from: $C = 0.225\,(N-1)\,A/D$, where N is the number of plates, A is the area of a single plate in square inches and D is the spacing in inches. Remember that you need a 30,000-V rating for 500 W—½-in spacing for a high-Q loop.

A Broadband Matching Network

The next step is to build a matching network to allow us to put power into the loop. Some builders use a coupling loop, but such a method is very critical. The amateur "Army Loop" used a very inefficient network. The easy way turns out to be the best—a simple form of gamma match that does not use reactive components. A piece of ¼-in copper tubing is soldered to the loop and to the coaxial cable connector (see Fig 2). A perfect match can be achieved by bending the tubing, and if the match is made at the center frequency of the loop, the SWR will be 2:1 or less over a 2-to-1 frequency range.

A Remote Motor Drive

There isn't space in this article to cover all the details, but take it on faith that you need a stepper motor with a gear drive to give adequate tuning resolution. The computations are left to you. (Hint: A 10-foot loop will have a 14-kHz bandwidth at 14 MHz. A 50-pF capacitor can tune over a 16-MHz range with 180° rotation.) A possible answer is a motor, part no. 3004-001, and controller, part no. 22001, available from Hurst Manufacturing Co, Princeton, IN 47670. The cost of both units is about $90. The controller is an integrated circuit that requires a speed potentiometer, control switches and a 12-V source.

Loop Construction

Fig 2 shows construction details for the octagon loop. The octagon shape is easy to construct using 45° elbows, available at any plumbing store. Just determine the size of your loop and cut eight equal-length pieces of copper pipe to total the circumference. Solder all lengths with 45° elbows to form the octagon. Make a cut in one side of the loop and install a copper T. Split and flatten a 3-in piece of pipe to make a mount for the coaxial-cable connector and solder it to the loop next to the T. On the side opposite to the coaxial connector cut out a section about two inches long. Mount a clear piece of ¼-in-thick plastic sheet to the gap and mount the tuning capacitor, motor and a high-voltage coupler for the capacitor on the plastic. Install another T about 6 inches from the capacitor/motor and run the control cable from the lower T to the upper T inside the copper pipe—in one T and out the other. Connect the tuning capacitor stators to the ends of the gap with pieces of copper strap soldered on each end. Cut a piece of ¼-in copper tubing the length of one side of the octagon. Bend it to conform to the shape of the loop and solder one end to the coaxial cable connector and the other end to the loop. Wrap it with plastic electrical tape.

Mount the completed loop vertically on a wooden pole (no metal allowed). Connect the receiver to the loop and find the resonant frequency by listening for a noise peak in the receiver.

Tuning Up

Connect an SWR bridge at the base of the loop. Turn on the transmitter and tune the loop or the transmitter frequency for maximum output as indicated on the SWR bridge or a field strength meter. Bend the matching network tubing to achieve minimum SWR. That's all there is to it!

If you have a lossy tuning capacitor or metal in the vicinity of the loop, you won't be able to get a low SWR and the bandwidth will be high. You will lose some efficiency, but you may not be able to get far enough away from the metal that is causing the problem (such as power lines). Just enjoy your antenna and realize that 6 dB is probably only one S unit. If you must operate near metal, you can extend the length of the ¼-in copper-tubing matching section. Trial and error with the extended matching section should result in a lower SWR.

After the antenna is working to your satisfaction, build a box from pieces of plastic to shield the tuning unit from the weather. Any good sign shop will cut the pieces to size for you. Don't use colored plastic because the materials that give it color are conductive. (Mine caught fire one night!)

Conclusion

Since there are few low-loss capacitors commercially available, except vacuum variables, a variable capacitor has been designed specifically for this application (see Fig 3). This capacitor has an effective capacitance

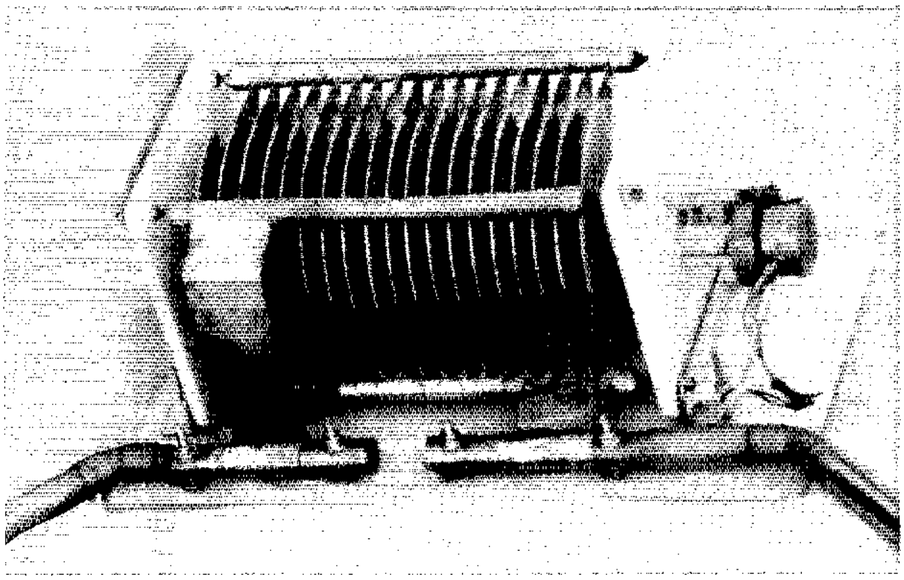

Fig 3—The W5QJR variable capacitor for loop antennas. Note the mounting details.

of 150 pF (300 pF per section) and uses the butterfly concept rather than the normal split-stator mechanical design. It has copper stator plates, with spacing ¼ inch on each section to allow high-power operation. The large capacitance range allows coverage of all the HF ham bands from 3.5 to 30 MHz with just two loops.[4]

I would like to thank Roger Faulstick, KD4AS, for his encouragement and all the work he has done performing experiments and collecting meaningful performance data. I also wish to acknowledge and thank all those who have written to me with encouraging comments.

Notes

[1]K. Patterson, "Down To Earth Army Antenna," *Electronics*, Aug 1967.
[2]L. McCoy, "The Army Loop in Ham Communications," *QST*, Mar 1968, pp 17-18.
[3]G. Hall and B. Schetgen, "Six Winners Emerge from the ARRL Antenna Competition," *QST*, Feb 1985, pp 44-47.
[4]This capacitor is available from W5QJR Antenna Products, PO Box 334, Melbourne FL 32902. Send a business-size SASE for further information.

Satellite DXing

(continued from page 32)

mitter is enabled. When you switch back to receive, the sequence is just the opposite. First, the transmitter is switched off, then the power amplifier is disabled, and then the TR relays change state.

Proper TR sequencing is easy to implement with simple circuitry described in *The 1986 ARRL Handbook*.[5] If you wish to purchase a sequencer, check with the equipment suppliers listed in Part 2 of this series. I've found out the hard way that some form of automatic TR sequencing is necessary with remotely controlled equipment to protect the unwary preamp from cockpit error. Most of us are more fallible than the GaAsFET can stand.

Receiving

The only additional equipment I have found useful applies to those of you who use a receiving converter and an HF receiver for downlink reception. I built an in-line switchable attenuator to use between the converter output and the antenna jack of my 10-meter receiver. I use the attenuator to lower the AGC level and improve the perceived signal-to-noise ratio. In addition, by adjusting the attenuator so the S meter on my HF rig rests at zero, I can give more-accurate signal reports. The attenuator circuit is shown in Chapter 25 of *The 1986 ARRL Handbook*, but I modified it so that there are only three steps: 5, 10 and 20 dB. These three settings allow attenuation in 5-dB steps from 0 to 35 dB.

Station Control

Depending on how complicated you make your satellite setup, you might want to combine most of the switching and control circuitry into a single box so that you have ready access to all controls. Fig 14 shows the system I use. A Minibox cut to a low profile (small enough to fit underneath a transceiver) contains all of the switches I need to control my station, as well as the TR sequencer circuit board. With these switches, I can change polarization on both antennas from RHCP to LHCP; activate, at will, the 2-m and 70-cm preamplifiers; and switch the power amplifier in or out of the line for QRP/QRO operation. I also have the option of manual PTT. The microphone PTT line activates the sequencer.

I hope that this discussion has provided some food for thought for your station. The setup is really not complex; by no means do you need all of the gadgets described here. Perhaps it is all in the mind of the beholder—I happen to enjoy building and modifying equipment. In any event, the last installment of this series will discuss finding and operating through OSCAR 10.

Notes

[1]A. Zoller, "Tilt Rather Than Twist," *Orbit*, Sep/Oct 1983, pp 7-8.
[2]J. Reisert, "VHF/UHF World—Protecting Equipment," *Ham Radio*, Jun 1985, pp 83-87.
[3]C. Osborne, ed, *Southeastern VHF Society Newsletter*, May 1983.
[4]G. Krauss, "VHF and UHF Low Noise Preamplifiers," *QEX*, Dec 1981, pp 3-6.
[5]M. Wilson, ed, *The 1986 ARRL Handbook* (Newington: ARRL, 1985). Available from your local radio store or from ARRL for $18 ($19 outside US). Add $2.50 ($3.50 UPS) per order for shipping and handling.
[6]Sequencing ideas are shown on pp 31-6 to 31-12, 32-37 and 32-38.

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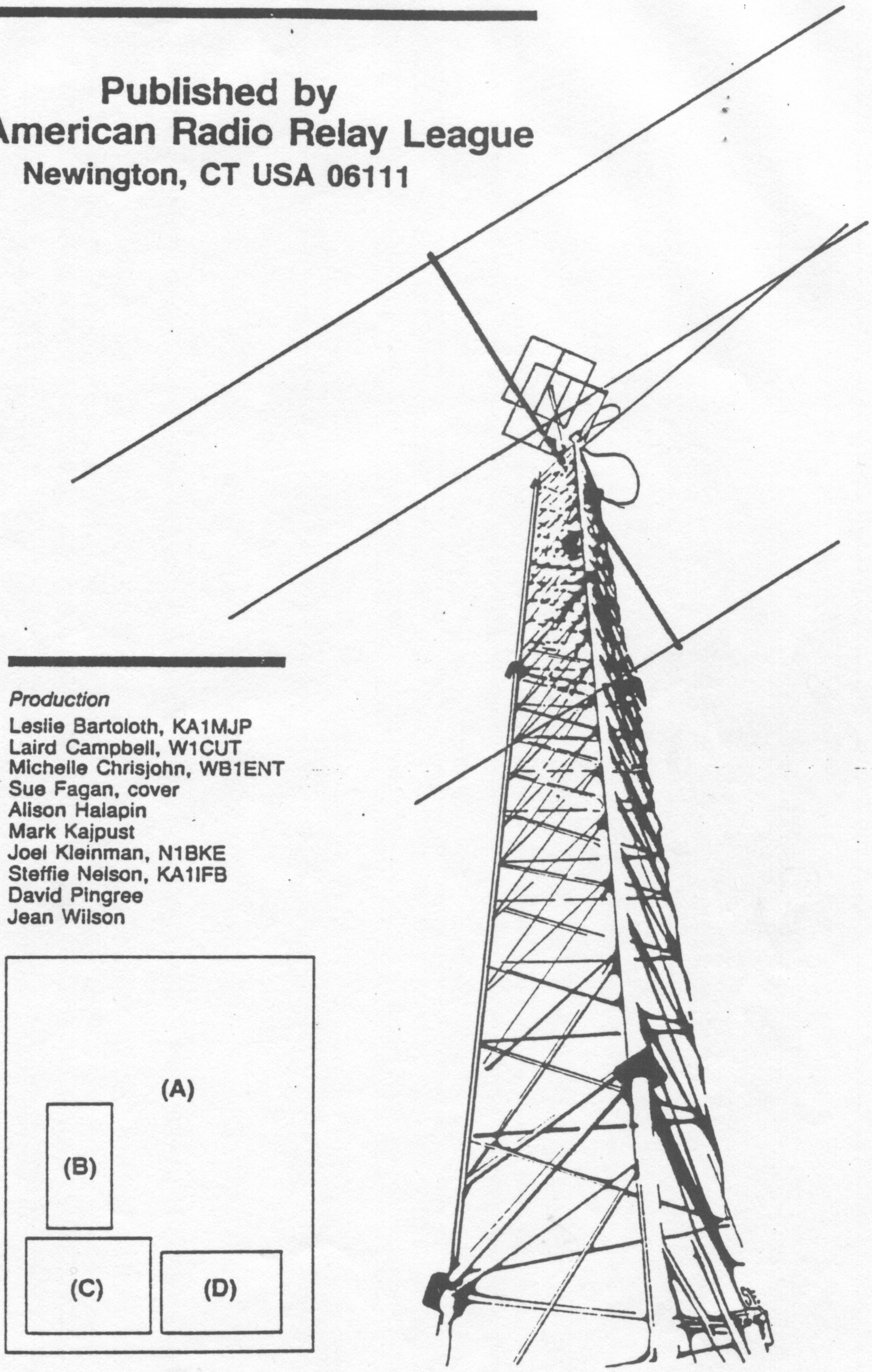

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A—Photo of 120-foot tower at W1AW by Meyers Studio.
Moon photo courtesy Chuck Hutchinson, K8CH

B—Photo courtesy Bob Cutter, KI0G

C—30-foot polar-mount dish at K5AZU

D—12 17-element long-boom 2-meter Yagis at N5BLZ

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 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.

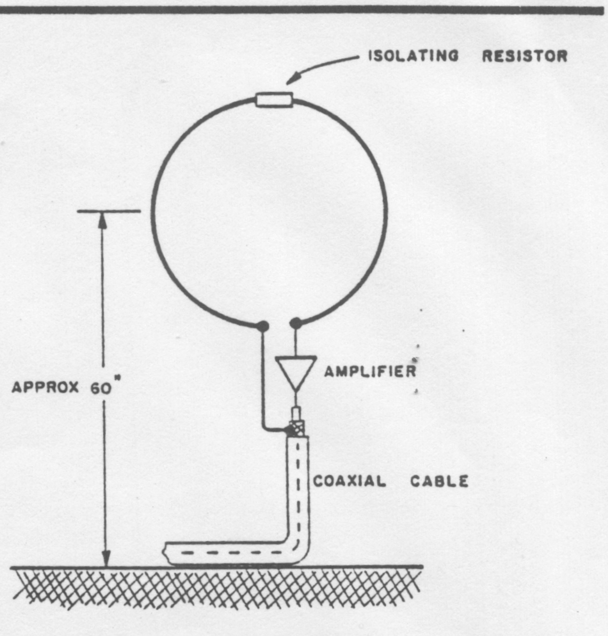

Fig 13—A single wide-band loop antenna used in an aperiodic array.

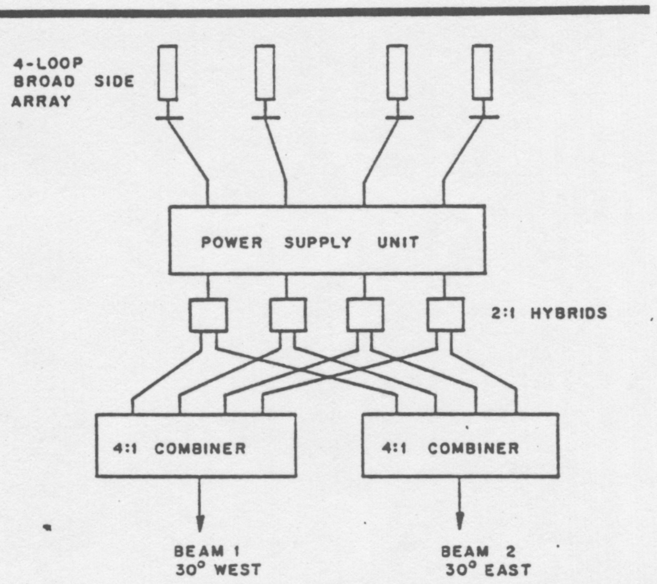

Fig 14—Block diagram of a four-loop broadside array with dual beams separated by 60° in azimuth.

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 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 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 a transmitting loop 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

Table 3
Transmitting Loop Equations

$X_L = 2\pi fL$ ohms

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

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

$$V_c = \sqrt{PX_LQ}$$

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

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

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 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 da and construction details for the Hart loop are presented lat in this chapter.) Here we cover some matters which ar common to both antennas.

The radiation resistance of a loop in ohms is given b

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

where

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

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

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

where

η = antenna efficiency, %
R_R = radiation resistance, Ω
R_L = loss resistance, Ω

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 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.

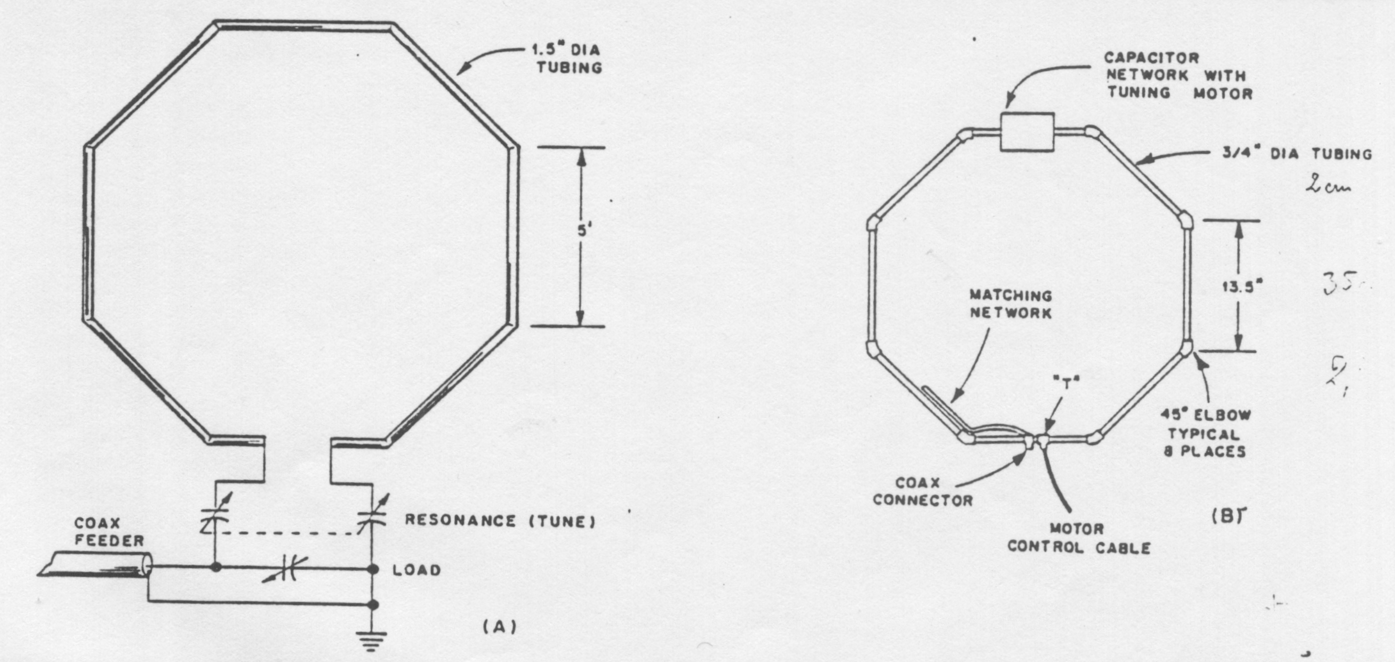

Fig 15—At A, a simplified diagram of the army loop. At B, the W5QJR Hart loop, which is described in more detail later in this chapter.

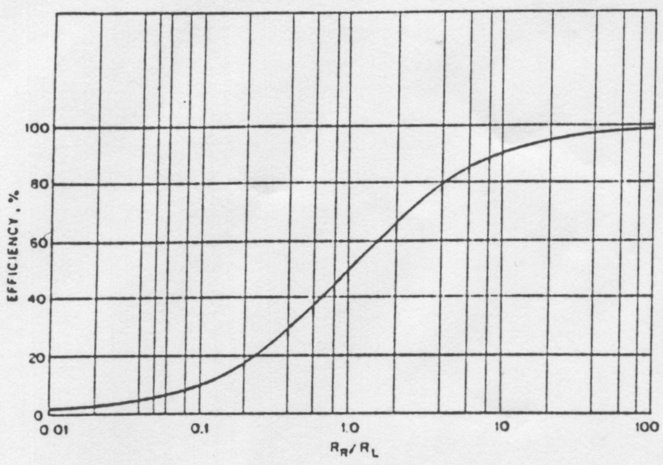

Fig 16—Effect of the ratio of R_R/R_L on loop efficiency.

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 the capacitors have a high RF current rating, such as transmitting micas or the Centralab 850 series. Be aware that even a 100-watt transmitter can develop currents in the tens of amperes, and voltages across the tuning capacitor in excess of 10,000 volts. This consideration also applies to any conductors used to connect the loop to the capacitors. A piece of no. 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. It includes information extracted from his book, *Small High Efficiency Antennas Alias the Loop*.

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.

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. The most important aspect of the development was establishing a complete set of mathematical equations to define the loop. This was followed by designing a simple feed system, and finally a practical tuning capacitor was found. The results of this development program are presented here. Fig 17 presents computer-derived data for various size loop antennas for the HF amateur bands.

Loop Fundamentals

A small loop has the radiation pattern shown in Fig 18. The pattern is easily conceived as a doughnut with a hole (null) in the pattern through the center of the loop at low elevation angles. When the circumference of the loop is less than ⅓ λ, regardless of the shape of the loop (round or square), that pattern will be obtained. In the majority of applications the loop will be mounted vertically. Mounted this way, it radiates at all vertical angles in the plane of the loop.

The loop has been defined mathematically by the

Loop No. 1
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

Loop No. 2
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

Loop No. 3
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

Loop No. 4
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 20. The capacitor specification data is based on 1000 W of transmitted power. See text for modifying these specifications for other power levels.

equations in Table 4. By using a computer and entering the circumference of the loop and the conductor diameter, all of the performance parameters can be calculated from these equations. Through such an analysis, it has been determined that the optimum size conductor is ¾-inch copper pipe, considering both performance and cost.

The loop circumference should be between 1/4 and 1/8 λ at the operating frequency. It will become self-resonant above ¼ λ, and efficiency drops rapidly below 1/8 λ. 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

Loop No. 5							
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

Loop No. 6					
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

Loop No. 7					
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

Loop No. 8				
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

Fig 17 Continued.

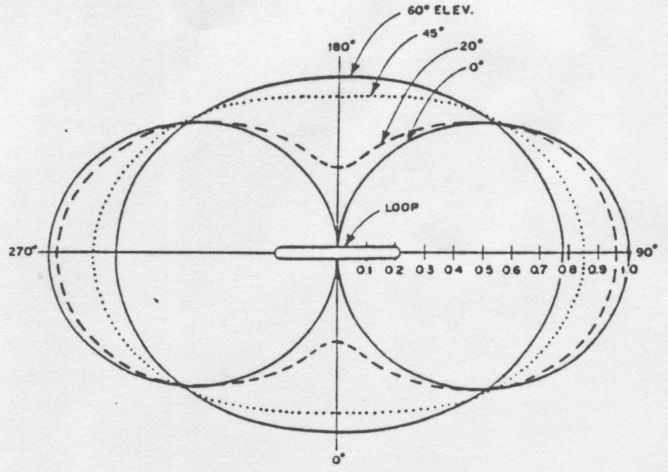

Fig 18—Azimuth patterns of a small vertical loop antenna at various elevation angles. The loop is bidirectional, with the greatest signal strength in the plane of the loop, as shown. In these directions the loop is vertically polarized.

because of the loop image. The length of each radial need be only twice the loop diameter. It should be noted that ¼ λ radials should be used for loops mounted over poor ground to improve performance. Data for Fig 17 was computed for ¾ 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 ¼ 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 shape of the pipe forms a single-turn coil. The value of inductance and stray capacitance can be calculated and a corresponding value of tuning capacitance calculated to provide resonance for a given frequency. Fig 19 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

Table 4
Basic Equations for a Small Loop

Radiation resistance, ohms	$R_R = 3.38 \times 10^{-8} (f^2 A)^2$
Loss resistance, ohms	$R_L = 9.96 \times 10^{-4} \sqrt{f} \frac{S}{d}$
Efficiency	$\eta = \frac{R_R}{R_R + R_L}$
Inductance, henrys	$L = 1.9 \times 10^{-8} S \left(7.353 \log_{10} \frac{96\,S}{\pi d} - 6.386\right)$
Inductive reactance, ohms	$X_L = 2 \pi f L \times 10^6$
Tuning capacitor, farads	$C_T = \frac{1}{2 \pi f X_L \times 10^6}$
Quality factor	$Q = \frac{f \times 10^6}{\Delta f} = \frac{X_L}{2(R_R + R_L)}$
Bandwidth, hertz	$\Delta f = \frac{f \times 10^6}{Q} = (f_1 - f_2) \times 10^6$
Distributed capacity, pF	$C_D = 0.82S$
Capacitor potential, volts	$V_C = \sqrt{P X_L Q}$

where
- f = operating frequency, MHz
- A = area of loop, square feet
- S = conductor length, feet
- d = conductor diameter, inches
- η = decimal value; dB = $10 \log_{10} \eta$
- P = transmitter power, watts

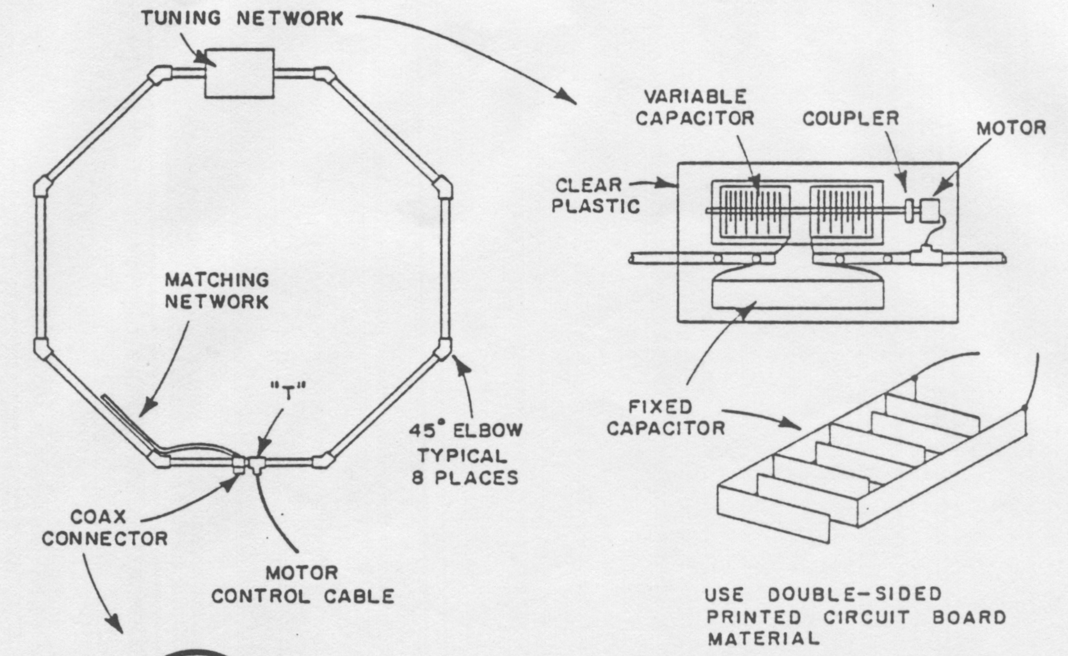

Fig 20—Loop construction details. Fig 18 gives loop design data for various frequency ranges. A variable capacitor designed specifically for transmitting loop use is available from W5QJR Antenna Products, PO Box 334, Melbourne, FL 32902. (Send SASE for information.) See text for information on tuning motor.

capacitor and drive motor. The side of the box that mounts to the loop and the capacitor should be at least 1/4 inch thick, preferably 3/8 inch. The remainder of the box can be 1/8-inch plastic sheet. Any good sign shop will cut the pieces to size for you. Mount the loop to the plastic using 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 × 4-inch lumber with 1 × 4-inch boards on either side to form an I section. Hold the boards together with ¼-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 ¼-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 ¼-inch tubing line, as shown in Fig 20, 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 tuning 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, 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 (½ λ) in length and 120 feet high (¼ λ). A ¼-λ 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 21. 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_{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.

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 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

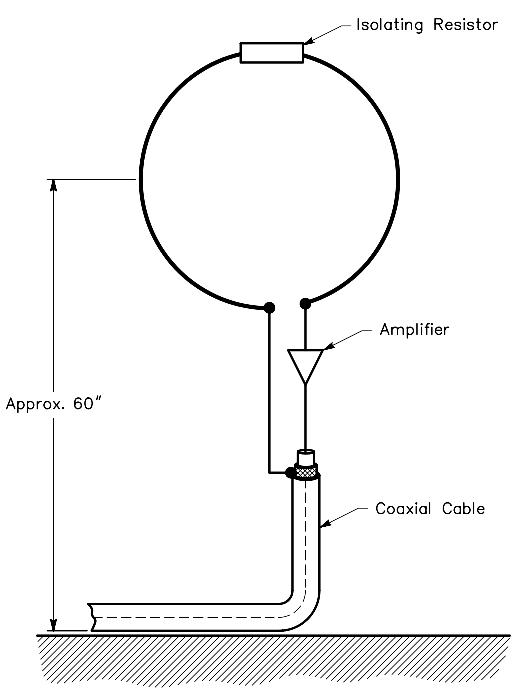

Fig 13—A single wide-band loop antenna used in an aperiodic array.

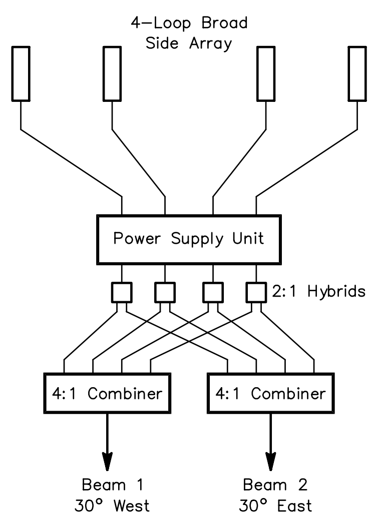

Fig 14—Block diagram of a four-loop broadside array with dual beams separated by 60° in azimuth.

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

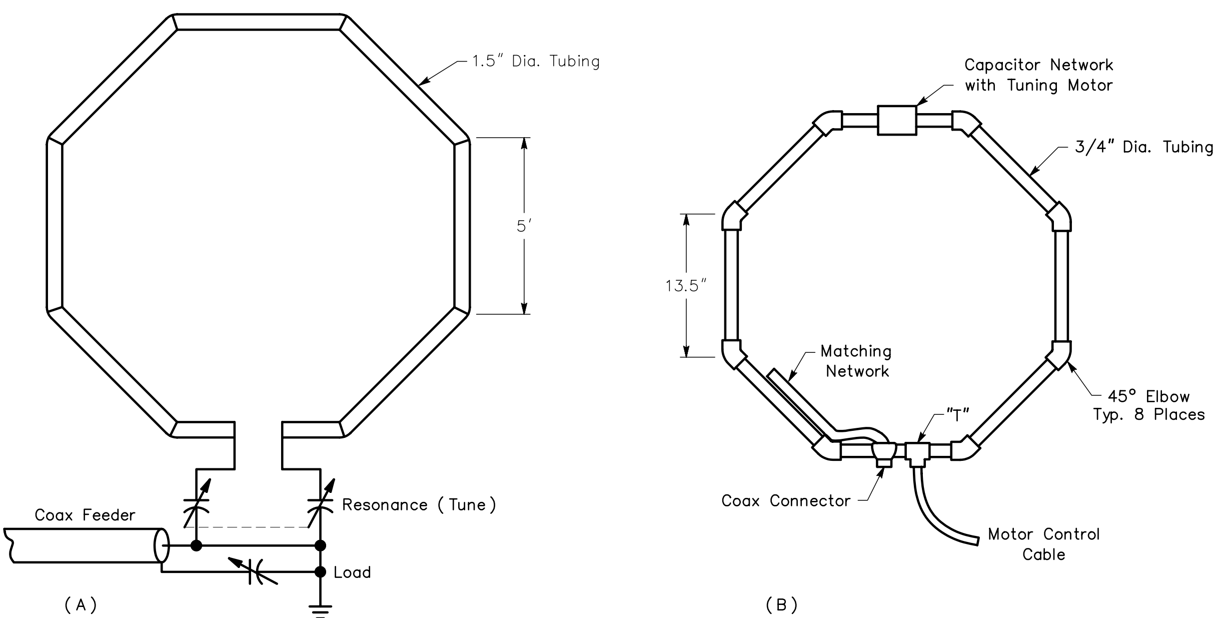

Fig 15—At A, a simplified diagram of the Army Loop. At B, the W5QJR loop, which is described in more detail later in this chapter.

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 $\pi \times 0.5^2 = 0.785$ 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.

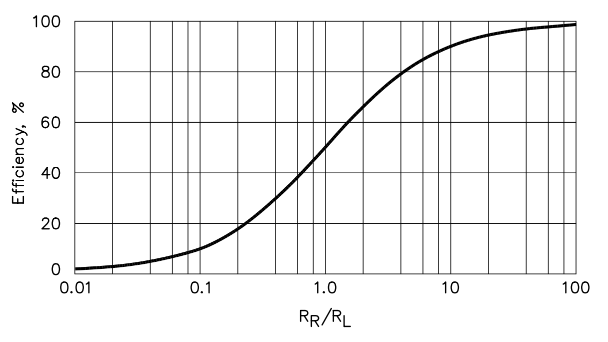

Fig 16—Effect of ratio of R_R/R_L on loop efficiency.

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.

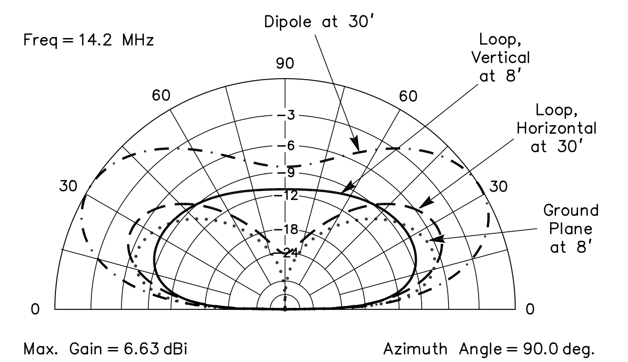

Fig 17—Elevation-plane plot at 14.2 MHz, showing response of an 8.5-foot circumference octagonal copper loop (width of 16.2 inches), compared to a full-sized λ/4 ground-plane vertical with two elevated λ/4 radials, the same small loop flipped horizontally at a height of 30 feet, and lastly, a λ/2 flattop 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.

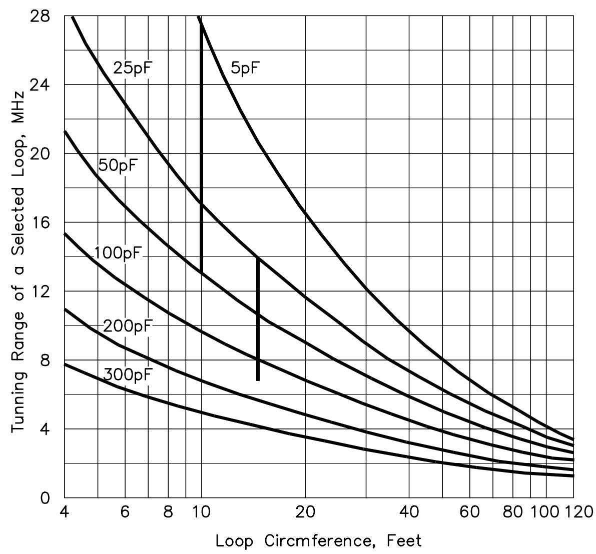

Fig 19—Frequency tuning range of an octagon-shaped loop using ¾-inch copper water pipe, for various values of tuning capacitance and loop circumference.

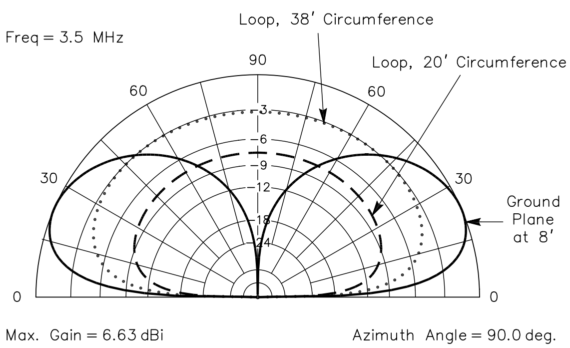

Fig 18—Elevation-plane response of three antennas at 3.5 MHz—a 20-foot circumference octagonal copper loop, a 38-foot circumference copper loop and a full-sized λ/4 ground plane with two elevated radials. The bottom of each antenna is mounted 8 feet above ground for safety. The 38-foot circumference 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.

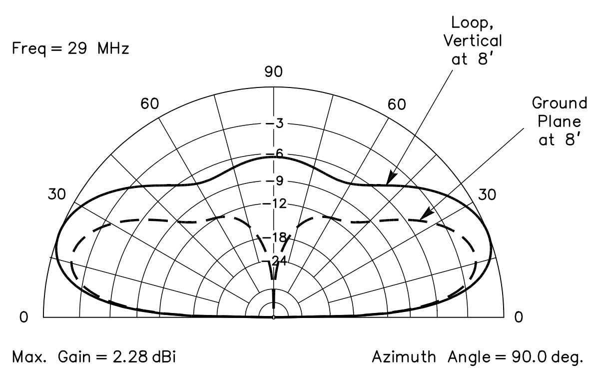

Fig 20—Elevation-plane plot for a 16.2-inch wingspan octagonal copper loop at 29 MHz, compared to a λ/4 ground-plane antenna with two resonant elevated radials. The gains at low angles are almost identical, but the loop exhibits more gain at medium and high elevation angles. Again, the bottom of each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

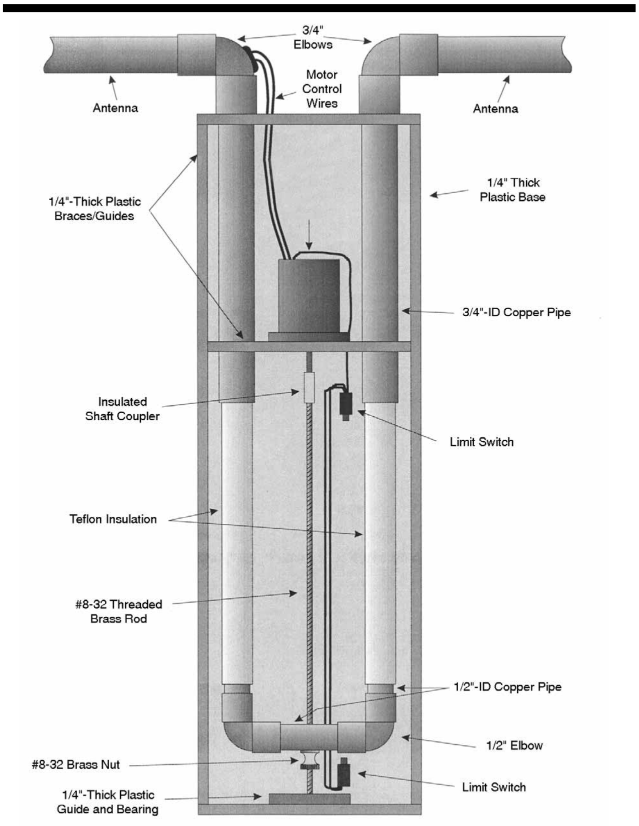

Fig 21—A practical trombone capacitor designed by Bill Jones, KD7S, for his compact transmitting loop. This capacitor has a tuning range from 12 to almost 60 pF, and can withstand at least 5 kV peak. The 10-inch ½-inch ID tubes are covered with Teflon-sheet insulation and slide into the ¾-inch ID copper 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, WØRPV, 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 × 4 1/2-inch aluminum plates separated by a piece of window glass that is 8 1/2 × 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.

WØRPV 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 WØRPV 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.

WØRPV 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

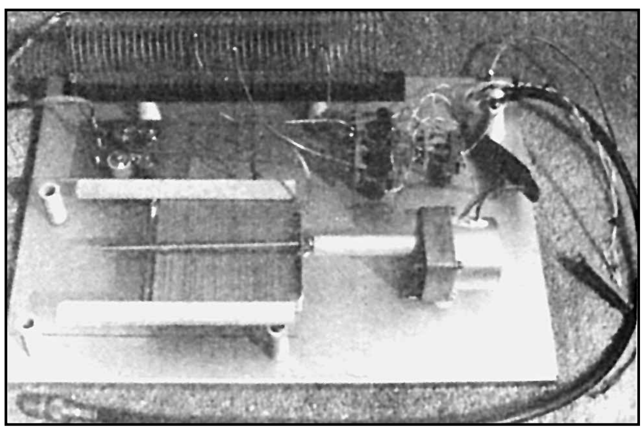

Fig 22—The picture-frame-glass variable capacitor design of Richard Plasencia, WØRPV. Two aluminum plates separated by a piece of glass scavenged from a picture frame create a variable capacitor that can withstand 12,000 V, with a variable range from 16 to 542 pF.

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.

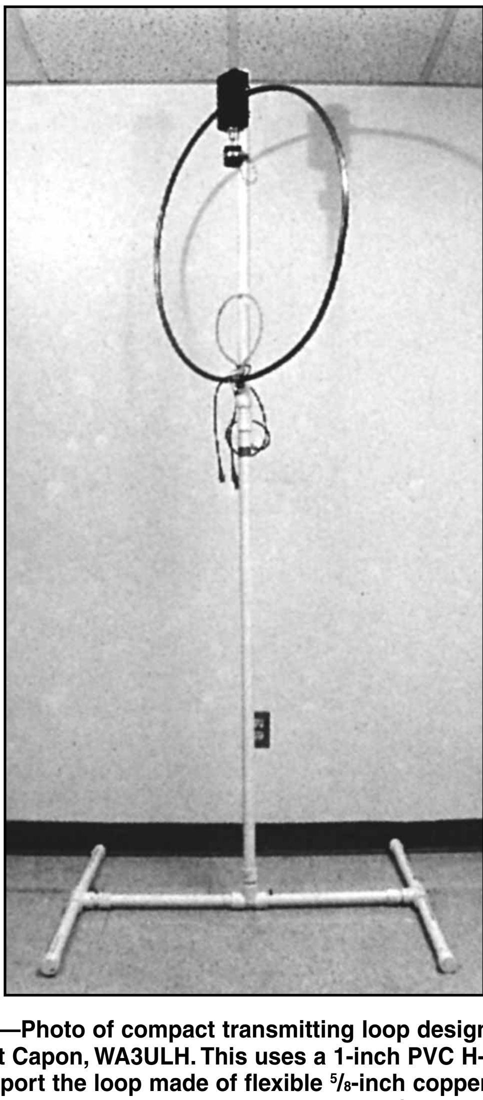

Fig 23—Photo of compact transmitting loop designed by Robert Capon, WA3ULH. This uses a 1-inch PVC H-frame to support the loop made of flexible 5/8-inch copper tubing. The small coupling loop made of RG-8 coax braid couples the loop to the coax feed line. The tuning capacitor and drive motor are at the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

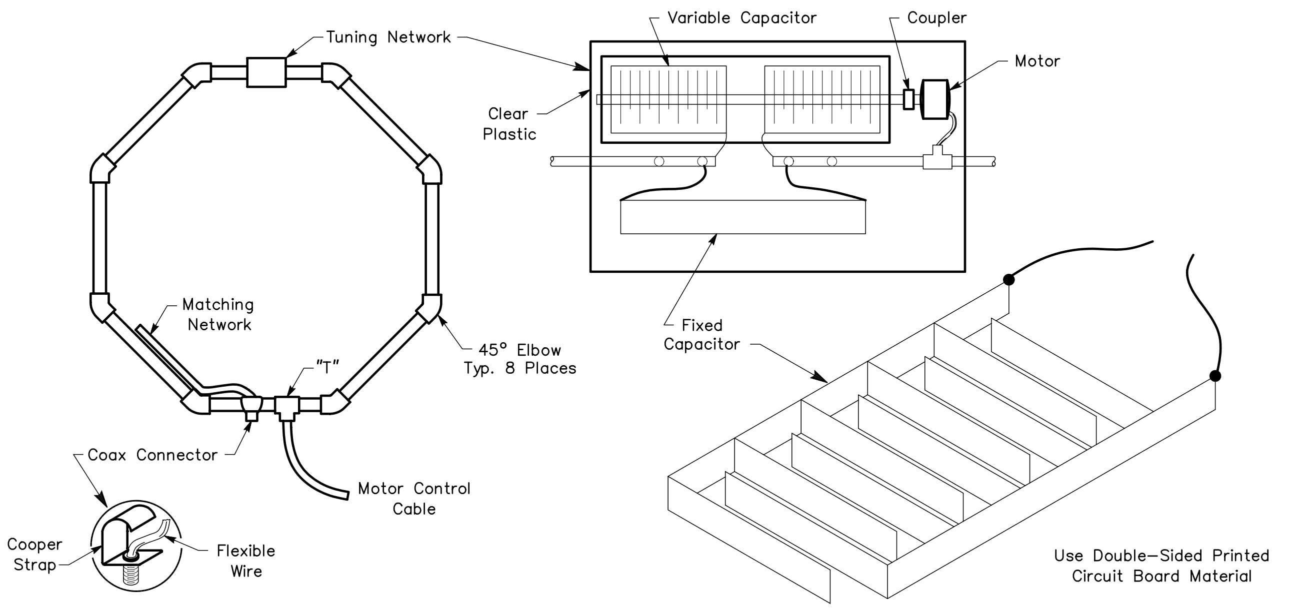

Fig 24—Octagonal loop construction details. Table 4 gives loop design data for various frequency ranges.

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.