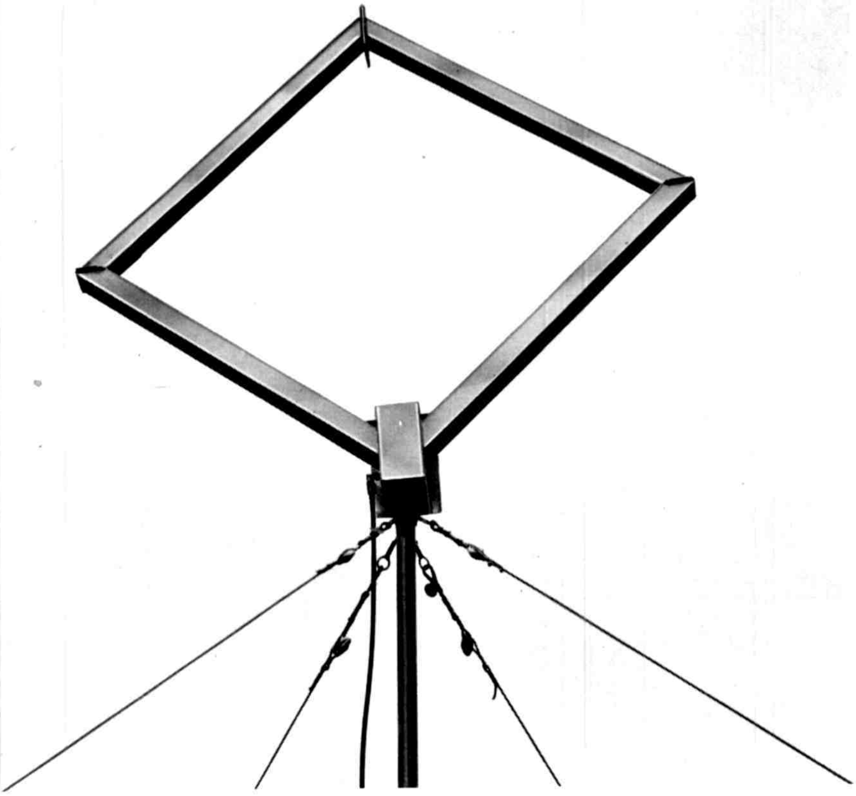

loop antennas

A discussion of small loop receiving antennas and details on their construction for the low-frequency bands

Most amateurs use the same antenna for both receiving and transmitting. This makes a lot of sense on vhf, and on 10, 15 and 20 meters, but at the lower frequencies which are more susceptible to noise interference entering via the antenna (160, 80 and 40 meters), the small loop receiving antenna has some advantages in reducing the susceptibility to certain types of noise. This article will attempt to expain the loop's operation in the simplest possible terms and will describe several practical loop antennas which are suitable for amateur use.

The electric- and magnetic-field components of an incoming electromagnetic wave are at right angles to each other. The plane formed by these components is at right angles to the direction of wave arrival. With the wave polarization and the direction of wave travel shown in **fig. 1**, both the electric and magnetic field components excite current flow in the vertical portions of the simple unshielded loop. The current induced by the electric field is due to the difference in charge impinging along the length of the vertical elements, while the current due to the magnetic field is because of the motor-generator action of the vertical conductors cutting the lines of force in the magnetic field as it moves past the conductors.

The currents due to both field components are mutually in phase, and although neither the electric nor the magnetic field components can exist without the other in the radiated electromagnetic field, the loop antenna behaves identically with excitation from either or both field components.[1]

While the voltage available at the terminals of a dipole is simply proportional to the current induced in the dipole, the voltage available at the terminals of a small loop is proportional to the *difference* between the

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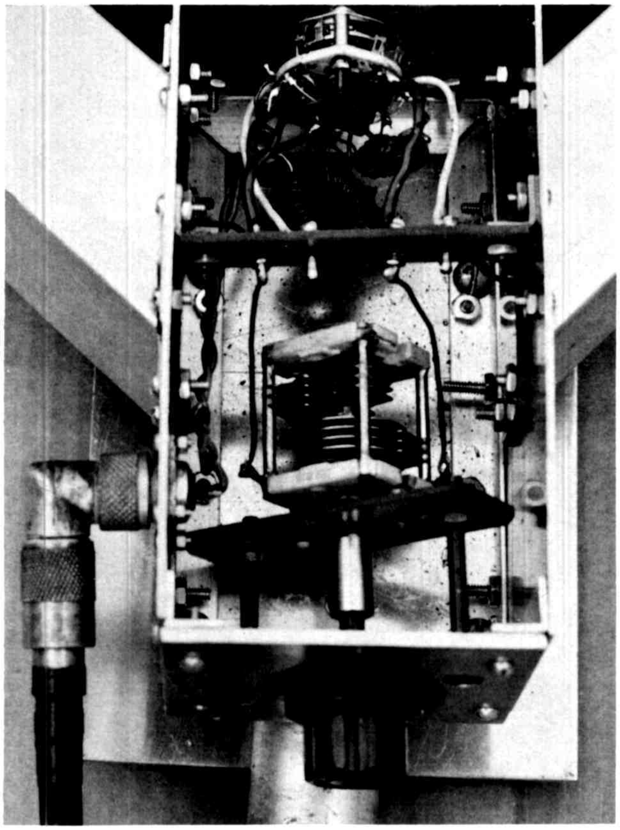
currents induced in the two opposite vertical loop elements. No currents are *induced* in the top or bottom horizontal conductors connecting the vertical elements.

When the *axis* of the loop is pointing toward the signal source as in **fig. 1A**, the two vertical elements of the loop are excited at the same phase point of the wave front. Thus the current induced in both elements is of the same amplitude and phase, and flow in the same absolute direction (see **fig. 2**). However, the two currents are actually flowing in opposite directions with respect to a continuous, one-way travel around the loop, and therefore cancel each other, producing zero net voltage.

On the other hand, when the *plane* of the loop is pointing toward the signal source, as in **fig. 1B**, maximum voltage is produced because the two vertical elements are now in positions of maximum *difference* in phase relationship with the wave front, with the resulting difference between the currents induced in the vertical elements producing a maximum voltage. In fact **fig. 1B** shows that during the portion of the wave cycle when the field is changing most rapidly, the currents in the two elements are flowing in *opposite* absolute directions (one flowing upward and the other downward), with the result that both currents are actually flowing in the *same* direction around the loop, and are therefore mutually aiding instead of opposing as in **fig. 1A**. For orientations of the loop at angles in between the two just described, and in general, the voltage produced is proportional to the cosine of the angle formed between the loop plane and direction of the wave propagation, as in **fig. 1C**. The resulting figure-eight radiation pattern is thus a perfect pair of circles tangent to one another as shown in **fig. 3**.

Junction box for the square loop antenna containing 80/40 bandswitch, balun and tuning capacitor.



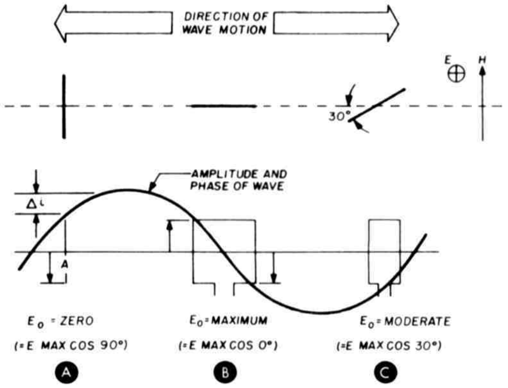


fig. 1. Directivity of the loop arises from the interception of the wavefront by each half of the antenna. In (A) the currents are of equal amplitude and phase, producing no net voltage difference at the output. In (B) the currents are at maximum amplitude and phase difference, producing maximum output voltage. In (C) the current difference between loop halves is moderate, producing a corresponding voltage difference at the output terminals. Voltage output is small for angles larger than 60 degrees.

For several basic reasons, nearly all practical loop antennas are electrostatically shielded by means of an open-turn shield. One reason is that electrostatic shielding is a convenient way of achieving a capacitance balance between the two opposite halves of the loop and ground. Without this balance the figure-eight pattern would be distorted and the nulls misplaced and obscured. Second, the open-turn shield shown in **fig. 3** forms a balun, permitting the loop to feed an unbalanced load without upsetting the loop-to-ground balance. And third, electrostatic shielding renders the loop insensitive to the electric component of a passing wave. This has an insignificant effect on the reception of a wave propagated in the far field (radiation field). However, in the case of several types of man-made noise interference, the effect is to reduce the reception of the noise.

If the electrical disturbance producing the interfering noise is confined primarily to the *induction* field (as many such noise disturbances are), the electric compo-

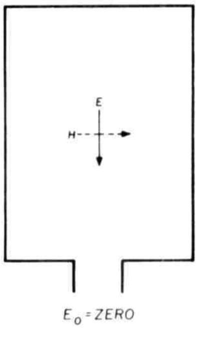


fig. 2. Electric (E) and magnetic (H) components of a wavefront impinging upon a loop antenna, showing current flow in the loop. When the plane of the loop is parallel to the wavefront, as shown here, output voltage is minimum (see fig. 1A).

nent generally predominates over the magnetic field. Since the shielded loop is sensitive only to the magnetic field, there's a noticable reduction in noise pickup as compared to that of a vertical dipole. Providing the desired signal is not arriving from the same direction as the noise, some additional reduction in noise interference level is also available due to the directivity of the loop radiation pattern. Simply pointing the axis of the loop in the direction of the noise will minimize the noise pickup, while the desired signal still arrives from a favorable angle on the directivity pattern.

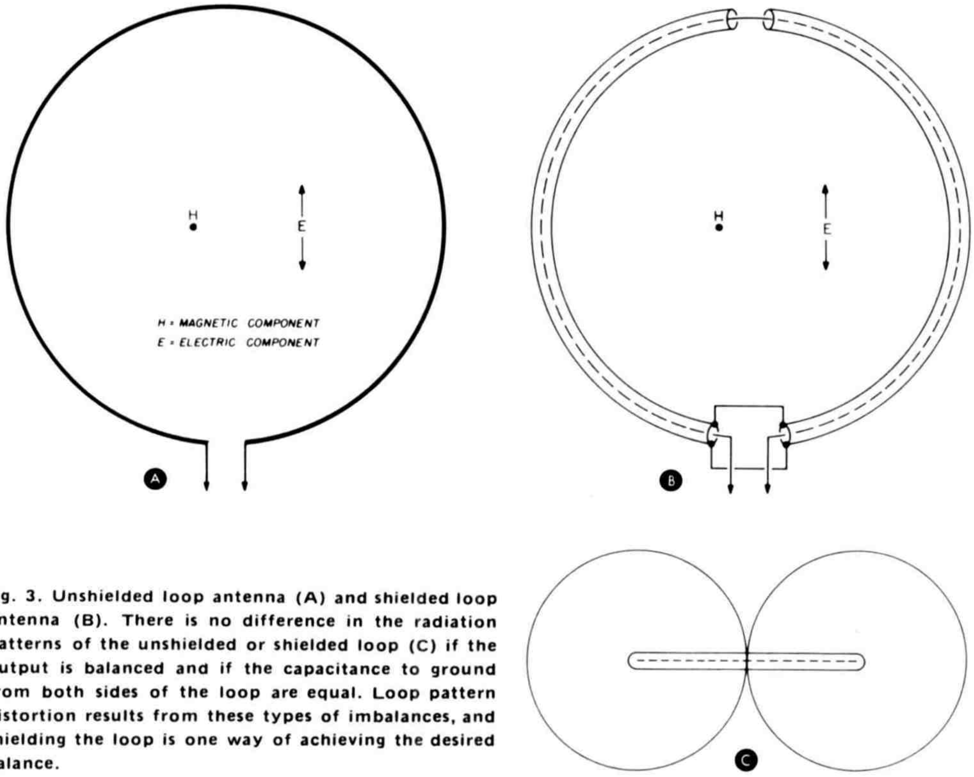


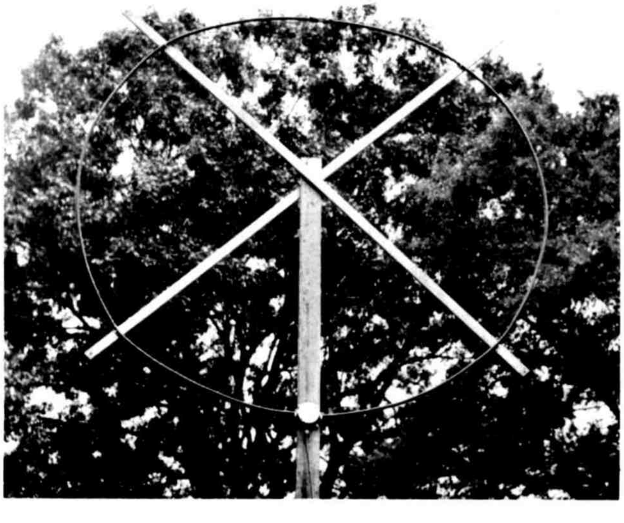
fig. 3. Unshielded loop antenna (A) and shielded loop antenna (B). There is no difference in the radiation patterns of the unshielded or shielded loop (C) if the output is balanced and if the capacitance to ground from both sides of the loop are equal. Loop pattern distortion results from these types of imbalances, and shielding the loop is one way of achieving the desired balance.

In general, atmospheric noise is propagated as a *radiation* field, generated by the electrical discharges that attend thunderstorms, both locally and throughout the world. Noise from an electrical storm concentrated in a single direction may be reduced by the directive properties of a shielded loop, but not by its insensitivity to the electric field. On the other hand, interference from precipitation static will be effectively reduced by the shielding properties of the loop because precipitation static is caused by an *induction* field localized directly around the receiving antenna.

The illustration of **fig. 1** is greatly exaggerated. When a loop 6½ feet (2m) between legs is used on 80 meters, the maximum wavefront intercepted represents only a small fraction of the energy intercepted by a half-wavelength dipole. However, such a small antenna is still adequate for good signal reception.

References 2 and 3 state that a maximum wire length of about 0.08 wavelength will produce currents throughout the loop of relatively equal amplitude and phase. This condition will produce the figure-eight pattern illustrated, but lengths in excess of this criteria will cause some pattern distortion. Reference 4 states that loops as large as 0.1 wavelength in diameter (0.314 wavelength circumference) can be used without serious pattern distortion. However, this reference is confined to aperiodic loops, while reference 2 deals with loops that are tuned, providing higher Q. The higher Q changes the current and phase difference in the loop wire, resulting

The coaxial loop of fig. 4 as built by the author.



in the shorter specified loop lengths (0.08 wavelength maximum).

The advantage of dual-band reception from a single loop further compromises the design criteria. For those who wish to retain the criteria of references 2 and 3, table 1 has been included. Corrections to table 2 must be made to compensate for this altered construction. Single-band designs would do well to follow the referenced design for maximum performance.

effects of nearby re-radiation

If there are metallic structures near the loop antenna of ample conductivity and size, such as power lines, homes with electrical wiring, water and furnace air-conditioning ducts and piping, as well as antennas, towers and guy wires, etc., signals will be injected into a loop antenna from both the direct signal and re-radiation from these nearby structures. If such structures have high Q and are at or near resonance at the frequency of the exciting signal, their energy may approach that of the direct signal and cause appreciable deviation to the true bearing of the signal source. The resultant voltage induced into the loop will be the vector sum of the amplitude and phase of the multiple sources. Since the amateur is not generally interested in obtaining accurate bearings of signal sources, such deviation is relatively unimportant. What is of prime importance is the amplitude of the desired signal and, secondarily, the depth of

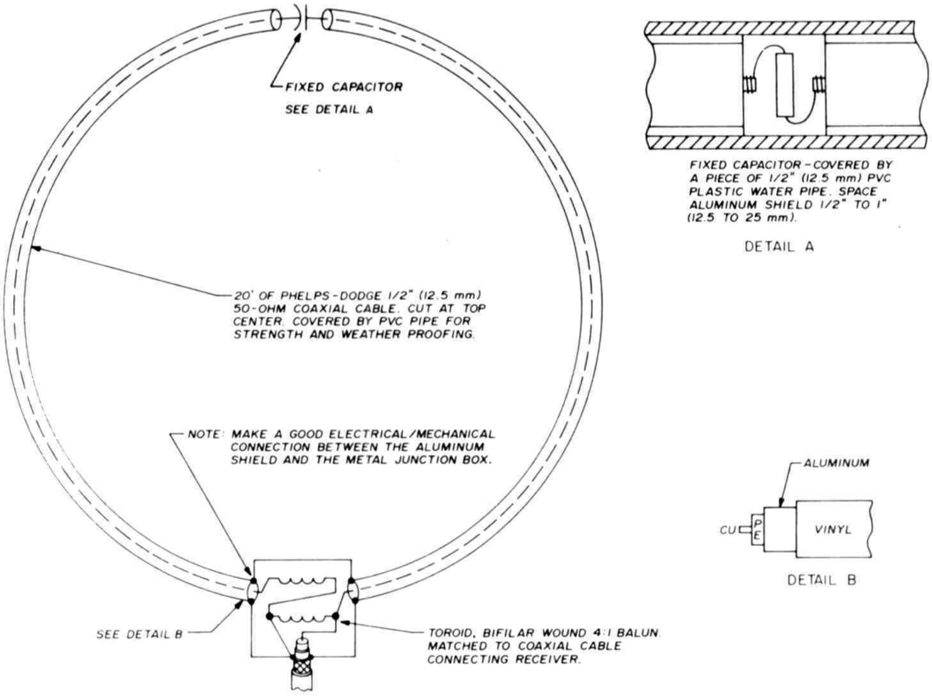
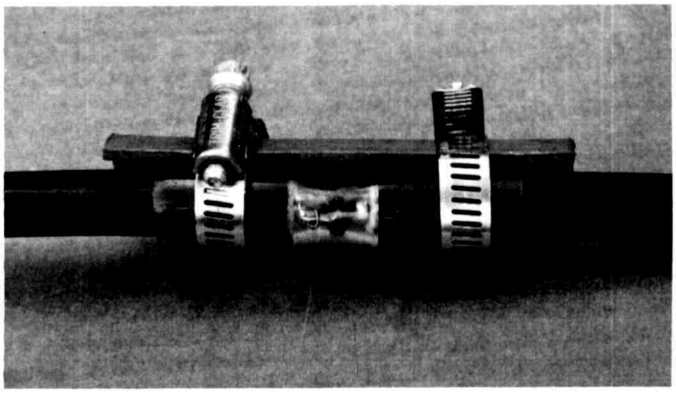


fig. 4. Single-turn coaxial loop antenna suitable for use on 80 and 160 meters. The toroid transformer balances the loop output to ground, whether shield is present or not. Typical dimensions are listed in table 2.

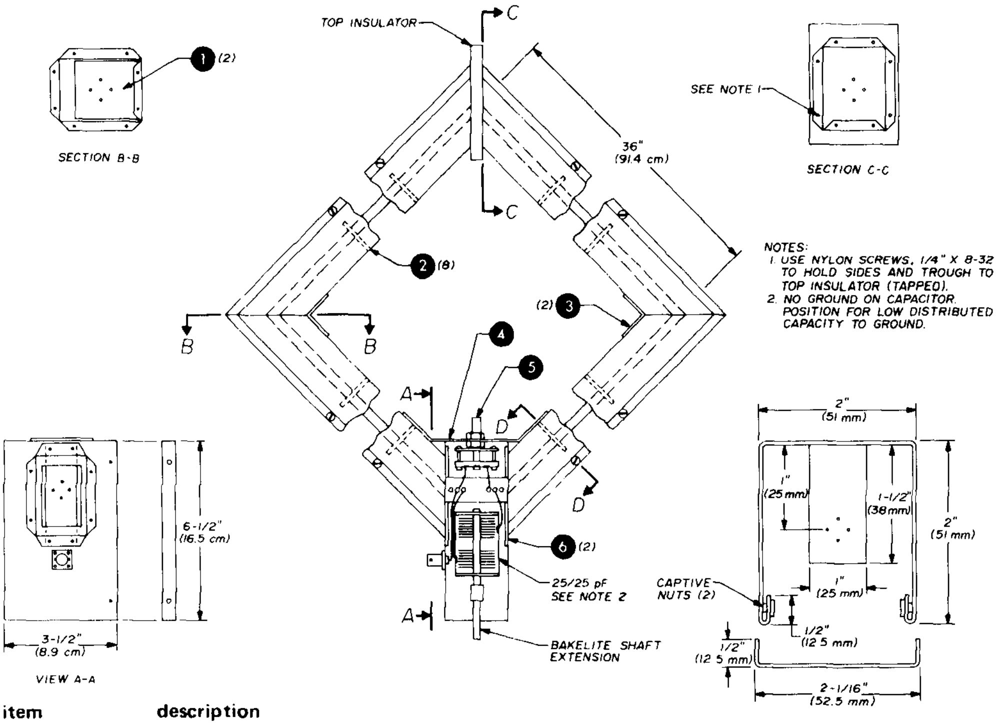
table 1. Maximum wire length for direction-finding loops as specified in references 2 and 3 (0.08 wavelength).

frequency (MHz)	wavelength (meters)	maximum wire length
1.8	166.7	43' 7" (13.28m)
1.9	157.9	41' 4" (12.60m)
3.5	85.7	22' 6" (6.86m)
3.6	83.3	21' 10" (6.67m)
3.7	81.1	21' 4" (6.49m)
3.8	78.9	20' 9" (6.32m)
4.0	75.0	19' 8" (6.00m)
7.0	42.9	11' 3" (3.43m)
7.1	42.3	11' 1" (3.38m)
7.2	41.7	10' 11" (3.33m)
7.3	41.1	10' 9" (3.28m)

Detail of the break in the coax at top of loop. See detail B in fig. 4.



the null available to reduce the strength of an interfering signal.



item	description
1	corner insulator 2x2x1/16" (51x51x1.5mm)
2	insulator spacer, 1½x1x1/16" (38x25x1.5mm)
3	stiffeners, semi-hard aluminum, 2" (51mm) wide, 1/16" (1.5mm) thick
4	stiffener, semi-hard aluminum, 2" (51mm) wide, 1/16" (1.5mm) thick
5	five-pole, double-throw rotary switch
6	insulator, junction box, 1½x4x1/16" (38x102x1.5mm)

fig. 5. Double-turn, square-loop antenna for 40, 80 and 160. Typical loop dimensions and tuned-circuit components are listed in table 2.

If installed with the axis of the loop horizontal, only signals from the horizon i.e., low angle or ground wave, will produce the deep nulls shown. Signals from higher vertical angles will not have their wave front parallel to the plane of the loop and even though the azimuth is correctly set, the signal received will still be appreciable.* Therefore, do not expect many signals to show an extremely sharp null unless provision is made to tilt the loop axis in elevation as well as azimuth.

As shown in **fig. 4**, a practical loop antenna may be built from a single turn of coaxial cable. The shield must be broken as previously explained to remove the "shorted turn" effect. A loop so configured will almost completely shield the electric component of the wave. To insure retention of the figure-eight pattern the two halves of the loop must maintain symmetry as closely as possible.

Detail B of **fig. 4** shows the method used to insert a capacitor between the ends of the inner conductor as well as providing spacing of the outer shield. Any insulated covering that will provide strength to this point of the loop will be satisfactory, but it should also provide a weatherproof seal to keep moisture out of the break. Before placing the cover on the break, check for peak performance on your desired portion of the band. I used a grid dipper in the shack and tuned its signal in on the receiver. I noted each frequency for S-meter reading, then substituted various fixed capacitors (and combinations) to center the required bandpass.

An alternate construction method is shown in **fig. 5**. This illustration should provide most of the required construction details. The stiffeners at the junction box, J, and the two side corners were added to reduce the floppyness that existed without them. An even number of turns is required for symmetry since both the inductor and the capacitor are located in the junction box. Two turns (33 inches or 83.8cm on a side) are adequate for 80 and 160 meter operation. For 40 and 80 meters, two turns (16 inches or 40.6cm on a side) would comply with the design criteria of reference 1. For single-band operation, the lengths given in **table 2** provide an optimum signal-to-noise ratio and should result in maximum performance.

The tuneup procedure for the square loop is similar to that for the circular loop. Using a length of coaxial cable with a loop at the end attached to the output

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*This feature of the loop enhances its ability to null out interfering signals, particularly local ground waves or electrical noise, while still maintaining reception of skywave signals. **Editor** connector, the grid dipper is used to get the resonant frequency of the system near that required. (Caution: The grid dipper will also show a dip at the resonant length of the coaxial cable used.) Vary the number of turns on the primary of the toroid and the fixed paralleling capacitor until the loop shows peak pickup near your favorite spot in the band. Then position the loop where it is to be permanently mounted, with the required length of coaxial cable to connect it to the receiver, and inject a grid dipper signal into it. Plot the S-meter reading for each frequency. Adjust the inductor and capacitor until the bandpass is centered on the desired frequency.

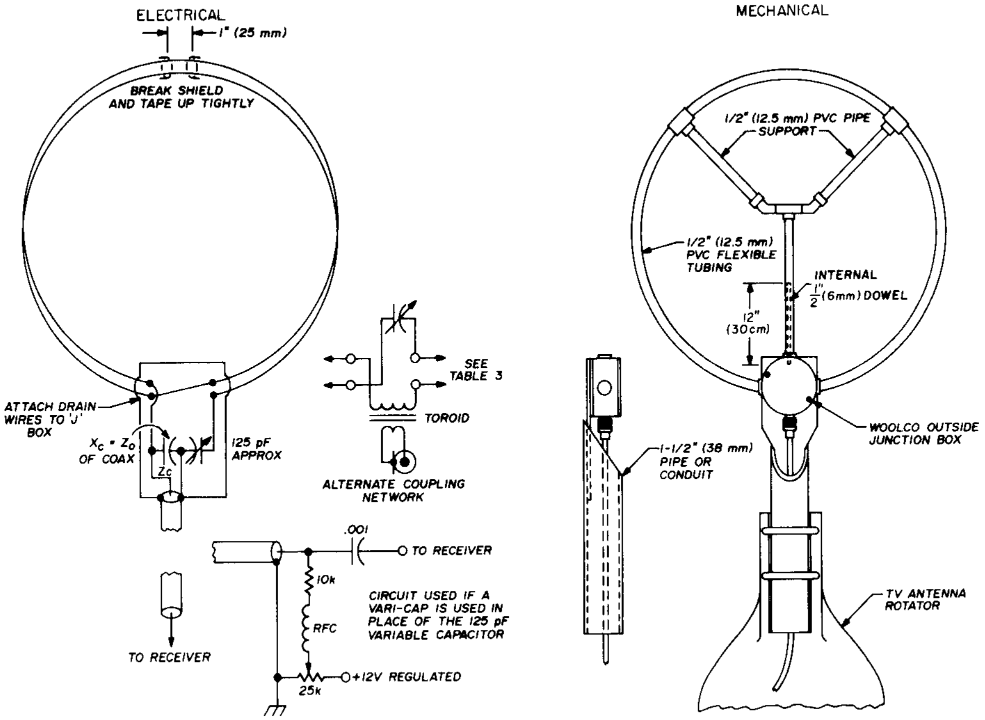


fig. 6. The Hula-Hoop designed by W5DS. The alternate coupling network is suggested. Component values for the coupling network are given in table 3.

table 2. Wire lengths and tuning capacitors used in the loops of figs. 3 and 4.

	frequency (MHz)	loop size	wire length	number of turns	toroid turns primary	toroid turns secondary	capacitor (pF) variable	capacitor (pF) fixed
coaxial cable loop	1.8 MHz	8'3" (2.5m)	26' (7.9m)	1	20/20 balun		0	500
	3.8 MHz	6'3" (1.9m)	20' (6.1m)	1	10/10 balun		0	125
square loop	1.8 MHz	36x36" (91x91cm)	48' (14.6m)	4	40	8	15-15	0
	3.5 MHz	36x36" (91x91cm)	24' (7.3m)	2	24	6	15-15	40
	7.0 MHz*	36x36" (91x91cm)	24' (7.3m)	2	12	7	15-15	75

*This loop built before reading references 2 and 3 so wire is considerably longer than 0.08 wavelength. Although it works fine, the design criteria of those references is recommended.

A third arrangement is shown in **fig. 6**. It was suggested by Bob Edlund, W5DS, who has named it the "Hula Hoop Loop" due to the basic material used to support the loop wires. A single-turn of TV twinlead is used to provide a two-turn loop when series connnected. I have substituted an alternate coupling network shown in **fig. 6** that provides slightly better pickup and higher loaded Q. It has been incorporated in all loops shown in **figs. 4, 5** and **6. Table 3** lists the required components.

The Hula-Hoop was separated, and the twinlead inserted. The loop is then spirally covered with folded (two layers, 3-inches or 76mm wide) heavy-duty aluminum foil with a number-15 (1.5mm) aluminum drain wire to provide connection for the foil shield. This was then continuously taped with vinyl electrical tape for weatherproofing. The aluminum wire is connected to the junction box to provide a path to ground for currents induced by the electric component of the wave.

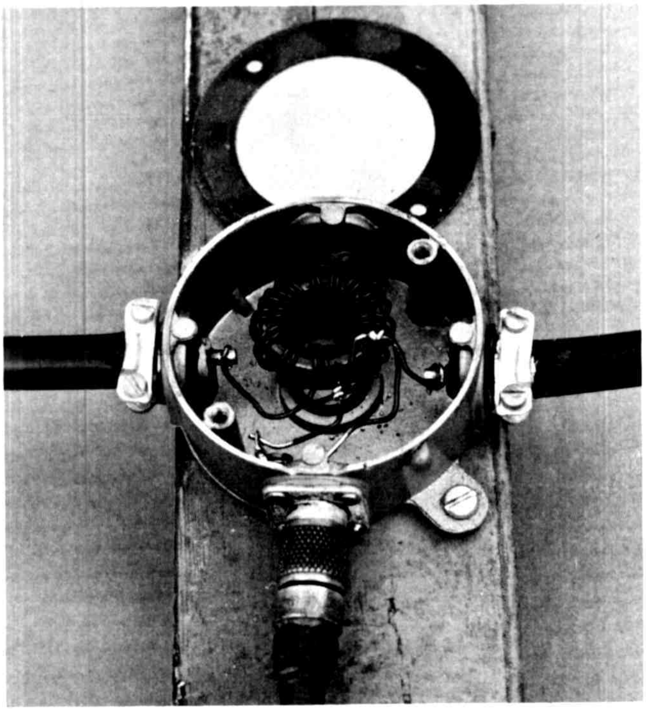
I used a 10-foot (3-meter) length of ½ inch (12.5mm) PVC tubing in place of the Hula-Hoop. This in turn is supported by ½ inch (12.5mm) PVC water pipe and fittings to form a Y-shaped support for the loop. A ½-inch (12.5mm) wooden dowel, boiled in beeswax, was inserted into the vertical member of the Y support, terminating in the junction box to increase strength against wind torque at this point. The coupling networks shown will provide a good match between the loop and the coaxial line to the receiver.

In an attempt to remotely tune the loop a voltage-variable capacitor (varicap) was substituted for the capacitor in the loop-coax coupling network. John Venters, K4UR, suggested, and provided, a silicon planar epitaxial diode (ITT type BA163) which, when reverse biased with 1 to 12 volts dc, provides a capacitance range of 10 to 260 pF. However, when feeding the varicap via the rf coaxial line with the required rf chokes to isolate the dc from the rf, the loaded Q dropped to about 10 (indicating the introduction of some form of undesired loss resistance). The convenience such a device would provide is worth further investigation; however, still to be found is a way to use the varicap and retain high Q. With the coupling networks shown, the loaded Q is in the vicinity of 75. This provides a 50-kHz bandwidth (at the 6 dB points) which is adequate on 80 meters if you operate near one spot most of the time.

table 3. Components for the alternate coupling network shown in fig. 5.

frequency	twinlead length	loop diameter	approximate capacitance (pF)	type	toroid primary turns	secondary turns
1.8 MHz	20' (6.1m)*	3'3" (99.1cm)	150	T106-2	14	8
3.5 MHz	10' (3.0m)	3'3" (99.1cm)	110	T68-2	12	7
7.0 MHz	5' (1.5m)	1'7" (48.2cm)	75	T56-2	10	6

*Two turns (be sure capacitor is centered in loop).


The 4:1 balun for the coaxial loop, mounted in the Woolco junction box.

In all loop configurations and couplers I tested there is a loss of about two S-units of signal pickup with respect to the vertical radiator I use for transmitting on 40 and 80 meters. Some of the weaker signals are then below the noise level of the receiver. A low-noise front-end preamplifier/preselector, similar to that described recently in *QST*[5] provides about 20 dB gain and puts the signal back up where the receiver can detect even the weakest signals.

conclusions

Comparing the loops against my "Five Band, Tower Antenna System"[6] for receiving, I get about five S-units reduction of man-made noise and precipitation static,* with only a loss of a couple of S-units of signal pickup.

Since the radiation resistance of such a small loop on the wavelengths involved is less than one ohm, it would make a very poor transmitting radiator.

*Atmospheric noise is propagated entirely by the radiation field so it *cannot* be reduced by using a shielded loop antenna. Precipitation static which is due to wind-blown rain, on the other hand, is an induction field and *can* be reduced by using a shielded loop. **Editor**

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