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An Improved Feed Network for Loop-Type Receiving Antennas

A few years ago, I decided to build a "shielded-loop" receiving antenna (see Figure 1). The antenna was very straightforward — simply a loop of coax with a gap in the shield opposite the feed point. I looked at many feed network designs but concluded that all were unsatisfactory for one reason or another. Problems included low efficiency, difficulty of adjustment, mechanical complexity, feed line decoupling issues and lack of frequency agility. I ended up designing an improved feed network. This article describes a feed network for a 20-foot circumference loop that covers from 1.6 to 5 MHz via remote tuning. It does *not* require a preamp or a separate balun.

Theory

There is an inherent tradeoff between efficiency and bandwidth. I opted for greater efficiency, figuring I could live with limited bandwidth. Good efficiency would eliminate the need for a preamp and its attendant risk of overload from nearby AM broadcast stations. The problem of limited bandwidth could be mitigated by incorporating the capability to remotely tune the loop from the shack, so a design with tuning diode compatibility would be needed. Ideally, a tuning range of at least 1.8 to 4 MHz would be desirable, in order to cover 160 and 80 meters.

The first step was to model the equivalent circuit of the antenna. There is some controversy about how shielded loop antennas work. One theory says that the center conductor of the coax works pretty much the same as a non-shielded loop; all the outer conductor (braid in the case of coax cable) does is act as an electrostatic shield — and add some stray capacitance. Certainly, adding a gapped shield to a loop does not change its inductance or Q, so this theory has some foundation.

Another theory is that the outer conductor is the true antenna: The center conductor merely conducts the signal from the gap to the feed point, and the fields inside the coax are entirely the result of currents inside the coax and not radio signals impinging on the outside of the coax. As it turns out, both theories make identical predictions regarding the terminal voltages and currents, which, in turn, agree with experimental observations. Therefore, the model in Figure 2 is valid, regardless of the theory used to describe the antenna.

To shield or not to shield? That is the question: Why use a shielded loop instead of a simple wire loop. With the shielded loop, the only place with high external fields is the gap, and it's as far as possible from the feed line. The high fields at the feed point can be shielded by building the feed network inside a metal box. With an unshielded loop, the high fields at the feed point are exposed to the nearby feed line and are at risk of coupling to it. Coupling to the feed line can degrade the loop's nulling ability.

The literature on loops contains many references to a maximum loop circumference; the various numbers are in the neighborhood of 0.10. *The ARRL Antenna Handbook* cites the number 0.085

I decided to design the loop to be 20 feet in circumference, which reaches this maximum size around 4 MHz. The inductance is around 9 µH, and the effective series resistance is approximately 0.5 Ω, assuming the loop is made of RG-6 coax. One-quarter of the total capacitance of the coax appears in parallel with the inductance (the capacitances of each half of the loop coax are effectively in series). It would be possible to add a series capacitor to resonate the inductance, which
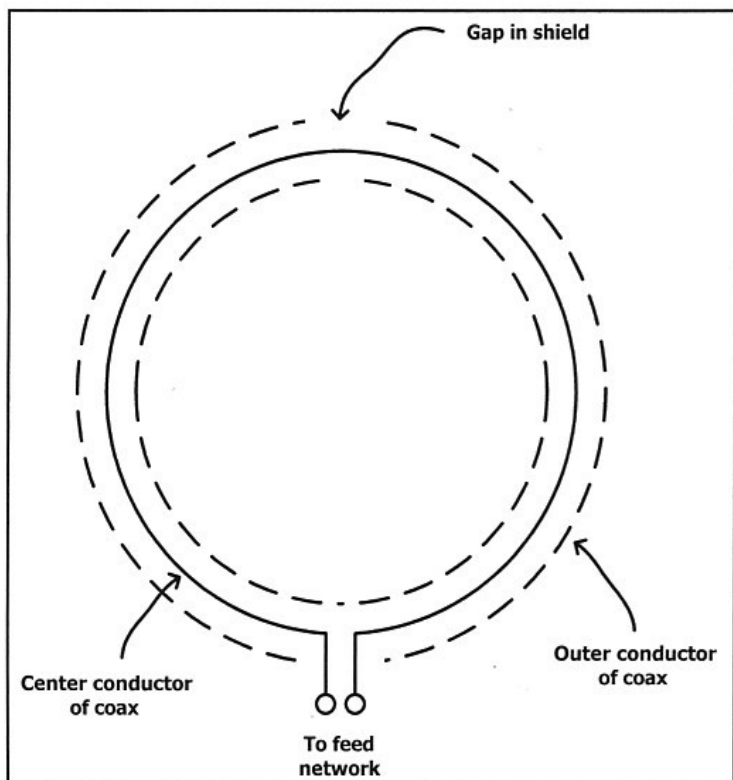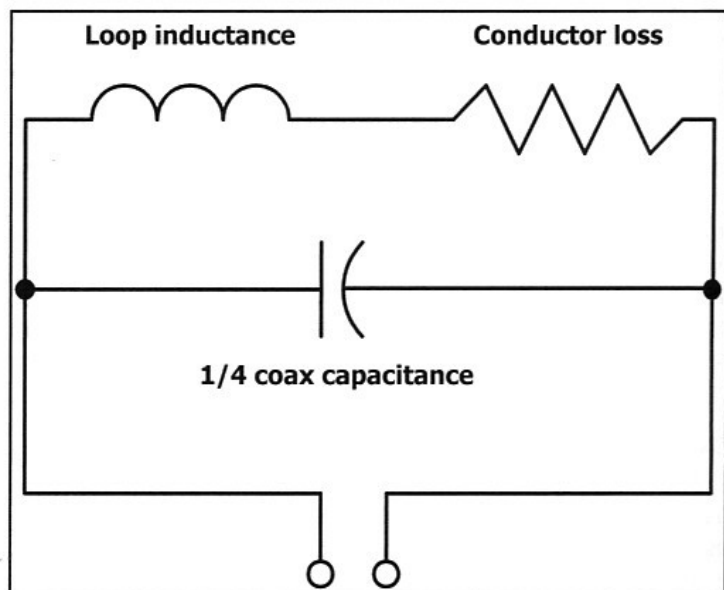

Figure 1 — The receiving loop configuration

Figure 2 — The effective impedance configuration of the loop

would result in an 0.5 Ω output impedance. This seemed impractical, however, especially if remote tuning were necessary. Alternately, the tuning capacitor can be connected in parallel. Figure 3 depicts the equivalent circuit, where the parallel resistance (R_p) is more than 10,000 Ω and varies somewhat with frequency.

An experimental loop was built using AM radio tuning diodes (varactors) as the parallel capacitance, and R_p was measured at 5000 Ω on 160 meters and 10,000 Ω on 80 meters using a vector impedance meter. The decreased value was probably due to the finite Q of the varactors as well as some loss in the coax interior. Two NTE618 diodes in parallel were able to tune from approximately 1.6 MHz to 5 MHz, easily covering both bands.

Now all that was necessary was to come up with a transformer design that could transform 50 or 75 Ω to 5000 Ω or so. The conventional way of designing small-signal broadband transformers would be to design the transformer (T_1) so that the magnitude of the shunt impedance on the primary would be at least two to three times the 5000 Ω source impedance — 10,000 to 15,000 Ω. This would be difficult. However, the shunt impedance can be broken down into an effective parallel resistance R_p and an effective parallel reactance, X_p. The parallel reactance is simply absorbed into the overall tank circuit formed by the loop and tuning diodes. Any leakage inductance is also absorbed by the tank. The coupling coefficient of the transformer, however, is at least 95 percent, so there isn't much leakage inductance. A slight readjustment of the diode bias voltage can compensate for the parallel reactance (X_p) — capacitive or inductive. This reduces the transformer design problem solely to meeting the R_p requirement.

The conventional wisdom in building broadband, small-signal transformers is to use a high-permeability ferrite core. This application is special, however. A medium-permeability (u=125), low-loss (Q=300) ferrite material, such as Fair-Rite 61, is an excellent choice for this transformer because it can achieve very high values of R_p and its relatively low parallel reactance is tolerable in this particular application. With a suitably sized core and 50 turns on the primary, an R_p value of more than 10,000 Ω can be realized. With five turns on the secondary, the source impedance varies from approximately 40 to 80 Ω over 1.8 to 4 MHz. This provides an acceptable match to either 50 or 75 Ω feed line. In a receiving situation, even an SWR of 3:1 causes a mismatch loss of only 1 dB, so the slight mismatch in this case has a negligible effect.

The transformer also serves as a balun and feed-line decoupler. The common-mode impedance is determined by the inter-winding capacitance of the transformer, which is only a few picofarads, resulting in a common-mode impedance of many thousands of ohms. There is no need for a separate balun or ferrite beads on the feed line, as often seen with other loop designs.

Circuit Description of the Reference Design

There are three configurations of the reference design: Standard, strong-signal and fixed-tuned. A PC board was laid out to accommodate any version by mounting the appropriate components and jumpers. Figure 4 shows the basic tank circuits for all three versions. The standard configuration has two NTE618 diodes in parallel, while the strong-signal configuration has eight NTE618 diodes in series-parallel. The capacitance is the same for both versions, but the push-pull configuration in the strong-signal design largely cancels distortion from strong AM broadcast stations. My QTH is six miles from a 50 kW station on 1140 kHz, and I found the standard configuration was able to withstand this station and numerous others in the area. I also built a version of the loop that was twice as large (40 feet of coax). The additional 10 dB of signal due to this loop made it necessary to use the strong-signal configuration, however.

The fixed-tuned version is recommended for SO2R stations, where *zero* distortion is essential due to really strong signals. In this version, the antenna is tuned by an array of eight fixed capacitors. Two pin shunts — the type commonly found on computer mainboards — are used to select the capacitors, allowing tuning to about 10 kHz resolution.

Figure 5 shows the schematic of the PC board at the antenna end. A number of wildcard components allow setting it up for any of the three configurations. Table 1 shows the components needed for each configuration. The capacitors or diodes resonate the loop, which drives T_1, the transformer described earlier. The dc control voltage for the tuning diodes is fed via the center conductor of the coax feed line and then through R_1 to the cathodes of the diodes. R_2 and R_3 are connected to the coax feed line's outer conductor and provide the dc return to the diode anodes. R_2 and R_3 are redundant in the dc sense but are used as a pair so their stray capacitance does not unbalance the loop. C_5 is a blocking capacitor to keep the dc from being shorted by the secondary winding of T_1. The diodes are reverse biased and draw negligible leakage current, so R_1–R_3 can be very high values in order to present very high impedance to RF and not degrade the feed-line decoupling. It is not
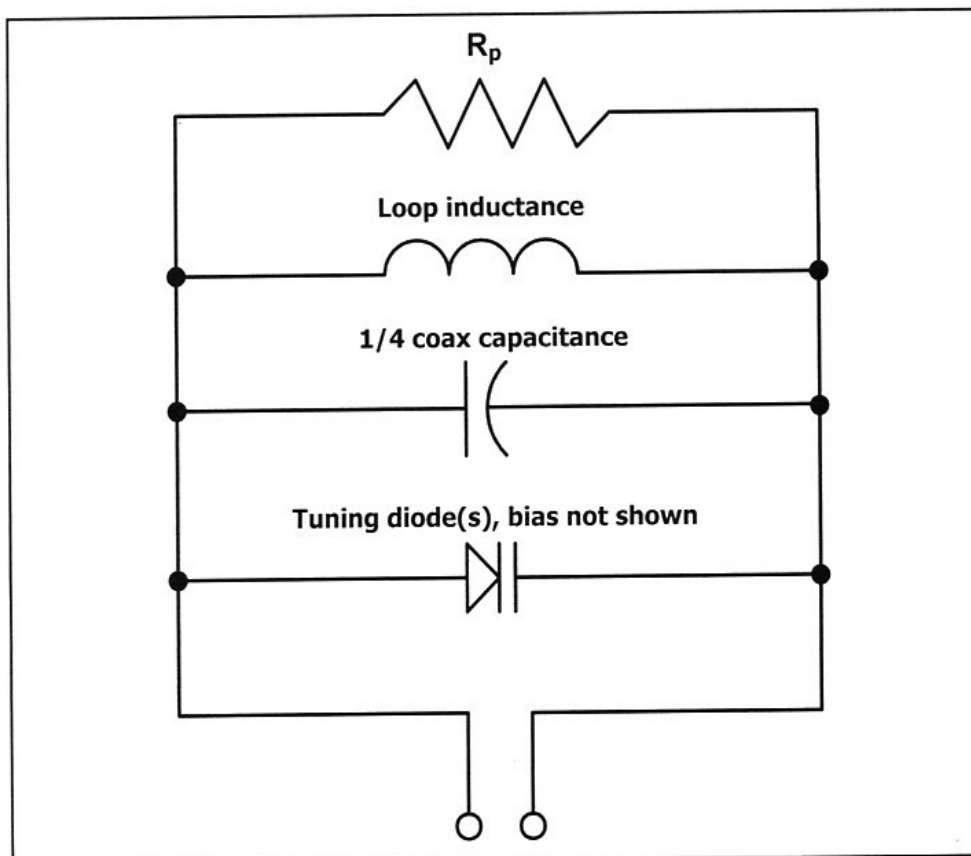

Figure 3 — The equivalent circuit of the loop

R_p

Loop inductance

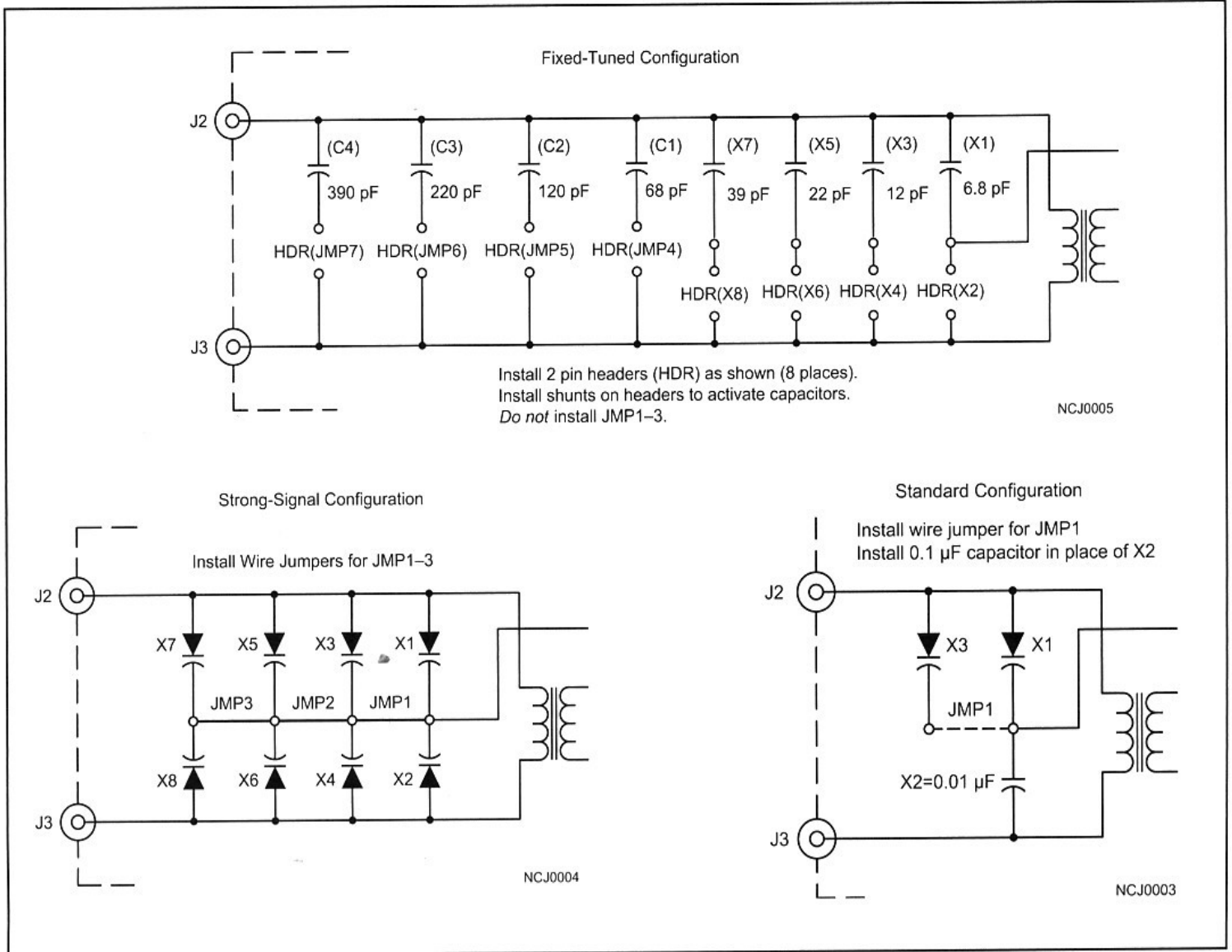1/4 coax capacitance

Tuning diode(s), bias not shown

Figure 4 — Three alternative reference designs for the standard, strong-signal, and fixed-tuned antenna PCB configurations.

necessary to use inductors.

The antenna board is mounted in a metal box, and the loop's coax outer conductor is connected to the box at both ends. The *feed line's* outer conductor does *not* connect to the box, however; it only connects to the transformer's secondary winding.

Figure 6 shows the schematic of the controller PC board. The dc is applied through R_4, a high-value resistor, instead of through an inductor. RF from the antenna is conducted to the receiver through C_6. VR_1 controls the tuning voltage, from 0 to 8 V. The board can be operated from a 9 V battery or from an 8 V voltage regulator (IC_1) running from 11 to 15 V dc. Battery life should approach the shelf life due to the minuscule current draw. When an external power source is plugged in to J_6, the battery is automatically disconnected.

The controller board feeds dc bias for the varactors through the center conductor of the feed line. A capacitor passes the RF through to the receiver. The controller can be powered either from a 9 V battery or from an external dc source, such as a "wall wart" transformer or even the shack's +13.8 V dc power supply.

For battery operation, the unregulated battery voltage is fed directly to a high-resistance potentiometer. The high impedance is possible because of the low current draw of the diodes in reverse bias. Very little current is taken from the battery, so it should last a long time. For external dc

Table 1
A component list for each configuration.

| Component	Standard	Strong-Signal	Fixed-Tune
		Configuration	
X1	NTE618	NTE618	6.8 pF
X2	0.1 µF	NTE618	2 pin header
X3	NTE618	NTE618	12 pF
X4	none	NTE618	2 pin header
X5	none	NTE618	22 pF
X6	none	NTE618	2 pin header
X7	none	NTE618	39 pF
X8	none	NTE618	2 pin header
JMP1	jumper	jumper	none
JMP2	none	jumper	none
JMP3	none	jumper	none
JMP4	none	none	2 pin header
JMP5	none	none	2 pin header
JMP6	none	none	2 pin header
JMP7	none	none	2 pin header
C1	none	none	68 pF
C2	none	none	120 pF
C3	none	none	220 pF
C4	none	none	330 pF
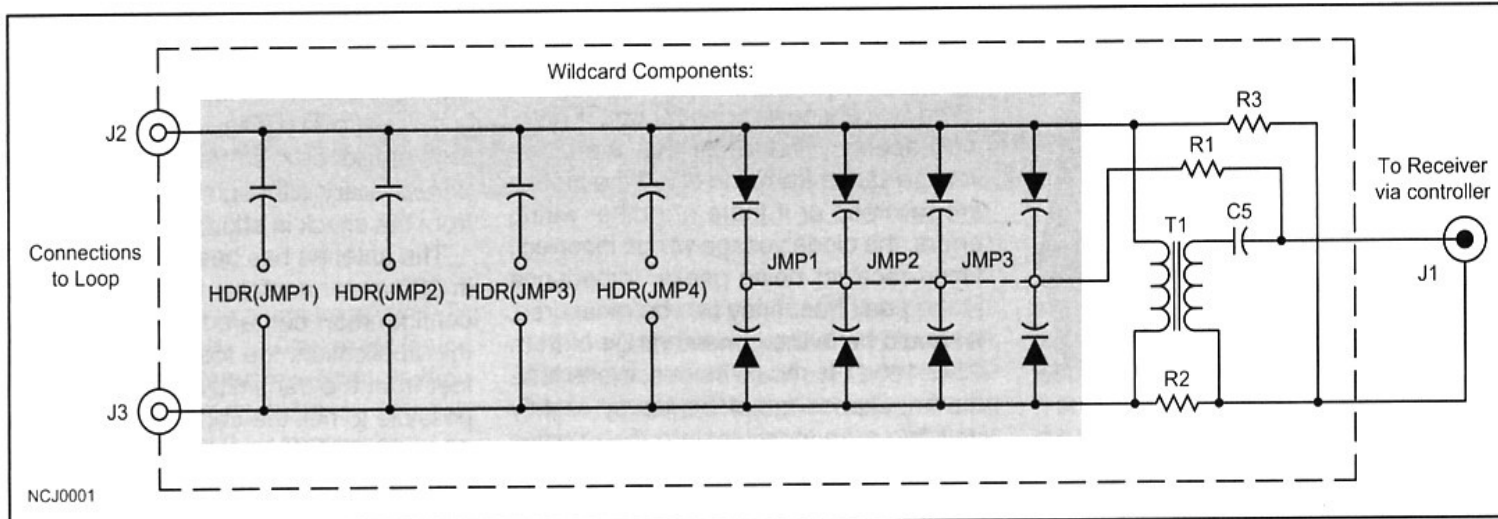
Figure 5 — The schematic of the PC board at the antenna. The shield is *not* connected to the box at J1; the shields are connected to the box at J2 and J3.
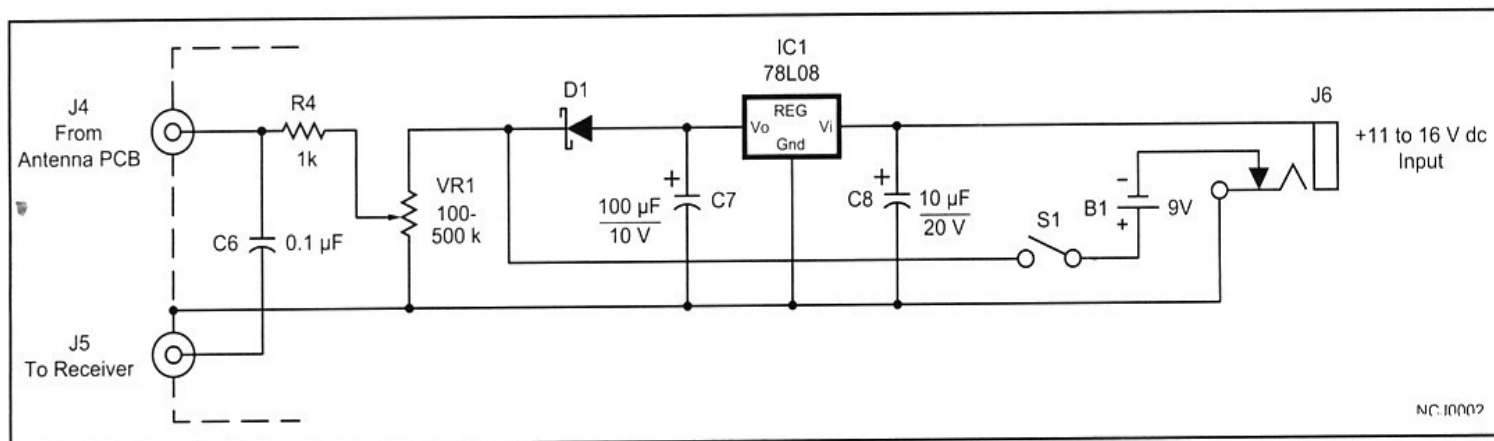

Figure 6 — The schematic of the controller PC board. The shields are connected to the box at J4 and J5.

operation, an 8 V voltage regulator (IC$_1$, a 78L08) stabilizes the voltage and removes hum and noise. Plugging in an external power source automatically disconnects the internal battery.
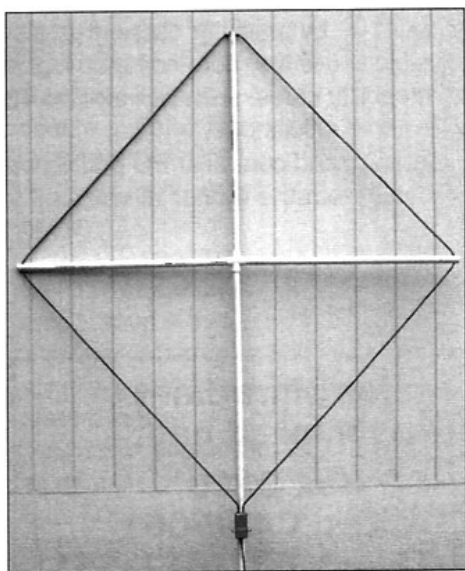
Construction

Figure 7 — The complete receiving loop, as built

Figure 7 shows the complete antenna. The antenna starts with a cross of 1-inch PVC pipe. The lower arm is 78 inches long, and the other three arms are 42 inches long. One-half-inch holes are drilled near the ends of the 42-inch arms, and the loop coax is threaded through the holes. It is not necessary to glue the PVC together; friction is sufficient to hold it in place. This makes a convenient portable antenna that can be disassembled. For fixed use, a concrete umbrella stand works well and allows the loop to be rotated by hand to get the best null before clamping in place.

Figure 8 shows the antenna PC board in its die-cast aluminum box, which is held to the PVC frame by a U bolt. Two holes are drilled in the top of the box for the F connectors that go to the loop. A slot is cut in the bottom of the box for the F connector that goes to the feed line. The upper F connectors are first inserted in their holes by tilting the PC board, then swinging the bottom end of the board down with the lower F connector clearing the slot. The lower F connector should *not* touch the box. It is a good idea to stuff the slot with

some foam material to keep insects out while still allowing condensation to drain.

The lower end of the PC board is supported by 6-32×1 standoffs. In winding T$_1$, 28 AWG enameled magnet wire is recommended for the 50-turn primary. For the

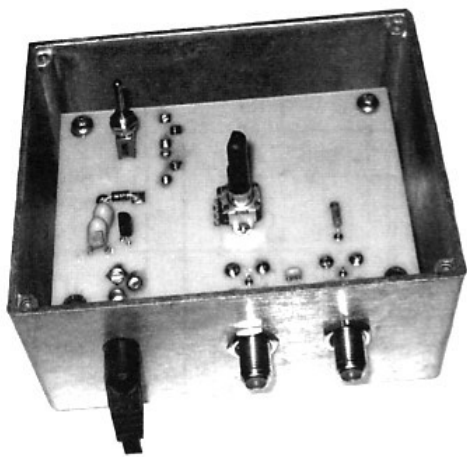Figure 8 — The antenna PC board in its die-cast aluminum box

Figure 9 — The controller PC board, mounted in a die-cast aluminum box

5-turn secondary, light-gauge wire wrap or hookup wire can be used. Wire dress is not critical, but it's advisable to cover the whole core fairly evenly — first with the secondary, then with the primary. Do *not* segregate the windings, as this will increase leakage inductance. Winding polarity doesn't matter. T_1 is held in place by a nylon screw and washer through the center of the toroid.

The tuning diodes' polarity is denoted by a square pad for the cathode and a round pad for the anode. The silkscreen on the board also shows the trapezoidal shape of the package as an additional aid. It is also a good idea to refer to the NTE618 data sheet available at **www.nteinc.com/specs/600to699/pdf/nte618.pdf**.

The controller PC board (see Figure 9) is also mounted in a die-cast aluminum box on 6-32×1½ standoffs. The 2.5 mm power connector and F connectors mount on the bottom — or circuit — side of the board. The control pot and on/off switch mount to the top — or component — side, and their shafts go through holes in the lid. The 9 V battery mounts to snap connectors on the bottom of the PC board. The F connectors mount to the wall of the box. The power jack is accessible through a hole in the wall of the box. The tantalum capacitors' polarity is denoted by a square pad on the positive lead and a round pad on the negative lead. The capacitors usually have a line on the positive end.

Testing

With the remote-tunable versions it should be possible to peak up receiver noise by varying the control pot. If nothing happens, first verify that the diode voltage varies from 0 to 8 V. If the diodes are reversed or if there are other wiring errors, the diode voltage will be incorrect. Once receiver noise peaks, impedance at the peak frequency can be measured. It should be in the general range of from 25 to 100 Ω. It should be possible to tune the impedance meter frequency slightly and find a frequency where the reactive component of impedance goes through zero (resonance). The 5-turn primary can be changed to 4 or 6 turns to modify the impedance if necessary, although it is not critical.

For the fixed-tuned version, program the capacitors for an initial estimate. For example, on my loop, 680 pF tuned to 1830 kHz. For 80 meters, start with 150 pF. Measure the resonant frequency (ie, where reactance is zero) and note the error percentage. If it is x percent high in frequency, increase capacitance $2x$ percent. If it is x percent low in frequency, decrease capacitance by $2x$ percent. It should be possible to hit optimum tuning in two or three tries.

As an additional check, verify that the loop has the usual nulling properties. With the loop broadside to a signal, it should null that signal. It is often possible to null power line noise.

Performance

The only novel aspect to this design is the feed system, so this antenna will not do anything magic that loops using other feed systems cannot do. As with other loops, it is handy for nulling power line noise or for finding power line noise. The loop also can be remotely located away from a source of QRM, such as a plasma TV, and/or oriented to null it. It can also null a nearby ham signal. The 20-foot circumference turns out to be a good compromise in terms of efficiency and mechanical complexity. The noise off the antenna, without a preamp, easily overcomes receiver noise if the receiver's internal preamp is enabled. Some users may want a preamp anyway, in order to get the signals up to the level where the AGC is more effective. The bandwidth is a few tens of kilohertz, so frequent retuning is unnecessary, although the remote tuning from the shack is effortless.

The antenna has been used for SO2R in 160 meter contests in the fixed-tuned configuration centered at 1830 kHz. In this application, the loop was about 900 feet from the transmitting vertical. It was possible to null the transmitted signal by 40 to 60 dB by carefully aiming the loop broadside to the vertical. This allowed simultaneous transmitting and receiving on 160 meters. Operation was possible with as little as 5 to 10 kHz spacing. A fair amount of 160 meter DX has been copied on the loop.

Variations

The reference design provided here is a known starting point that works. Most aspects of the design are not critical. The basic principles of the feed network can be applied to loop antenna variants. For example, I built a double-size version using 2-inch PVC pipe and 40 feet of coax. It had about 10 dB more signal (*not* signal-to-noise ratio), but was quite a mechanical monstrosity. I don't recommend building the loop with hard line. Although this construction will result in better efficiency, it also reduces the bandwidth nearly to the point of impracticality.

Many other AM radio tuning diodes can be used, such as the MVAM109 series, if you can find them. The NTE618 is the only varactor diode currently available to hams as a new (not surplus) part. The core of T_1 was chosen to be large enough for easy winding. Smaller or larger sizes also will work fine, as long as they have a similar value of A_L or can achieve a sufficient value of A_L by stacking cores. It is also possible to use the more-common higher permeability cores, such as Fair-Rite 43, at reduced efficiency.

Antenna and controller PC boards are available from the author at **www.n6rk. com**. **NCJ**