Joe Carr's Radio Tech-Notes

Small Loop Antennas

Joseph J. Carr

Universal Radio Research
6830 Americana Parkway
Reynoldsburg, Ohio 43068

Small Loop Antennas

Joseph J. Carr

Small loop antennas are defined as loops that have a total wire length of less than 0.15 wavelength (0.15λ). These antennas perform quite differently than large loop antennas such as the bisquare or quad loop. Small loops are used in radio direction finding, and in ordinary DXing for receiving weaker stations in the presence of strong interfering stations.

The performance of the small loop is less than that of other antennas (e.g. the half wavelength dipole), but its extremely sharp nulls and broad maxima frequently make it the antenna of choice on very crowded bands. In those cases you are swapping gain for signal-to-QRM ratio.

Small loop antennas are used mostly on the lower frequencies. Although designs exist for the upper end of the high frequency shortwave band (and some for VHF bands), the principal uses are in the VLF through mid-HF spectrum (roughly 10 KHz to 8,000 KHz).

Loop antennas can have a circular, square, rectangular, hexagonal or octagonal shape. In this paper we will take a look at the square form because they are relatively easy to build compared with the other forms (including circular). The square loop is not only mechanically easier to build, it performs very nearly the same as circular loop antennas of similar size.

Figure 1 shows the basic square loop antenna, with sides of length "A". The depth ("B") is the width of the windings, either coplanar or parallel planar with respect to each other (the parallel planar case is shown).

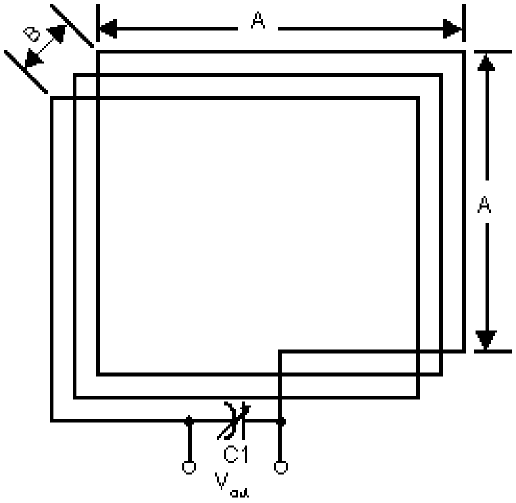

Fig. 1

The gain of the loop is less than a dipole for the same frequency, and you should normally expect to see very low signal voltages at the output terminals for any given electrical field strength. The output voltage can be increased significantly if the loop is tuned to resonance by a parallel capacitor, such as C1 in Fig. 1. Although untuned loops are used, the increase in output signal voltage is approximately equal to the Q of the tuned circuit. Values of 50 to 100 are normally "worst case" for the Q of practical loop antennas, and Q values approaching 1,000 are not impossible to obtain.

The use of tuning greatly increases the signal voltage at the resonant frequency. But there are trade-offs to consider. The tuning control is most conveniently adjusted by hand, which means that a need to change frequency requires the loop to be close at hand. Remote tuning becomes a problem (although variable capacitance diodes - varactors - are sometimes used to overcome this problem). On the plus side, loops attenuate unwanted signals by two mechanisms: nulls in the pattern (of which, more shortly) and tuning discrimination. If there are strong local signals even slightly removed in frequency from the desired signal, then the discrimination of the tuning circuit's selectivity helps attenuate that signal. The loop improves the ability of the receiver with regard to overload, desensitization, and intermodulation distortion (with the power levels seen on AM and LF band broadcast band transmitters, this can be a significant improvement in performance!).

Some loop antennas are designed as transformers, and have a low impedance coupling loop wound along with the antenna loop (Fig. 2). For medium wave loops, the coupling winding can be only one turn, although for LF and VLF loops up to five turns are used. Even at the LF BCB, however, a one-turn coupling loop is often found sufficient.

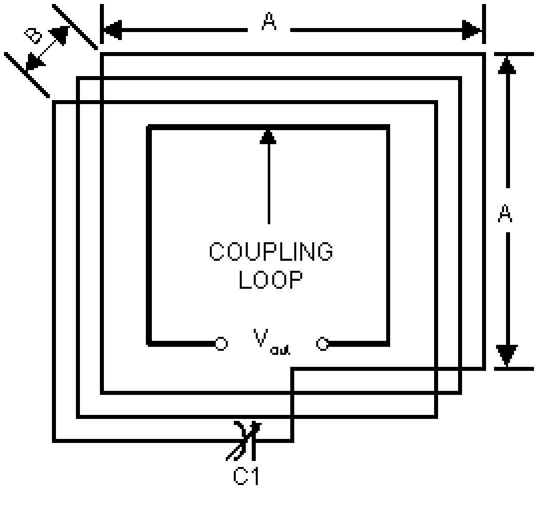

FIG. 2

The azimuthal radiation or reception pattern for the ideal small loop antenna is shown in Fig. 3. It is a "figure-8" pattern with the maxima off the ends of the loop, and minima (nulls) perpendicular to the loop. This pattern is exactly the opposite of most large loops where the maxima are perpendicular to the plane of the loop and minima are off the ends. The nulls of practical loops run from 20 dB relative to the minima for sloppily assembled projects, to 40 dB for well done jobs. With nearly perfect assembly, and some additional features, loops with nulls up to 60 dB are possible. Some literature claims 80 dB nulls, but I am skeptical of these results. A 60 dB reduction is 1,000,000:1, which is difficult to achieve in practice (an 80 dB reduction is 100,000,000, so you see the basis for my skepticism).

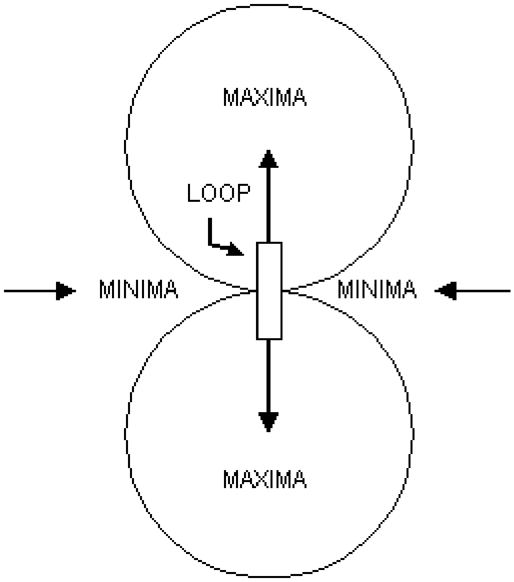

FIG. 3

The idealized pattern of Fig. 3 can be distorted by local interaction with the Earth, buildings, and other conductive or dielectric objects nearby (another reason for skepticism about extremely high null figures).

Larger sized small loops have a greater aperture, or capture area than smaller small loops (if you can follow that logic!), so will present a high signal voltage to the receiver. At some point, however, the loop is no longer "small," so the pattern achieved will not be as shown earlier. There is a distinct trade-off between loop size and signal levels, both for electromagnetic reasons (i.e. small loops are $\leq 0.15\lambda$) and mechanical reasons (large loops are harder to assemble and use). For most common uses, loops of 24 to 48 inches per side are preferred. The loops prepared for this and my prior papers on loops were 24 inches and 36 inches per side because these sizes correspond to material sizes available in hobby shops and DIY hardware stores.

The inductance of a loop can be calculated from Equation (1) below. Once the inductance is found, the capacitance needed to resonate the loop can be calculated from Equation (2).

$$L_{mH} \quad = \quad K1\, N^2 A \left[\; Ln\left(\frac{K2\; A\; N}{(N+1)\; B} \right) + K3 + \; \left(\frac{K4\; (N+1)\; B}{A\; N} \right) \; \right] \qquad (1)$$

Where:

LμH is the loop inductance in microhenrys
A is the length of the side of the loop in centimeters (cm)
B is the loop depth in centimeters (cm)
N is the number of terms
K1, K2, K3 and K4 are factors described in Table 1.
Ln is log (natural)

Table 1

Loop Geometry	K1	K2	K3	K4
Square	0.008	1.4142	0.37942	0.3333
Hexagonal	0.012	2	0.65533	0.1348
Octagonal	0.016	2.613	0.75143	0.0715
Triangle	0.006	1.1547	0.65533	0.1348

And for resonating capacitance:

$$C_{pF} \quad = \quad \frac{1 \times 10^{18}}{4 p^2 \;\; f^2 \;\; L_{mH}} \qquad (2)$$

Where:
C_{pf} is the resonating capacitance in picofarads (pF)
f is the resonant frequency in Hertz (Hz)
$L_{\mu H}$ is the loop inductance in microhenrys (μH)

If the math of Eq. (1) is a bit daunting for you, then there are some guidelines that will allow you to empirically home in on the correct size, inductance and resonating capacitance of the loop:

1. At 1,000 KHz, 10 turns provides 98 μH of inductance
2. At 5,000 KHz, 3 turns provides 4.6 μH of inductance

With these reference points you can experimentally scale the loop to the size that you require. Keep in mind, however, that the operating frequency should be in the range 100 KHz to 7,500 KHz. A little "cut-and-try" will go a long way if you find the arithmetic a little bit of a headache.

Constructing the Loop Antenna

Loop antennas can be built in a number of different ways. The method shown here for square loops is probably the simplest. The loop supports are made of wood of a type easily available in hobby shops and do-it-yourself hardware stores. Figure 4 shows the basic structure of the square loop antenna.

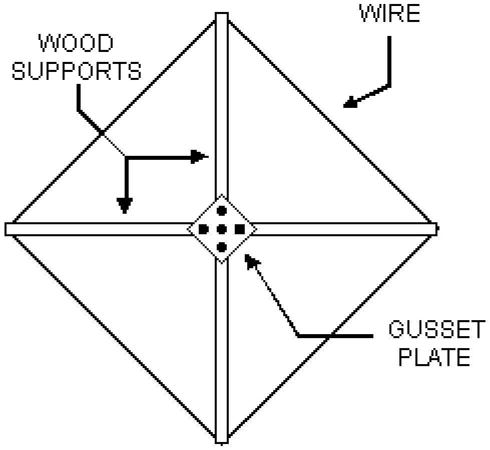

Fig. 4

The wooden crossarm supports are made of wood. In one model I used 24-inch × 2-inch spruce panels. This lumber can be purchased from hobby stores that cater to model builders. Another possibility is to use 2-inch × 1-inch lumber from a hardware or lumber store. The two wooden crossarms are each notched at the midpoint halfway across the width of the piece of lumber. When these two pieces are fitted together, a cross shape is formed. A pair of square gusset plates are used for stiffening. One plate is fastened to each side of wooden supports. Screws and carpenter's glue are used to assemble the unit. It is also sometimes necessary to place stiffeners at the corners of the two supports (Fig. 5). These can be fastened with wood screws and glue.

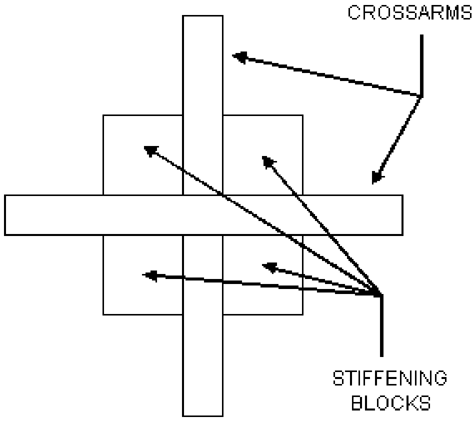

Fig. 5

The wires are strung along the outside edges of the wooden crossarms. Some builders slot the ends of the crossarms, while others drill small holes through which the wires are threaded (Fig. 6).

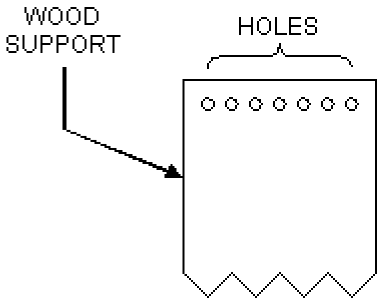

Fig. 6

I personally find the slots easier to work with, but others find the holes easier. The holes are a bit more stable, however, so may be the method of choice.

Using the Loop Antenna

The loop antenna has deep nulls perpendicular to the plane of the loop, and maxima off the ends of the loop. The usual way to use the loop for general DXing is to position the nulls such that they eliminate interfering signals that would otherwise obscure the desired signals.