1.0 Introduction

At HF single turn loop receiving antennas usually provide adequate signal output but at MF and especially LF that is usually not the case because for the same incoming signal strength loop output decreases with frequency. Given practical limits on loop diameter the usual solution is to add more turns to get more signal. Initially this works but as more turns are added at some point the rate of increase will plateau and then start to fall. For a given diameter there will be a broad optimum number of turns for maximum signal output at a given frequency. Choosing an appropriate number of turns is a key part of loop design at LF and MF.

There are many possible loop shapes but the diamond and octagon shapes shown in figure 22.1 are most common. Irregular shapes can be used but symmetric shapes have better pattern nulls.

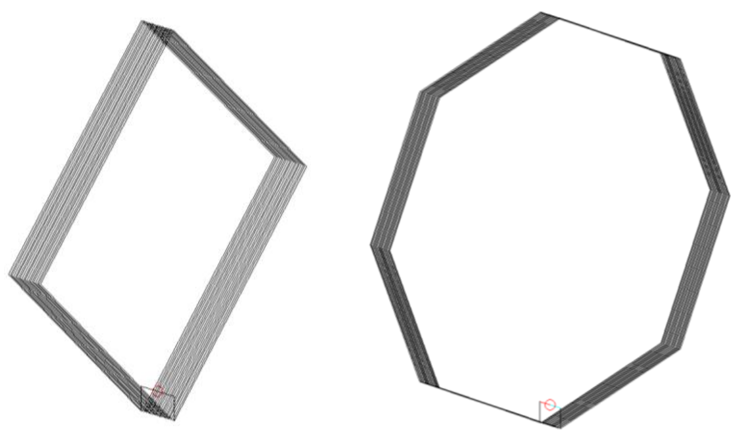


Figure 22.1 - Typical loop shapes.

There are two winding configurations in general use: solenoids, where the turns all have the same diameter, like a normal air wound inductor, or a flat spiral where the turns are all in the plane of the loop with a progressively decreasing turn diameters spiraling in. There are tradeoffs between these choices: a flat spiral is simpler and does not need wire combs at the ends of the support arms. In a solenoidal winding each turn has the same area whereas in a flat spiral the area of each turn decreases which reduces output. However, when the number of turns and wire spacing are small and the diameter large, the signal reduction with a spiral is modest. Spiral windings tend to have lower Q than solenoidal which also reduces the output. Examples of each of these configurations are shown later.

1.1 Loop voltage

The following discussion assumes the loop is small enough that it responds primarily to the magnetic field component (Ho) of the incoming wave. Real loops respond to some degree to the E-field components resulting in a reduction in broadside null depth and the introduction of some horizontally polarized signal. Figure 22.2 is a sketch of an idealized loop.

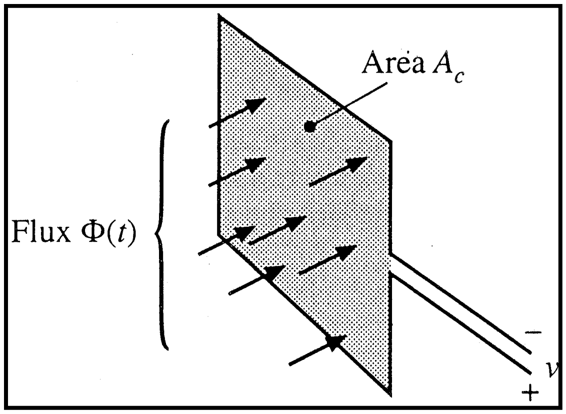


Figure 22.2 -Magnetic flux through an open circuit loop.

The voltage induced in the loop by the incoming signal can be expressed by:

$$\boldsymbol{v \propto \Phi N f = H_o N A c f} \quad (1)$$

Where:

Φ=H_oAc=flux through the coil, H_o= peak field intensity [A/m], v= peak voltage [V] at the feedpoint with no load (open circuit), N= number of turns, Ac= area of the coil [m^2] and f= frequency [Hertz].

For a given signal (H_o) at a given frequency (f) to increase the output voltage (*v*) we can increase the number of turns (N) and/or the area of the loop (Ac).

How does a loop compare to a vertical whip for signal output for the same incident vertical field E [V/m]?

$$\boldsymbol{v = E * he} \quad (2)$$

Where *he* is the "effective height".

For a simple vertical:

$$he = \frac{h}{2} \qquad (3A)$$

For a loop:

$$he = \frac{2\pi AcN}{\lambda} \qquad (3B)$$

For example, if h=20' for the whip *he*=10'. For a ten turn loop with a diameter of 10' at 475 kHz, *he*≈9.5'. For the same incident field we would expect similar output from either antenna. However, going down to 137 kHz, *he* for the whip remains 10' but for the loop *he*=2.75'. The loop output will be down ≈-11 dB compared to the whip. That's one reason 2200m loops need more turns than those for 630m.

1.2 Resonant loops

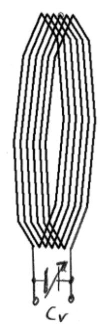


Figure 22.3 - Multi-turn loop with a shunt tuning capacitor (Cr).

The examples in this section use an 8' diameter octagonal loop with 12 turns of #18 wire, the bottom of the loop 8' above average ground. The impedance, measured between the open ends of the loop with Cr=0, has multiple alternating parallel and series resonances as shown in figure 22.4.

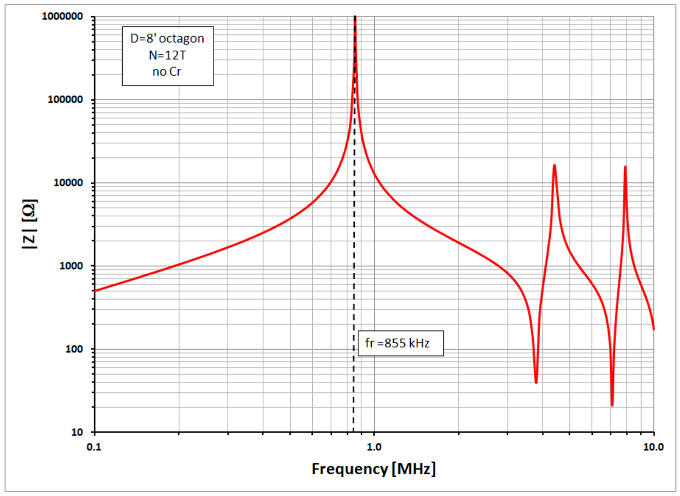


Figure 22.4 - Feedpoint impedance of an untuned 12T D=8' octagonal loop.

Loops are usually used at frequencies below the lowest resonance, which will be referred to as the "self resonant frequency" or "fr". The "operating frequency" is "fo". Loops may untuned for broadband use or resonated with a capacitor to maximize output at a chosen fo. To lower the resonant frequency a shunt capacitor (Cr) can be added between the ends of the coil. Setting Cr=100 pF the resonance for this loop shifts as shown in figure 22.5. Without Cr fr≈855 kHz, with Cr the resonance is shifted down to 475 kHz=fo.

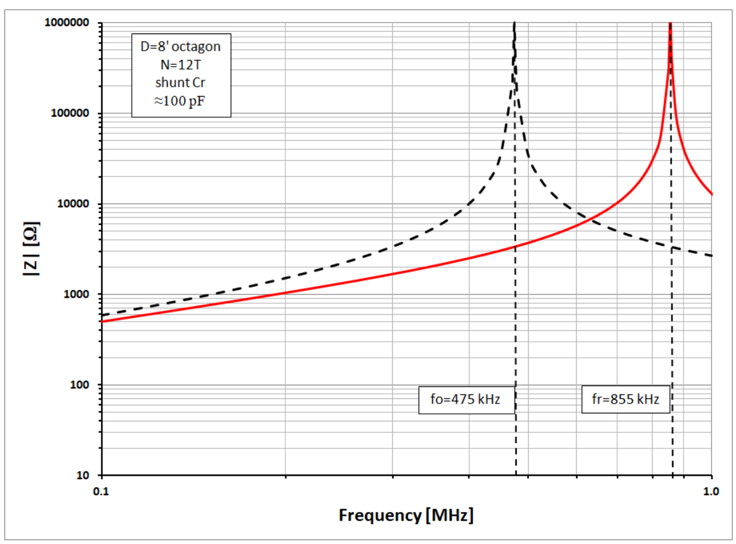


Figure 22.5 - Resonance shift with Cr=100 pF.

Figure 22.6 is an equivalent circuit for the loop, where R_a represents a combination of radiation, wire loss and ground loss resistances, L_a is the inductance of the loop and C_a is the distributed capacitance within the winding.

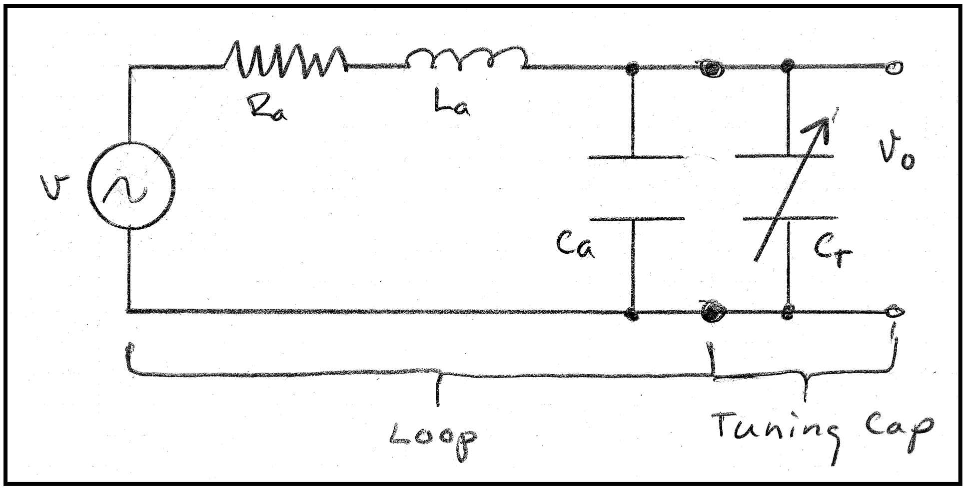


Figure 22.6 - Multi-turn loop equivalent circuit.

A multi-turn loop is simply a coil and we can express it's Q in the usual way:

$$\boldsymbol{Q = \frac{2\pi f L_a}{R_a}} \quad (4)$$

The output voltage, with the loop tuned to resonance, will be:

$$\boldsymbol{v_o = Qv} \quad (5)$$

Note that the open loop voltage *v* from figure 22.2 is multiplied by the loop Q. Q's of several hundred are possible leading to large increases in v_o. This is a primary reason for resonating a loop. Resonating will also sharply reduce bandwidth allowing the loop to act as a filter improving rejection of out-of-the-band signals. There is a downside to narrow bandwidth, the 630 and 2200m bands are narrow enough that fixed tuning can be usually be used but the 160m and 80m bands are much wider so adjustable tuning will likely be needed if the loop is used over a significant part of these bands.

As shown in figure 22.5 the impedance of a resonant loop is very high, hundreds of kΩ. How do we couple that to a 50 or 75 Ω feedline effectively. A transformer would need a turns ratio of 100-150:1, usually not practical. Traditionally a balanced amplifier with high impedance differential inputs and low impedance balanced outputs (see figure 22.7) has been used. In years past vacuum tubes were used but today junction FET's are used. Unfortunately commercial amplifiers for amateur use are not available so home brew is needed.

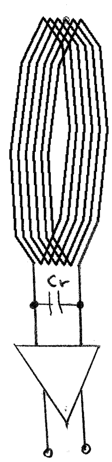


Figure 22.7 - Resonant loop with an amplifier.

There is another problem with this arrangement, because of the very high impedances at the ends of the loop it is very sensitive to capacitive coupling to a feedline and/or nearby conductors. Figure 22.8 illustrates the effect of on radiation pattern if the feedline shield were connected to one side of the coil.

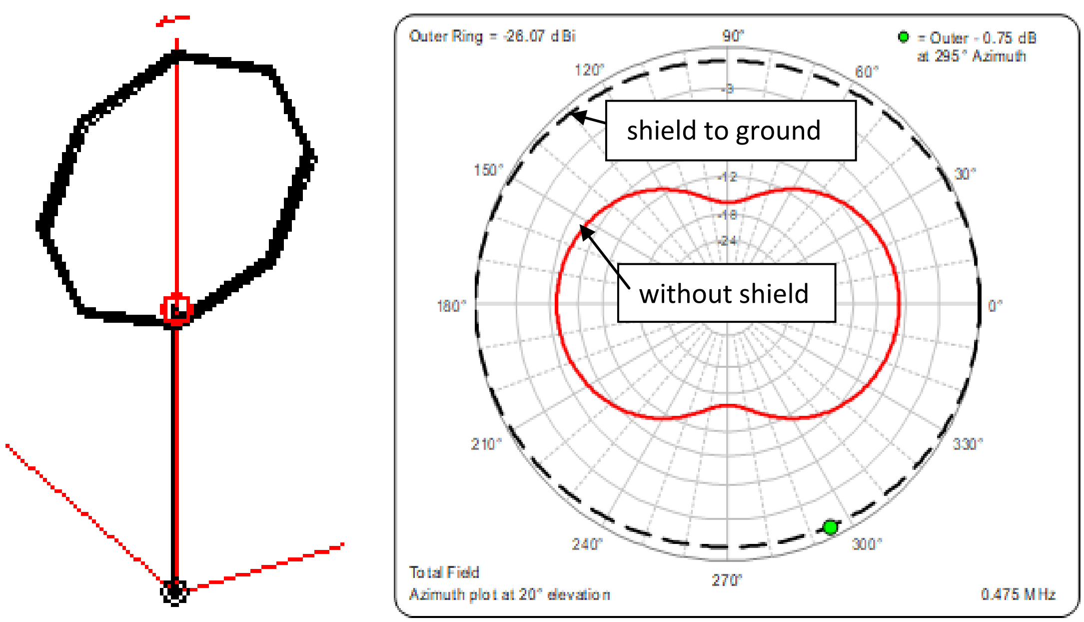


Figure 22.8 - Effect of a grounded feedline shield on radiation pattern.

The feedline is acting as a simple vertical with it's output adding to and overwhelming the loop output. This is an extreme example but even much smaller couplings can degrade the pattern. Fortunately there are alternatives which can reduce this problem.

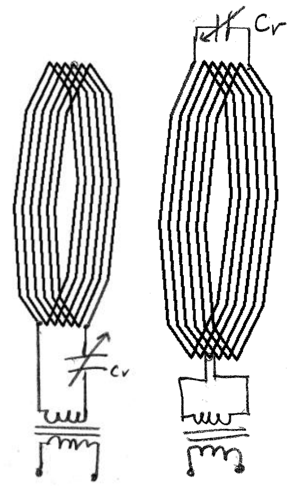


Figure 22.9 - Alternative feedline connections.

As shown in figure 22.9A instead of a shunt capacitor across the ends of the coil a series capacitor can be used to resonate the loop. The effect on feedpoint impedance is shown in figure 22.10.

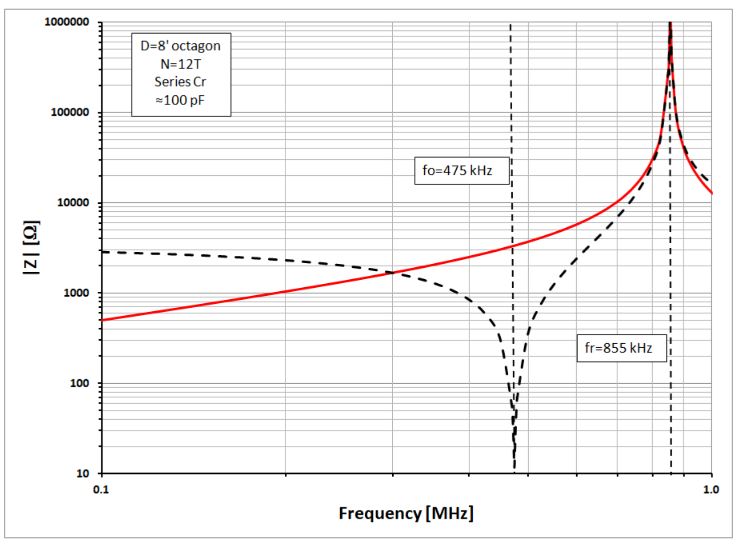


Figure 22.10 - Feedpoint impedance with series Cr tuning.

The original high impedance parallel resonance at fr is still present but adding Cr in series has introduce a low impedance or "series resonance" at fo. What's going on here? Figure 22.11 shows an equivalent circuit for this arrangement. The loop near fr is represented as a parallel resonant circuit. Normally fo will be well below fr where the loop is just a lossy inductor. Cr is added to series resonate this inductance at fo.

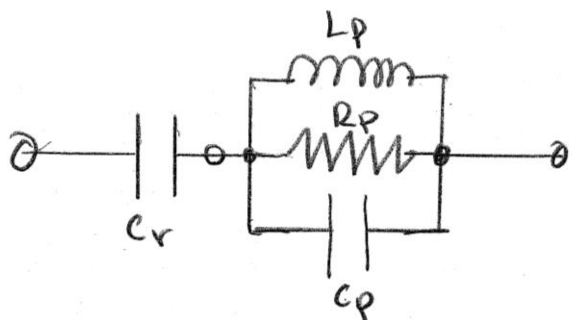


Figure 22.11 - Equivalent circuit with Cr in series with loop.

The feedpoint impedance at fo will now be very low, in the range of 5-100 Ω which is very suitable for a matching transformer as shown in figure 22.9. Typically the transformer will be a few turns on a small binocular ferrite core. Besides providing matching the transformer will decouple the loop from the feedline reducing coupling to the feedline. Typically the inter-winding capacitance between primary and secondary will be of the order of 10-15 pF which is more than adequate for 630 and 2200m loops and may be ok for 160m. For 80m loops this may be too much.

Fortunately we have another alternative as shown in figure 22.9B. Instead of attaching the feedline across the ends of the loop we can open the center of the loop and use that as the feedpoint leaving Cr across the ends of the winding. Why does this help?   Figure 22.12 is shows the relative current distribution across the coil. The current is low at each end and maximum in the center.

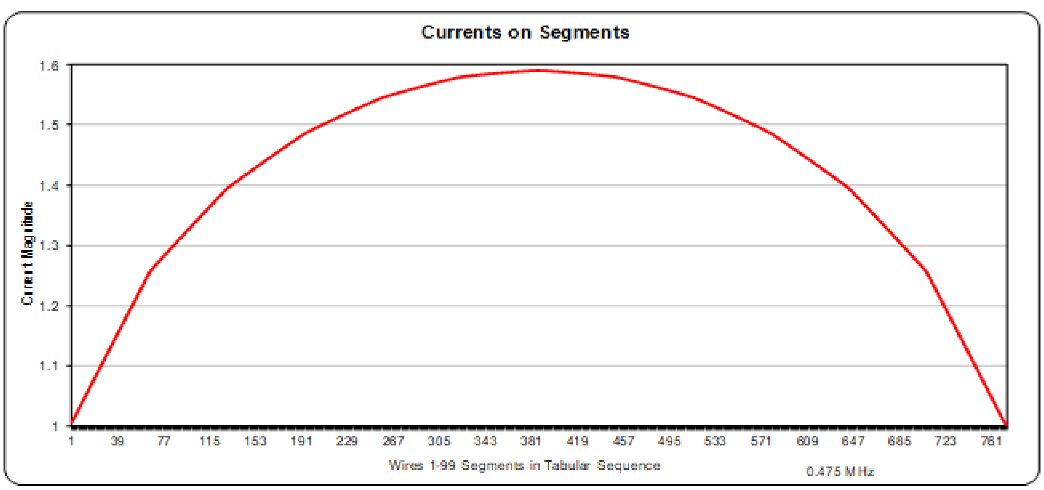


Figure 22.12 - Relative winding current across the coil.

This current distribution affects the voltage distribution along the coil. At the ends the current is low and the voltage high but at the center, where the current is much higher, the voltage is lower. Capacitive coupling to nearby conductors is very sensitive to voltage differences. Connecting the matching/isolation transformer to the center of the coil minimizes stray coupling. The feedpoint impedance for this case is shown in figure 22.13.

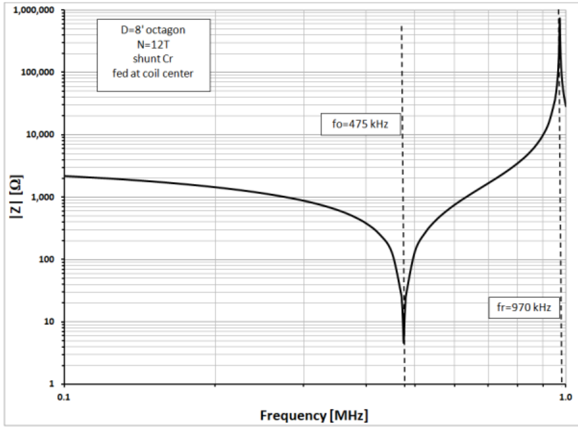


Figure 22.13 - Impedance of center fed coil.

There is now a series resonance at fo=475 kHz and fr has been shifted upward to 970 kHz.

There is one more way to feed the loop at it's center, tap across the winding as shown in figure 22.14. This allows some adjustment in impedance simplifying the transformer design.

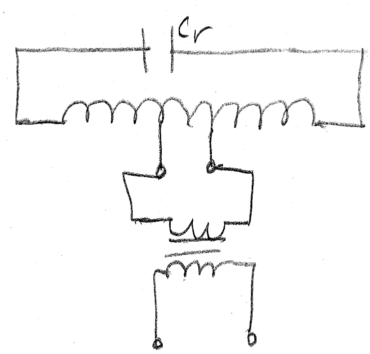


Figure 22.14 - Tapping across turns in the middle of the coil.

1.3 Choosing N

The goal is to choose a value for N which maximizes v_o for a given fo and A_c. The Q of an inductor has a broad maximum at f=0.45fr. As we add turns fr decreases and it would appear from equation (5) the optimum N is one which has fr=fo/0.45=2.22fo. Increasing N further will begin to reduce Q. However, increasing N also increases the loop voltage (*v*). As a result a limited increase in N provides more output despite some reduction in Q. The maximum is very broad and setting fr=fo/0.6=1.7fo is a good compromise. This corresponds to fr> 6 MHz for

80m, fr>3 MHz for 160m, fr>800 kHz for 630m and fr>230 kHz for 2200m. We can predict fr using modeling combined with experimental checks and create graphs that give a good estimate of fr versus N for different loop sizes and geometries as shown in figures 22.15 and 22.16. These examples assume a solenoidal winding with #20 wire and 0.5" spacing between turns. Different wire sizes or spacings will affect the value for fr but not grossly so the graphs provide a useful general guide. The graphs have horizontal dashed lines for fr=1.7fo for 80 through 2200m.

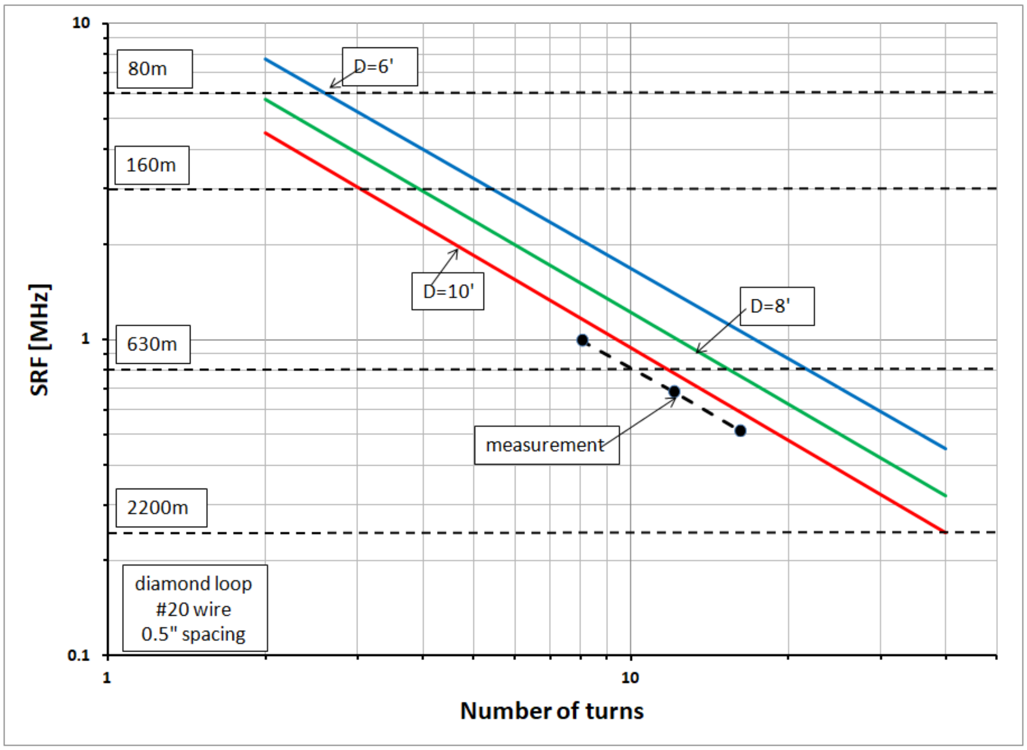


Figure 22.15 - fr versus N for diamond loops.

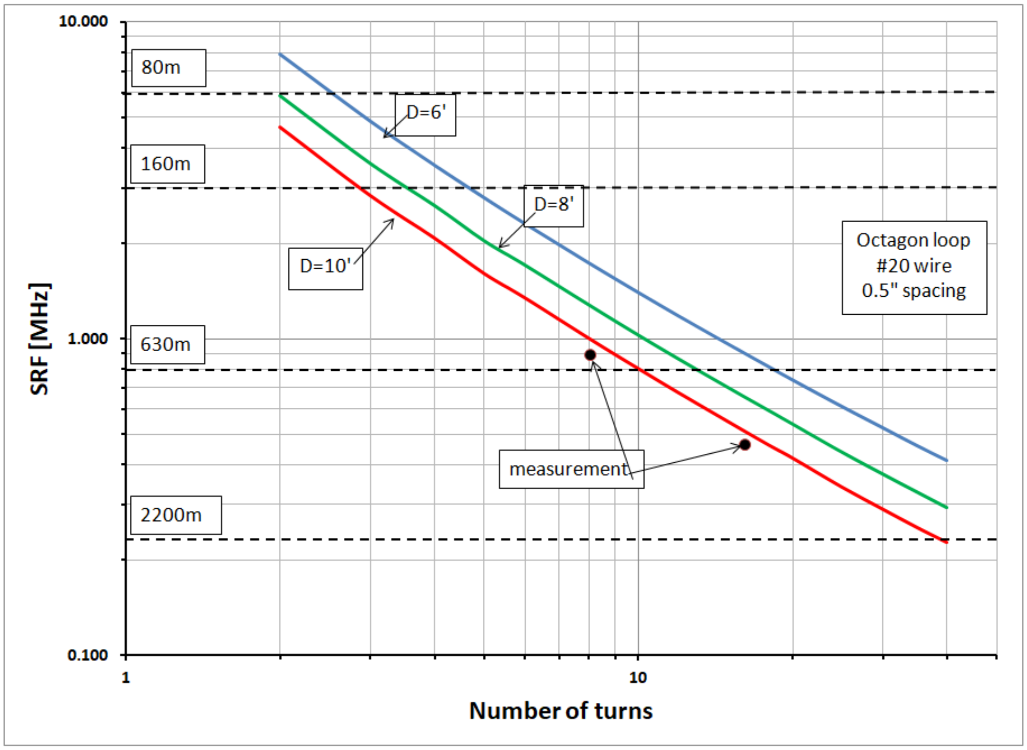


Figure 22.16 - fr versus N for octagonal loops.

On 80 and 160m 6' and 8' loops with a few turns should work well. On 630m a 10' diamond loop with N=10-12 turns or a smaller 8' diamond with N=14-16 turns would be good. For octagonal loops fewer turns can be used: on 630m, N=9-11T for a 10' loop and N=12-14 for an 8' loop. The optimums are broad, the choice for N is not critical.

For 2200m with a 10' octagon N needs to be about 40 turns. With 1/2" wire spacing this means a 20" wide wire comb making for a mechanically large loop which may not be practical. There are alternatives: use a significantly larger diameter or use fewer turns and increase the value of Cr. Reducing the number of turns and increasing Cr will work at the price of reduced Q and vo. Much larger diameter loops are practical and examples are given in a following section.

To check the accuracy of modeling predictions in figures 22.15 and 22.16 five antennas were built and fr measured. Those points are indicated on the graphs. The agreement between modeling and experiment was quite good. Measured values tend to be slightly lower than modeled due to capacitive loading from the measurement apparatus.

1.4 Practical Examples

Loops can be fabricated from inexpensive PVC pipe which, along with associated fittings, is readily available at home improvement stores. Suitable pipe sizes vary from 1/2" to 1" and are available in different wall thickness: thin wall class 1120, and heavier schedules 40 and 80. For most loops 1120 will be lighter and less expensive but still have adequate strength. For smaller loops 1/2" is ok but for 8'-12' loops 3/4" or even 1" will provide a more durable structure. Alternative materials, such as wood, can also be used.

The multi-turn loops typical at LFMF often need several hundred feet of wire. The wire size is not critical anything from #14 to #22 will work. Larger wire diameters will yield higher loop Q but in general #18 or #20 wire works well and is relatively economical. Some of the least expensive wire is intended for buried wire "dog fences" and available in 500' rolls at home centers. Shop around, prices for the same wire size can vary dramatically!

Mechanically the simplest form is a flat spiral diamond wound on a PVC pipe cross like that shown in figure 22.17. This construction may not be beautiful but it will work and is a reasonable starting point to see if a loop is going to be useful.

Figure 22.7 - PVC pipe support for a diamond loop.

Octagonal loops are more complicated to fabricate but usually more robust and provide better performance. Figures 22.18 and 22.19 show some examples.

Figure 22.18 -Lattice construction, W7IUV

Figure 22.19 -Radial arm construction, W7IUV

Figure 22.20 - Wire comb held in a slotted PVC T - W7IUV.

As shown in figure 22.20 the wire comb is made from a flat strip of plastic with slots cut with a saw. The T is then slit on the outside with a saw and the comb forced into the slot. Depending on slot width the fit will usually be tight so the comb can be driven in with a mallet. Note the single wire inboard from the main winding. In this loop W7IUV used a single turn internal coupling loop to extract the signal. This is discussed in section 5.3 (24th edition).

Figure 22.21 - Reinforced octagonal loop, N6LF.

Figure 22.21 shows a more robust octagonal loop used at N6LF. The octagonal ring used straight sections of 1/2" PVC and 45° elbows. The ring was bolted to the radial struts.

Figure 22.22 provides some additional construction details. On the left is an example of a flat spiral winding and on the right a typical plywood hub using "C" clamps to secure the radial pipes. Performance is improved when the loop raised above ground. Keeping the lowest point of the loop 8'-10' above ground surface is good practice.

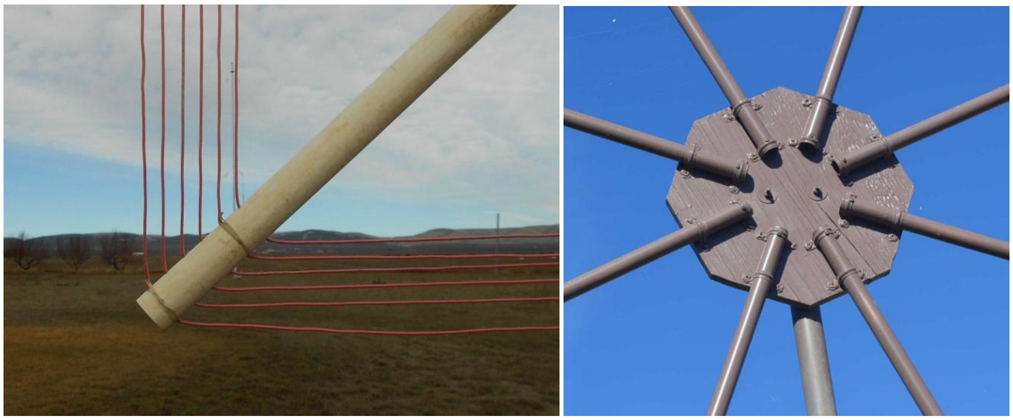
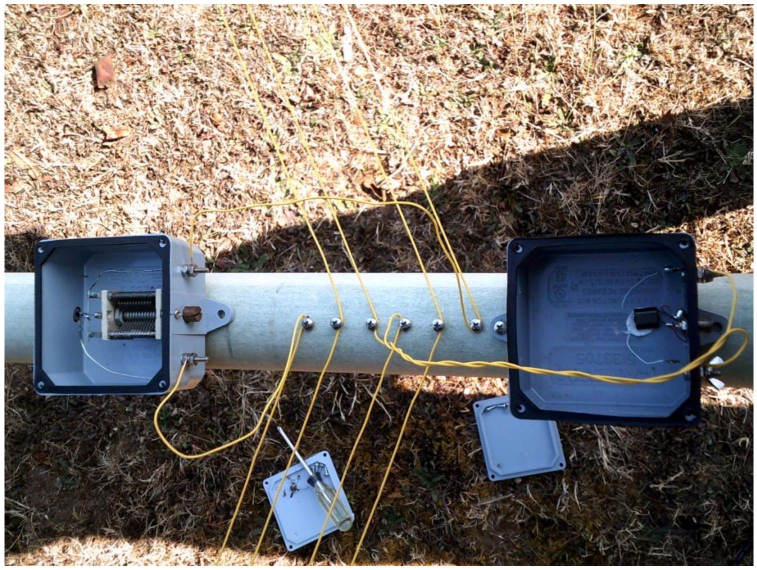


Figure 22.22 - Flat spiral winding and hub examples -W7IUV.

Using PVC pipe loop diameters of ten to twelve feet are probably the largest practical however, there are other constructions that allow much larger diameters which are particularly useful for 2200m. Figure 22.23 shows a pair of 24' diameter loops (one diamond and one octagonal) built using hubs and arms salvaged from an old 20m Quad. The windings are flat spirals spaced ≈1". For 630m only four turns were needed. For 2200m ten turns would be enough.

Figure 22.23 - Large diameter diamond and octagonal loops- N6LF.

The low impedance feed point and Cr placement shown earlier in figure 22.9B were used. Cr and the matching transformer are shown in figure 22.24.



Figures 22.24 - Resonating capacitor (Cr) and matching transformer - N6LF.

Figure 22.25 - Center hub - N6LF.

The support post was a 3" diameter fiberglass tube salvaged from a cell tower antenna. A 20' length of the 3" schedule 80 PVC would work as well. Even a wooden post could be used.