Big Untuned Single Turn Air Core Loop Antennas
For LW And MW Phased Antenna Systems

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Recently I spent a lot of time trying to develop a phased antenna system which produced good steered nulls from about 200 to 2000 kHz, i.e., including both the LW and MW bands. A pair of spaced (noise reducing) inverted L's won't do unless you have a lot of real estate because they would need to be spaced about 500 feet apart to satisfy the 1/10 wavelength criterion for good nulls at 200 kHz. An active dipole and inverted L don't need any spacing, so I designed and built an active dipole. But to my surprise the active dipole was increasingly less sensitive to daytime ground waves from the middle to top end of the MW band, presumably because of the dipole's insensitivity to vertically polarized waves (though why the dipole was not insensitive at the low end of the MW band and in the LF band is a mystery to me). This was quite disappointing because I had developed a really good active dipole amp with input 3rd order intercept $I3_{in}$ about +48 dBm and input 2nd order intercept $I2_{in}$ about +88 dBm. I briefly considered a small active loop antenna, but based on my experiences with them and from what others have said they are insensitive, and since they must be amplified, they can and will have intermod problems in high RF environments. The only thing left to try, or so it seemed, was a big untuned single turn air core loop.

After an intergalactic Google search on loop antennas (looking for big single turn air core loop antennas) I came up with exactly... nothing. So I took a 100' spool of Radio Shack #18 stranded (7 x 26) speaker wire, pulled it apart to make two 100' lengths, soldered one end together, hung it up as a 15' by 85' vertical rectangle (one 85' side on the ground, the other 85' side suspended 15' up in the air and center fed), attached my standard 100 ohm twinlead (more RS speaker wire), connected the other end of the twinlead to my modified Misek phaser, and had a listen on my R-390A in the MW band. Not bad, considering that I had made no attempt to impedance match (I didn't even know the impedance of the loop at that point). Because I had read somewhere that the impedance of untuned loops is quite low and that a step up transformed should be used, I took a 9:1 impedance ratio broadband transformer (3:1 turns ratio) outside and connected it as a step up transformer (as if the loop were the lower impedance). Back inside at the R-390A I found that signal levels from the loop were much lower. So back outside I went and reversed the transformer to make it a step down transformer. Back inside I found that the signal levels were great, perhaps slightly greater than from my 45' inverted L's (which are more than sufficient for my location). To check out the LF band I used an NRD-525. Signals were also great there, again comparable to my inverted L's. Next I checked the nulling performance (it was early afternoon). Nulling of groundwaves was excellent both in the LF and MF bands. I waited until dark to check out the MW skywave nulling quality of the big one turn loop against an inverted L. The first night no meaningful comparisons with my spaced inverted L's could be made because skywave propagation was unstable, making it impossible to maintain long periods of deep skywave nulls. The next day I put up a 2nd big one turn air core loop at a right angle to the first (#1 figure 8 nulls were E-W so its deepest nulls were its N-S cardioid patterns; #2 nulls were N-S) so its deepest nulls were its E-W cardioid patterns). The next night propagation was stable, and I found that skywave nulls using a loop and inverted L were excellent, just as good (in the MW band) as using a pair of spaced inverted L's. The following day I discovered that I could hear WSM Nashville 650 and WOAI San Antonio 1200 at mid day and throughout the afternoon using a loop and an inverted L (which I have never heard before at mid day using my pair of phased inverted L's). Apparently the loops have better signal to man-made-noise ratios than noise reducing (isolated grounds and 9:1 impedance matching transformers) inverted L's.

Next, I analyzed the big single turn loop to determine the optimum matching transformer. I found the following formula at http://www.qsl.net/in3otd/rlsim.html.

$$L(uH) = 0.4[(L + W) \ln(4LW/D) – L \ln(L + \text{sqrt}(L^2 + W^2)) – W \ln(W + \text{sqrt}(L^2 + W^2))] + 0.4\{2\text{sqrt}(L^2 + W^2) + D – 2(L + W)\}$$

where L and W are the length and width of the loop, D is the diameter of the wire, and all measurements are in meters.

Using this formula, I determined that the inductance of my loop was about 100 uH. So at 1.000 Mhz the loop reactance is about 600 ohms (2 pi f L where f is in Hz and L is in Henrys). Transmitting antenna analysis software, like EZNEC 4.0, using average ground parameters, gave about 50% higher, or about 900 ohms. I have no idea which value is more nearly correct for a receiving antenna.

I used Kirchoff's voltage law, the fundamental law of complex power (P = VI*, where I* is the complex complex conjugate of the current I), and differential calculus to determine what value of a resistor R placed across the loop terminals should have for maximum transfer of power from the loop to the resistor. I found that R = 2 pi f L where f is the frequency in Hz and L is the loop inductance in Henrys, i.e., that R should have the same value as the loop reactance. Because the value of R decreases as frequerncy decreases, a single optimum value of R is not possible.

Can a single value be chosen for R without seriously compromizing signal levels? Let us suppose that we match at 1.700 Mhz, so that 1020 ohms gives maximum power transfer. For my 15' by 85' loop a 10.2:1 impedance step down transformer would be optimal at 1.700 Mhz for matching to 100 twin lead. The 9:1 transformer I used is close enough. But what about the LF band? At 200 kHz the optimal value of R is 120 ohms. I calculated the power transfer using a 900 ohms resistor at 200 kHz and compared it to the optimum power transfer using 120 ohms. The loss when using 900 ohms turned out to be be only 4 dB, hardly noticeable. If you wish, you could use remote relay switching to short turns of the matching transformer, but it doesn't seem worth the effort. I seriously doubt you would hear any DX if you matched at 200 kHz that you would not also hear hear if you did not match at 200 kHz.

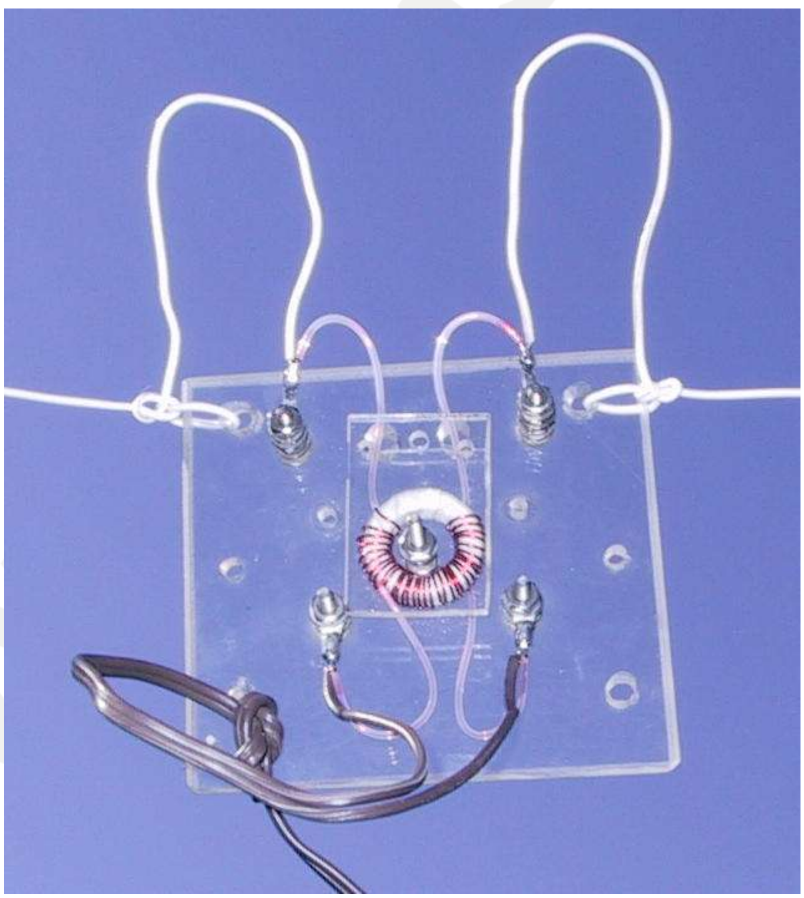
How big is big enough? I don't know the answer to that. It probably depends on the mimimum levels of ambient man made noise at your location. The voltage induced in a loop by a passing radio wave is directly proportional to the area of the loop. So if, for example, you want 6 dB additional "gain," you will need to double the area of your loop. Then you will need to calculate the new value for R. For example, if I doubled the length of my loop, the inductance would increase to about 144 uH, so the reactance at 1700 kHz would be about 1400 ohms. In this case a 3.75:1 step down transformer could, but I might just use the original 3:1 that I am using now. For a ("10 dB gain") loop 3 times as long as I am currectly using (300' by 15' or so) I probably wouldn't bother calculating the inductance, but just use a 4:1 turns ratio transformer.

After I had these big loops up for a week or two I decided to reconfigure them as square (more or less) loops and hoist them as high in the air as was feasible using the tall pin trees in my yard. This required four 100 foot lengths of 1/4 inch nylon rope, a sling shot, some lead (fishing) weights, and some thin nylon fishing lime. First (after more than one try!) the fishing line with lead weight attached was shot over a high limb and used to pull the nylon rope over that limb. After three more ropes were in place, the antennas were raised. The end results were two big loops, about 60 ' wide by 40' high, with bottoms about 10' off the ground, and tops about 50' up in the air. Signal levels were slightly higher with these elevated somewhat square loops, about 6 dB more (because of their larger areas), but this did not translate into hearing any more stations than could already be heard with the more modest loops. The larger aperture elevated loops were also not any quieter that the more modest loops. Eventually I will probably return to my original more modest loops, but for now I'll leave the more impressive one up for bragging rights and to perplex the neighbors, who have started calling me Marconi.

How big is too big? I don't know that either. Someone (like Bjarne) with a lot of real estate and few or no nearby transmitters will have to determine that.

These big single turn air core loops are not intended as stand alone antennas (though I suppose they can be used as such), but rather as one of two (or more) antennas used in a phased array. I use Misek's phaser, but with a push-pull Norton amp in place of the amp Misek used, and with several other modifications. Other phasers will not work as well. At present I have two noise reducing inverted L's spaced 180 feet apart, and two big loops (one E-W) and one N-S). I phase the two L's against each other, and phase an L (the quieter one, located further from the power lines) and a loop against each other. I have foiund that for best skywave N-S nulls, the N-S loop is generally best. And for best skywave E-W nulls, the E-W loop is generally best. However, I have found at least one exception to these rules. Until I put up my E-W loop, I was never able to null the skywave of WOAI San Antonio 1200 (to the SW of me) deeply or for very long. Now, however, the E-W loop does an excellent job of nulling the WOAI skywave.

Below is a photo of my big loop matching transformer assembly.



The toroid is an amidon FT-114-75 (A_L about 3000, permeability u = 5000, about 1.14 inch outside diameter) with a large piece of clear plexiglass as strain relief assembly and a small piece of clear plexiglass for clamping the transformer. Both pieces of plexiglass are recycled, as you can see from the extra holes. The lugs are attached to the plexiglass with stainless hardware for stability, and are used as solder connections for the antenna wires, twin lead wires, and antenna transformer wires. The loop antenna wires and twin lead wires are routed through holes in the plexiglass and tied into square knots for strain relief. The toroid is wrapped with Scotch Glass Cloth Electrical Tape for insulation (high permeability ferrite is a semiconductor and, consequently, should be insulated from the enameled wire whose insulation can be broken by the hard ferrite while you are winding the transformer). The primary is about 24 turns # 20 enameled copper wire, and the secondary is about 8 turns # 20 enameled wire. Teflon insulation is used on the transformer (to prevent grounding by unexpected accidents).

The twin lead need not be shielded because it is inherently immune to local noise and unwanted signals. If your phaser has an unbalanced antenna input, you will need to make a 1:1 balun. Another FT-114-5 will do, this time using an 8 turn primary and an 8 turn secondary. The two primary leads are soldered to the two lead in wires (and insulated from each other). The two secondary wires are connected to the binding posts (be sure to tin the ends with solder to remove all the enamel) of a binding post to BNC adapter. You can, of course, use coax from the antenna transformer to youe phaser, but that is an inferior way of connecting the antenna to your phaser (or receiver), and almost guaranteed to pick up local noise and will definitely pick up unwanted signals

As for phasers, all of the commercial ones and most of the non-commercial ones have given phasers a bad name. All of them can produce decent nulls on local noise and daytime groundwave signals if (big IF) your antennas generally provide approximately equal signal levels and generally are spaced appropriately (about 0.1 wavelength for a pair of inverted L's, or close spaced for an inverted L and a loop). However, even in these cases is is often extremely difficult to generate the nulls. For nighttime skywave nulls, all of them vary from poor to awful performance. If you thought nulling daytime groundwaves was difficult with them, nulling nighttime skywaves can be virtually impossible. And even if you are able to generate a null, the null will not last. I know. I've been there and done that. Yep. I've built just about every phaser whose schematic has been published: delay line phasers, active phase shift phasers, narrow band LC phasers. None of them worked well. I even bought an active phase shift phaser just in case I hadn't built it correctly from the schematic. Guess where it is now? In the Ruston land fill! And another phaser that I didn't buy, a friend of mine tried out on loan. It worked equally poorly.

There is probably little or no reason to build one of these big loops (and a noise reducing inverted L) for a phased array unless you also build the only phaser worth having, the one developed by Victor Misek. Russell Scotka and I have been using modified Misek phasers for many years now. If properly built (especially with high reliability potentiometers), they are easy to use and last almost forever. I have had mine in continuous operation since 1995 and it works as well today as it did when I built it. For detailed information on our modified Misek phaser, see the article "MW Phaser #2," by Dallas Lankford in The Dallas Files at www.kongsfjord.no.