My Portable Magnetic Loop Antenna

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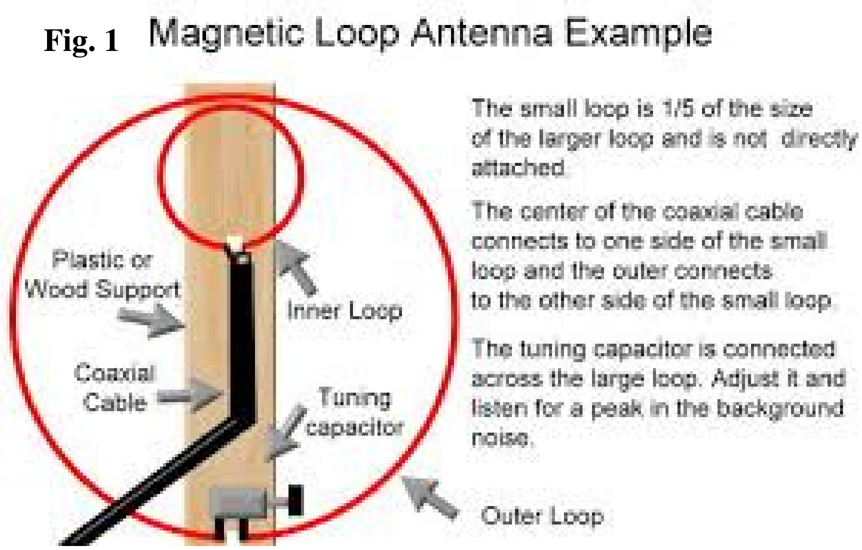
I. Introduction

After reading about the famous "AlexLoop" antenna (see http://alexloop.com/), I was motivated either to buy one of those or to create my own *portable magnetic loop antenna.* I decided it would be more fun to build one myself, and I proceeded along that path.

What is a magnetic loop antenna? This name is usually applied to an "electrically-small" loop, with a circumference certainly less than ¼ wavelength, and often as small as 0.1 wavelength at its lowest operating frequency. With an interest in operating the antenna from 40m through 15m, I made my loop with a circumference of about 11.5 feet, or a diameter of 3.67 feet, which is very close to the AlexLoop size of one meter in diameter.

Here is an example of a typical magnetic loop antenna. By the way, the term "magnetic" is ascribed to such a loop because in the near field, the magnetic field is very strong. (Note that with a dipole, the electric field is very strong in the near field.)

Fig. 1



http://26hs4316.wordpress.com/antenna-construction/magnetic-loops/

II. Receive Properties of a Small Loop

A loop antenna is tuned to a resonance on receive by adjusting the tuning capacitor (Fig. 1). Because atmospheric noise dominates over receiver noise in the HF bands, and because the tuning is quite narrowband, a small loop antenna can produce a signal-to-noise ratio that is oftentimes much better than a dipole for the same band. The gain of a loop may be lower than that of other antennas, but what matters is the signal-to noise *ratio*, which will be better with a well-designed loop.

III. Transmit Efficiency

Before proceeding with a description of my antenna, it is important to appreciate what one can expect from a small loop antenna, especially on transmit. First of all, let us consider three possible attributes of an antenna: small size, wide bandwidth, and high transmit efficiency. At best, one can achieve excellence in only two of these three properties at a time. In particular, for a loop, we achieve small size by virtue of construction. It is possible to achieve high efficiency by proper loop design. But then we must sacrifice bandwidth. The loop is tuned by the tuning capacitor, and the resulting bandwidth is very narrow in an efficient loop. In fact, the greater the efficiency, the narrower the bandwidth will be.

By transmit efficiency, we mean that percentage of power applied to the antenna which is transmitted into the air. Another way of looking at this is to compare the power transmitted into the air for a loop and for a dipole operating at the same frequency, for the same power applied to the respective antennas from the transmitter.

Note also that a dipole needs to be elevated at least a half-wavelength for best results. On the other hand, loop antennas are virtually ground independent, and operate just fine (in a vertical position) just a few feet off the ground, supported, for example, by a small tripod.

An excellent discussion of the theoretical and practical aspects of small loop antennas is given in: http://www.aa5tb.com/loop.html . An Excel spreadsheet is also available from that website for calculating various parameters (bandwidth, efficiency, peak voltages, etc.) from the loop antenna dimensions and input power.

IV. Effect of Loop Dimensions and Construction on Transmit Efficiency

Small loop antennas can be almost as efficient as dipole antennas. However, this requires that the loop have a circumference which is not too small, perhaps somewhere in the 1/8 to ¼ wavelength range. Also the loop itself needs to be wide diameter (1-inch or more) copper tubing, noting that RF currents circulate in the loop on its surface only to a small "skin-depth".

The radiation resistance – that part of the antenna's feedpoint resistance caused by the radiation of EM waves from the antenna – is very small in a loop antenna. For example, a loop with diameter 3.67 feet (a little over one meter) and with a loop conductor diameter of 3 inches (rather big) has a radiation resistance $R_r = 0.019\ \Omega$ at 7 MHz and $R_r = 0.039\ \Omega$ at 10.1 MHz. The maximum ideal efficiency of such a loop will be 47% on 40m and 76% on 30m, which is starting to compare quite favorably with a full size dipole on these bands. Loss in this otherwise ideal antenna is due only to RF energy dissipated in the skin-depth of the loop conductor.

Because of the tiny radiation resistance values, however, the requirements of the construction are severe. Any loss in the joints of the loop or in the tuning capacitor could overwhelm the radiation resistance. We must avoid such loss by soldering or welding the loop together, and by using extremely low-loss tuning capacitors (e.g. butterfly, split-stator, or vacuum capacitors). Another issue is the fact that extremely high voltages are generated across the tuning capacitor's terminals, even at QRP power levels.

The abovementioned website from AA5TB discusses the construction requirements and also provides numerous links to hams who have built wide varieties of small loop antennas. MFJ sells a magnetic loop antenna which reportedly works quite well and uses a thick aluminum conductor for the loop which is welded to a butterfly tuning capacitor.

V. Portable Loops – Evaluating Efficiency

My goal was to build a *portable* loop: something that can be thrown into the trunk of my car, transported to a remote location, and put together rapidly. The antenna also had to handle as much as 50 watts applied to it. (It is worth noting that the AlexLoop is rated at only 10 watts CW.) With such construction constraints, I came to realize that I could never achieve an efficiency to make the loop competitive with a dipole. But that would be the wrong comparison to make. A more appropriate comparison would be to other *small and portable* antennas, and there is published data to draw upon for this. Using results and methods published by Phil Salas:

http://www.ad5x.com/images/Presentations/Antenna%20Efficiency.pdf

I was able to contrast the efficiency of my loop antenna to mobile whips and also to my own portable vertical antenna (15-foot base-loaded whip with a single tuned counterpoise for either 40m or 30m, my main bands of interest). The approach for both the vertical and loop antennas is first to *measure* the 2:1 SWR bandwidth, and then to work backwards from that information (and the dimensions of the antenna) to calculate the efficiency. Phil Salas' presentation and AA5TB's Excel spreadsheet develop the formulas for this.

Note that the measurement of the 2:1 SWR bandwidth assumes 1:1 matching at the center frequency. If the match at the center frequency was 1.5:1, for example, we would actually have to measure the ***2.5***:1 SWR bandwidth. Because the match at resonance for the magnetic loop is, in practice, very good, we need not worry too much about this issue.

The results, to be presented later, show that my loop antenna is in the same league as typical mobile-sized vertical antennas (and even my 15-foot loaded whip), while, at the same time, being compact and requiring neither a ground plane, a counterpoise, nor high elevation. The loop is very narrowband, however, and that is, in fact, the tradeoff.

VI. My Loop Antenna

Please refer to Fig. 2a below. I used LMR-400 coaxial cable with PL-259 connectors to form a 3.67-foot diameter loop. It is the outer shield of the coax that actually forms the loop. This coax (0.405" in diameter) and has a solid center conductor, making it easier for any loop formed from the coax to maintain a circular shape. It is still easy to wind up the coax into a small bundle for easy transport as shown in Fig. 3 (p. 5). The inner or coupling loop, made of RG-8X coax, was set to one-fifth the size of the main loop to obtain an impedance match to 50Ω at resonance, as described in

http://www.ahars.com.au/documents/the_underestimated_magnetic_loop_hf_antenna_vers%201.1.pdf .

While the coupling loop can be a simple loop of stiff wire, it is best to use a shielded loop, which affords the best immunity from electrostatic noise on receive. There are many variations on shielded coupling loops, and these are described in

http://www.nonstopsystems.com/radio/frank_radio_antenna_magloop.htm .

The arrangement I used is shown in Fig. 2b, where the RG-8X coax feedline is formed into the coupling loop with the center conductor shorted back to the shield as shown.

Fig. 2a: Loop Antenna and Steve, AB2EW

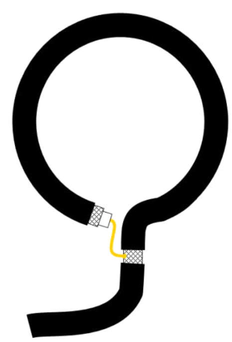


Fig. 2b: Shielded Coupling Loop

The supporting frame of the antenna is ½ inch PVC pipe. The tuning capacitor is in the box on the bottom. I tried three different capacitors: a split-stator type taken from a receiver, a medium power unit taken from a 200-watt MFJ antenna tuner, and a high-power unit taken from an MFJ 1.5kW antenna tuner. With the first two capacitors, I observed arcing beyond 40 watts input to the antenna on both 30m and 40m. The high-power capacitor displayed no arcing on these bands at a 50-60 watt level; it was not tested beyond that. I used plastic cable ties to attach the coupling loop to the top of the main loop. I used a planetary 6:1 reduction drive with the variable capacitor to make tuning easier. That part is available from:

http://midnightscience.com/catalog5.html#part4B .

The best tuning capacitors have all-welded or all-soldered plates and a butterfly or split-stator arrangement to avoid making contact via a sliding mechanical contact to the rotor plates. I actually soldered a wire to a rotating plate to avoid contact loss in the two capacitors I used from my MFJ tuners. A close-up of my high-power capacitor is shown in Fig. 4 below. You may notice that I have removed some of the rotor plates. This was done to get a more favorable capacitance range. This capacitor will resonate the loop over 40m – 20m; the other lower-power capacitors will resonate the loop over 40m – 15m.

Fig. 3: Disassembled loop antenna, including tuning capacitor, frame pieces, and tripod. The width of the tuning capacitor box and attached PVC pipe is about 32”. Everything fits easily into a 32”-long duffle bag I bought at Walmart.

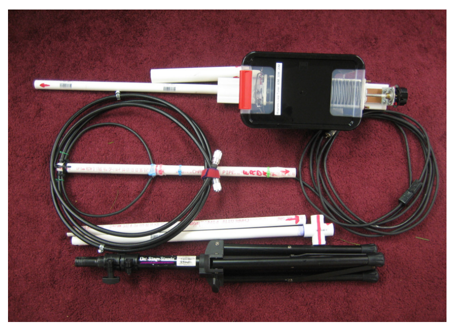
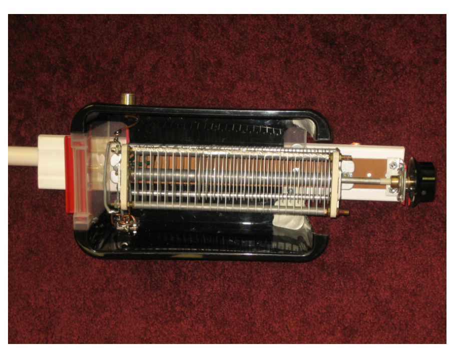


Fig. 4: Close-up of high-power tuning capacitor. The length of the box is about 12”.



VII. Measured Efficiency of Loop and Comparison to Other Portable Antennas

In the table shown below, we compare the performance of four different vertical antennas to that of our magnetic loop on 40m and 30m. We also give measured data for the loop on 20m. We show more measured data for the loop when the medium-power tuning capacitor is used. The verticals use either a single counterpoise wire or a "good" ground described by Phil Salas as one having a loss resistance of 8.9Ω.

On 40m, where achieving good results with any small antenna is rather difficult, the efficiencies range from 1.3% for the 6.67' vertical with the single 25' counterpoise to 12.7% for both the Carolina Bug Catcher and the 15' vertical with a single, elevated, quarter-wave counterpoise. The loop's efficiency on 40m is 4.6%. The efficiencies of all the antennas increase with frequency.

Antenna	Dimension	Counterpoise	Band	2:1 SWR BW	Rad. Res. Ω	Loss Res.	Efficiency
Base-loaded vertical (AB2EW)	6.67' tall	Single wire, 25' long, on ground	**40m**	185 kHz	0.863	65.3Ω	**1.3%**
			30m	410 kHz	1.78	69.3Ω	**2.5%**
Base-loaded vertical (AB2EW)	15' tall	Single wire, λ/4 long, elevated 5'	**40m**	248 kHz	4.68	32.1Ω	**12.7%**
			30m	505 kHz	9.02	29.8Ω coil + ground ↑	**23.2%**
Carolina Bug Catcher (Phil Salas' data)	7' tall	Typical good ground, (7-15Ω)	**40m**	30 kHz	2.45	8.9Ω ground, 7.9Ω coil	**12.7%**
Hamstick (Phil Salas' data)	7' tall	Typical good ground, (7-15Ω)	**40m**	50 kHz	2.45	8.9Ω ground, 20.5Ω coil	**7.7%**
Magnetic Loop (high-pwr tuning cap)	3.67' diam. LMR-400 coax	None. Bottom of loop up 6', on tripod	**40m**	19 kHz	0.0092	0.191Ω (skin + contact loss resistance)	**4.6%**
			30m	36 kHz	0.039	0.329Ω	**10.7%**
			20m	64 kHz	0.145	0.526Ω	**21.6%**
Magnetic Loop (med.-pwr tuning cap)	same	same	**40m**	20 kHz	0.0092	0.126	**4.4%**
			30m	34 kHz	0.039	0.227	**11.0%**
			20m	56 kHz	0.145	0.336	**24.7%**
			17m	89 kHz	0.403	0.408	**43.3%**
			15m	115 kHz	0.736	0.340	**61.0%**

VIII. Conclusions

The loop antenna described here provides a convenient portable solution which does not require radials, counterpoises, or high elevations. A good mobile whip with a low loss coil and a good ground is more efficient than the loop. But the loop may very well be easier to use in special environments such as indoor locations, limited-space areas, or anywhere where it is difficult to establish a good ground via radials or counterpoises. It should be noted that the efficiency of a loop increases rapidly as you increase the thickness of the loop element and as you increase the diameter of the loop. For fixed operation, larger non-portable loops mounted a few feet off the ground will provide performance comparable to that of an elevated, full size dipole.

IX. Special Note

I contacted Alex at http://alexloop.com/ to ask him what the efficiency of his loop antenna was on 40m. His answer was "not more than 5%". This agrees quite closely with my results, which makes sense since the dimensions and construction of our respective loops are similar. Thank you, Alex, for sharing this accurate technical detail.

X. On-the-Air Evaluation

I made a couple of 40m contacts to "4-land" in my limited on-the-air trials with the loop antenna. Reception was very good with antenna, which was mounted in my backyard with the bottom of the loop about 4' off the ground. I easily heard a number of European DX stations on 30m, but did not try to work them.

XI. LMR-600 and Future Possible Improvements

In an effort to improve the efficiency of my antenna, I constructed a loop of the same diameter using LMR-600 coaxial cable, whose diameter is 0.6". The results were discouraging. On both 40m and 30m there was very little change in performance over the LMR-400 loop. On 20m the efficiency did increase from 21.6% to 32.9%.

Theoretically, the larger-diameter coax should improve efficiency. The capacitor and other contact losses almost certainly swamped out any efficiency improvement afforded by the LMR-600 cable, at least on 40m and 30m.

The major losses of the portable magnetic loop arise from the capacitor and from the SO-239 sockets used to secure the loop. A vacuum capacitor would improve the efficiency, but at significant cost (≈$300). The screw-type coax connectors are needed for portability, but they undoubtedly add many milli-ohms of loss resistance.