The Optimum Magnetic Loop

The magnetic loop antenna is a ham favories, if for no other reason than it's a small antenna that can often rivals larger antennas. Further, being made from hardware store materials, it's a popular home-brew project. For for this book, it's possibly the very best application of metal foil tape for antenna building.

Figure 1: A low-cost 45-inch square optimized foil tape and PVC magnetic loop example

But popular and innovative as many mag loop designs are, poor performance, high cost, difficulty in building and low neighbor appeal, often plague home-brew builders and owners.

This chapter has two goals, therefore: (1) to take a quick but comprehensive look at all the key factors needed to optimize a mag loop and (2) to present essential details of an example mag loop project, an optimized inexpensive foil tape and PVC pipe design.

Fuller mag loop concept explanations and more-detailed building instructions for this design may be found on the internet in the Amazon Kindle e-book, "Seeking the Optimum Magnetic Loop Antenna" by the author here.

The Optimizing Factors

For satisfying results from a mag loop builders and buyers need to implement all these factors:

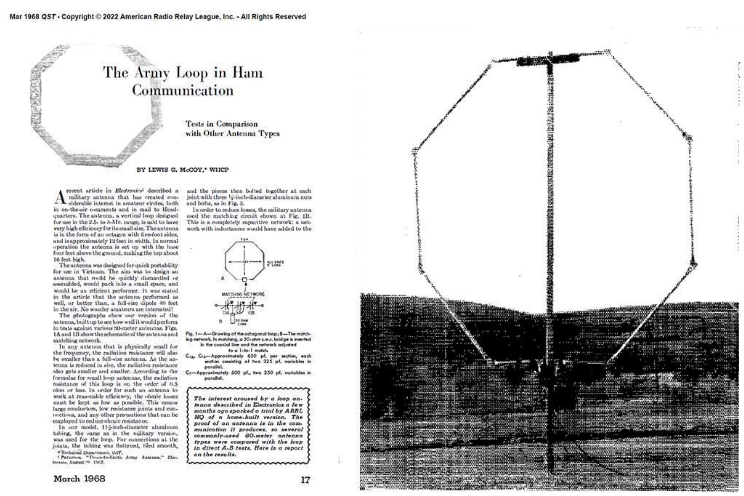
(1) Loop shape
(2) Construction material
(3) Conductor diameter
(4) Loop size
(5) Matching mechanism
(6) Tuning method

For there are serious pitfalls in each.

Factor 1 – Loop Shape

Historically, magnetic loops for ham radio first appeared in March 1968 in QST from radio luminary Lew McCoy (SK), as “The Army Loop in Ham Communication,” Figure 2. Originally designed by Kenneth H. Patterson for the U.S. Army for use in Viet Nam, it was 12 feet in diameter, made of eight 5 ft. aluminum sections flattened at both ends, bolted together for conductivity, and matched by three large variable capacitors.

What’s important here is that Lew McCoy’s article established the shape of the Army Loop as a “quasi-de-facto standard” for the ham community, despite the fact that neither an octagon nor even a circle is necessarily optimum.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The Army Loop in Ham Communication

Tests in Comparison with Other Antenna Types

BY LEWIS G. McCOY,* W1ICP

A recent article in *Electronics*[1] described a military antenna that has created considerable interest in amateur circles, both in on-the-air comments and in mail to Headquarters. The antenna, a vertical loop designed for use in the 2.5- to 5-Mc. range, is said to have very high efficiency for its small size. The antenna is in the form of an octagon with five-foot sides, and is approximately 12 feet in width. In normal operation the antenna is set up with the base four feet above the ground, making the top about 16 feet high.

The antenna was designed for quick portability for use in Vietnam. The aim was to design an antenna that could be quickly dismantled or assembled, would pack into a small space, and would be an efficient performer. It was stated in the article that the antenna performed as well, or better than, a full-size dipole 40 feet in the air. No wonder amateurs are interested!

The photographs show our version of the antenna, built up to see how well it would perform in tests against various 80-meter antennas. Figs. 1A and 1B show the schematic of the antenna and matching network.

In any antenna that is physically small for the frequency, the radiation resistance will also be smaller than a full-size antenna. As the antenna is reduced in size, the radiation resistance also gets smaller and smaller. According to the formulas for small loop antennas, the radiation resistance of this loop is on the order of 0.5 ohm or less. In order for such an antenna to work at reasonable efficiency, the ohmic losses must be kept as low as possible. This means large conductors, low resistance joints and connections, and any other precautions that can be employed to reduce ohmic resistance.

In our model, 1½-inch-diameter aluminum tubing, the same as in the military version, was used for the loop. For connections at the joints, the tubing was flattened, filed smooth, and the pieces then bolted together at each joint with three ¼-inch-diameter aluminum nuts and bolts, as in Fig. 3.

In order to reduce losses, the military antenna used the matching circuit shown at Fig. 1B. This is a completely capacitive network: a network with inductances would have added to the

Fig. 1—A—Drawing of the octagonal loop; B—The matching network. In matching, a 50-ohm s.w.r. bridge is inserted in the coaxial line and the network adjusted to a 1-to-1 match.

C1A, C1B—Approximately 650 pf. per section, each section consisting of two 325 pf. variables in parallel.

C2—Approximately 500 pf., two 250 pf. variables in parallel.

The interest aroused by a loop antenna described in Electronics *a few months ago sparked a trial by ARRL HQ of a home-built version. The proof of an antenna is in the communication it produces, so several commonly-used 80-meter antenna types were compared with the loop in direct A-B tests. Here is a report on the results.*

* Technical Department, QST.

1 Patterson, "Down-to-Earth Army Antenna," *Electronics*, August 1967.

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Figure 1: The Original March 1968 Army (magnetic) Loop

Two centuries ago, Michael Faraday discovered that a small magnetic loop works by area, not shape. It is true that a circle or octagon is smallest by area, but a square of the same area as a 3-foot circle is only 4½ in. larger at the corners. The difference is trivial.

But having to form large diameter tubing into a circle is not trivial for most hams. Similarly, the expense of elbows for octagons is also not trivial. A square, therefore, is frankly much closer to what could be called the “epicenter” of mag loop building. Even perhaps more meaningful to some, neighbors and HOA’s won’t as easily notice a square – “Its probably just a rose trellis.”

Factor 3 – Construction Material

The most surprisingly useful mag loop optimization factor – choosing the optimum building material – is dictated by skin effect. Skin effect is the widely known tendency for AC (alternating current), especially at radio frequencies, to flow only on the surface of conductors, Figure 3. At RF only a very thin "skin," thinner even than portrayed in the figure, conducts almost all the current. The center of the conductor does not even have to exist.

This is, however, an advantage for the loop builder. Only a thin layer of self-adhesive metal foil tape on non-conductive material such as common PVC water pipe is just as effective at conducting radio frequency current as solid metal. Heavy solid metal pipe is unnecessary for mag loops.

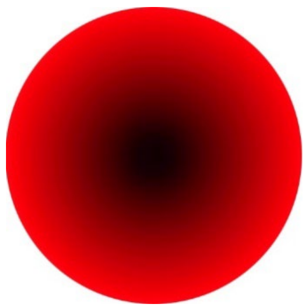


Figure 2: AC or RF current (red) in the cross section of a conductor. The center isn't used.

Figure 3 shows the skin depth in mils (1/1000 in.) for copper and aluminum by frequency.

Band m	Aluminum mils	Copper mils
80	1.7	1.4
40	1.2	1.0
20	0.9	0.7
10	0.6	0.5
2	0.3	0.2
0.7	0.2	0.1

Figure 3: Skin depth by frequency for copper and aluminum. Notice how thin it is here on the ham bands

Also note that it is thicker for aluminum than copper. So even though aluminum is 44% less conductive than copper, greater skin depth makes up for reduced conductivity. Copper is not superior to aluminum for building magnetic loops.

There is, though, a very big disadvantage in skin effect. Only a small amount of a conductor's cross section is available for use. Therefore, only if the conductors of mag loop are large can they be efficient. The next optimization factor will make this very plain.

No other building material, therefore, compares to PVC pipe and self-adhesive metal foil tape for optimizing a mag loop, especially for cost, weight and difficulty of handling. The cost differential is similar for all pipe sizes. For example, a 10 ft. length of 1½ in. PVC pipe (the sample loop), cost $16 at the time of writing. 10 ft. of 1½ in. copper pipe was $128. One might consider this in light of an 80-meters mag loop which can be optimally built with 4 in. pipe. Only in plastic pipe and foil, though, is this tenable.

Factor 2 – Conductor Diameter

By far the most important mag loop optimization factor is, however, the size of a loop's conductors. For it relates directly to loop efficiency, hence performance. Notice in Figure 3 how quickly the efficiency of the sample loop becomes unacceptable (red) if smaller conductors are used.

	160m	80m	40m	20m	10m
1/8 in.	0.1	0.5	5.8	41.1	88.7
1/4 in.	0.2	1.1	11	58.2	94
1/2 in.	0.3	2.1	19.8	73.6	96.9
1 in.	0.6	4.2	33	84.8	98.4
2 in.	1.2	8	49.6	91.8	99.2

Figure 4: % of transmitter power making it to the antenna for the 4ft. square sample loop by conductor size.

Briefly, the efficiency of an antenna is a ratio between the power wasted as heat in simple conductor resistance, compared to the percentage that gets made into radio waves in an antenna's radiation resistance. Radiation resistance is simply a measure, in Ohms, created in an antenna by the loading of space. Very small antennas, such as magnetic loops, are extremely subject to loss if radiation resistance gets low compared or conductor resistance increases. Again, this is the major mag loop optimizing factor.

Key Optimization Factor 4 – Loop Size

Loop size is more a matter of choice than optimization. There are, however, consequences and limitations to making larger magnetic loops: For example, cost, difficulty of construction and awkwardness of use all increase very rapidly with size.

Perhaps more important for a loop builder to understand is that a mag loop has an upper operating frequency limit that is set by loop size. Electrically a mag loop is a parallel tuned circuit – a "tank circuit" – a one-turn coil in parallel with natural distributed capacity. Even without an added tuning capacitor a mag loop has a self-resonant frequency. The 4 ft. square example loop self-resonates at roughly 31 MHz with no capacitor across its gap. This is the maximum usable frequency of this loop.

I intentionally made it this size so that it could work 10-meters. A larger loop wouldn't have been able. In fact, the example loop is actually a 45 in. square to make its self-resonant frequency limit safely above 10-meters.

Factor 5 – The Matching Mechanism

This factor is purely a matter of optimization to your choice. Antennas do not care how one couples transmitter power to them, as long as there is a 1:1 SWR match to the transmission to insure a maximum transfer of power to the antenna. Matching and tuning are, therefore, not performance optimizing issues, bkut for cost and ease of building they are.

Figure 5 shows the match method I consider near "ham central." A gamma match or Patterson's original triple rotary capacitor match would work as well, but to me are less than optimal.

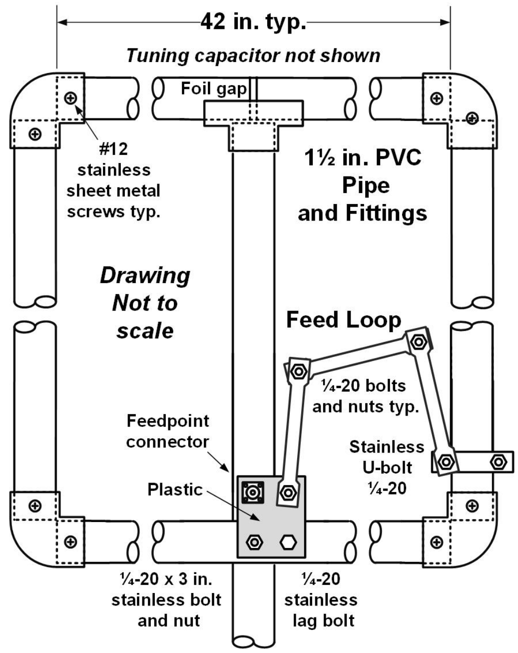


Figure 5: Essential elements of the sample loop showing feed loop. (not to scale) Tuning capacitor is not visible.

A small separate matching loop, roughly 1/5 the size of the main loop is the most-frequently-seen method. I instead prefer to tap the main loop as an auto-transformer, Figure 6. In theory, both work much the same and adjust similarly.

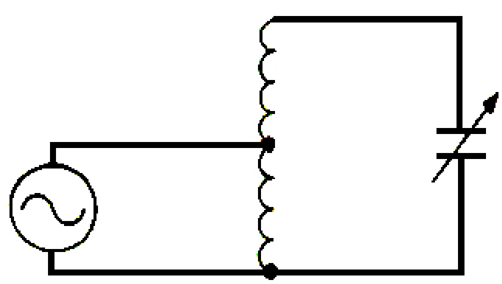


Figure 6: Schematic of the matching method

However, for mechanical stability, ease of construction and simplicity of adjustment, I prefer the method of Figure 6. It utilizes some of the conductor for both loops. To me it more universal.

The matching adjustment arm, Figure 5, is three 14 in. lengths of ½ in. aluminum tubing, flattened for 1½ in. at both ends and drilled for 1/4 -20 stainless bolts and nuts. It’s also attached to a moveable U-bolt to accommodate a very wide range of mounting locations. Similar to a separate coupling loop, it is optimally located opposite the gap in the loop, near the low impedance point of the loop.

Factor 6 – The Tuning Method

Traditionally, to allow a mag loop to tune below its natural self-resonant frequency, a tuning capacitor is shunted across the small gap. The width of the gap isn't critical; here it's ¾ in. Figure 7 is an EZNEC graph of the capacity needed to tune the sample loop down to 40-meters.

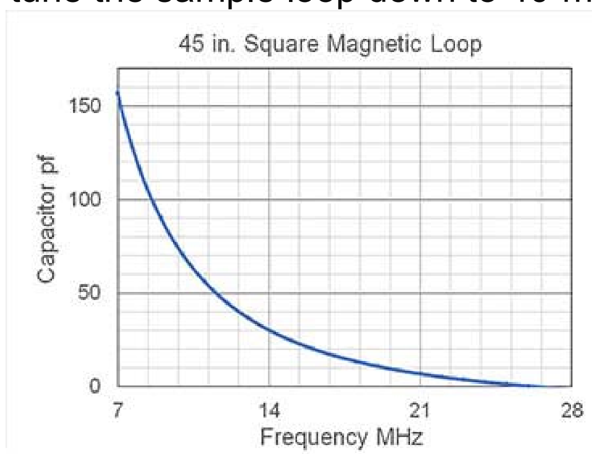


Figure 7: EZNEC estimated capacity to tune the sample loop from 10 to 40-meters

The Tuning Capacitor

For cost optimization, and also mainly as an example, I chose a very simple and inexpensive home-brew manual tuning capacitor, Figure 8. It works very well, however. You may or course substitute a motor-driven wide-spaced rotary capacitor or a vacuum variable as a convenience optimization. I personally do not mind stepping outside for a band change or a small frequency adjustment.

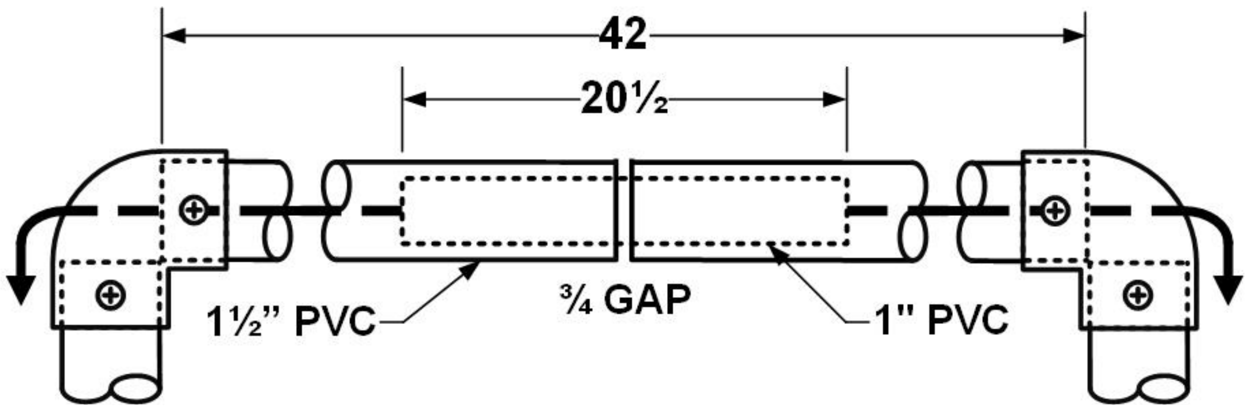


Figure 8: Simple low-cost home-brew manual tuning capacitor

The capacitor consists of a 20½ in. length of 1 in. PVC pipe that slides inside the top 1½ in. PVC pipe of the main loop. It is moved for adjustment by pull cords. Both pipes have a layer of foil on the outside surface. These form, the plates of two capacitors in series that can straddle the foil gap in the main loop.

NOTE: Due to the inconvenience of PVC pipe sizes, the 1 in. inside pipe needs to be made larger in diameter to increase the capacity and tuning range of the simple tuning capacitor. I used two or three layers of common poster cardboard, under the aluminum foil. The inner pipe with foil needs to fit snugly but also slide easily.

When the inner pipe is centered on the gap, capacity is maximum (roughly 30 pf). When it is at the end, there is no added capacity and the loop tunes to its self-resonant frequency. The tuning range of this capacitor is roughly 31 to 12 MHz, enabling 10, 12, 15, 17 and 20-meters.

To reach 40-meters, a small group of the 3000 Volt ceramic disc capacitors in parallel can be added across the gap. Figure 9 shows the small toy knife switch assembly from Amazon that I use. On 40-meters the capacitor now only covers the 40-meter band.

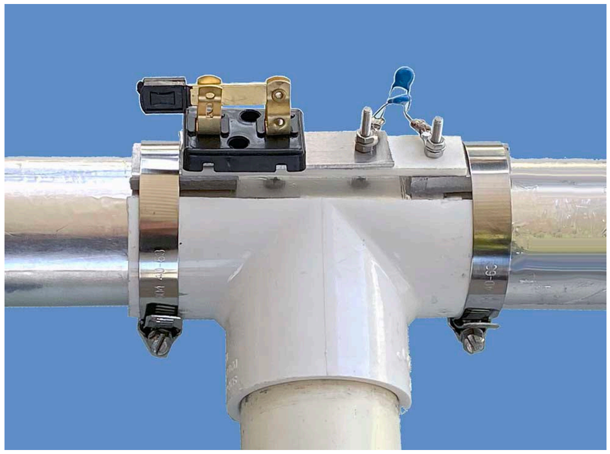


Figure 9: 40-meter switch

Applying Foil Tape to the Pipes

Self-adhesive tape can be tricky to apply smoothly. Figure 10 and the steps below illustrate my method.

Figure 10: Applying foil tape to the 42 in. 1½ in. PVC pipes (four)

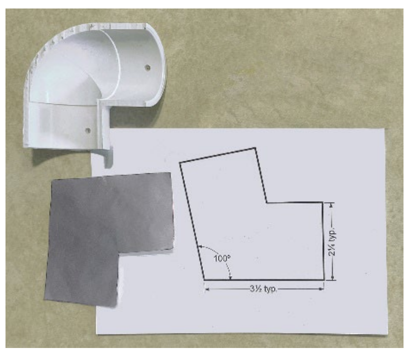
1. Cut each strip of tape 4 in. longer than the pipe.
2. Place it on a flat surface, backing side upward.
3. Crease across the ends, roughly 1½ in. from the ends and fold back the protective backing to expose the glued surface of a small tab.
4. Carefully turn the whole tape strip over and stick the exposed tabs tightly to a flat surface. Short-pile carpet is ideal. Gently smooth out the entire tape strip lengthwise to keep it flat.
5. Gently remove the remaining protective backing, to expose the entire adhesive surface.
6. Precisely place the pipe down in one quick stroke on the adhesive surface lengthwise in the middle. If you get it crooked, it can’t be straightened. Be careful.

7. Snip off the tabs stuck to the flat surface with a scissors and turn the pipe over, laying it carefully it back down.
8. Roll the pipe back and forth a little to begin sticking the foil tape to the entire length of the tape.
9. Turn the pipe over again and smooth out wrinkles with a short length of small diameter PVC pipe.
10. Trim the excess foil from the pipe ends

Applying Foil Tape to the Elbows

Conductivity at the split corner elbows must be maintained, but its application can be even trickier than for the pipes.

1. Cut eight pieces according to the template from the 4 in. aluminum tape. including the protective backing,



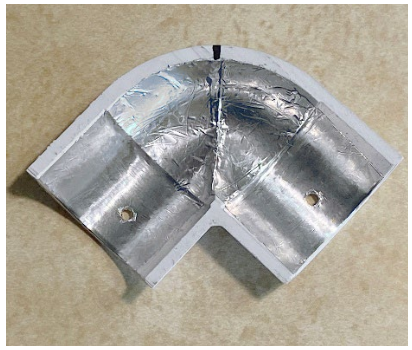
2. With protective backing still attached, form the foil to the inside shape of the cut in half elbow. Capture in foil an impression of the outer curve of the elbow.

3. Remove the formed foil, turn it over, snip off only the corner of the backing just inside the impression of the outside curve.

4. Turn the foil back over and adher the small exposed trangle of adhesive to the elbow in its original position. Then lift most of the foil and backing and remove the remaining backing

5. Carefully adher the foil inside the elbow, being very careful not to split it over sharp edges.

6. Trim off the excess foil.



Finally assemble the entire antenna, following Figures 5 and 8 as guides. Use stainless sheet metal screws to attach the elbows to the side pipes. The facing foil surfaces at the pipe ends inside the elbows, along with the sheet metal screws created good conductivity at the corners.

Magnetic loops are perhaps the very best application for metal foil tape used as an antenna building material. Also, the 45 in. square loop is possibly as close that a home builder can come to the optimum mag loop for the largest number of hams. And this design is still a work in progress. Share your results and your innovations, preferably with photo(s).