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Practical Experiments with Magnetic Loop antennas

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The magnetic loop is an unusual antenna, as with all smaller than perfect antennas, it has some drawbacks and some benefits. I decided that the benefits outweigh the drawbacks for my particular case. My situation is probably similar to a number of other radio amateurs; I travel around a lot with my job, and sometimes end up staying in foreign countries for extended periods of time. In order to fill my evenings with something other than foreign television (or drinking in the bar), I prefer to sit in my room and work the DX on the radio. Though this situation may not be typical of all of radio amateurs, the need for a small, effective and portable antenna will surely hit home with a number of them.

- **My first attempt at a magnetic-loop antenna**

I built my first Magnetic loop antenna after having seen one at the local radio club, (Echelford Amateur Radio Society). It was built by Peter, G2HS from copper plumbing pipe and I was impressed with the strength of the signals he could 'pull-in' with it just sitting in the meeting room in Staines, Surrey.

I started with about 3.5 metres of RG-8U coax and shorted the inner and outer together and attached a 400pF variable capacitor to the two free ends. I nailed it to a wooden post that was about 50mm square. The feeding loop was made out of RG-58U. It was simply a stripped back piece of the outer shield, connected to the inner conductor to create a loop shape; this was also nailed to the wooden support at the bottom of the loop, (opposite the side with the variable tuning capacitor).

I was surprised to see that it worked really well, considering it took less than an hour to put together and cost almost nothing. It did suffer from drooping, after sitting in the corner of the shack for a couple of weeks, but this was easy to cure by adding a crossbar to support the RG-8U.

However, the design was very prone to changing resonance with the environment and the weather. I think this was due to the co-ax I used not being new and it probably had a high moisture content as well as a higher DC resistance than would be ideal for a high Q loop.

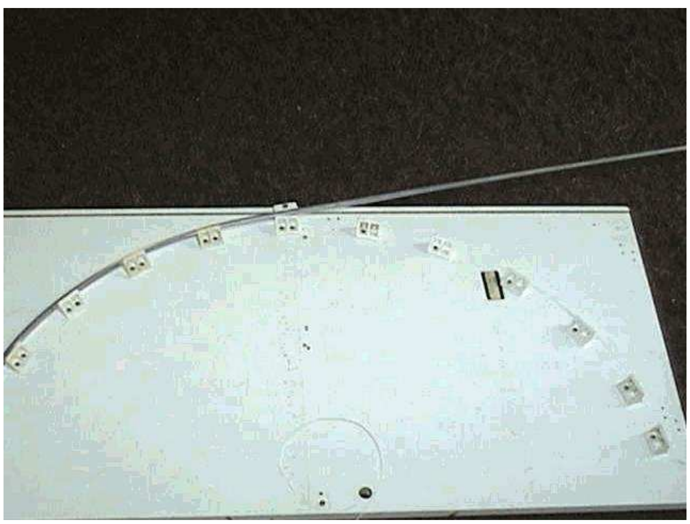
- **The next version**

I decided to build the next version on a similar basis to Peter's (but, using solid aluminium rod), I built a simple jig from an old bit of MDF board. By marking the board into one half of the diameter of the circle I wanted, and fixing some guides to the board I made a template for the loop. These guides were bought from the local DIY shop and are designed as corners for MDF furniture.

With these guides in place, I was able to create a former around which I could bend the aluminium rod to the correct shape.

The MDF board was marked out using a piece of scrap wood marked to the correct radius and nailed to the centre line of the board, then a pencil was used to scribe the arc onto the board. The guides were attached to the MDF using 20mm MDF screws which can be purchased at any DIY shop.

The guides were aligned with the edge of the curve and screwed securely to the MDF. There were a total of seventeen guides, seven on each side of the centre line, on the inside of the line. The other three were positioned on the outside of the half circle; one at either of the two ends and one in the middle.

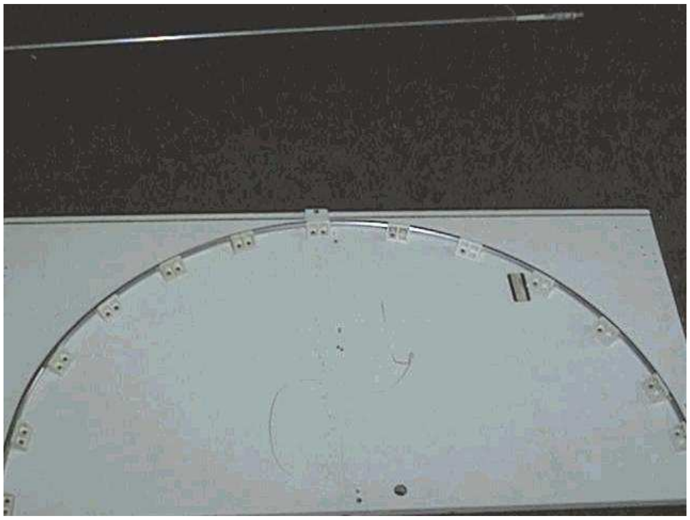


I started to bend the aluminium rod on the left hand side, the tubing was placed between the bottom left outside guide and the leftmost inside guide. A sideways pressure was then applied to the free end of the tubing, until the tubing shaped itself to the position of the second guide. This process was repeated until the tubing was a tight fit with all fourteen inside guides and resting against the outside guides; this defined the shape of half of my magnetic loop antenna. This makes a loop with a diameter of approximately one metre.

When the half circle was aligned with all the guides, it was cut off, level with the edge of the MDF board, leaving about 500mm of spare rod.

The second length of aluminium rod was bent and cut, in the same fashion, completing the bending process and providing me with two identical half circle shapes, which were used to make the complete loop.

The two half circles were joined at the bottom using a 50mm section of straight aluminium tubing which had an inner diameter of 10mm. The two half circles



were inserted into this section and screwed firmly in place with 2 zinc screws. At the top, a space between the two sections was left to seperate the top of each half of the loop.

By adding this small section of tubing, with the gap between the two half circles, it automatically creates the gap at the top of the loop, which works out at about 20 mm. This appears to be an adequate spacing for at least a power level of one hundred watts of RF into the loop.

The support for the loop was made using a length of 32mm plastic plumbing pipe. This was drilled through in two directions (at 90 degrees) near the bottom for the spare 500mm pieces of tubing to make a base for the antenna, which was screwed to a scrap piece of MDF board (750mm square), allowing it to free-stand. The two 500mm pieces were deformed slightly to provide secure contact with the MDF base board and then screwed into the plastic pipe and onto the MDF board, to keep them in place and provide a sturdy base for the antenna.

A 12.5mm hole was drilled clean through the plastic pipe 1.10 metres from the top of the pipe. Through this hole, the, now complete, loop was inserted and positioned so that the connector between the two halves was centred in the plastic pipe. The top was then marked for the topmost free ends of the loop and the pipe drilled with 10mm holes so that each end of the loop was a snug fit into the plastic pipe.

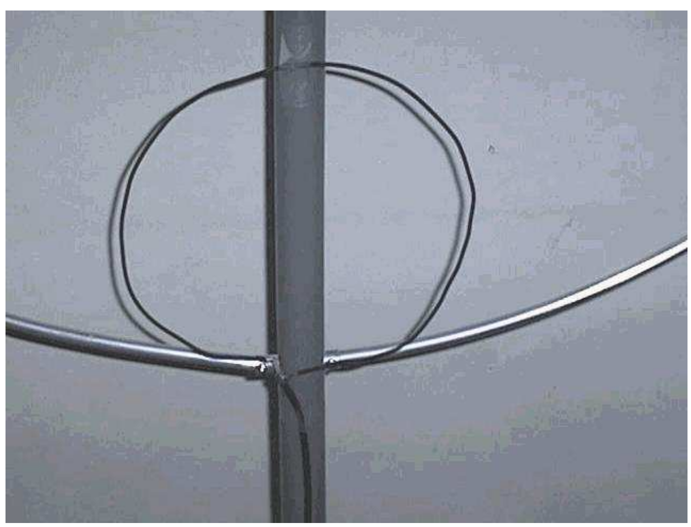
I cut a small 50mm section from the two-metre length to enable me to test it for conductivity. I place the cut-off section in my 1000W microwave oven, next to a glass of water (The water stops the oven from being damaged if the sample proves to be a perfect insulator!). The microwave was set to 30 seconds at full power and after this time, I removed the sample and checked its temperature, In this case, there was no measurable change in temperature and this is a good indication that the material is not conductive to RF. Some samples I tested have melted before the 30 seconds were up, so care must be taken when removing the sample from the oven, as the possibility of a nasty burn is possible.

The high quality, 300 picoFarad capacitor was purchased at a rally (for ten pounds from Syon Trading), screwed to the plastic pipe and connected to each of the free ends of the loop using RG8U co-axial braid using zinc self-tapping screws. It is important to note that a very good low resistance joint is required, as the voltage present at the open ends of the loop is extremely high (if not lethal!). I made my connections by first tinning the co-axial

braid and then drilling a pilot hole in the aluminium rod and screwing the zinc-plated screws through the braiding and into the aluminium rod. Zinc-plated screws can be purchased from most DIY shops.

For testing, with low power levels, I attached a large insulated knob to the capacitor. (see photo).

In the full power version, I changed the knob for a one-half metre length of fibreglass dowel rod with a hole drilled to fit the shaft and secured this with a pin through the dowel and the shaft. This provided a secure and reasonably 'back-lash' free tuning rod. The rod was held in place, next to the plastic pipe mast using the type of clips normally used to hold plumbing pipe to a wall. Three of these were screwed to the plastic pipe to hold the rod in place. A knob was fashioned from another piece of doweling and attached to the tuning rod to allow the capacitor to be tuned easily. This method of mounting can only be used if your capacitor has less than 270 degrees of travel, from minimum to maximum capacitance. In this case, mine has 180 degrees travel, which proved, in practice, to be too coarse without some sort of reduction drive.



Later, I fitted a 10:1 reduction drive and added some insulating supports that supported the rod away from the plastic pipe, allowing the doweling shaft to rotate through 360 degrees and provide finer control of the capacitor.

A lot of experimenting with the size and shape of the driven loop provided some interesting results... From a matching point of view, the best shape appeared to be one that followed the bottom shape of the loop for approximately half the diameter of the driven loop. This is difficult to explain, as are most things to do with how a magnetic loop works, but the results speak for themselves. The photograph shows the first 'conventional' driven loop, before I started playing with the shape.

The photo shows one of these low energy fluorescent lights held next to the loop while transmitting a carrier of ten watts into

the antenna.

In this version, my driven loop was made from a length of 16 SWG solid copper wire, which was 1/6th the circumference of the main loop. This ties in with other articles and research, which suggest the driven element loop should be in the range of 1/5th to 1/6th of the circumference of the main loop. The wire loop was connected to the feed co-ax, made using a new length of RG58, to the transmitter. The bottom half of the driven loop was taped to the main boom. The top half of the driven loop was then adjusted for maximum 2:1 SWR bandwidth at the point of resonance of the tuned loop. Adjusting the shape of the driven loop effectively alters the coupling between the driven and main loops by either increasing or decreasing the capacitance and reactance ratio of the resulting impedance. From a radiation point of view, there is little or no difference in the acceptance of the circuit to the RF dependant on this coupling. This means that the resonance of the loop is not really affected by the coupling between the driven loop and the main loop, it just affects the input impedance of the antenna to the transmitter and, obviously, more thorough research is needed to quantify and qualify this statement.

The results of using this antenna on the bands were outstanding, much better than the co-axial version I originally built. The bandwidth was wider, it was easier to tune and much more physically robust.

2:1 SWR Bandwidth Mag-loop 2

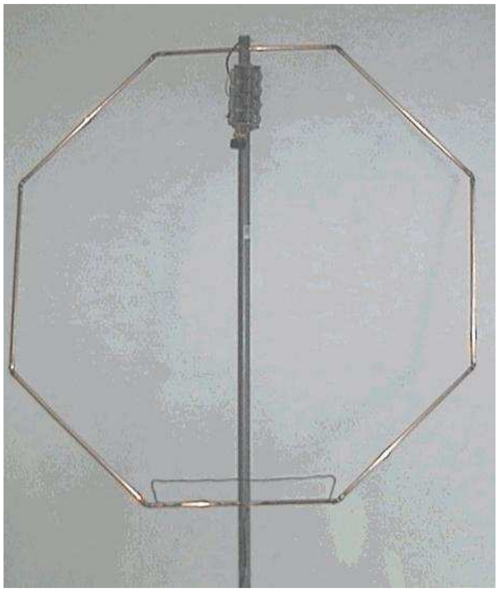
40 Metres	30 Metres	20 Metres
15 kHz	22 kHz	35 kHz

Looking back over the effort involved to create this loop, I decide to try and use less brute force and more modern materials to produce a similar result. It took me six full hours of hard work to build this version of the magnetic loop, which, for me, is a bit too much effort. So, I put my brain to work on making an easier to build version, with similar performance. Thus was born version three...The third attempt...

- **The third version…**

Well, having tried the quick and dirty co-ax version and the complex and time-consuming aluminium rod version, I started to form the idea of the best of both worlds. I wanted the ease and speed of building that the co-ax version had, and the performance and durability of the complex version. This took some lateral thinking… but I think I achieved it.

Now, my skills as a plumber leave a lot to be desired, but I can just about cut a straight line with a saw, so I decided that my latest design would have to require



the minimum of plumbing knowledge and the associated plumbing skills. This is what I came up with...

For the main loop, it requires only eight straight cuts of copper pipe, some screws and some soldering (which I was definitely getting better at...).

I purchased two, two-metre lengths of 12mm copper plumbing tubing and eight 45-degree angle corners from the local DIY shop. I also purchased a neat tool called a pipe-cutter. You insert the pipe at the correct place, turn a screw, and spin the tool around the pipe; this results in a perfectly straight cut with a clean bevelled edge, with none of the inaccuracies of sawing and filing. It cost only a few pounds, and is definitely a great asset to my toolbox.

So, I spun this new tool around the copper tubing and, in less time than it would take to saw one section, I had eight 500mm sections ready to go using only six cuts.

The 45 degree corners were of the pre-soldered, pre-fluxed variety and the only physical work was to use a kitchen scrubbing pad to clean the copper pipes, before inserting them into the angles and soldering them in place.

I used my trusty Gaz-torch to do the soldering. This is best done outside and with a big enough area to lay all the sections out flat on the ground. This ensures that the loop is two-dimensional and not three-dimensional, when it is soldered. The octagon was made in two halves to allow it to be fitted onto the support mast. Each half was made with 3 sections of pipe and four of the 45 degree corners.

After having made each half of the octagon from the component parts, one of the other two left-over pipes was chosen as the top and a 20mm section was removed from the exact centre of this piece, using the pipe-cuter tool. Each of the 240mm pieces was then soldered, one to each half octagon.

Again, I used a 32mm plastic pipe for the main support boom. Drilled at the appropriate places, in a similar manner to version two, so that the top was about 50mm from the top of the plastic pipe.

The remaining piece of copper pipe for the loop was inserted through the bottom holes in the support mast and then soldered to each half loop, forming the complete loop with a 20mm gap at the top. The free ends, at the top of the loop, were inserted through the plastic mast and secured with a screw on the inside of the plastic pipe. This stops the free ends from accidentally slipping out of the support mast.

2:1 SWR Bandwidth Mag-loop 3

160 Metres	80 Metres	40 Metres	30 Metres
12 kHz	30 kHz	50 kHz	65 kHz

Peter, G2HS suggested a capacitor of 500pF for a loop of this size, and he was, yet again, proved correct. I had a 350pF capacitor fitted to the system, which was like a larger version of a 365pF Broadcast tuning capacitor, though it did tune on 40 and 30M there just was not enough capacitance for the lower frequencies. I added a fixed capacitor of 200pF and then it was possible to tune the lower two bands, but not the higher ones, and I was never going to be able to transmit 100 Watts into it. Peter came up with a 1000pF 3000 volt variable capacitor which he sent to me, to get the loop QRV on all four bands. With the 1000pF capacitor fitted to the mast and connected to the loop, the figures in the table were realised.

The feed loop for this version was also made from 16 SWG solid copper wire, and the shape adjusted, as in version two, for maximum 2:1 SWR bandwidth. This resulted in a rectangular shaped feed element. More reminiscent of a folded dipole. I can't really explain why this shape worked better than any other, it just does, and I'm happy to accept the concrete fact, rather than delve into the calculations of why. I also discovered that the material for the driven loop, and its shape, are important factors, as well as its overall length. This is another interesting subject which requires further scientific investigations.

I tried a 12.5mm copper pipe driven loop, made from the same stock as the main loop, and discovered that it is definitely the shape, more than the thickness, which makes the biggest difference to the bandwidth. This was not what I had expected, from a casual correlation to other antenna which I have designed in the past. Usually thicker elements provide a wider bandwidth. Perhaps it is due to the percentage of the frequency in use, that no great difference was noted.

The copper pipe driven loop was much more robust than the wire loop, but was more difficult and time consuming to construct and alter. So, yet again, another trade off decision must be made here.

With no real advantages to the performance of the antenna, I decided to opt for the wire loop version, especially during the prototype phases.

To ensure that there is a good electrical connection between every piece of copper pipe and the corner joints, I screwed a brass screw through each corner joint and into the copper pipe and soldered them in place. The main problem with high-Q loops is DC resistance losses, (especially when it is made of so many individual sections and joints), and this simple measure ensures that the connections are good and solid.

The version three antenna took a total of about two hours to construct, from the start, to the first QSO. The assembly was easier than expected, especially with the pipe-cutting tool, and the performance was even better than the solid aluminium version. The loop was made larger than the aluminium rod version so that it would cover the 160 metre and 80 metre bands. The total diameter of the loop is 1.35 metres compared with the 0.98 metres of the aluminium rod version.

The only real set-back with this antenna is that it would not fit in my car, so it has become a permanent fixture in the shack, instead.

- **The six metre version**

Just for fun, more than anything else, I decided that the next version I would built would be for six metres, I scaled everything down from the aluminium rod version (version two) and came up with a loop which had a diameter of 250mm (or just about 10 inches). This made the driven loop a diameter of 45mm and a capacitance of only 75 picoFarad. I wasn't going to work any great DX with this antenna, but with F2 and Sporadic-E on 50Mhz, I think some reasonable contacts will be possible. The size and simplicity of construction are the main factors to consider when I designed this minuscule antenna.

I bought a one metre length of 5mm rod from my favourite DIY shop for the main loop. For the former, I found a plate in the kitchen with the right dimensions and traced around this onto a piece of scrap wood, then carefully cut it into a circular shape. This wooden circle was screwed to a larger board and a plastic MDF corner brackets was also screwed into position to hold one end of the rod, while it was bent around the wooden former, to form an almost perfect circle. The material used for brake pipes could also be used, and is easy to obtain from most local exhaust and brake centres.

The ends of the rod were trimmed to size and fitted through a holed drilled in a 350mm length of 32mm plastic pipe, which was left over from the version two antenna. With this antenna, I decided that the capacitor could be mounted on the base board, so the loop was mounted through the plastic in the 'upside-down' position, compared to a traditional magnetic loop. I didn't have a 75pF capacitor, so I removed some plates from a 365pF broadcast tuning variable. This proved very satisfactory. The capacitor was screwed to the base plate and short insulated leads were clamped to the 5mm rod using two large 'chocolate-block' electrician's connectors.

A 32mm hole was drilled in the centre of the base plate for the plastic mast to fit snugly into the base. The base plate was a piece of MDF board which was cut to the size of my DX70. The reason for this was to allow operation of the rig with the antenna sitting on top. Four rubber feet were attached to the base plate, to stop the base scratching the rig, and also to allow the internal speaker to be heard in the shack without being muffled by the base plate. I also built a small SWR bridge onto the base plate making the assembly complete and self-contained.

A small plastic 'freezer box' was fitted over the capacitor and an insulated extension with a plastic knob was added, to keep prying fingers out of the potentially lethal voltages present on the capacitor when transmitting. The SWR bridge was calibrated for the fixed power out of the DX70 and set to the reflected mode, so that a continuous reading of the SWR was possible on the meter. I "borrowed" the circuit for the SWR bridge from a cheap CB SWR bridge I bought for 50 pence at a rally. It is not "bird thru -line" accurate, but good enough for the job at hand.

This version works quite well, I have heard beacons as far away as Spain and Portugal from my QTH in The Netherlands.

- **Conclusions**

I took the version two antenna to Germany with me, while there on business, set it up in the hotel room and started operating in the evenings on 40M. In the first week I had already worked stations in 5B4, 4Z4, DL, PA, ON, G, GM, GI, GU, EA, 9A1, UA3, OE, IK, OM3, YL and LY. The worst report I received was a 559 from another magnetic-loop user in England. Especially on 40 metres, where the QRN can be high, the magnetic loop performs extremely well.

So, if you think, like I used to, that a small antenna could not possibly perform well, think again,

and try a magnetic loop.

- **Thanks**

Many thanks to all the authors of antenna articles all over the world, for inspiration and tips and a special thanks to Peter Hale G2HS for introducing the magnetic loop to me and his help during the testing and design phases.