A Crossed Field Loop Antenna for 3.5 MHz

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The Crossed Field Antenna (CFA) has been the subject of much controversy over recent years. The writer describes experimental work carried out on a CFA Loop for 3.5 MHz including the problems in making it work and the performance achieved. This is another antenna which might be useful for someone with limited space to erect a larger 80 metre antenna.

Introduction

In a previous article, I described EH type dipoles for 20 and 40 metres. This leads to the question - what about one for 80 metres? Based on the recommended design dimensions found on the Internet, this would require a PVC tube 200 mm in diameter and around 2 metres high. For 80 metres, perhaps a small Crossed Field Loop might be another choice for a more compact antenna. I have experimented with such an antenna made up with a coax cable loop less than 1 metre square. In the following paragraphs, I describe how I made this type of antenna operate and what results were achieved.

Some Basic Requirements

It is not my intention to discuss fundamentals of the Crossed Field Antenna (CFA) which was first introduced by Professor Maurice Hately (GM3HAT) except to say that he also introduced the Crossed Field Loop.

To achieve the desired crossed field, the Crossed Field Loop has two adjacent loop circuits separately fed and the RF currents are forced through these two circuits 90 degrees out of phase with each other. However this is not easy to achieve. Because of mutual coupling between the two circuits, the tendency is for the two circuits to resonate as one so that currents within them assume the same phase relationship.

My initial thoughts were to reduce the coefficient of coupling between the two loops to as low as possible. However, I eventually came to the opposite conclusion. The two loop circuits are in fact cross connected in anti-phase and I found it was desirable to have as large a coefficient as possible so that mutual inductance between the two was largely cancelled. This is achieved better by using a coaxial cable (one conductor inside the other) in preference to two side by side conductors.

To achieve the 90 degrees phase shift between the two currents, external reactive circuits are used. To force the two currents to not take up single resonance in the coupled loops, the inductance of the external series components is made large compared to the cross connected inductance of the loops. For example in the 3.5 MHz loop described here using RG59/U cable, the cross connected inductance is around 0.5 uH and the series inductors are around 5 uH.

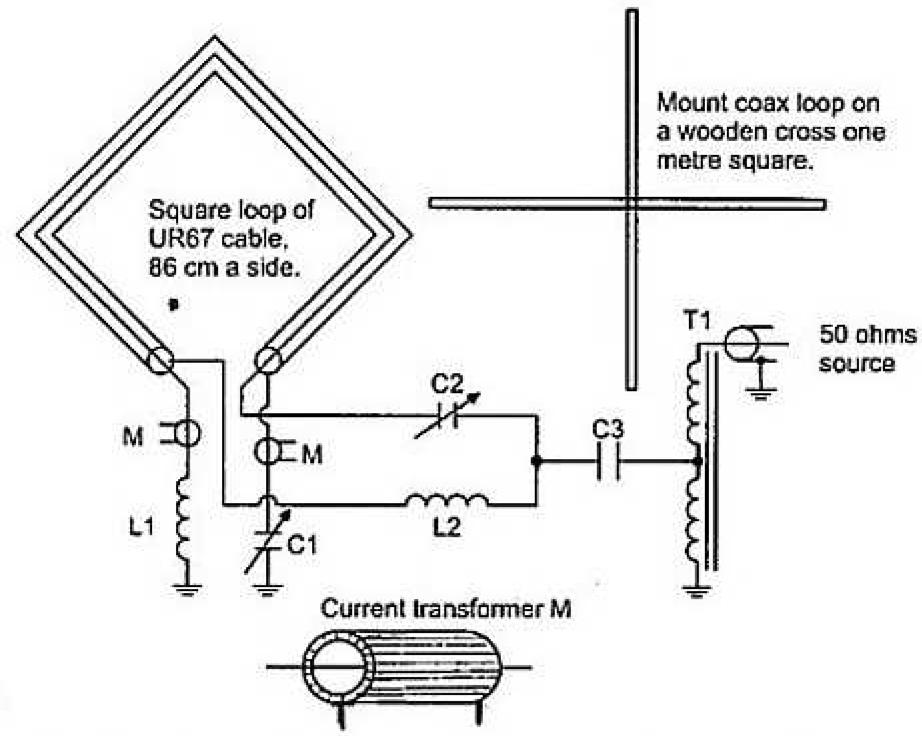
Some form of monitoring the two phase currents is needed to adjust the two loop currents for the 90 degrees shift. When correctly adjusted, one loop circuit is actually resonated just below centre frequency and the other just above. It is no good adjusting just for lowest SWR as the result may be single resonance of the combined circuit and in effect, operation in a low efficiency magnetic loop mode.

To monitor the phase difference, a current transformer in series with each loop leg is coupled to a dual trace CRO. I initially passed the loop legs through the centre of ferrite toroidal cores but I found these saturated as power was increased causing distortion of the monitored waveform. They also they introduced an accountable loss resistance component in series with the loop radiation resistance. The lower the ferrite permeability, the lesser the effect but I ultimately got rid of the ferrite and passed the wires through small insulated sleeves used as formers to support a 20 turn secondary winding.

Monitoring with the CRO can be quite tricky. I was side tracked many times by residual signal induced by direct induction from the loop into the CRO probe leads and which interfered with phase monitoring signals.

The 3.5 MHz Loop

After a lot of experimentation, I finished up with the arrangement shown in figure 1. The square loop is mounted on a wood cross with cross arms 1 metre long. UR67/U coax cable forms a square with sides of 86 cm. (Of course any other type of coaxial cable would have also done the job).



- **L1 - 5.5uH, 22 turns, 2cm diam, spaced 30mm**
- **L2 - 5 uH, 20 turns, 2cm diam, spaced 27mm**
- **C1,C2 - 160pF Variable Vane Type Trimmers (Screwdriver Set)**
- **C3 - 680pF 500V Foil Type Mica**
- **T1 - 2:1 Toroidal Transformer (10 Turns Bifilar on 3cm Toroidal Core)**
- **M,M - Current Transformers - Phasing Monitors for CRO.**
  Insulating Sleeve, outer diam - 9mm,
  Inner diam - 4mm, length - 8mm.
  Wire passes through centre of sleeve.
  20 turns of light gauge wire wound around outside.

Figure 1 - CFA Loop for 80 Metres - Circuit Diagram

The series inductors are wound on 2cm diameter ribbed ceramic formers which I had on hand. I found I needed

slightly more inductance in series with the inner loop than for the outer loop. For C1 and C2, I initially used wide spaced variable capacitors padded up to the required capacitance values with paralleled mica capacitors but I had trouble with the mica capacitors failing, possibly due to the high RF currents in the circuit. So I eventually fitted the 160 pf vane type air dielectric trimmers which were just large enough in their maximum capacity to achieve tuning. The plate spacing of these capacitors limits maximum power to about 30 watts above which arcing occurs across the plates. However this was sufficient power for me to carry out the experiments.

With the loop currents adjusted for the required 90 degrees shift, I found a need for a small amount of phase correction overall and hence the inclusion of capacitor C3. Loaded resistance of the adjusted circuit turned out to be around 10 to 12 ohms and this allowed a fairly reasonable match to 50 ohms with 2:1 transformer T1, giving 4:1 impedance ratio.

When the loop currents are roughly equal and 90 degrees out of phase as indicated by the CRO, SWR can be very close to 1:1 at the tuned up reference frequency. Moving up or down the band from this frequency alters the relativity of amplitude and phase between the two currents, alters the load impedance and alters the SWR. For a given fixed adjustment, SWR can be held within 2:1 over a frequency range of 75 kHz.

I am not sure in what plane this antenna should best operate. The photos of Professor Hately show him holding his antennae in the horizontal plane. However I arranged for a friend, 7 km distant, to monitor signal level for different orientations of the loop. My loop was elevated around 2 metres above the ground and my friend received via a loaded vertical antenna. The highest signal level he received was with the loop plane vertical and at right angles to the direction of transmission. With the loop plane still vertical but in line with the direction of transmission, the signal was 1.5 S points lower. With the loop plane horizontal, the signal was one S point below the first test. All in all, it didn't seem to be all that important how the loop was orientated. However from our tests, it did seem best with the loop in the vertical plane and at right angles to the direction of transmission.

The signal was also compared with that from an end fed V, a little over a quarter wave long and operated against ground as a Marconi antenna. The signal level received from this was close to three S points above the highest level signal from the loop.

Loss resistance

On air tests indicated that the loop performance was something like 20 dB down on a full sized wire antenna. The question arises about where the power goes that feeds into the loop. How much is actually radiated and how much is lost in heat in the loop circuits? I made some measurements to get some idea of what proportion of power might be lost in the RF resistance of the loop windings and the series inductors. This was done by measuring the approximate inductance and Q factor of each and deriving, from these, values of loss resistance. These were evaluated as follows:

Outer Loop Conductor = 1.5 ohms
Inner Loop Conductor = 2.2 ohms
Each Series Inductor = 1.2 ohms

Total resistance is the outer loop circuit is therefore (1.5 + 1.2) = 2.7 ohms. Total resistance in the inner loop circuit is therefore (2.2 + 1.2) = 3.4 ohms. The parallel resultant of these is close to 1.5 ohms. Assuming that this figure is part of the 10 ohms load resistance measured, one could assume that the proportion of power lost due to loss resistance in the loop circuits is therefore (1.5/10) x 100 = 15 % or less than 1 dB.

Can we assume that the remaining 85% is radiated and if so, is much of it being lost in the wrong direction (Perhaps straight up due to ground reflection)? Or perhaps there is high absorption into the earth or surrounding objects.

Comparisons

It has been suggested that I compare the performance of this CFA Loop antenna with the Magnetic Loop but it is not easy to make direct comparisons. The CFA loop, designed for 3.5 MHz, is just under a metre square. To compare with a magnetic loop of similar dimensions, I have a magnetic loop, also just under a metre square, made of 20mm diameter copper tube designed to be quite efficient at 21 and 14 MHz. At 21 MHz it has a calculated efficiency of 89% and at 14 MHz a calculated efficiency of 68%. With extra tuning capacitors it could work at 7 MHz and 3.5 MHz but efficiency falls to a calculated figure of 15% at 7 MHz and only 1.5% at 3.5 MHz

On 14 and 21 MHz, the magnetic loop performs as well as a full sized wire antenna but because of the low efficiency at 3.5 MHz, it would clearly be around 20 dB down in performance on the full size antenna. Tests using my 3.5 MHz CFA dipole have indicated that its performance is also around 20 dB down on a full size wire antenna.

Made to the right dimensions for the particular frequency, the magnetic antenna works extremely well. However it has a limitation in its very high Q resulting in limited bandwidth and the need to progressively retune as the band is scanned. At 14 MHz, the calculated bandwidth for my magnetic loop is 19.6 kHz. At 3.5 MHz, there might be a real problem as the calculated bandwidth is only 1.6 kHz. By comparison, the 3.5 MHz CFA loop holds a tolerable match over a 75 kHz range.

Some Conclusions

Well I can’t say I am madly excited about this antenna. It will transmit and receive but not as well as a quarter wave Marconi antenna. (My observations indicate around 20 dB difference both on receiving and transmitting). On the other hand, it might be the answer where one needs to get on 80 metres, at least with some sort of signal, but doesn’t have the space for a larger antenna.

I see no problem for the home constructor in making the unit if he can find some suitable variable capacitors of high enough capacitance and which will withstand both high voltage and high RF current. I see a problem if the home constructor doesn’t have some means to monitor and set the two loop phase currents correctly.