

Receiving loop study

Rudy Severns N6LF

Introduction

Both vertical and horizontal loops are useful receiving antennas. One of the attractions of such loops is the presence of a pattern null broadside to the plane of the loop which can be used for RDF or nulling of undesired signals such as local RFI. But, as shown by AA7FV^[1], the null depth can be disappointing, more a broad shallow minimum than a sharp null. Orientation, structure and installation can affect the pattern but these can be addressed with careful construction and placement. What is not generally appreciated is that even for an ideal loop in free space there can still be substantial radiation/reception broadside to the plane of the loop due to non-uniform current distribution around the loop. In horizontal loops over ground non-uniform current results in substantial response to vertically polarized signals in addition to the desired response to horizontally polarized signals.

The purpose of this note is to show the radiation patterns, explain the reason for broadside response and demonstrate several ways to suppress that response. The discussion includes experimental measurements on an actual antenna. EZNEC Pro/4 V7.0^[2] with the NEC4 or 5 engines and AutoEZ V2.0.7^[3] from Dan Maguire, AC6LA, were used for the modeling part of the discussion.

Single source loops

In very small loops relatively deep nulls ($>20\text{dB}$) are possible but the signal level to the receiver might be low, perhaps too low, a problem often seen at LF and MF. The simplest fix is to increase the size of the loop to provide more signal. Unfortunately as the loop diameter increases the null depth decreases. This decrease is intrinsic not a construction or installation fault. This part of the discussion assumes a lossless vertical loop in the X-Z plane in free space. Our concern is the undesired broadside response along the Y-axis perpendicular to the plane of the loop.

The lowest frequency self-resonance in a closed loop occurs when the perimeter of the loop (lw) is $\approx 0.5\lambda_0$ but discussions of loop receiving antennas often suggest limiting lw to $< 0.08\lambda_0$. What is the reasoning behind this limit? We can answer this question by modeling a loop as shown in figure 1 varying lw over a range, $0.01\lambda_0$ to $0.5\lambda_0$. At 160m this corresponds to loop diameters of 2' to 90'.

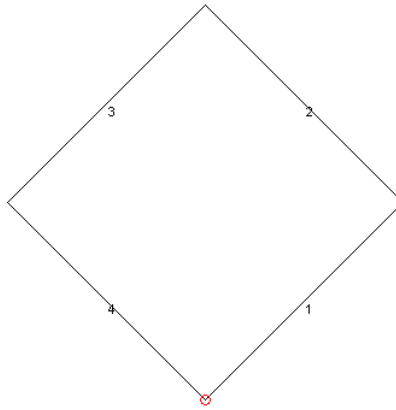


Figure 1 - Single turn loop with one source.

Azimuthal radiation patterns at 0° elevation (X-Y plane) for two cases, $lw=0.01\lambda$ and $lw=0.47\lambda$, are shown in figure 2 where 90° is broadside to the loop. The left hand patterns are for the small loop and the right hand patterns the large loop. Figure 2A is the total response (E_V+E_H) showing the degradation of the broadside response as lw is increased.

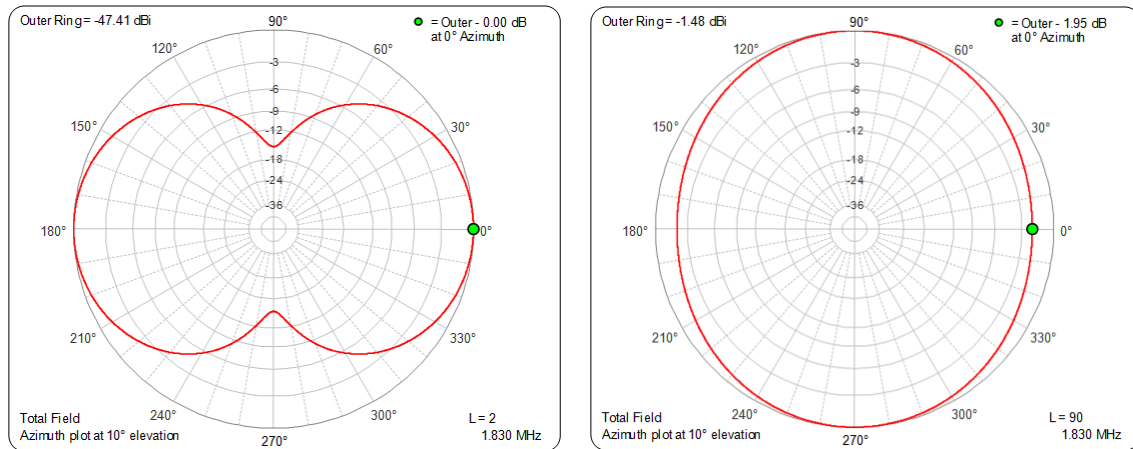


Figure 2A – Total response.

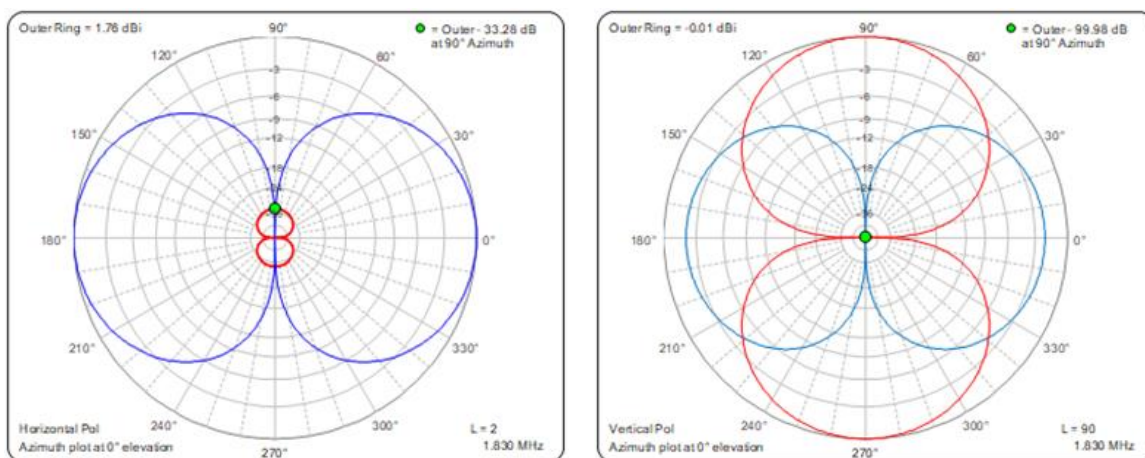


Figure 2B – E and H responses separated.

In the larger loop there is no null at all in fact the broadside response is greater than the end-fire but this is a bit misleading. Figure 2B shows the pattern separated into the vertical (E_V) and horizontally (E_H) polarized components. The blue is E_V and red E_H . For the small loop (left) the broadside null is very deep and the E_H response small but with the large loop there is no null, $E_H > E_V$! The null reduction is due to the introduction of E_H response while the E_V pattern is stable. What's going on here? The E_V response looks like a classic magnetic dipole but the E_H response looks a lot like an electric dipole.

Loop E and H-field response

A loop responds to an incident EM field in two modes: as a magnetic dipole and as an electric dipole. Figure 3 illustrates the magnetic dipole mode where the loop is responding to the H-field component of the incoming wave. This is the mode most people visualize when thinking about loops.

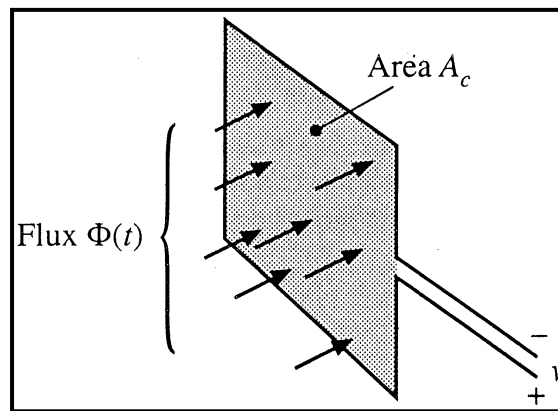


Figure 3 -Magnetic flux through an open circuit loop.

In addition to the magnetic dipole mode a loop will also respond to the E-field like a short electric dipole. This is explained well in references [4] and [5]. These references separate the two modes as shown in figure 4.

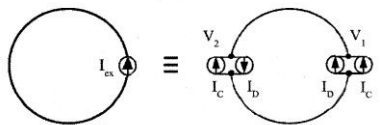


Fig. 7. Lumped-element single-feed loop.

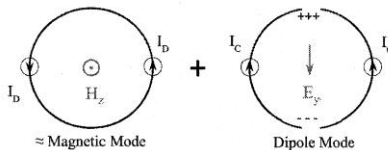


Fig. 8. Lumped-element single-feed loop (modes decomposed).

Figure 4 – Mode separation. From Rezaei et al [5].

When lw is small the electric dipole is small and there is little broadside E_H response. But like a normal electric dipole, if you make it longer you get more signal. The electric dipole mode is the source of the E_H response.

One way to explain this response and how it changes as lw is increased is to look at the current distribution around the loop. In an ideal magnetic dipole the current around the loop is uniform (constant) but this is not the case for real loops as shown in figure 5. In this example loop currents are shown for $lw=0.01\lambda_0$, $0.105\lambda_0$, $0.263\lambda_0$ and $0.421\lambda_0$. The feed point is between the left and right ends of each contour with a source current of 1A. The same segment size was used for each loop so the larger loops have more segments. For a small loop ($lw=0.01\lambda_0$) the current amplitude around the loop is very uniform but as lw is increased the current distribution becomes progressively more non-uniform especially as lw approaches self resonance. The decrease in null depth with increased loop size is a direct consequence of non-uniform current distribution. This suggests that if the current in larger loops could be made more uniform the broadside response might be reduced significantly.

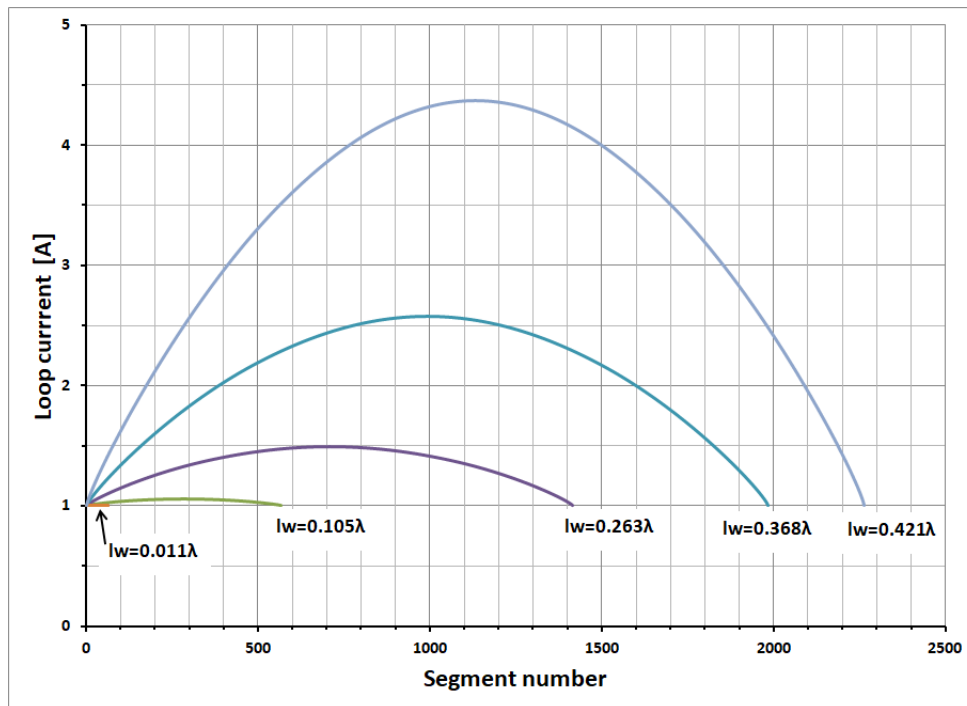


Figure 5 – Current distribution around the loop with for different lw .

Dual source loops

One way to reduce the current amplitude variation around the loop and suppress broadside response is to use two sources instead of one. This arrangement is shown in figure 6, with a source at each side of the loop.

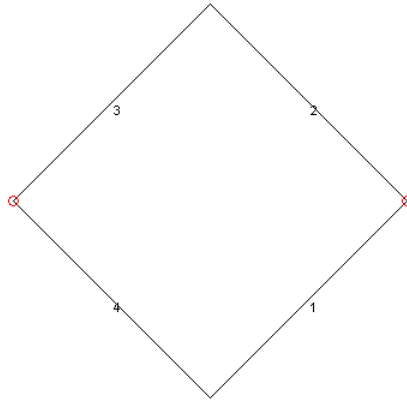


Figure 6 – Dual source loop model.

The current distribution around loops of different sizes with two sources are compared to those with a single source in figure 7 where the dashed lines are for a single source and the solid lines two sources.

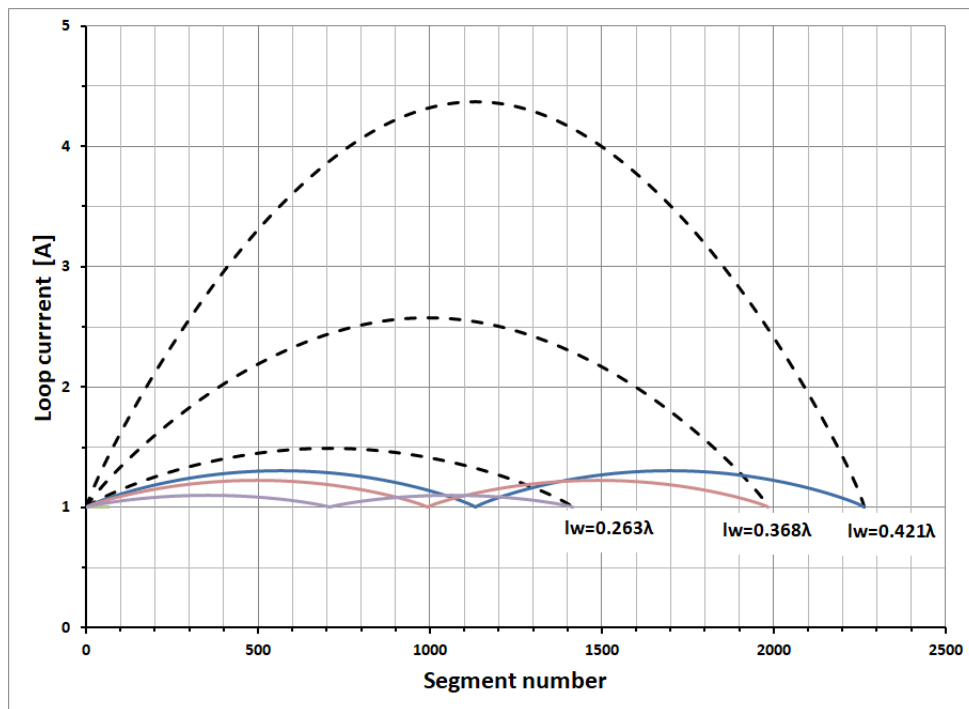


Figure 7 – Single and dual source loop current distributions.

Note the drastic reduction in current variation around the loop. This results in suppression of the broadside E_H radiation along the Y-axis as shown in figure 8 which is an elevation plot at 90 deg azimuth, i.e. the pattern is in the Y-Z plane. The blue line represents E_H with a single source and the red line E_H for a double source. The patterns are for a 90' diameter diamond loop at 1.83 MHz ($lw=0.47\lambda$).

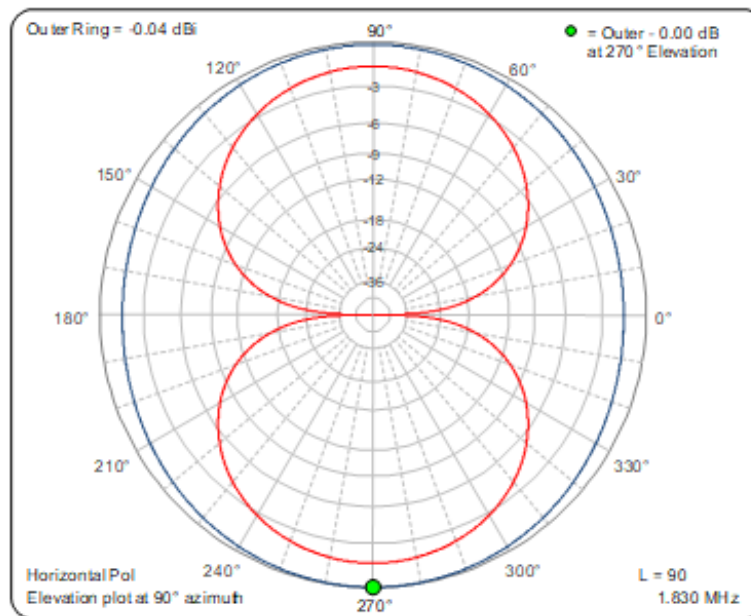


Figure 8 – Dual source loop radiation patterns, Y-Z plane.

Using two sources a deep null is maintained along the Y axis for both E_V and E_H even when lw approaches $0.5\lambda_0$. Even a very large loop can have a good broadside null allowing the use of much larger loops with greater signal output.

To help explain what's happening figure 9 shows the modes for the dual-source loop.

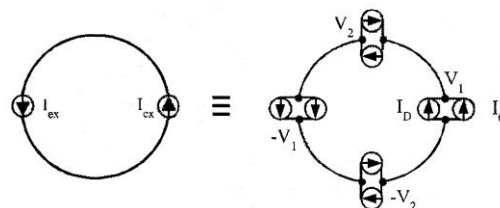


Fig. 9. Lumped-element dual-feed loop.

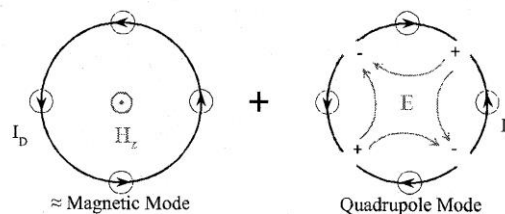


Fig. 10. Lumped-element dual-feed loop (modes decomposed).

Figure 9– Loop modes with two sources. Rezaei et al [5].

The idea is that the magnetic mode stays the same but the dipole mode is converted to a quadrupole reducing E_H broadside by 30-40 dB.

An EMI sensor

A common means for implementing dual sources is illustrated in figure 10.

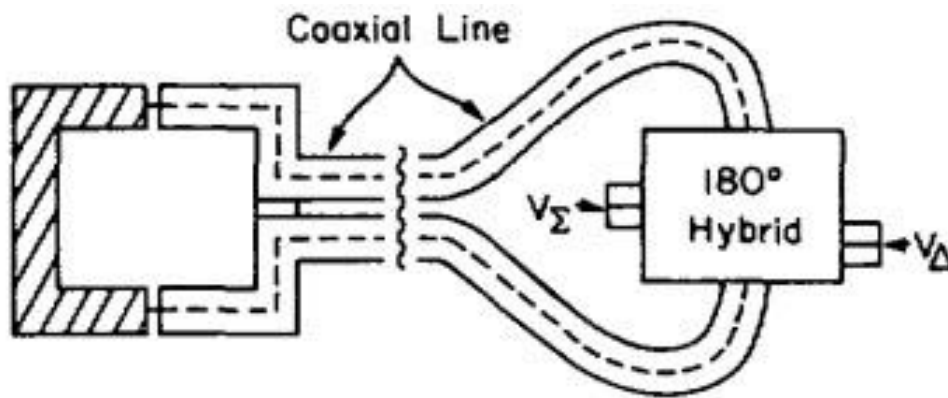


Figure 10 – Dual feed loop. Dyson [6].

This arrangement is often used for EMI testing. The loop has two feedpoints each connected via a cable to a hybrid combiner. The outside of the cable shields form the lower part of the loop. Taking the difference between the two signals (A-B) you have the H-field.

The K6STI loop

In his September 1995 QST article ^[7] Brian Beezley, K6STI, showed another way to excite a loop with dual sources. Figure 11 is a sketch showing the arrangement.

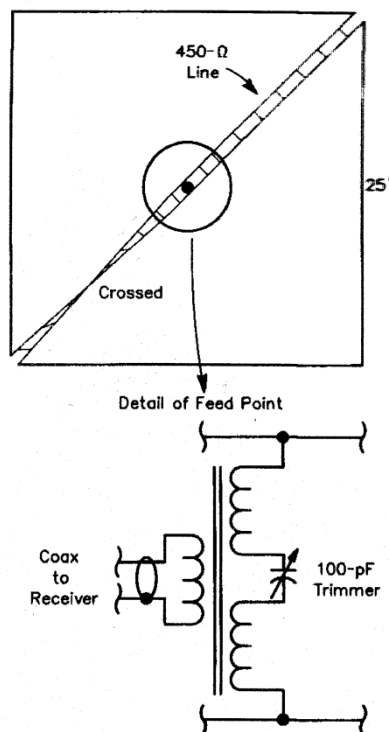


Figure 11 - K6STI dual-source loop ^[7].

Brian's loop was horizontal a short distance above ground. He wanted to suppress vertically polarized local noise for which it was very effective.

A double loaded resonant loop

The dual feed schemes shown in figures 10 and 11 work well over a wide bandwidth but are somewhat complex. If a narrow band resonant loop can be used then the same effect can be achieved with only one source and two tuning capacitors (C_r) in series with the loop as illustrated in figure 12. The squares represent capacitors and the source is a circle.

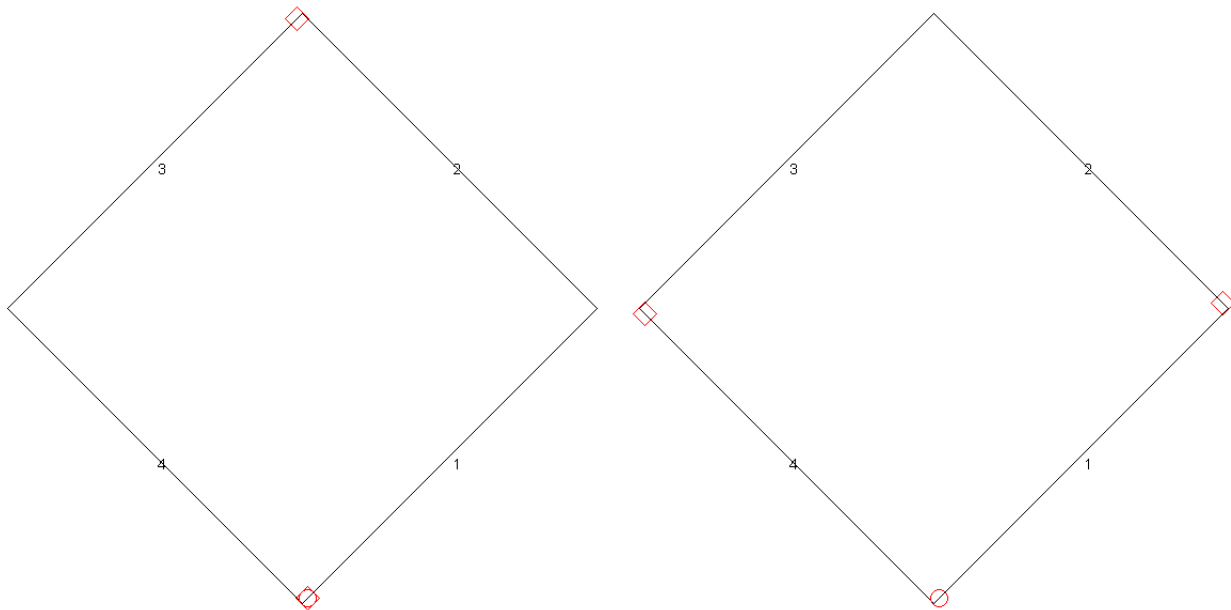


Figure 12 – Single source dual C_r loop example.

With the feedpoint at the bottom of the diamond there are two ways we might insert two capacitors: at the top and bottom or at the right and left corners. The difference between the two is the feedpoint impedance. With C_r at top and bottom (in parallel with the source) the feedpoint impedance will be high, i.e. a parallel tuned circuit. With C_r at right and left corners the feedpoint impedance will be low as in a series tuned circuit.

Figure 13 shows the current distribution around the loop and the azimuthal radiation patterns at 0° elevation for two cases: the blue lines are for a single C_r at the bottom of the loop and the red lines are for two C_r loads, one across the feedpoint and the other at the top. The loops are 50' in diameter. The loop is excited with a 1A current source across the lower C_r . Note the large current values showing the current magnification due to the loop Q. For the single load $C_r=75$ pF and for the double load $C_r=185$ pF for each capacitor. Notice that the effective series C_r is different ($185/2 \approx 92$ pF versus 75 pF) for the two cases even though the loop size and resonant frequency are the same.

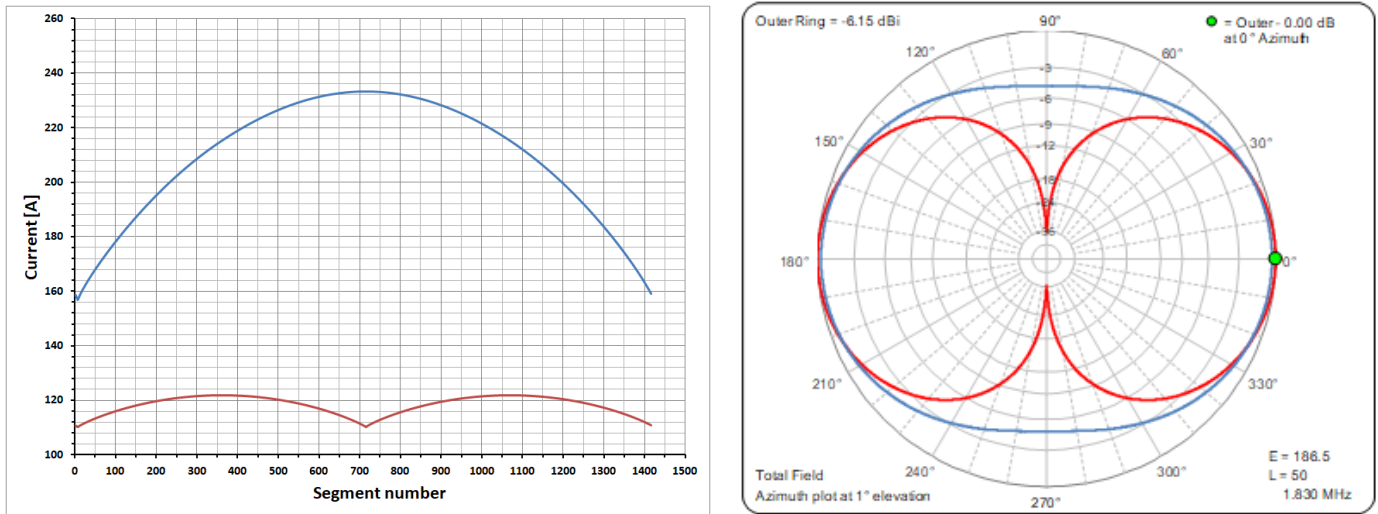


Figure 13 – Loop current and radiation patterns at 0° elevation (X-Y plane).

This implies that the effective inductance of the loop is reduced when the current distribution is altered so let's take a moment to review the definition of inductance (L) in terms of stored energy (U):

$$U \equiv \frac{LI^2}{2} \quad (1)$$

I is the current at the inductor terminals. Rearranging (1) to define inductance in terms of stored energy:

$$L \equiv \frac{2U}{I^2} \quad (2)$$

Figure 13 shows significantly lower average loop current for the 2 Cr case which implies less stored energy in the field which in turn translates to lower effective value for L . This is not something new, an ordinary solenoidal coil will display changing values for L as the operating frequency approaches the self resonant frequency of the coil due to the non-uniform current distribution. The use of two resonating capacitors is a narrow band solution but if that's acceptable it provides performance equal to the two source arrangement. We could of course take this idea one step further and insert series Cr at all four corners however, that additional complication would net us only a small improvement in nulling. In these examples I've placed the Cr at the corners, that's not sacred, any symmetric placement of the capacitors will give the same result.

It should be noted that I am not the first to suggest inserting series capacitors in a loop antenna. Arnold McKinley in his textbook on loop antennas^[8] points out that his father, an amateur, as early as 1963 had been doing this in his 20m "Closed Circuit Resonant Loop Antennas". Unfortunately I have not been able to identify his call sign or track down any articles on this work but he was probably 60 years ahead of me.

Up to this point the examples have been in free space which raises the question: Is what we've learned of any practical use?

A practical example

For some time I've wanted to examine the effect of antenna polarization on the reception of 20m signals at my QTH possibly using polarization diversity. One way to do this would be to have two antennas, one responding only to E_v and the other responding only to E_H . Each antenna could be connected to a separate receiver decoding the same WSPR signal at the same moment in time. The receivers would need to be identical with the same settings. In theory this approach could provide a quantitative measure of the incoming signal to noise ratio (SNR) for each polarization. A simple $\lambda/4$ vertical with a radial ground system would be fine for E_v and I wondered if a dual source horizontal loop could be used for E_H ? So I modeled, built and field tested a horizontal dual Cr loop comparing it to a $\lambda/4$ vertical with 16 radials. The loop model is shown in figure 14.

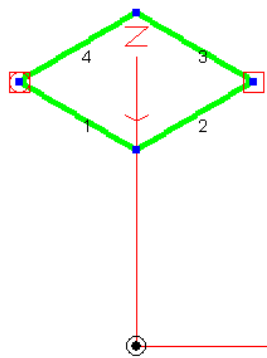


Figure 14 – Horizontal loop with two Cr.

The loop is fed across one of the capacitors. The resonant frequency was set to 14.0956 MHz the WSPR reference frequency for 20m.

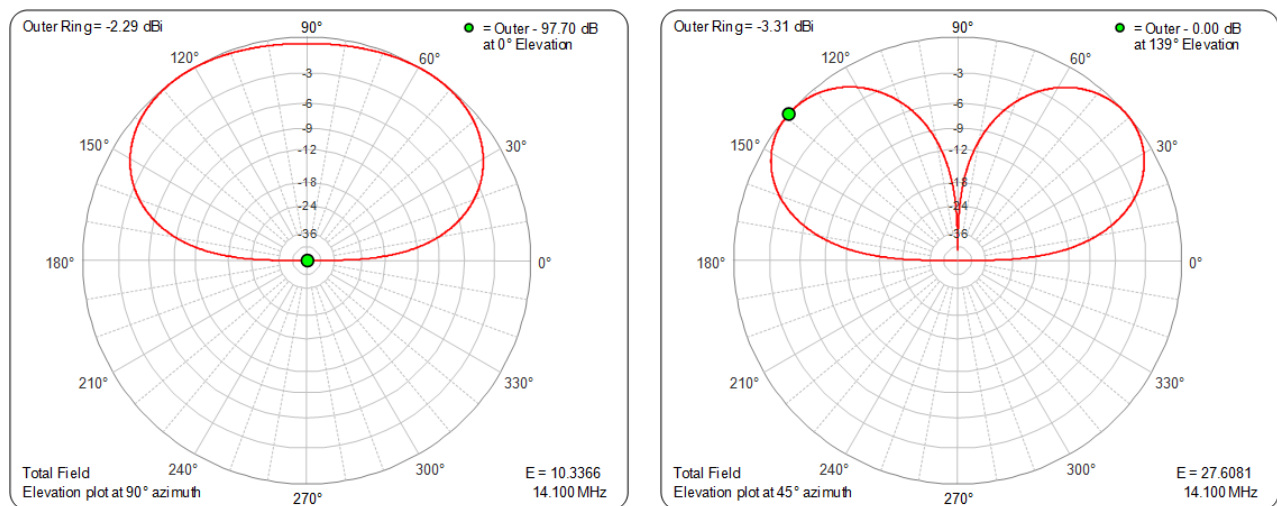


Figure 15 – Total radiation elevation patterns. Left=1 Cr and Right=2 Cr.

Before building the antenna I modeled it with the results shown in figures 15 and 16. Note, the left patterns are for the case of a single Cr and the right patterns are for dual Cr. Elevation patterns at 45 and 90 azimuths were selected to show the maximum values for E_V .

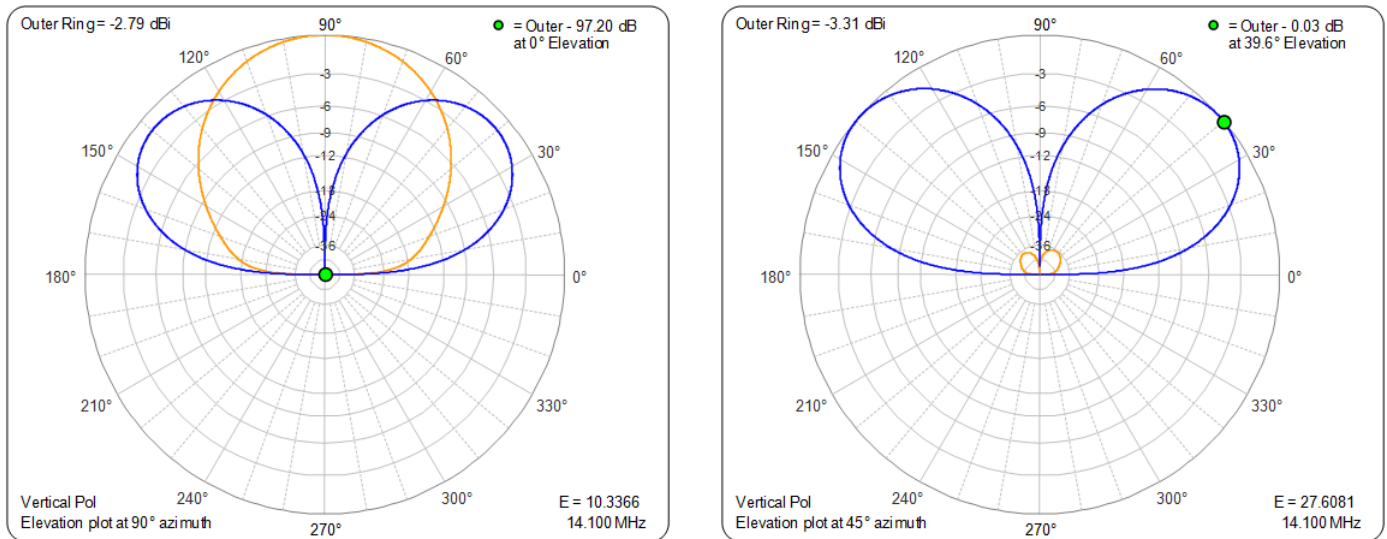


Figure 16 – Elevation patterns separated into E_V (yellow) and E_H (blue) components.

The dual capacitor patterns looked very promising with very little E_V so I built a test antenna using #18 wire, a diameter of 117.5" and elevated 10' above ground.

The resonating capacitors were short sections of RG8X coax which allowed me to trim their length to resonate the loop. The output signal was taken across one of the resonating capacitors using a balanced high impedance buffer provided by Greg Ord, W8WWV. The resonant frequency of the loop was determined using a vector network analyzer in the transmission mode (S21). A wire loop excited by the VNA transmit-port was placed on the ground under the loop. The output from the buffer on the loop was fed back to the VNA receive-port measuring |S21|. The capacitors were trimmed until |S21| peaked at the WSPR frequency. For the experiment the E_H antenna was the loop and the E_V antenna the vertical.

WSPR results

Figure 17 is a pair of graphs for a 24 hour run on 13-14 August 2023. Each point is pair of SNR reports, one from each antenna, for the same station, at the same time, i.e. simultaneous decodes for the same station, W4WLO or VK4GRA. Note the SNR values vary by 30 dB because the measurements were taken over a 24 hour period including both day and night propagation.

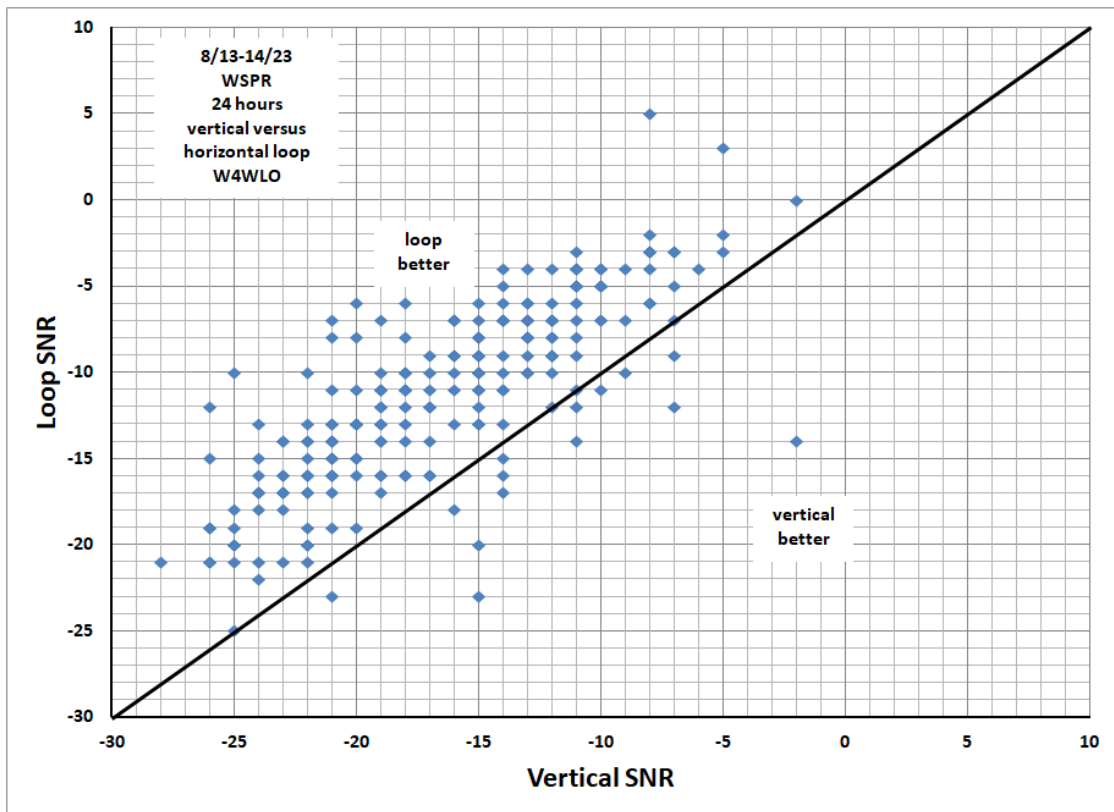


Figure 17A - WSPR SNR comparison for W4WLO.

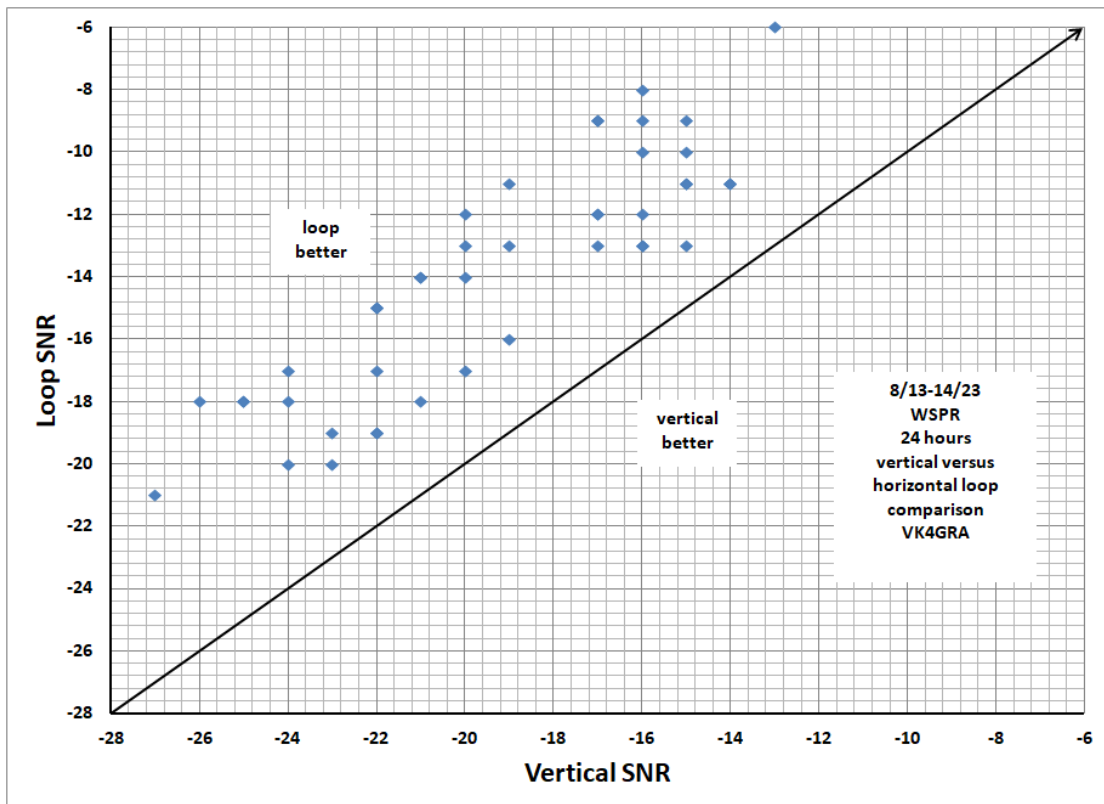


Figure 17B - WSPR SNR comparison for VK4GRA.

The diagonal lines represent equal SNR reports on both receivers. Points lying below this line mean the signal on the vertical had a better SNR than the loop. Conversely points lying above the line represent loop SNR better than vertical. Both day and night, the loop with horizontal polarization was superior in most cases to the vertical with vertical polarization. This was especially true for the VK4GRA signals which represent a much longer path than W4WLO. This pattern was repeated on other runs on different days. It would be easy to jump to the conclusion that for reception on 20m horizontal polarization is distinctly superior to vertical but be careful. These graphs represent measurements made at my QTH with my particular local noise environment on a particular day. This may very well not be representative of other locations or other times of the year or the solar cycle.

Conclusions

The source of the broadside response is the superposition of magnetic and electric dipole modes. Going to dual sources provides a substantial cure for the problem. When limited bandwidth is acceptable dual symmetrically placed resonating capacitors are a simple practical solution.

References

- [1] Darrel Emerson, AA7FV, Patterns and Polarizations of Modestly-Sized Loop Antennas, QEX September/October 2019, pp. 13-16
- [2] <https://eznec.com>
- [3] <https://ac6la.com>
- [4] Whiteside and King, The Loop Antenna as a Probe, IEEE Transactions on Antennas and Propagation, May 1964, pp. 291-297
- [5] Rezaei et al, An Analysis of the Magnetic Field Antenna, IEEE Transactions on Antennas and Propagation, Vol. 69 No7 July 2021, pp. 3654-3663
- [6] John Dyson, Measurement of Near Fields of Antennas and Scatterers, IEEE Transactions on Antennas and Propagation, Vol AP-21, No 4, July 1973, pp. 446-460
- [7] Brian Beezley, K6STI, A Receiving Antenna that Rejects Local Noise, QST September 1995, pp. 33-36
- [8] Arnold McKinley, The Analytical Foundations of Loop Antennas and Nano-Scaled Rings, Springer 2019