



Experiments on Loops above Ground

David Jefferies

Introduction

antenneX readers, especially those who contribute to the antenna discussion forum, find the subject of loop antennas perennially interesting. Usually the loops under discussion are small magnetic loops, with circumference very much less than a wavelength.

In this article, some experiments on the radiation resistance and resonant frequency of FULL WAVE loops are presented. A circular loop of wire of circumference 500mm has been offered up to an aluminium rectangular “ground sheet,” and the resistance at resonance has been measured, together with the frequency of the resonance (where the reactance of the loop vanishes). These are plotted against the distance between the ground sheet and the centre of the loop. Two cases have been considered: the loop plane parallel to the ground, and the loop plane perpendicular to the ground with the feed at the point furthest from the ground.

500 mm is of course half-a-metre and so we would expect a full wave resonance close to 600 MHz. The experiments were conducted in a screened damped chamber using a ferrite-quenched 50-Ω coax feed connected to a network analyser. In the absence of a ground sheet we see the SMITH chart plot characteristic of a loop antenna shown in **Figure 1**.



Figure 1 – free space loop antenna

We are going to be interested in the point labelled “Marker 2” which is closest to the centre of the SMITH chart in this plot. The point and frequency at which the trace crosses the SMITH chart real axis (horizontal diameter) moves as we offer the loop up to the aluminium ground sheet. The general shape of the curve remains the same however.

SMITH chart plot of loop

In **Figure 1**, the network analyser is swept from 1 MHz to 801 MHz in 1-MHz increments, and the resulting points are joined by the light-coloured line. At each frequency the analyser measures the modulus and the phase of the reflection coefficient at the connection between the loop antenna and its feed. This is presented on the SMITH chart and interpreted by software as a measurement of the driving point impedance (resistance and reactance) of the loop.

At low frequencies the loop wire looks like a good approximation to a short circuit, so the trajectory starts near $Z=0$ at the left hand side of the SMITH chart. As the frequency is increased, the normalised inductive impedance of the loop increases and eventually the radiation resistance rises also.

When the loop is a half-wavelength in circumference, close to 300 MHz, the plot on the SMITH chart crosses the real axis and the driving point resistance is close to 2.5 k Ω . This still represents a reflection coefficient close to 1, and may be interpreted as a parallel resonance of loop inductance and capacitance.

At 619 MHz we see the full wave resonance. The loop is close to a wavelength in perimeter and the driving point resistance is about 136 Ω . The antenna now is an efficient radiator, coupled quite well to the 50- Ω feed.

There is more discussion of this behaviour in two previous articles I wrote for *antenneX* magazine. Archive IV number 42 and Archive VI number 69. Now, the radiation pattern of a loop between these two resonances (300-600 MHz in our case) is highly dependent on frequency and departs considerably from the ideal small magnetic loop pattern that many people may have in their minds. This is because the current distribution around the loop is no longer constant, as can be seen in the Archive VI number 69 article referred to above.

The loop parallel to the ground

First of all we examined the loop plane parallel to the ground sheet. **Figure 2** shows a representative situation. The perpendicular distance from the wire to the aluminium sheet was varied and measured. The aluminium sheet was about 0.8 metres wide and 1.2 metres tall.



Figure 2

In **Figure 2** we see the blue anechoic-material spikes of the chamber. The absorption at 600 MHz (where the wavelength is 500 mm) is quite reasonable as the depth of the anechoic spikes is about 200 mm, or 0.4 wavelengths. Under the anechoic spikes the chamber wall is metal, perhaps mild steel or possibly aluminium.

Resonant frequency of parallel loop

In **Figure 3**, the resonant frequency (as measured with the network analyser) is plotted against the distance between the loop and the aluminium ground sheet. Characteristic oscillations may be seen. This shows how a loop may be detuned by the presence of adjacent objects. We see maxima in the plot about every 250 mm which is every half wavelength. This is to be expected from fundamental transmission line theory and SMITH chart behaviour, for the round trip delay increases by a whole cycle each time the loop is moved half a wavelength from the reflector.

<http://www.ee.surrey.ac.uk/Personal/D.Jefferies/transmission.html>

<http://www.ee.surrey.ac.uk/Personal/D.Jefferies/smith.html>

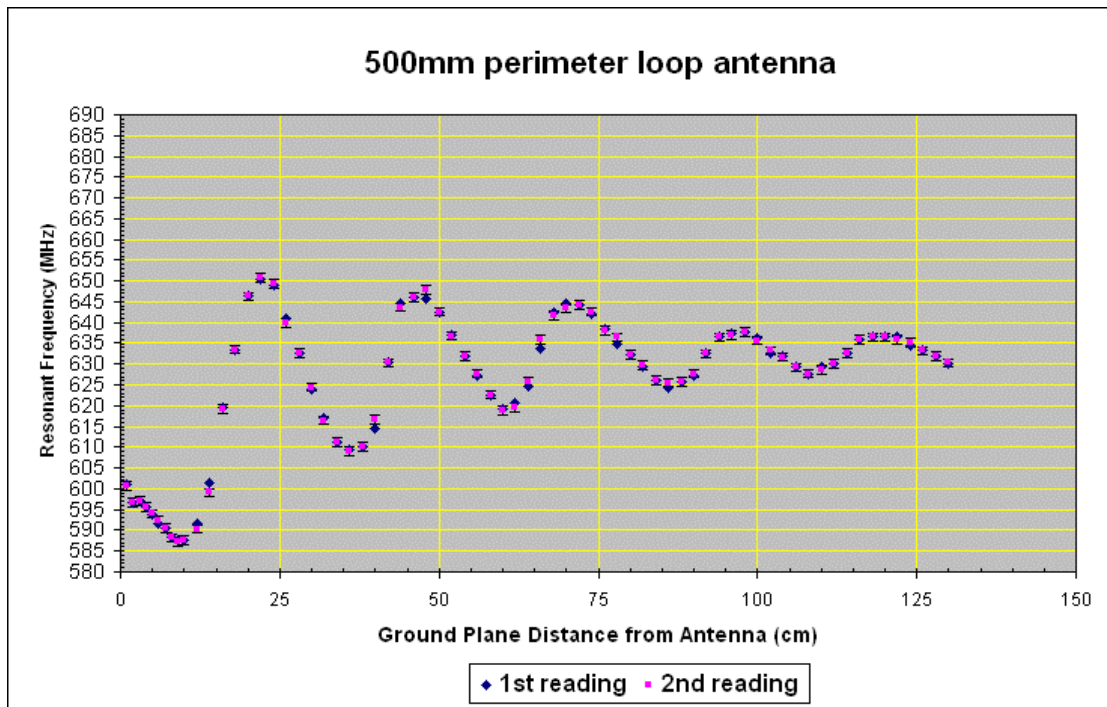


Figure 3

Driving point resistance of parallel loop

Similar oscillations are seen in the measurements of resistance at full-wave resonance. A plot is shown in **Figure 4**.

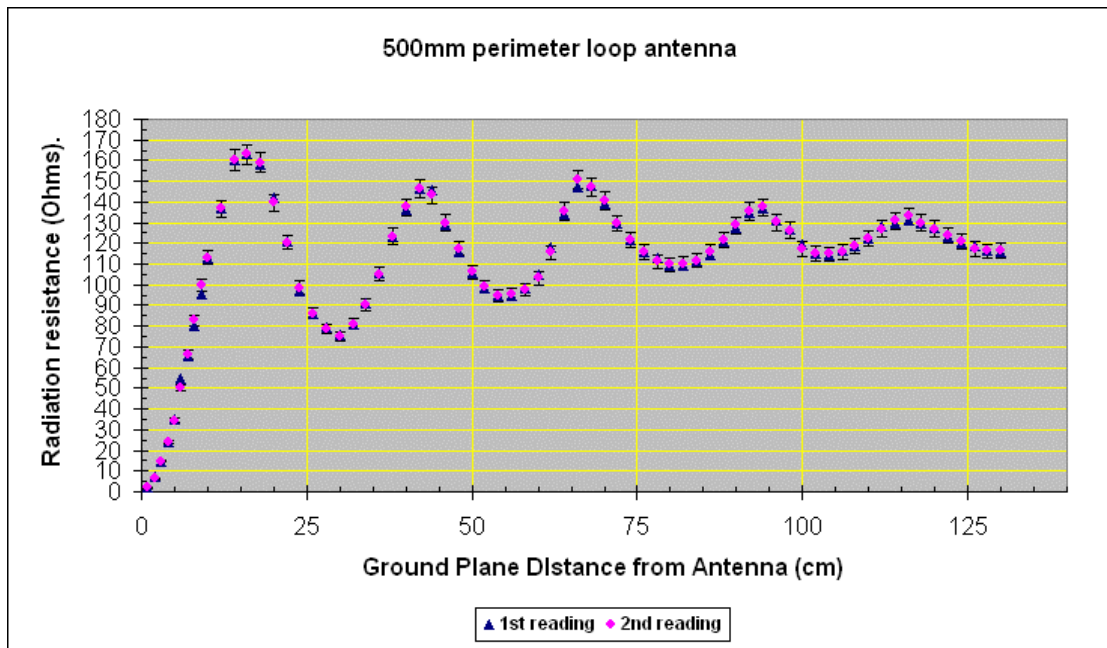


Figure 4

Now, we can see the driving point resistance falling to zero as the loop is brought in to close proximity with the ground sheet. This is to be expected, and is also observed when a dipole is brought close to a reflector. In the case of the dipole, the currents in the reflector are oppositely directed. In the case of a magnetic loop (which this isn't) the currents induced in the ground sheet would be in the same sense as in the driving loop. But this full wave loop is closer to an electric dipole in its behaviour than to a magnetic loop.

The first maximum in resistance of about 165Ω happens at a distance from the ground sheet of about 160 mm or $\lambda/3$. This is an experimental observation that should provide grist to the theorists. After that, the peaks in resistance happen again at repetition distances of a half wavelength or 250 mm. The influence of the ground extends out to about three wavelengths.

Loop perpendicular to the ground

Figure 5 shows the experimental arrangement, and for purposes of ease of measurement, the distance above ground plane in the following plots was taken to be the minimum distance; that is, from the left hand side of the loop wire in the picture to the metal sheet.

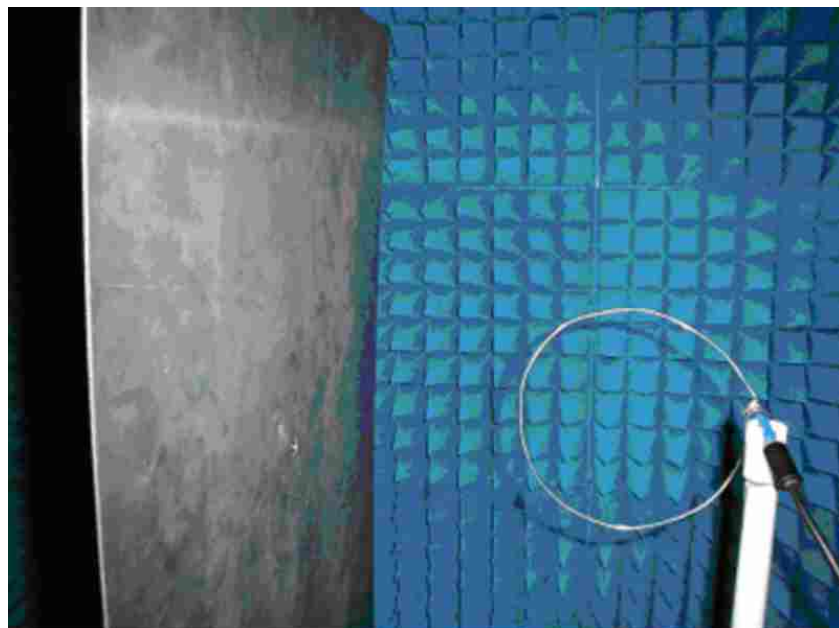


Figure 5

Resonant frequency and distance, perpendicular loop

In **Figure 6** we show the resonant frequency of the perpendicular loop, from the point where the loop perimeter opposite to the feed touches the ground plane, to the point where it has been withdrawn by 1.5 wavelengths.

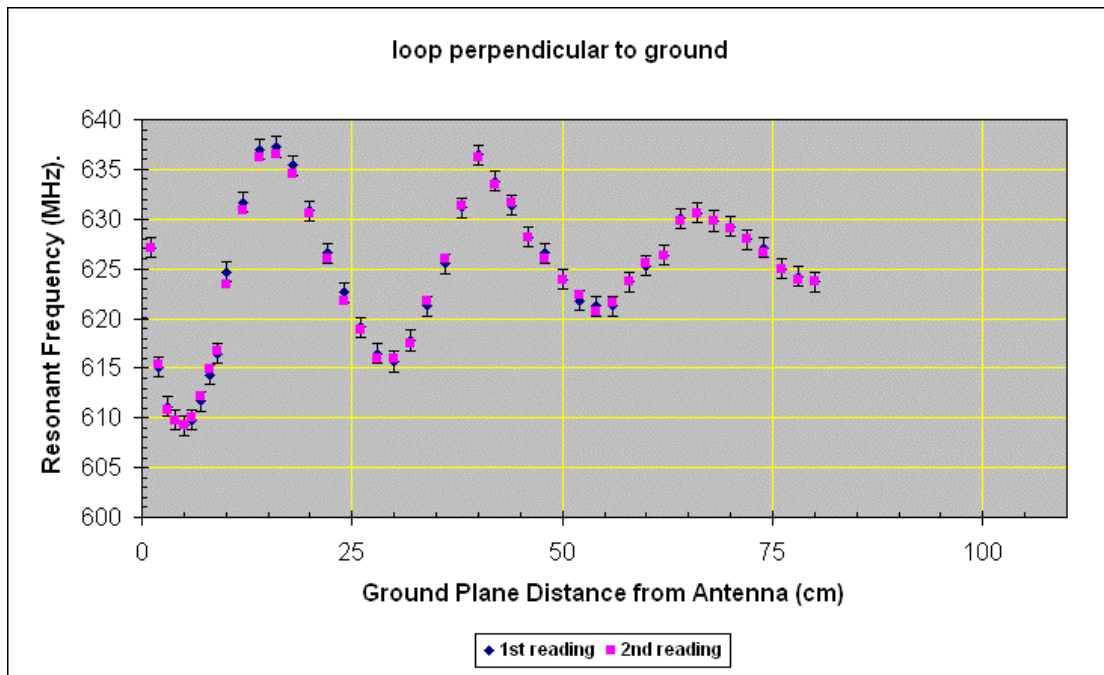


Figure 6

In this case we see that the ground plane has little effect for the case where the loop touches it, compared to the case when the loop is a long way away. Again, the curves repeat every half wavelength as the distance between loop and ground is increased.

Driving point resistance, perpendicular loop

Figure 7 now shows the driving point resistance of the perpendicular loop as the distance from the ground plane is increased.

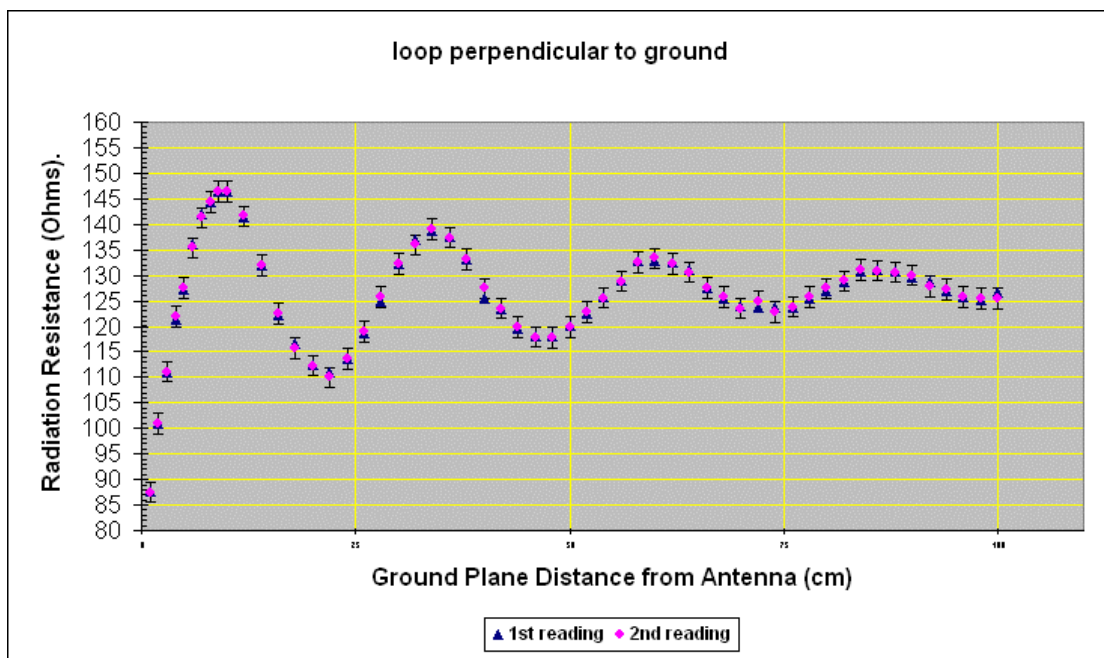


Figure 7

Discussion

In simulation studies of this type, it is usual to keep the frequency fixed (one could choose exactly 600 MHz in the case of a half-metre perimeter loop) and then investigate the variation of resistance R and reactance X against some parameter such as distance above the ground. In our case we have chosen to record the frequency at which the reactance X passes through zero as an “output measure”. The results give us a clearer idea of how the tuned performance of the loop varies above ground, and of how much percentage change there is in the important properties of the loop for practical purposes.

We might well ask “when is a loop not a loop?” Mike Underhill and Mike Blewett originally addressed this issue by identifying the dipole mode, where the current reverses its sense of travel as we progress around the loop circumference, in a way similar to the folded dipole and discussed in Archive VI number 69 *antenneX*. Subsequently Alan Boswell performed some simulations that support Underhill and Blewett’s assertion, and calculated the quantitative proportions of loop and dipole mode in a circular loop antenna for various circumference sizes in terms of the wavelength.

Our results here are for a full wave loop antenna which is behaving largely as if it was a folded dipole. We also have measurements on a square loop, and on a diamond loop, and it would be interesting to repeat these observations for a true folded dipole.

The dipole mode of the loop with the feed diametrically opposite the ground plane behaves as if the equivalent folded dipole was placed parallel to the ground. An alternative would have been to make measurements with the feed of the loop 90 degrees rotated around the loop axis, so that the feed enters from the bottom of the loop, and lies parallel to the ground. This we did not do, but it is probable that the results would have been markedly different, as it would be equivalent to the case where the folded dipole is perpendicular to the ground.

It is clear that for the full wave loops, the ground proximity effects are large and important. They behave in the same way as the proximity effects for an ordinary dipole. The ground has more impact when the plane of the loop lies parallel. Using the methods of this study, it would be quite hard to repeat the observations for an untuned small magnetic loop antenna, and no inferences should be drawn from the present work about the behaviour of such small antennas close to ground. However, we might expect that the ground coupling is larger for the parallel case.

Also of interest is the distortion that the ground plane makes to the radiation pattern, and the current experimental study has nothing to say about this. It is possible to speculate that the behaviour as frequency and separation are varied would be very complicated, and one might hazard a guess that NEC simulations would not be very helpful because of the sensitivity of the patterns to these parameters. In practice, one might be happy to live with the uncertainty about the radiation pattern, for the efficiency of a full wave loop, which approaches 100%, is its principle advantage.

Acknowledgements

The measurements reported here were taken by a University of Surrey (UniS) MSc student in the summer of 2005. Miss Hasifah Binti Abd-Halim picked up the use of the HP network analyser under the guidance of Dr G G Johnstone and did an exemplary job of amassing data and processing them with software into graphs and tables. She also performed a NEC simulation using an infinite ground plane that broadly supported the results presented above; the difference in detail may be ascribed to the size and conductivity of the actual aluminium sheet compared to the infinite and perfect ground plane of the simulation. This indicates to us that getting the description of the ground accurate is as important in a simulation as is describing the antenna structure properly.



David Jefferies

TO BIOGRAPHY OF AUTHOR

Dr. David J. Jefferies
School of Electronics and Physical Sciences
University of Surrey
Guildford GU2 7XH
Surrey, England

[D.Jefferies email](#)

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