

Report on Mutual Coupling and Impedance Measurements on Large Blade Dipoles

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In the following we describe the mutual coupling and impedance tests done on the two large blade dipole setups (LWA Memo #36) at the GSFC test site in June-July 2006. We used the RF-shielded dugout at the site to house the electronic equipment. This dugout has a flat, copper-covered, conductive roof, 12.5 m in diameter. There is an area of gravel of undetermined depth next to the dugout. Our measurements were made both over the copper and over the gravel.

1 Mutual Coupling Measurements

1.1 Introduction

As a bit of background, mutual coupling creates an unwanted signal in one dipole of an array by radiation from neighboring dipoles. The amplitude and phase of this signal depends upon the distance of the other dipole. As the phasing of the array is changed these unwanted signals change in phase and combine coherently with the ideal signal to generate phase and amplitude errors. (Signals can also be coupled through the transmission lines but these will be blocked by the baluns and other components in the LWA.) These coupled voltages result in error signals that, primarily, raise the sidelobe levels of the array being operated. The coupling is strongest between adjacent dipoles. For interior dipoles some cancelation of these effects occur because the coupling from dipoles on opposite sides of any given dipole are in the opposite sense. For dipoles near the edges of the array this cancelation does not occur. The following table gives a very rough idea of the magnitude of the errors involved:

Mutual coupling represents one of the most difficult problems that will be encountered in the design of the station and the primary antennas. It is imperative that it be investigated at an early stage in the design. That was the motivation for this project.

Coupling (dB)	Power Ratio	Voltage Ratio (i.e. Error Voltage/Ideal Voltage)
-15	0.032	17.8%
-20	0.010	10.0%
-25	0.0032	5.6%
-30	0.0010	3.2%
-35	0.00032	1.8%
-40	0.00010	1.0%
-45	0.00003	0.6%

1.2 Coupling data

The mutual coupling tests were made using two different setups, which can be seen in Figure 1. In both cases we transmitted a signal into one dipole and determined the amplitude and phase of the signal received by the other dipole. The first measurements were made before we were able to obtain the use of a Vector Network Analyzer. We injected a signal into one dipole from an HP signal generator and monitored this signal with the reference channel of an HP Vector Voltmeter while we simultaneously determined the amplitude and phase of the signal received by a second dipole with the second channel of the voltmeter. We made the usual tests to determine the losses and phases introduced by the transmission lines and baluns and to show that stray pickup was negligible. We made measurements at 10 MHz intervals from 10 MHz to 109 MHz (not exactly 110 MHz because of RFI at that frequency).

The second set of measurements was done in a similar way, but by this time a HP Vector Network Analyzer was rented and made available to us. In this case the signal was generated and measured by the network analyzer. We went through the usual calibration procedure, which involved the corrections for reflection and transmission losses, using features available in the analyzer. Measurements were done at 0.5 MHz intervals from 10 to 110 MHz. We found that both sets of measurements agreed very well.

1.3 Coupling between orthogonal dipoles on a single stand

In Figure 2 we show the coupling between the two orthogonal dipoles of a single antenna was pleasingly low, less than -40 dB in essentially all cases.

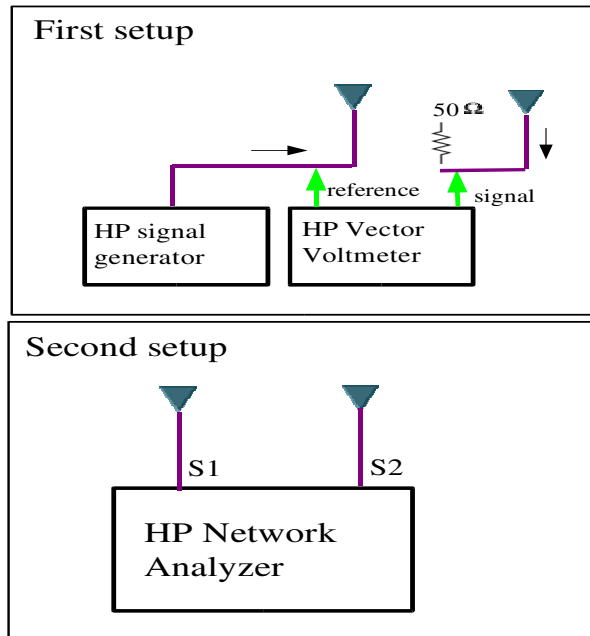


Figure 1: Schematic view of the experiment design. The calibration was done by taking into account the connecting cables, passive baluns, and pig-tails.

1.4 Coupling between dipoles on adjacent stands

We measured the coupling between dipoles of the two structures in the five orientations described in Figure 3. Two orientations when the structures were in a square configuration with their square sides aligned, i.e. staggered parallel dipoles and staggered orthogonal dipoles (these will be called parallel and orthogonal for simplicity), and three orientations when the structures were in a diamond configuration with their diagonals aligned, i.e. dipoles collinear, orthogonal, and broadside.

We made measurements at the closest possible spacing, 3.10m between centers for the diamonds and 2.63m for the squares, then at 4m spacing (the closest spacing in Emil's configuration), and at most 2m intervals out to a maximum spacing of 20m over gravel and 8m over copper. Figures 4, 5, 6

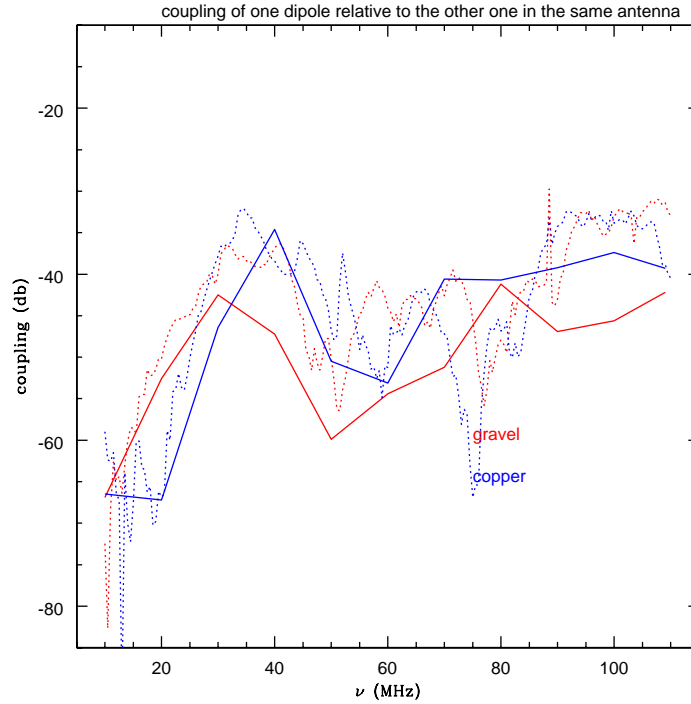


Figure 2: Coupling of 2 orthogonal dipoles in the same antenna, over two types of ground (copper in blue and gravel and red). The solid line corresponds to the first measurements (10 MHz resolution), while the dotted one corresponds to the second ones (0.5 MHz resolution). This line scheme will be used throughout this report, unless noted otherwise.

and 7 show the coupling when the antennas were separated by 4m, 6m, 8m and 20m. In the later case we show only measurements done over gravel.

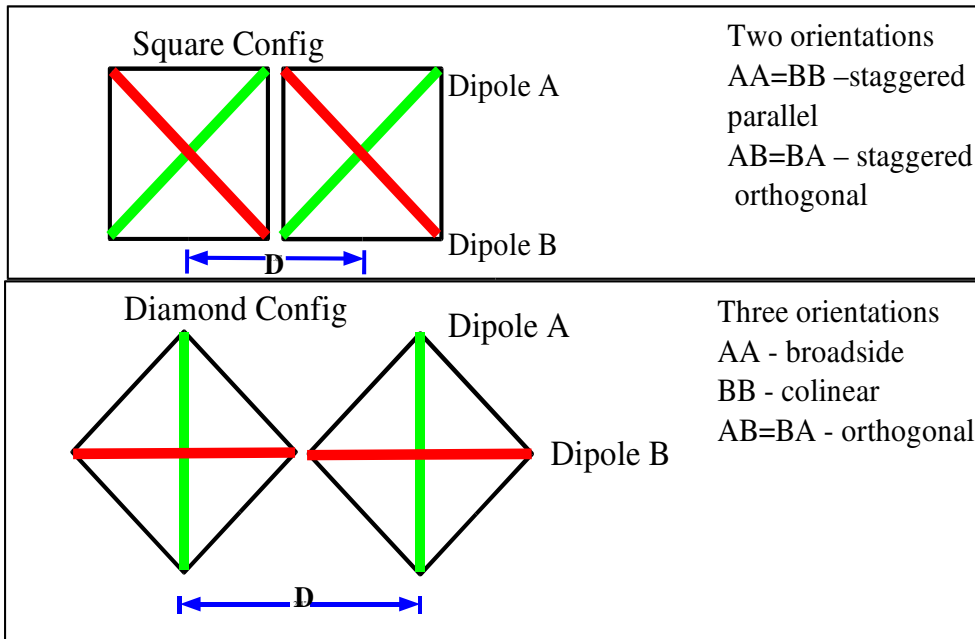


Figure 3: This Figure shows the two configurations used for our measurements, square (top) and diamond (bottom), and how the distance between the two dipoles was defined. We also list to the right of each panel which dipole orientations were measured, where the first letter corresponds to the dipole where the signal was emitted in the first antenna and the second one the dipole where the signal was being measured in the second antenna.

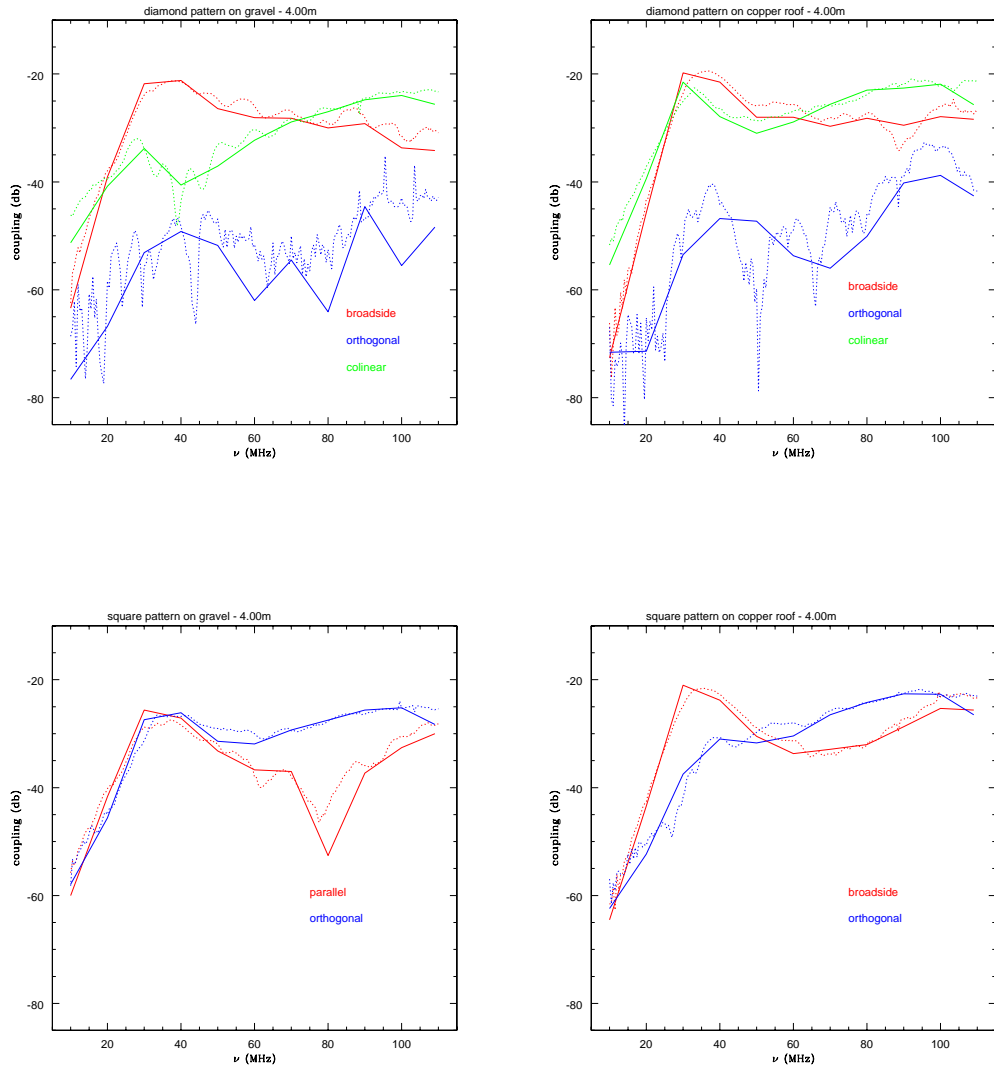


Figure 4: Mutual coupling for antenna in a diamond (top) and square (bottom) pattern, separated by 4 m. The left column shows the measurements made over gravel and the right one shows the measurements made over the copper roof. The solid and dotted lines correspond to the 1st and 2nd set of measurements, respectively.

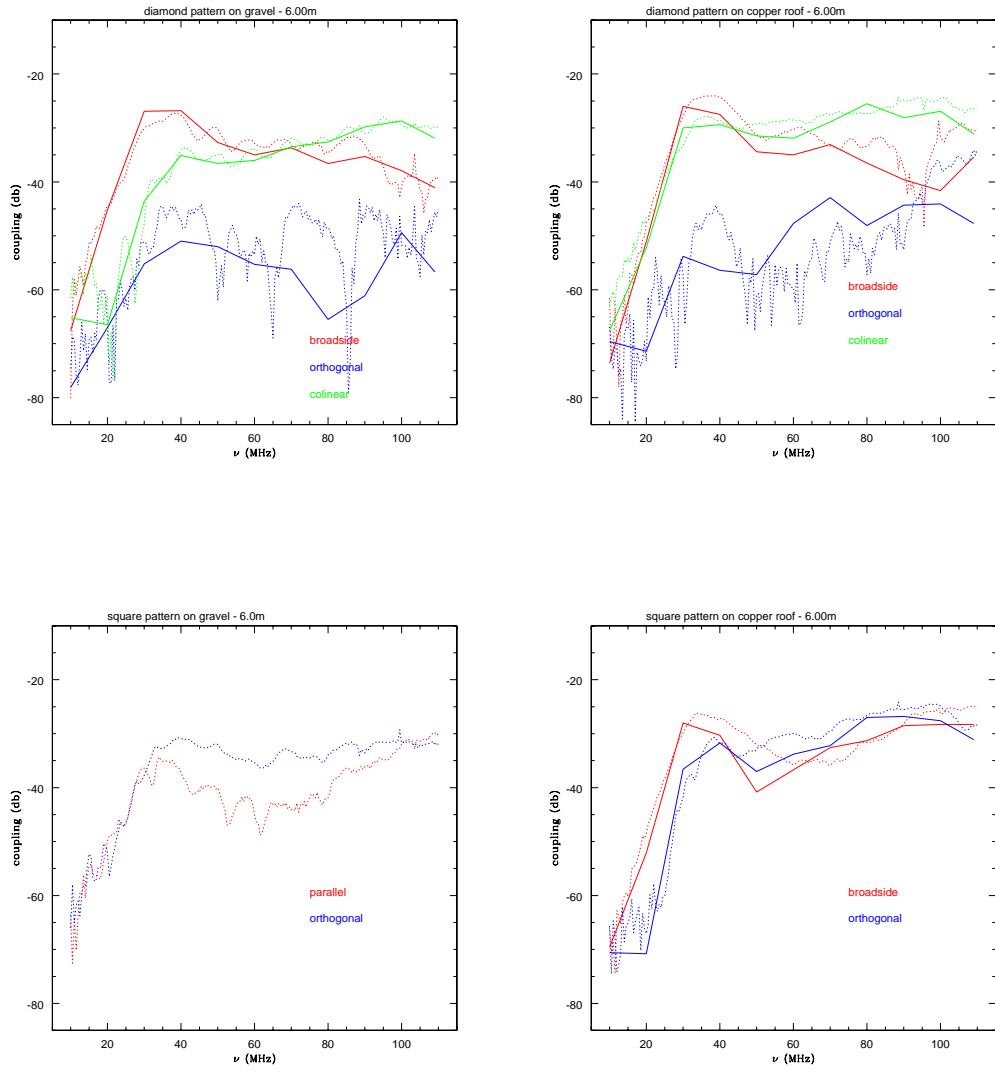


Figure 5: Mutual coupling for antenna in a diamond (top) and square (bottom) pattern, separated by 6 m. The left column shows the measurements made over gravel and the right one shows the measurements made over the copper roof. The solid and dotted lines correspond to the 1st and 2nd set of measurements, respectively.

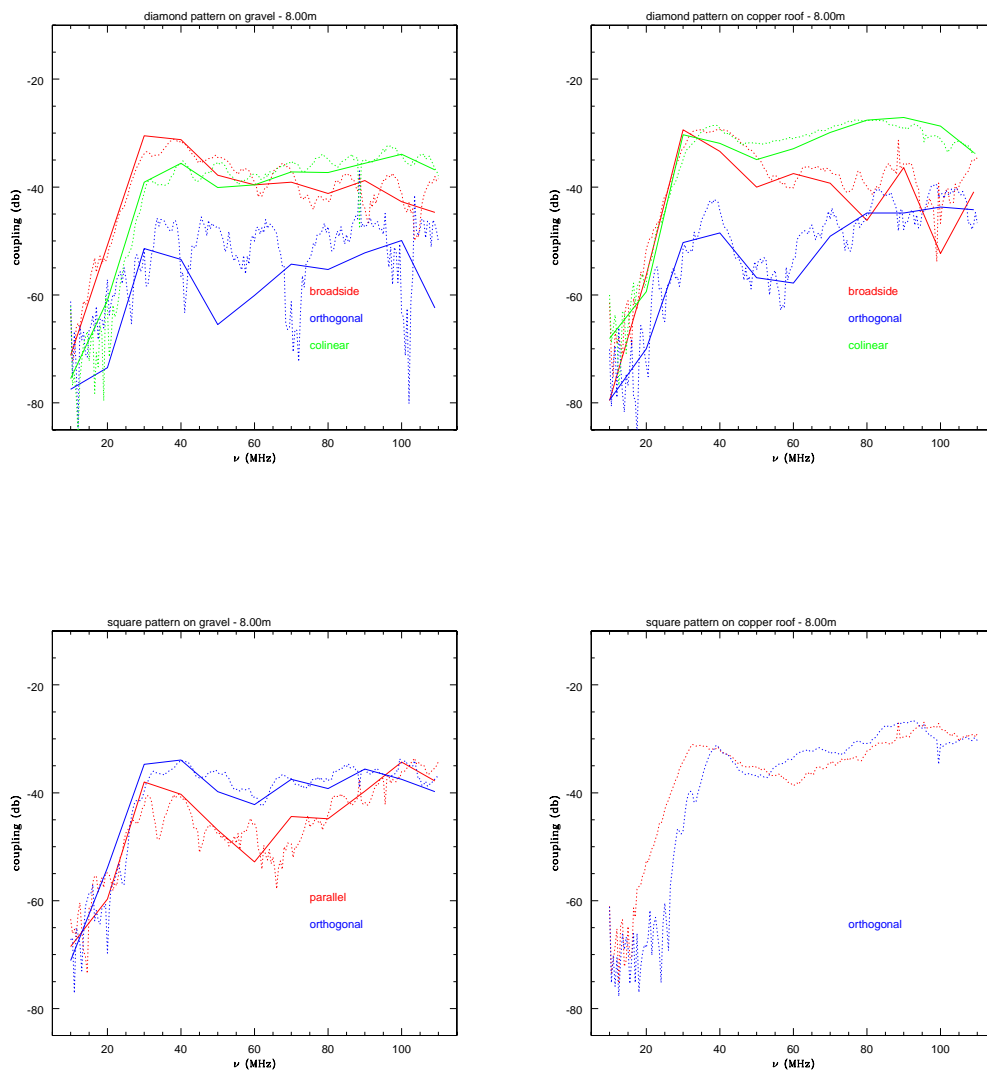


Figure 6: Same as Figure 4 but for a separation of 8 m. In the case of the square configuration the measurements over the copper roof were done only for the second setup.

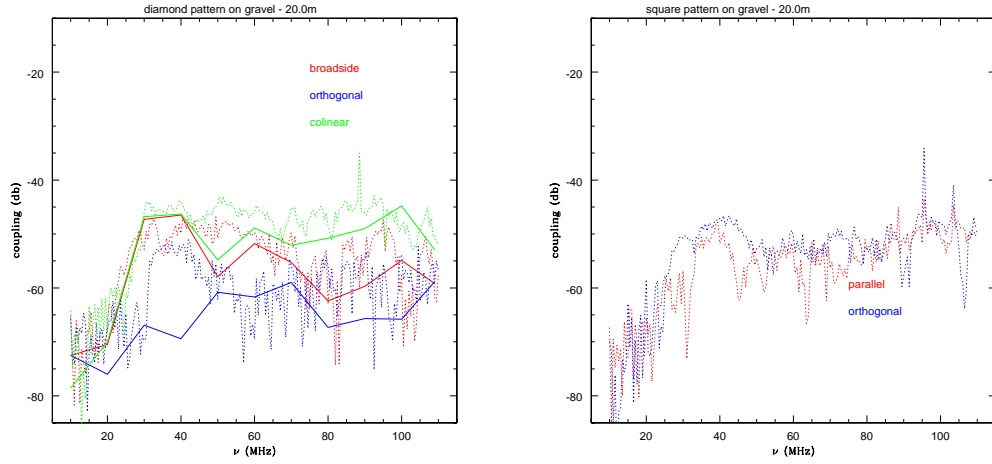


Figure 7: Same as Figure 4 but for a separation of 20 m over gravel for the diamond (left) and square (right) patterns. The measurements for the square pattern were made only for the second setup.

The coupling is generally somewhat higher (2 to 10 dB) over copper than over gravel. In all cases the coupling was very low (~ -70 dB) at 10 MHz, where the blades are too short to radiate appreciably, then rose to a maximum at ~ 30 MHz, and remained rather flat but declined by ~ 5 dB up to 109 MHz. The coupling between orthogonal dipoles in the diamond configuration was generally about 20 dB lower than between broadside and colinear dipoles. In the case of the square configuration, the coupling is similar for parallel and orthogonal dipoles at frequencies ≤ 30 MHz and ≥ 90 MHz, but at intermediate frequencies the coupling is higher for orthogonal than for parallel dipoles. This difference between the square and diamond configurations can be explained as an effect of the distance between the ends of the orthogonal dipoles. In the case of the square configuration the orthogonal dipoles are the closest ones, corresponding to a distance similar to that of the colinear dipoles in the diamond configuration, but at an angle of 90° . We also show in Figures 8 and 9 the coupling as a function of distance for the square and diamond configurations, respectively, over gravel. We see in these Figures that the maximum coupling at 4m spacing is ~ -20 dB, declining by ~ 5 dB for each 2m increase in spacing.

1.5 Discussion

In retrospect, the Network Analyzer tests were somewhat unnecessary; they show very few features of any importance that were not found with the simple Vector Voltmeter tests. However, it is very comforting to see that both sets of completely independent measurements agree well. This proves the validity of the data.

These results suggest that mutual coupling will be a serious problem but, hopefully, that it is manageable. Coupling errors will probably cause

appreciable sidelobe levels. Other plots of the data can be obtained from Henrique Schmitt.

The next step in this investigation should be to simulate these coupling data between pairs of single dipoles using EZNEC. If the simulations for the coupling between pairs of dipoles prove to be accurate, then the response pattern of the full station should be simulated. The patterns should be simulated with and without mutual coupling in order to assess the effects of mutual coupling on sidelobe levels, and upon array operation in general with respect to the scientific goals of the project.

2 Impedance Measurements

2.1 Introduction

Dipole impedance tests were first attempted with an HP Impedance Meter and hybrid balun. They did not produce sensible results and they also disagreed with simulated impedances. This is not understood. On the other hand, our measurements with the Network Analyzer, i.e. S11 and S22, appear to be very believable. They will be described below.

2.2 Impedance data

In Figure 10 we present the results of the impedance measurements. The panels in this figure show the Smith Charts for the impedance measurements over the copper roof (left) and over the gravel (right). In order to have an idea of how much the impedances can vary on different assemblies, we show the measurements of both antennas (top and bottom rows). Also, each panel shows two curves (red and black) corresponding to the two dipoles in each antenna.

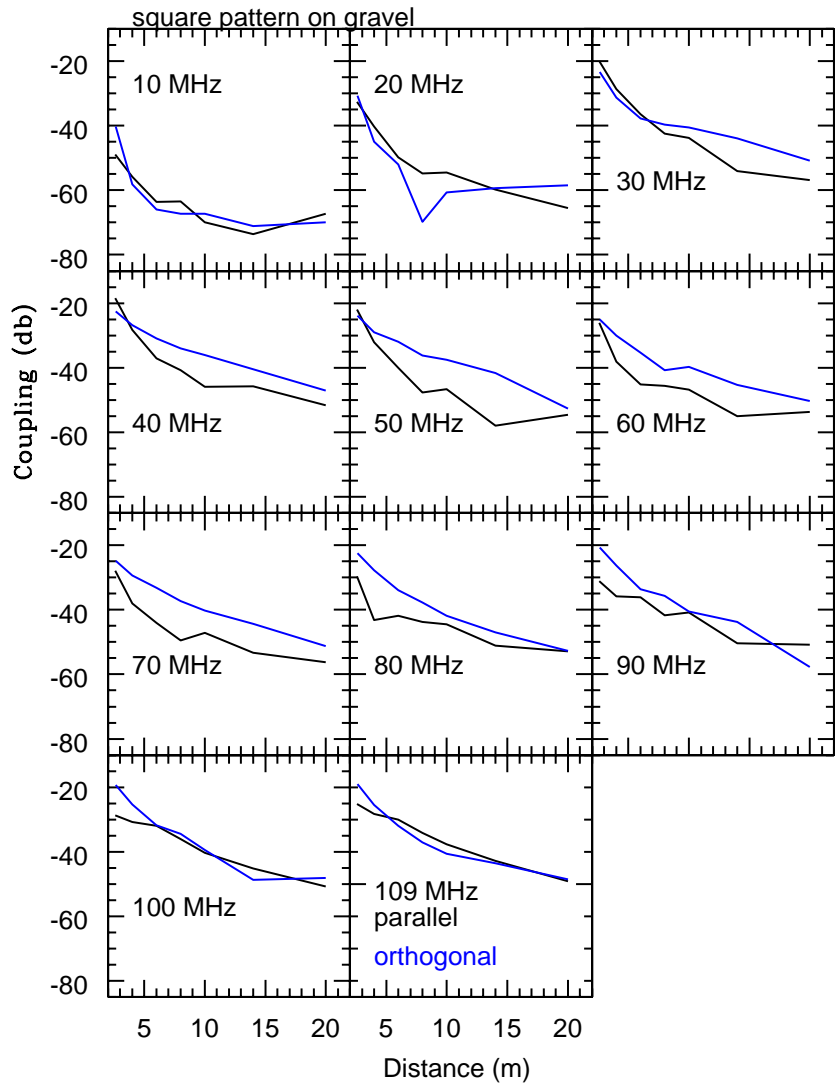


Figure 8: Mutual coupling measurements as a function of antenna separation. Each panel shows a different frequency for the square configuration over gravel.

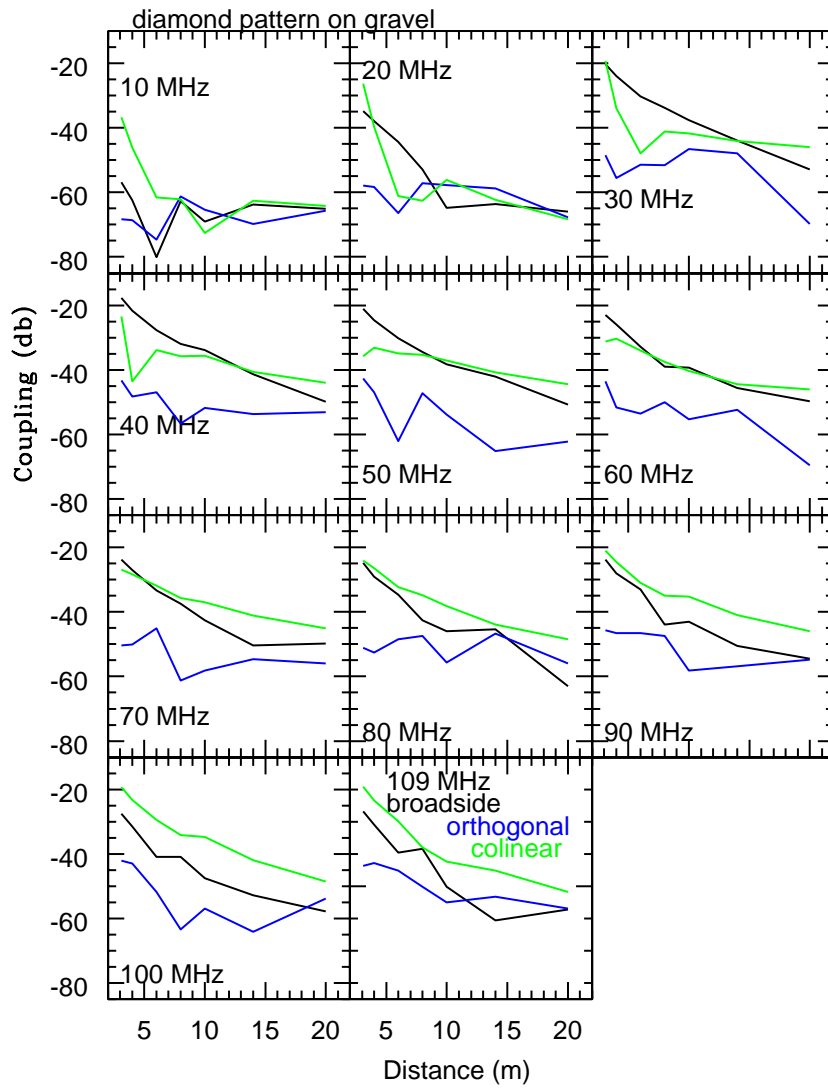


Figure 9: Same as Figure 8 for antennas in a diamond pattern.

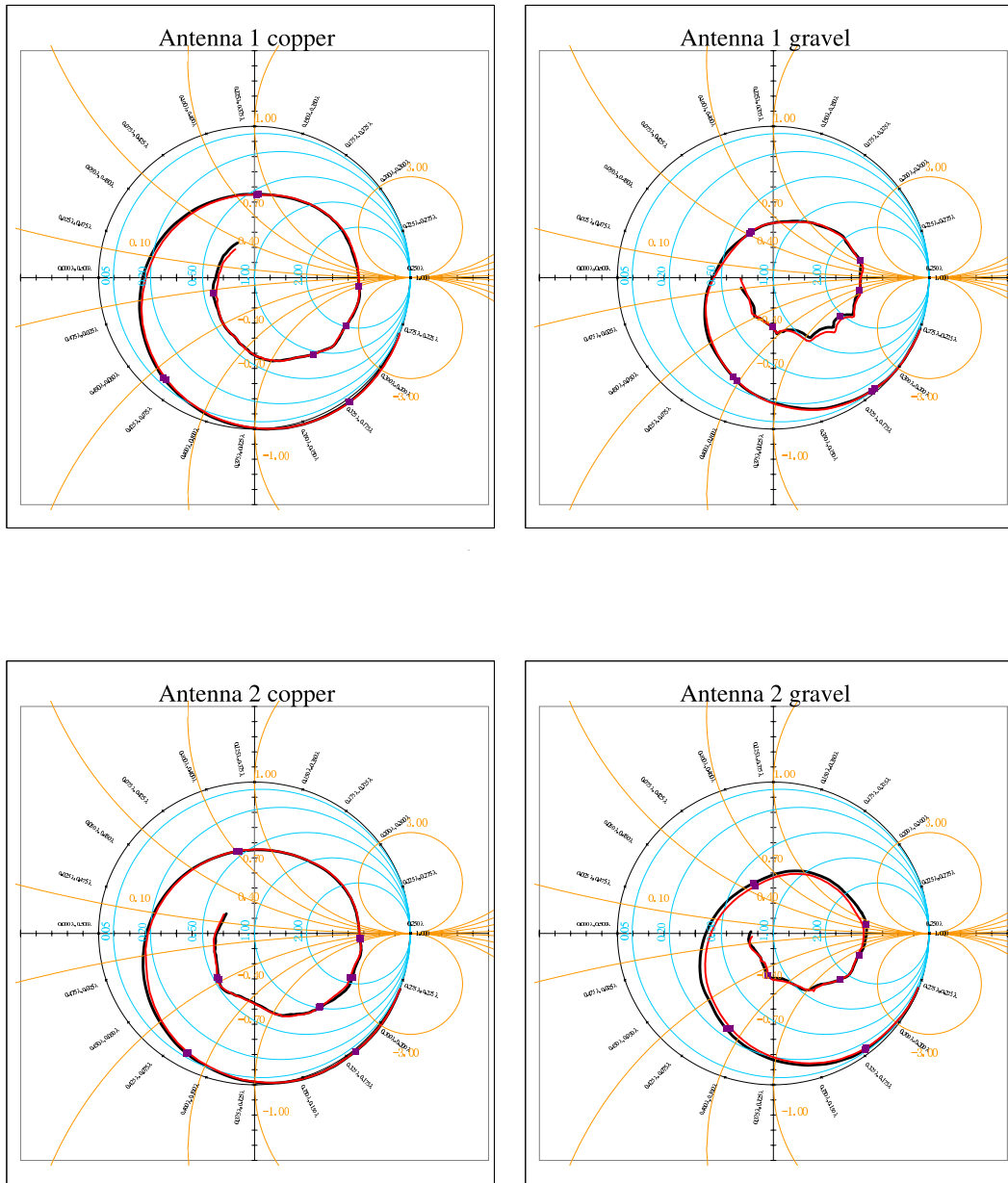


Figure 10: These panels show the Smith Charts of the impedance measurements. The top row corresponds to measurements made on antenna 1 over copper (left) and gravel (right), while in the bottom row we present the same measurements for antenna 2. The black and red curves correspond to the different dipoles on the same stand. These curves start at a frequency of 10 MHz in the outer part of the diagram (bottom right) and spiral inward until they reach 110MHz. The purple squares correspond to 7 selected frequencies (20, 30, 40, 60, 70, 80, and 100 MHz).

The main results that can be seen in these plots are that both antennas have very similar impedances over copper. There are small differences when comparing them in detail with the antennas are over gravel. These difference can probably be attributed to small differences in ground properties. The same can be said when comparing the measurement of both dipoles in the same antenna. The difference between copper and gravel seems intuitively reasonable. There is some absorption by the gravel, causing the SWR to be lower and the data are not as consistent over gravel.

In Figure 11 we present the result of impedance measurements obtained by connecting 100 nH inductors in the leads to a dipole.

One can see that the inductors slightly increase the SWR below 60 MHz. This probably is not of importance because the sky noise dominance of the system is high in this range and lowering the dominance will have little effect. Better matching is important in the 70 to 80 MHz range where the dominance may be marginal. These data suggest that it may be possible to design a very simple LC circuit that will bring the dipole into a good match over the 70 to 80 MHz range.

3 Acknowledgments

We wish to thank Brian Hicks who fabricated most of the subsystems used for this project and to thank Namir Kassim and Carl Gross who arranged for the rental of the network analyzer. We also would like to thank Nagini Paravastu for the help with the network analyzer operations, as well as Bob MacDowall, who arranged for us to have access to the Goddard Space Flight Center observing site.

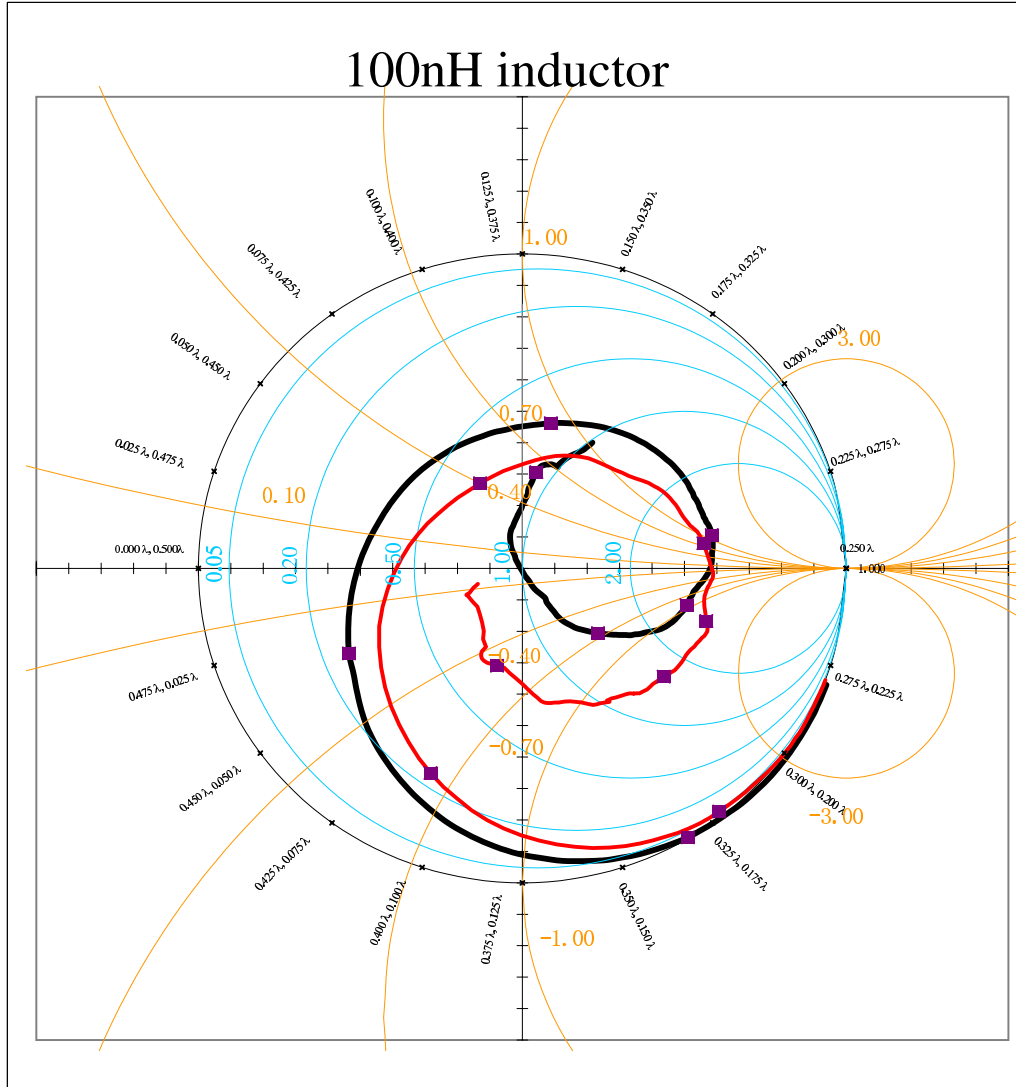


Figure 11: Smith Chart for the case where we placed 100 nH inductors in the pigtailed of one dipole being measured, but not the other. The measurements were made over gravel. The black line corresponds to the dipole with the inductors, while the red one corresponds to the dipole without inductors. The purple squares correspond to frequencies 20, 30, 40, 60, 70, 80, and 100 MHz, as in Figure 10.