DESIGN AND TESTING OF A FEED NETWORK FOR A TRANSPARENT ANTENNA ARRAY

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ABSTRACT

This paper describes the design and testing of a feed network for a transparent flat plate array antenna. This antenna is the top of a stack of three antennas that must occupy the same volume while pointing in different directions. At many pointing angles, the antenna will create blockage for the antennas underneath. In order to minimize the blockage, the array and its transmission lines must be as transparent as possible to the antennas underneath.

The flat plate array consists of active elements over a frequency selective surface (FSS) ground plane that is transparent at the frequencies of the antennas below. The feed lines must also be transparent to the antennas below. This is achieved by minimizing the total area occupied by the feed lines. Rather than the traditional corporate feed network, a series feed network was designed. Such a network requires that each individual feed point must be fed with a coupler where the coupling coefficient is adjusted to distribute the same power to each array element.

We will show the details of the design of the network as well as a set of measurements that show the performance.

Keywords: Antenna Measurements, Design Errors, Arrays, FSS, transmission lines, coupler,

1.0 Introduction

For a new type of communications antenna system, 3 antennas must occupy the same volume while pointing in different directions [1]. At many pointing angles, the antennas above will create blockage for the antennas underneath, as seen in Figure 1. In order to minimize the blockage, the array and its transmission lines must be as transparent as possible to the antennas underneath.

Each antenna is a flat plate array that consists of active circular polarized elements over a frequency selective surface (FSS) ground plane that is transparent at the frequencies of the antennas below. The traditional corporate feed is a common feed network for antenna arrays. However a corporate feed network occupies a large surface area with its feed lines. A new type of series feed network was developed which minimizes the total area occupied by the feed lines.

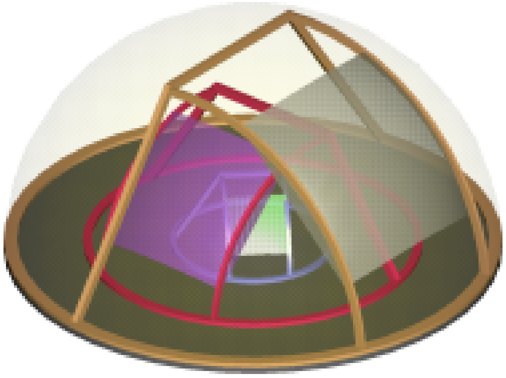

Figure 1 - Concept Drawing of Nested Antennas [1]

We will show the details of the design of the network as well as a set of measurements and simulations that demonstrate performance.

2.0 Feed Network

The feed network (shown in Figure 2) is a star shaped series transmission line structure designed to reduce the blockage presented to the underlying antennas. The transmission line is located in a layer behind a FSS ground plane and the active elements. This transmission line utilizes four quarter panels that can be fed with a 4 way power divider or can be used for monopulse tracking.

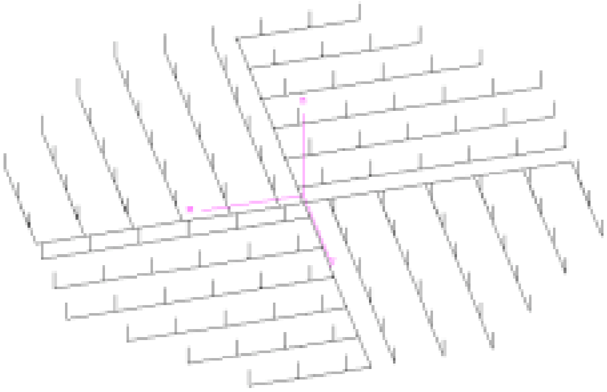

Figure 2 - Feed Network, full

Each quarter panel consists of a main line (ML in Figure 3) and 6 branch lines (BL1, BL2, BL3, BL4, BL5 BL6 in Figure 3) of multiple lengths. The main and branch lines both consist of a number of couplers connected in series with the coupled port of the coupler going to an output and the through output being connected to the input of the succeeding coupler. Each output of the main line is connected to a single branch line. Each branch line output is connected to a radiating element via a vertical microstrip transmission line.

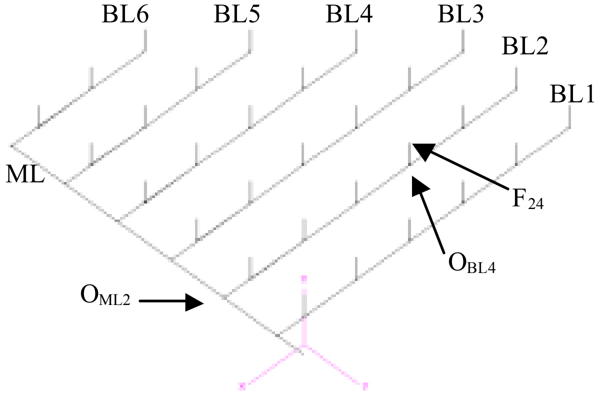

Figure 3 - Feed Network, quarter panel

This type of network requires a coupler where the coupling coefficient can be adjusted to distribute the same power to each array element. The power division must be carefully calculated in order to ensure equal power is delivered to the individual elements (see Table 1 and Table 2).

Table 1 - Main Trunk, Coupling

Connected Branch line BLm	Fed Elements/ Branch	Coupling C_{MLm} (dB)	Through T_{MLm} (dB)	Output O_{MLm} (dB)
BL1	6	-6.99	-0.97	-6.99
BL2	6	-6.02	-1.25	-6.99
BL3	6	-4.77	-1.76	-6.99
BL4	5	-3.80	-2.34	-7.78
BL5	4	-2.43	-3.68	-8.75
BL6	3	0	-Inf	-10.00

Table 2 - Branch Line, coupling

n	Coupling C_{BLn} (dB)	Through T_{BLn} (dB)	Output O_{BLn} for m =			
			1,2,3	4	5	6
1	-7.78	-0.79	-7.78	n/a	n/a	n/a
2	-6.99	-0.97	-7.78	-6.99	n/a	n/a
3	-6.02	-1.25	-7.78	-6.99	-6.02	n/a
4	-4.77	-1.76	-7.78	-6.99	-6.02	-4.77
5	-3.01	-3.01	-7.78	-6.99	-6.02	-4.77
6	0	-Inf	-7.78	-6.99	-6.02	-4.77

The main line output O_{MLm} is connected to BL*m* and can be calculated from the individual coupling and through outputs as below. Likewise, the branch line BL*m* output O_{BLn} is connected to the feed point output F_{mn}.

$$O_{MLm} = C_{MLm} + \sum_{1}^{m-1} T_{MLm}$$

$$O_{BLn} = C_{BLn} + \sum_{1}^{n-1} T_{BLn}$$

$$F_{mn} = O_{MLm} + O_{BLn}$$

Units for the above equations are in dB. Using the above equations yields a result of -14.77 dB for each feed point output F_{mn}

The transmission lines are printed on both sides on a layer of low loss substrate to reduce blockage (see Figure 4). Each side is identical. It is a simple exercise to use image theory to demonstrate that this is similar to the traditional method of printing microstrips over a ground plane [2]. This method provides a balanced transmission line to feed the radiating elements, eliminates a ground plane which would degrade transmissivity, and allows us control the transmission line impedance in order to obtain a good match between the transmission lines and the active elements.

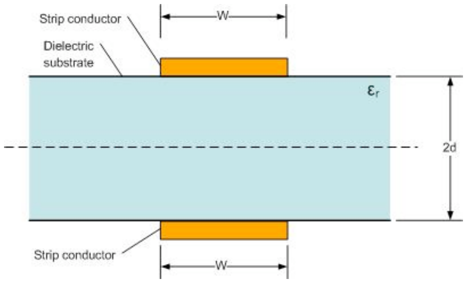

Figure 4 - Parallel strips

3.0 Couplers

Multiple types of couplers were considered as the basic building block for the feed network. The only restriction on the type of coupler is being able to achieve the tight coupling requirements. Two-line [3][4] and Lange couplers [5] were used in early designs.

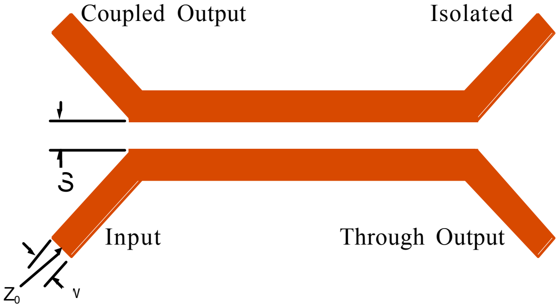

Figure 5 - Two-line Coupler

A two-line coupler (see Figure 5) was the initial coupler considered. The coupling ratio for a two-line coupler is dependent on the separation between the two horizontal lines (S in Figure 5). A prototype was fabricated using 2-line couplers, as shown in Figure 6. It utilizes 4 couplers in series in addition to a through port.

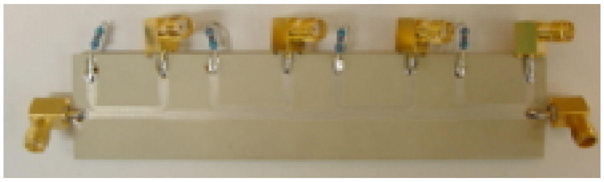

Figure 6 - Transmission Line Prototype

Data from the 2-line coupler transmission line is given in Table 3. Note that the designed values for this transmission line differs from the values given in Table 2. This was done due to inability of the two line coupler to achieve extremely tight coupling.

The design requires a separation of 3 mils was in order to achieve the required coupling performance. The minimum spacing specified by most PCB fabrication facilities is 3 mils. The design also requires a relative dielectric of 10.2 with a thickness of 0.25 inches. The high dielectric and thickness of substrate presents a significant problem for transmissivity.

Table 3 - Coupler Measurement Data

Port	Designed (dB)	Measured (dB)	ΔdB
Through	**-4.01**	**-5.61**	**-1.60**
S21	**-8.74**	**-8.67**	**0.07**
S31	**-8.73**	**-8.56**	**0.17**
S41	**-8.57**	**-9.12**	**-0.55**
S51	**-8.40**	**-8.09**	**0.31**

The quadrature hybrid coupler (see Figure 7) is an alternative that is typically configured as a 3 dB directional coupler. We can control the coupling ratio between the through and coupled output by adjusting the widths W_A and W_B [6]. Widths W_A and W_B are calculated from impedances Z_{0A} and Z_{0B} (given below) using standard microstrip design formulas [3]. P_A and P_B are the linear power outputs for the coupled and through outputs respectively.

$$Z_{oA} = Z_o \times \left(\frac{P_A / P_B}{1 + P_A / P_B} \right)^{1/2}$$

$$Z_{oB} = Z_o \times \sqrt{\frac{P_A}{P_B}}$$

The quadrature hybrid coupler was simulated using Agilent Design Software Momentum which uses a Method of Moments (MoM) technology to analyze the circuits. The design formulas yielded results with less than a 0.25 dB difference from desired coupling values. An iterative process was used to adjust the coupler dimensions to better match the ideal coupling. Final coupler values and simulation results are given in Table 4 and Table 5.

Table 4 - Main Line Coupler simulation results

m	Z_{0A} (Ω)	Z_{0B} (Ω)	C_{BLm} (dB)	T_{BLm} (dB)
1	44.54	98.06	-7.11	-0.94
2	43.09	84.91	-6.11	-1.22
3	40.57	69.42	-4.85	-1.73
4	37.91	58.14	-3.85	-2.31
5	32.73	43.30	-3.60	-2.50

Table 5 - Branch Line Coupler simulation results

n	Z_{0A} (Ω)	Z_{0B} (Ω)	C_{MLn} (dB)	T_{MLn} (dB)
1	45.52	110.02	-7.80	-0.79
2	44.54	98.06	-7.11	-0.94
3	43.09	84.91	-6.11	-1.22
4	40.57	69.42	-4.85	-1.73
5	35.35	50.00	-3.10	-2.92

Using a quadrature hybrid coupler as the basic building block we can use a substrate with a relative dielectric of 2.2 and a thickness of 0.031 inches, a substantial improvement over the two line coupler substrate. A full transmission line structure utilizing quadrature hybrid coupler is currently being fabricated.

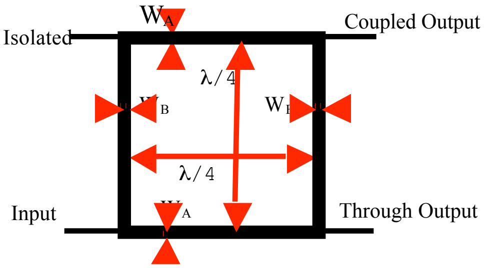

Figure 7 - Quadrature Hybrid Coupler

4. Transmissivity

A 2230 MHz array of active elements looking through the L band transmission line structure was modeled using a wire-grid method of moment (MOM) code developed at OSU [7][8]. The model is very accurate, however simulation runs can take several days (Pentium IV 3.0 GHz 1.0 GB RAM) depending on the simulation parameters.

The transmission line structure was rotated with respect to an axis set behind the 2230 MHz active elements. The 2230 MHz array was stationary. The maximum deviation from the free space boresight gain of the 2230 MHz array was 0.16 dB at ±5° rotation.

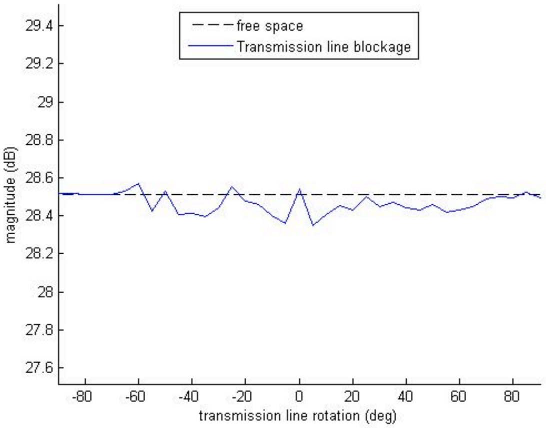

Figure 8 - Dipole looking through transmission Line structure

5. Phase distribution

In contrast to a corporate feed system, this transmission line design results in an unequal distribution of phase to the feed points due to different distances between the input and the individual feed point for the radiating elements. In order to achieve equal phase for each radiating element we can compensate by rotating the circularly polarized radiating elements. The vertical stub between the active elements and the branch coupler output is a turn in the microstrip transmission line. In order to accommodate the rotated CP elements, the microstrip transmission line and the substrate are twisted with respect to the plane of the couplers. The substrate chosen (Rogers Duroid 5880) retains the deformation without any resistance.

The method of rotating the CP antennas was demonstrated on a 1x4 array (see Figure 9). The phase of each element was measured by using a small loop antenna and disconnecting the remaining 3 antennas (see top half of Figure 10). The phase of the rotated antennas is given in the bottom half of Figure 10.

Note that the individual measured phase of unrotated elements ‘a’ and ‘b’ are equal. Observe that in Figure 9, the left two elements are rotated by the same amount. The measured phase of each rotated element is nearly equal at the design frequency of 1695 MHz (see the bottom half of Figure 10). For the final layout, each of the CP elements will be oriented such that the radiated CP signals are in phase.

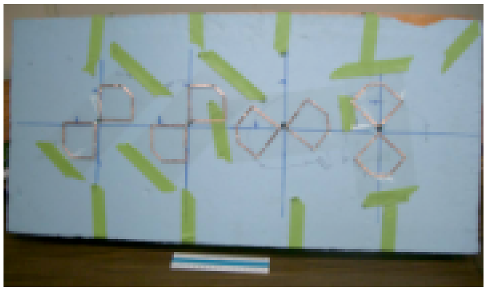

Figure 9 - Rotated Elements, from left to right, elements a, b, c, and d

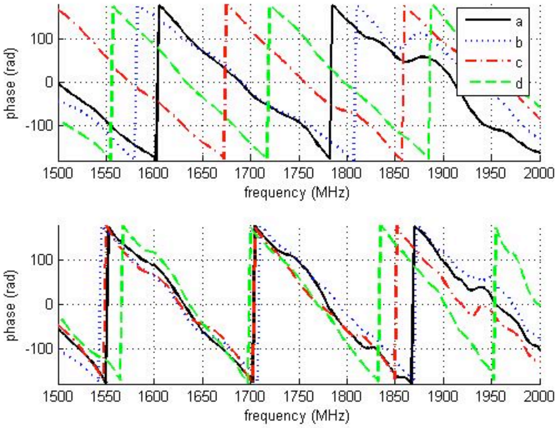

Figure 10 - Phase Measurement Data – unrotated antennas (top), rotated antennas (bottom)

7. Summary

The design and data is presented for a 12x12 L band array. The same concept is utilized for an underlying 14x14 S band array. Full transmission line structures using the quadrature hybrid coupler for the L and S band are currently being fabricated. Data on the new transmission line structures is expected in August 2005.

The three antenna structure is presently under construction. When completed, it will be possible to have three antennas operating independently in a single radome occupying the space normally needed for each of the three antennas. New data on the performance of the overall antenna structure will be available in early 2006. (A provisional patent has been filed.)

8. REFERENCES

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9. ACKNOWLEDGMENTS

This work was supported by Syntonics, LLC and the Space and Naval Warfare Sys. Command. under contract N00039-04-C-003.