Feed Networks for Electromagnetically Transparent Antennas

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Introduction

A new type of communications antenna system requires that antennas at L, S, and X band occupy the same volume while pointing in different directions [1]. At many pointing angles, the outer antennas will create blockage for inner antennas, as seen in Figure 1. In order to minimize blockage, an array and feed network must be as transparent as possible to the antennas underneath.

Each antenna is an array of circularly polarized (CP) elements over a frequency selective surface (FSS) ground plane. The FSS acts as a reflector for the array, but is transparent at the frequencies of the underlying antennas. 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 and is inherently not transparent. A series feed network was developed which minimizes the total area occupied by the feed lines [2].

This paper will discuss the design, simulation, and measurement of a transparent S band feed network. Results from integration tests of the feed network will be shown. Measurements of the antenna array integrated with the transparent feed networks will be shown. These measurements will demonstrate that the feed networks allow the arrays to function as an antenna while maintaining the transmission coefficient necessary for nested antennas.

Feed Network Design

The feed network (shown in Figure , right) is a series transmission line structure designed to reduce the blockage presented to the underlying antennas [2]. The transmission line is located in a layer behind a FSS ground plane and the radiating elements. This antenna array is divided into four panels and can be fed with either a 4-way power divider or be used for monopulse tracking.

The feed network for each quarter panel consists of a main line which feeds multiple branch lines of different lengths. Couplers are connected in series, with the coupled port used as output and the through port feeding the next coupler. The coupling ratio of each coupler is calculated to ensure equal power is delivered to each array element. These couplers are microstrip circuits printed on both sides of a thin, low loss, and low dielectric substrate [3]. This results in a balanced feed to the array elements.

Feed Network and Antenna Integration

Each feed network panel was manufactured in subsections, measured, and assembled. The complete output response of a quarter panel was synthesized using the measured results from the subsections. In Figure 2, an equal power distribution is demonstrated with a slight taper from the input to the outer edges. This taper will have the effect of reducing the sidelobe levels.

In contrast to a corporate feed system, this transmission line design results in unequal phase at each feed point due to different distances between the input and the individual radiating elements. In order to achieve equal phase in the radiated signal from each radiating element we must compensate by rotating the circularly polarized radiating elements in proportion to the phase at each output of the transmission line. The vertical stub of the feed network is designed to twist to permit the element rotation.

The phase for each output of the transmission line was calculated prior to integration. This calculation is based on the geometry of the transmission line and the phase outputs for each port of the couplers [4][5]. Using these phase values, the CP antennas were rotated to create a uniform phase distribution across the array.

Array Testing

The antennas were tested in the Compact Range at the ElectroScience Laboratory at The Ohio State University. Pattern measurements were performed on the S band antenna array. Blockage from the L and S band antennas at X band was measured.

An S band array of CP elements with the feed network was simulated using a wire-grid method of moment (MOM) code developed at OSU [6]. The model is very accurate, however simulation runs can take several days (Pentium IV 3.0 GHz 1.0 GB RAM). In particular, note that the measured and simulated directive gain patterns are in agreement (Figure 3, left), as evidenced by the beamwidth and the first sidelobe levels .

Due to deterioration of the conductive ink used to print the array elements, resistance in the conductor increased from a few Ohms to 30 or 40 Ohms. The consequence is a 6 to 8 dB drop in the array gain. An electrically and mechanically weak connection between the feed network and the elements was also present. This is a likely culprit for the unusually high sidelobe at 15 degrees.

Transparency

The free space S band array gain was measured and compared to the S band array gain with the L band array positioned at different angles. The different look angles of the L band array resulted in different levels of blockage of the S band array. The L band array provides less than 2.5 dB of attenuation when it fully obscures the S band array. The attenuation due to each L band array position is constant with respect to frequency. The boresight offset of the S band main beam due to blockage from the L band array is less than 0.5 degrees under any blockage condition.

The transparency of the L and S band antenna design was measured at X band (Figure 3, right). The transmissivity of the L band antenna is better at X band than that at S band. This is due to the presence of sidelobes in the FSS ground layer reflectivity which affects the transmissivity in nearby frequencies [7]. These can be with reduced by various FSS matching techniques

Summary

An antenna system which uses 3 independently pointing arrays operating at different frequencies in the same volume has been integrated and measured. In order to maintain transparency in the L and S band array, a combination of FSS technology and a series fed transmission line is required. The L band array structure provides less than 2.5 dB of loss at the S band operational band and less than 0.5 degree of boresight shift. The L and S band arrays both cause less than 1.5 dB of loss at X band individually and less than 2.5 dB combined.

An electrically transparent transmission line structure was built for the outer two arrays. This transmission line structure provides a balanced feed to an S band array of 172 elements. The radiation pattern of the integrated S band array structure was measured and is consistent with simulations once various losses are accounted for. The losses were due to problems that arose in the manufacturing of the array and not any inherent design flaw.

References

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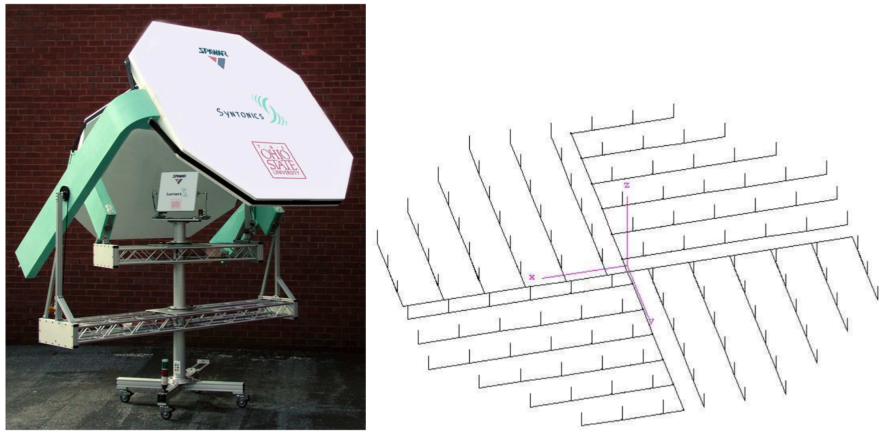

Figure 1: Left: Triband antenna, Right:Feed Network

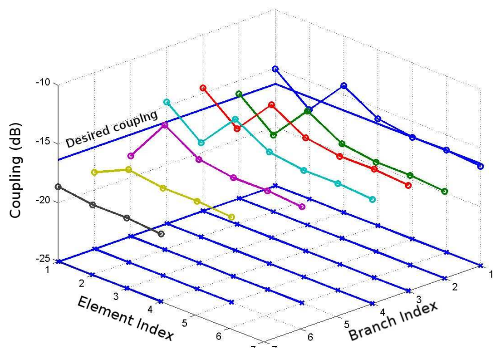

Figure 2: S band TL Signal Distribution

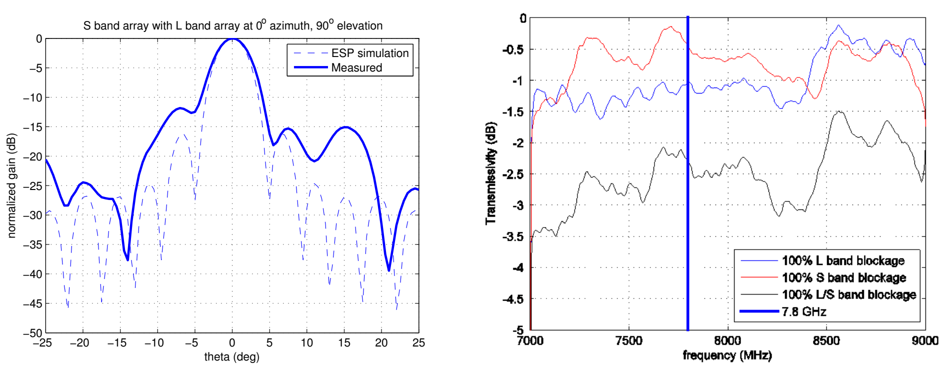

Figure 3: Left: Measured radiation pattern with loss compensation, Right: Transmissivity at X band