Designing a 32 Element Array at 76GHz with a 33dB Taylor Distribution in Waveguide for a Radar System

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Introduction

The use of radar systems for collision avoidance has been proposed at millimeter wave frequencies, e.g. [1]. This concept is being investigated for use on military vehicles. A system for robotic vehicles is being developed at the US Army Research Laboratory for operation at 76 GHz [2]. The system requires continuously scanning antennas to be mounted on the vehicle with narrow beams in the azimuth (horizontal) direction and broad beam in the elevation (vertical) direction. Several antenna designs have been reported to satisfy the requirements. A phased array can be used with active beam steering realized by switched inputs of a Rotman lens or MEMS phase-shifters [3].

This paper presents a linear horn array design for the receive antenna that produces the required 2-degree narrow beam in azimuth and the broad 30-degree beam in elevation. The arrays are stacked vertically with an azimuth tilt of 2 degrees between adjacent antennas to cover a scanning range of ± 15 degrees. The beam is switched in azimuth using a microwave switch connected to the outputs of the antennas. Figure 1 shows a block diagram of the stacked receive antenna and its connection to the radar system. Figures 2-3 depict a possible deployment of the antenna on the vehicle and beam coverage.

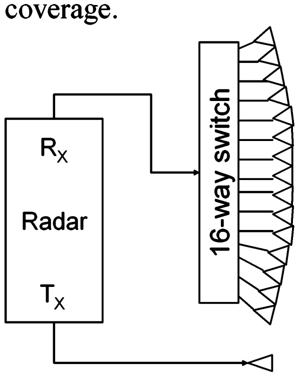

Figure 1 - Block Diagram

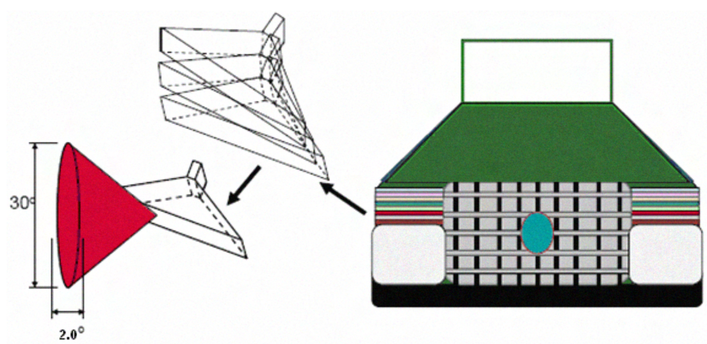

Figure 2 - Antenna Deployment on Vehicle

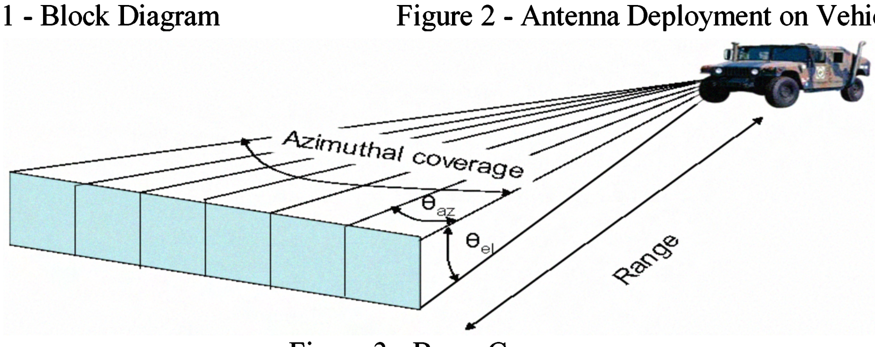

Figure 3 - Beam Coverage

Design

The receive antenna is composed of a 32-element array of pyramidal horns, fed with a waveguide power divider designed to produce a 33dB Taylor distribution across the array aperture. The antenna array measures 0.5" (height) X 7.0" (width) X 5.0" (depth). The horns are 1.3λ in the H-plane (array plane) and 2.0λ in the E-plane. The 5-stage H-plane waveguide power divider uses un-equal power splits in the 2nd through the 4th stages to achieve the required aperture distribution. The first and last stages use equal-split power dividers with a fourth port with a short-circuit termination to improve the impedance match. The equal power division in the 5th stage of the power divider represents a compromise that is needed due to the tight dimensions that are dictated by the element spacing. This resulted in a closer low-level grating lobe. This, however, does not compromise the side-lobe requirement within the operating scanning range of ± 20 degrees that is needed for the collision avoidance system. Detailed analysis and HFSS simulations of the design and power divider matching are included in the paper with the fabrication, measurements and characterization of the antenna. Figures 4-6 display HFSS's simulations of the E-fields in the 50/50 split, 93/07 split and the symmetrical half of the array with the Taylor distribution, respectively.

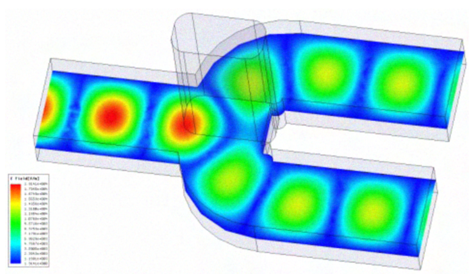

Figure 4 - Simulation of 50/50 power split.

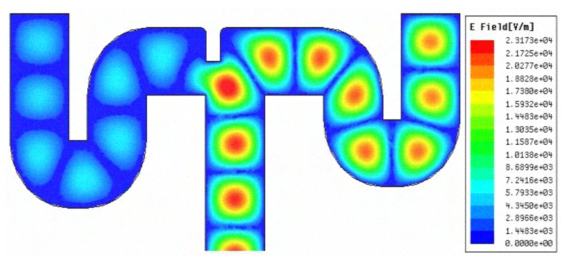

Figure 5 – Power split of 93/07.

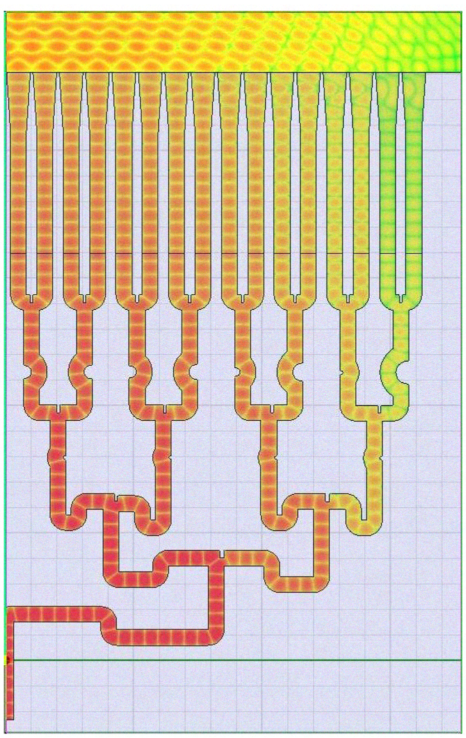

Figure 6 - Array half with Taylor distribution

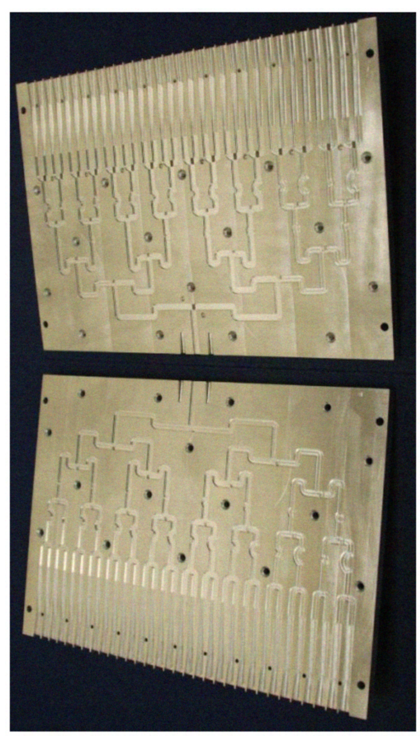

Figure 7 - Fabricated Array

Prototype

The antenna design shown in Figure 6 was fabricated as a fully integrated horn array and 5-stage power divider. The structure was milled in two pieces using numerical control techniques with very tight tolerances. Details of the surface tolerances and alignments of the two pieces will be included in the full paper. The fabricated antenna is shown in Figure 7. The two pieces of the fabricated antenna are almost identical. The 4th ports in the first and last stages of the power divider are added to one of the two pieces (the top piece in figure 7). This was implemented by milling a hole through and then inserting a piece from the outside of the structure to act a short stub. Again, tight tolerances have to be exercised in order to satisfy the RF boundary conditions.

Results

The fabricated receive antenna was measured at the operating bandwidth around 76GHz. The measurements included return loss, radiation patterns and gain. Return loss measured results are shown in Figure 8 and are compared with the simulation results obtained using HFSS. The results show a good agreement between measured and simulated data with a 0.3% frequency shift.

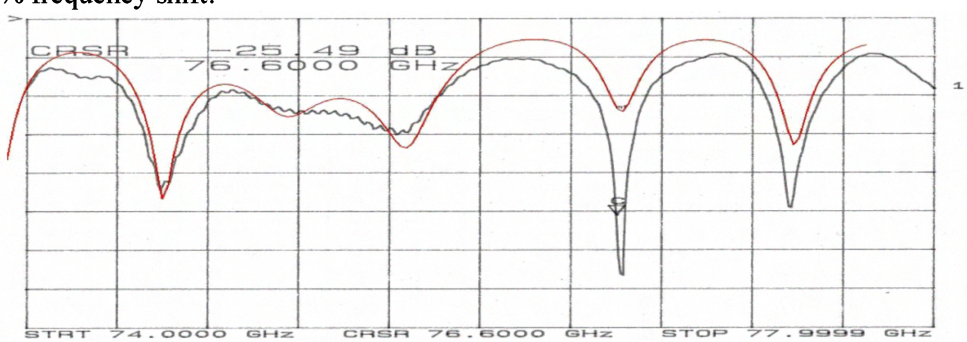

Figure 8 - Return Loss in HFSS (red) & Measured (black).

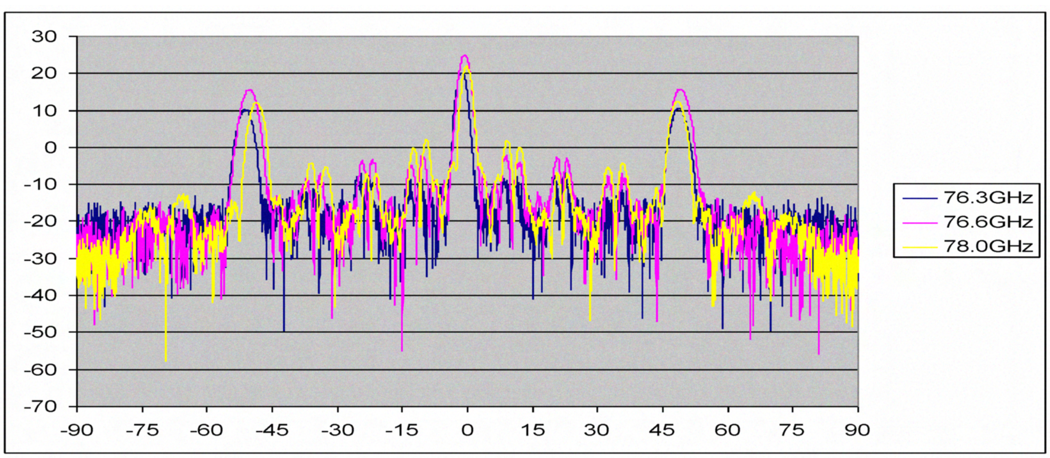

Figure 9 Measured Radiation Patterns.

Antenna pattern measurements were performed in a 45-foot tapered anechoic chamber at the US Army Research Lab facilities. The range of 45 feet is slightly less than the far-field condition of 2 D^2/λ for the 7" aperture at 76GHz. This may have an impact on the measured sidelobe levels. Details of the pattern measurements set-up, block diagrams, and other measurement details will be included in the full paper. Results of the pattern measurements and comparison with simulated results are shown in Figures 9 and 10. Figure 9 shows the measured radiation patterns across the full front range of $\pm$ 90 degrees at 76.325GHz, 76.6GHz and 78GHz. The highest gain is achieved at 76.6GHz, which coincides with the lowest measured return loss. The pattern in the region of interest for the collision avoidance application, $\pm$ 20 degrees, is shown in Figure 10 at 76.6GHz. The figure shows good agreement between measurements and simulation.

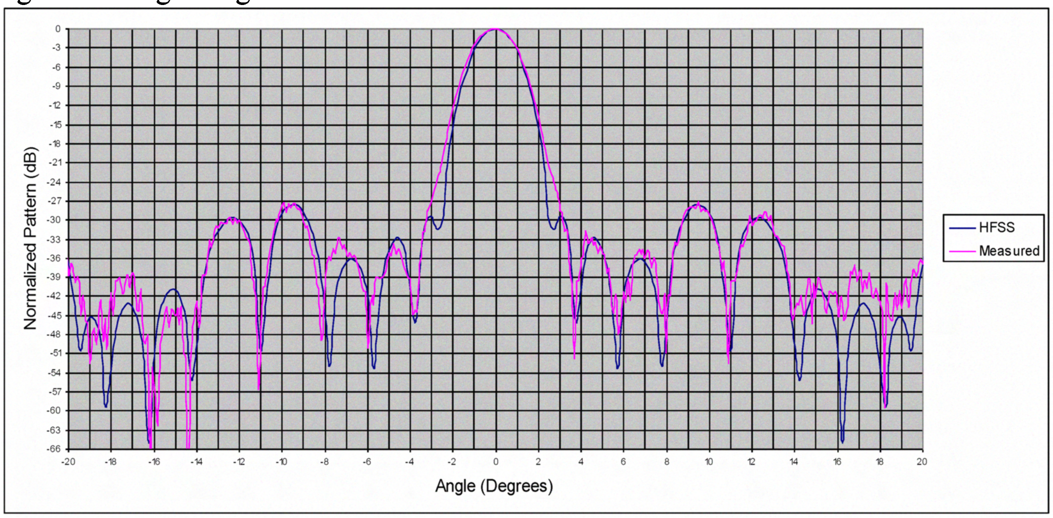

Figure 10 Radiation Patterns in HFSS & Measured.

Conclusion

A compact linear pyramidal horn array for a personnel avoidance radar system for robotic vehicles was designed, fabricated and measured. The array will be used as the receive antenna in a system that is presented in a companion paper [2]. The horn array is fed with a waveguide power divider that is designed to produce the required Taylor aperture distribution on the array front. The tapered aperture produces low sidelobes that are needed for low interference in the radar system. The 32-element array with 1.3 λ element size and element spacing in the azimuth direction produces a narrow beam. The beam is scanned using a microwave switch that operates on two 8 stacked arrays for 16 scanning steps covering a scanning range of $\pm$ 15 degrees. The scanning arrays act as the receiving antenna, where insertion losses have to be minimized for low noise figures. The low loss is achieved using the waveguide divider. The integration of the array and the power divider in one structure helps in reducing the losses. The transmit antenna is a pyramidal horn of dimensions 2.6 λ X 2.6 λ, which produces the required broadbeam. The transmit and receive antennas' gain satisfy the requirements for the radar link.

References

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[3] J. Schoebel, et. al., "Design Considerations and Technology Assessment of Phased Array Antenna Systems with RF MEMS for Automotive Radar Applications," IEEE Transactions on Microwave Theory and Techniques, 53-6, June 2005, pp. 1968-1975.