Design of an Antipodal Vivaldi Antenna for use in a Bi-Static Linear Array

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Abstract

This paper presents the design of an antipodal Vivaldi antenna as a building block for a bi-static one-dimensional (linear) antenna array. The array will provide suitable range, cross-range, and depth resolution for a variety of applications in nondestructive evaluation. The design, simulation, and prototyping of the antenna are the main focus of this paper. The design process focused on choosing a suitable operating frequency band, limited by available instrumentation and by physical size. Once the operating frequency band was selected, an antenna was designed in order to achieve satisfactory return loss and gain over the desired frequency bandwidth. Following a successful design simulation, a single antenna was prototyped and tested, and will be duplicated to create the full array of eight transmit and eight receive antennas.

Introduction and Background

In industrial applications, the need arises for a device designed for through-wall and sub-surface imaging. Microwave and millimeter wave nondestructive testing techniques have proven a viable, inexpensive way to produce images of objects and discontinuities through dielectric materials, namely concrete-based structures (through-wall) and soil (sub-surface). This paper presents the main component of an imaging array which is a wideband Vivaldi antenna. This paper will show the design of the antenna including simulation and measurement results.

The operating frequency requirements of the antenna were dictated by its application, available instrumentation, and physical size. Ideally, the antenna should perform well across a large bandwidth to provide adequate range resolution. While lower frequencies reduce the angular resolution, higher frequencies tend to attenuate through concrete-based structures and earth, thus the ideal device should also operate well at low frequencies [1]. Optimization of the antenna design would force a compromise between frequency bandwidth (range resolution) and angular resolution. The upper bound of this frequency band was limited by the available instrumentation (a vector network analyzer), and the lower bound was limited by the size of the antenna. The frequency band of 1 - 6 GHz was chosen as an optimal solution to the requirements. This frequency band also achieved the acceptable compromise between the required resolution and penetration depth due to the size limitations of the array.

Once the operating points of the antenna array were determined, a suitable antenna design was sought. In this case, a Vivaldi antenna design (an endfire, tapered-slot design made from a dielectric substrate of printed circuit board, or PCB) was utilized, as it possesses the desired characteristics (resulting from size constraints) of planar geometry and a thin profile (to accommodate multiple antennas in a linear array), the capability of operating at the frequency band desired, and a simple coaxial feed line [2],[3]. The PCB would be a double-sided copper clad FR-4 substrate; an inexpensive, widely available material with a low dielectric constant [4].

Simulation

Using CST-MWS [5], the antenna was simulated, tuned and optimized to minimize the reflection coefficient (S_{11}) within the desired bandwidth. The reflection coefficient represents the ratio of the reflected wave over the incident wave and provides an indication of the antenna's ability to transmit energy (as well as quantifying the energy reflected back to the source). The desired reflection response was initially set to be no greater than -10 dB throughout the operating bandwidth. To achieve this goal, the overall dimensions, exponential slope of taper, and the length and width of the feed line for impedance matching (~50Ω) were optimized. The overall dimensions (length and width) of the antenna were chosen to be half the wavelength (150 mm) at the lowest operating frequency (1 GHz), while the taper profile was chosen to be exponential with a taper coefficient that was manually adjusted to acquire the desired response. The simulated antenna design with the most optimal response was prototyped.

Prototyping

The prototyping of the board began with copper clad FR-4 substrate PCB. The desired tapered design of the antenna was printed from the CST-MWS design, transferred to the PCB, and etched out of the copper using ferric acid. An edge-launch SMA connector was soldered to the end of the antenna on the line feed strip, with the parallel-plates on either side. Using the vector network analyzer, the reflection coefficient data of the completed prototype was measured, and plotted against the simulation results.

Results and Conclusion

The completed prototype tracked closely with the simulation results across the desired range of frequencies. The S_{11}, or reflection coefficient characteristics, for both the simulation and prototype indicate a functional low frequency range down to 1.4 GHz. The design, simulation, optimization and prototyping of a single antenna having been successfully concluded, the next phase of this project involves building fifteen additional antennas for the completion of the bi-static linear array. When these are assembled, the entire device will be calibrated and tested by identifying conductive material in the lab environment. The calibrated array will finally be tested by field trials on known subsurface anomalies and structures.

References

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Biographical Information

Sarah Hatfield is a senior in Electrical Engineering at Missouri University of Science and Technology and works as an undergraduate laboratory assistant at the Applied Microwave Nondestructive Testing Laboratory. She is interested in real-time imaging systems, microwave and millimeter wave instrumentation and measurement, and RF design

Dan Schultz is a senior in Electrical Engineering at Missouri University of Science and Technology. His interests include circuit design and modeling, and systems theory.

Dr. Kristen M. Donnell is an Assistant Professor in the Department of Electrical and Computer Engineering (ECE) at Missouri University of Science and Technology (formerly the University of Missouri-Rolla). She is involved in the Senior Design program in the ECE Department and also serves as a faculty advisor on the project for which the Antipodal Vivaldi Antenna design will be used. Her current research interests include modulated antennas/scatterers, materials characterization, and microwave/millimeter wave measurements.

Dr. Mohammed Tayeb Ghasr is an Assistant Research Professor with the Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, Missouri University of Science and Technology (Missouri S&T). His research interests include microwave and millimeter-wave instrumentation and measurement, RF circuits, antennas, and numerical electromagnetic analysis.

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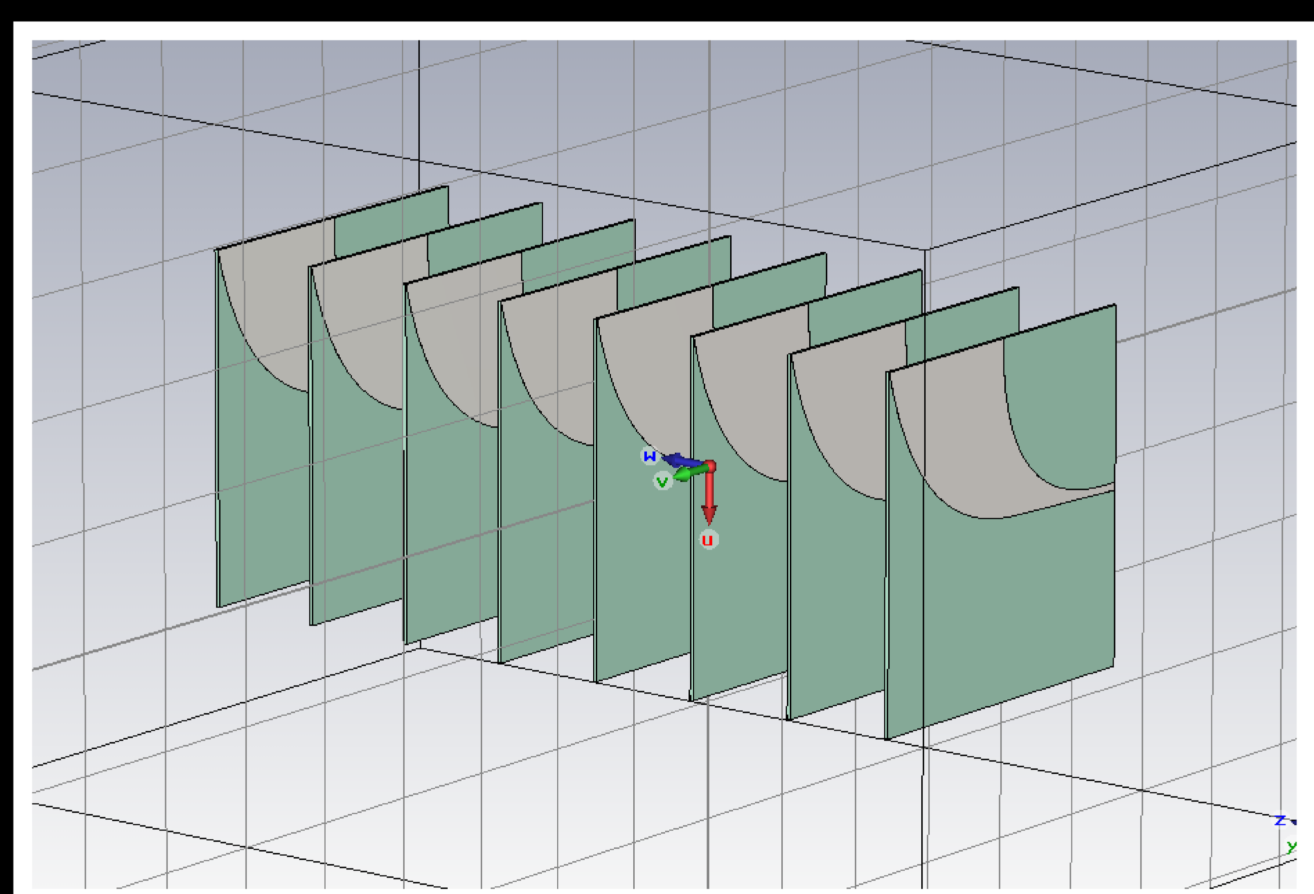
Ultra Wide Band Imaging

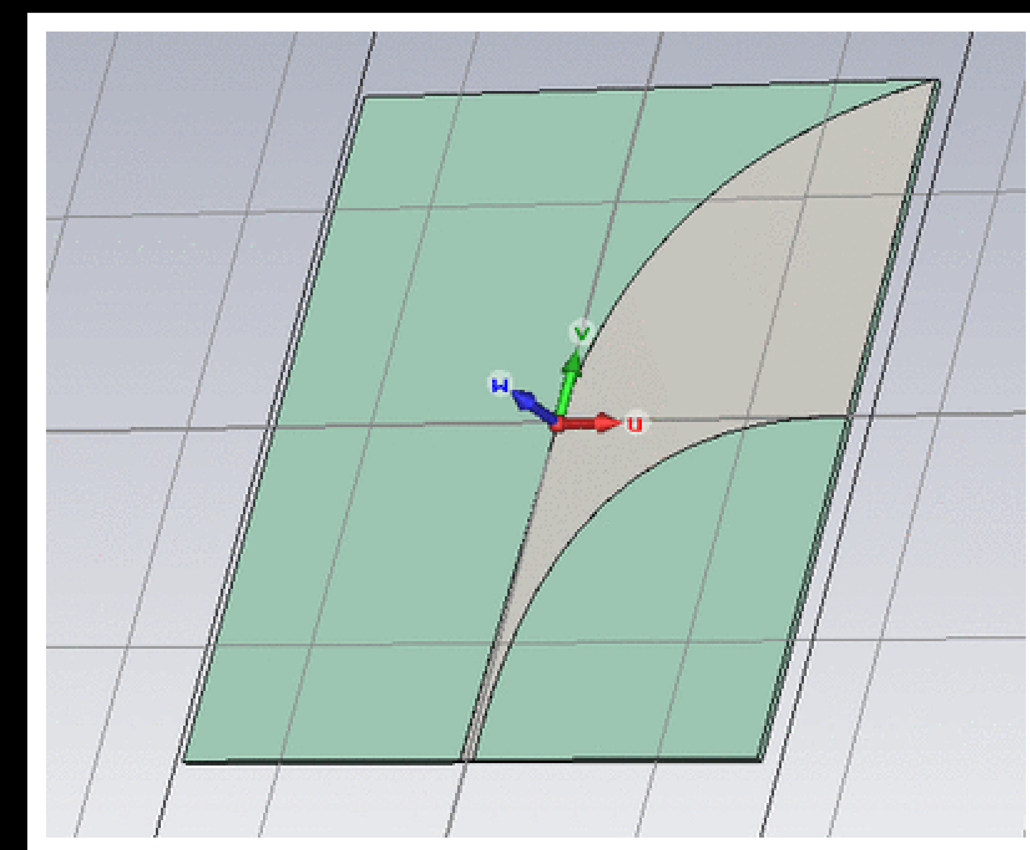
UWB microwave imaging techniques (0.3-300GHz) provide a method to locate objects, flaws, and other discontinuities behind or within a dielectric medium. With multiple antennas in a bi-static linear phased array, the data can be efficiently collected and processed to construct through-wall (concrete structures) and sub-surface (soil) images.



Concept Design of Antenna Array

Antenna Design Constraints

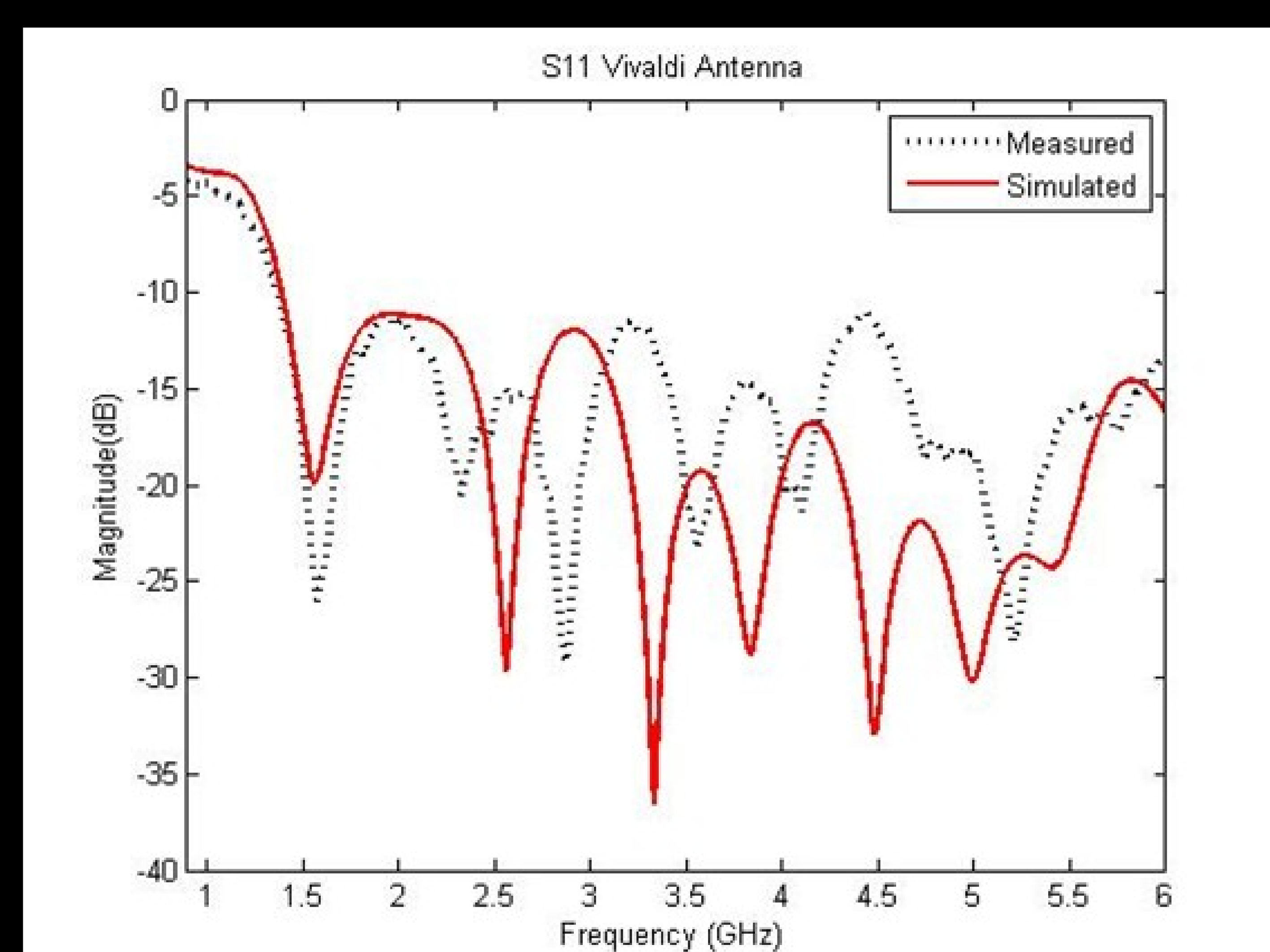
An antenna for use in this array design must have a narrow profile while being able to achieve high directivity across a large bandwidth. In order to construct the desired images, the antennas must also optimize low frequency performance without general forfeit of resolution. This trade off was considered optimal at a 150 mm width, which should ideally reach across a frequency bandwidth of 1-6 GHz. The upper bound is limited by the Vector Network Analyzer (VNA) used to provide the excitation signal. The lower bound will be determined by the antenna width, 150 mm, which provides a theoretical floor of 1GHz.



Design of Antenna using CST

Simulation of Antenna

CST-MWS [1] design software was used to simulate the antenna, fabricated as a copper clad PCB with FR-4 substrate construction. The PCB design optimizes performance within the stated constraints, offering wide bandwidth and narrow profile. Software simulation allowed for exploration of such performance-optimizing parameters such as exponential taper, variation of line feed, and antenna dimensions [2],[3].



Reflection coefficient characteristics by frequency, comparing simulation vs. prototype

Prototype Antenna Construction

The taper design was printed from the successful simulation, and masked onto a copper clad FR-4 PCB. Ferric acid was used to etch the cladding. An SMA edge-launch connector was soldered to the end of the line feed strip.

Completed Vivaldi prototype antenna

Conclusion

The completed prototype performed consistently with the simulation across the desired range of frequencies. The S_{11} characteristics for both the simulation and prototype indicate a functional low frequency range down to 1.4 GHz.

References

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