A Dual-Polarized Vivaldi Antenna For Tree Radar Applications

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***Abstract*— A dual-polarized Vivaldi antenna with a compact size and high gain performance is designed for tree radar applications. The antenna consists of four Vivaldi elements, two of which are orthogonal to the remaining two. Each pair of two elements works together in an array configuration to form a single polarization, while two pairs form a dual polarization with a shared aperture. To increase the radiation performance, planar directors and edge slots are introduced in the design of a single Vivaldi element, and a reflector is placed behind the Vivaldi elements. The simulation results show that the designed antenna achieves a high gain ranging from 5.5 to 15.6 dBi, while its cross-polarization discrimination is larger than 30 dB, demonstrating its high purity for each polarization.**

I. Introduction

The monitoring of the structural health of urban trees is important in tree risk management. Various non-destructive testing techniques based on sonic tomography, electrical resistivity, and radar technologies have been proposed for the health monitoring of trees so far [1,2]. Among these techniques, ground penetrating radar (GPR) is becoming more attractive as it does not require the installation of nails and microphones, unlike sonic tomography, while it is capable of providing 2D scans of higher resolution compared to those obtained by electrical resistivity [1].

Vivaldi antennas have been widely used for GPR applications for their ease of fabrication, wide bandwidth ratio, and lightweight [3-6]. The state-of-the-art dual-polarized Vivaldi antennas can achieve a wide bandwidth (e.g. 164% fractional bandwidth) [5]. However, the standard Vivaldi antenna's aperture is quite large, making this system impractical in terms of portability for tree radar applications. In addition, considering the multiple transmission mediums for tree radar scanning, the gains for the dual-polarized antenna system require improvements in the band of interest for better power transmission and reception.

In this study, we propose a compact dual-polarized Vivaldi antenna operating from 0.5 GHz to 3 GHz. The antenna utilizes planar directors, edge slots, and a reflector to improve gain and widen the bandwidth. The gain of the designed dual-polarized antenna varies from 5.5 to 15.6 dBi. Moreover, the system achieves more than 30 dB cross-polarization discrimination (XPD), which makes it highly suitable for polarimetric radar applications.

II. Single Vivaldi Element Design

To realize the dual-polarized Vivaldi antenna system, first, a single Vivaldi element is designed. The configuration of this Vivaldi element is shown in Fig. 1. In this configuration, a substrate with a relative permittivity of 4.4, a loss tangent of 0.0025, and a thickness of 1 mm, is modified by adding a semi-ellipse area to support directors. A microstrip-to-slot line with a radial stub, serving as the feeding structure for wide bandwidth matching, is introduced. To enhance the gain, three directors with a length of around $\lambda_g/3$ are used. Here λ_g denotes the wavelength at the center frequency of 1.4 GHz. We have to note that the three directors with a length of around $\lambda_g/3$ provide better gain improvement compared to the designs with one and two directors and increased the gain at 1.4 GHz by 0.8 dB. Subsequently, edge slots are introduced to improve the gain performance at the low-frequency range by suppressing currents at the edges and guiding them along the exponential-type slot. Finally, the gain of the single Vivaldi element is achieved to be varying from 4.87 dBi to 9.79 dBi, and the antenna can be operated in the band from 0.81 GHz to 3 GHz, as seen from the its reflection coefficient provided in Fig. 2.

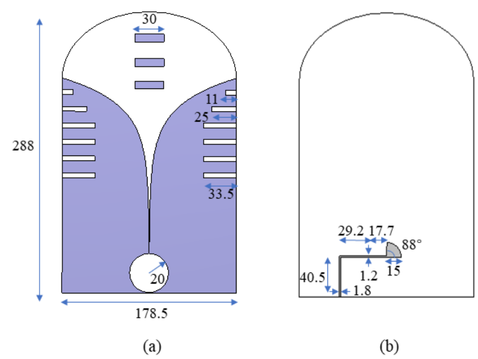

Figure 1. The configuration of a Vivaldi element; (a) Top view and (b) bottom view.

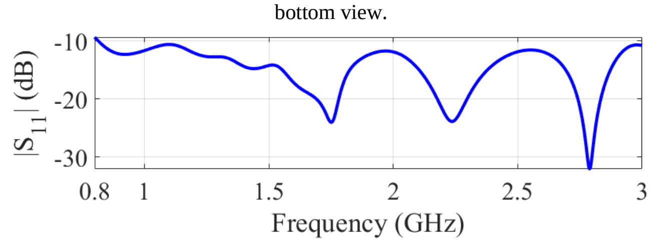

Figure 2. The reflection coefficient of the designed Vivaldi element.

III. Dual-Polarized System

Two Vivaldi elements constituting a pair are placed in parallel to form a single polarization. To achieve a dual-polarization, two pairs of two Vivaldi elements are positioned orthogonal to each other, as shown in Fig.3. While the parallel elements, constituting a 1x2 array, allow achieving a higher gain and widening the bandwidth, the coupling between orthogonal elements is minimal. The orthogonal pairs share the same aperture for radiation. A metal reflector is placed behind the Vivaldi elements to further improve the gain and suppress the back lobe. The width of the reflector is set as the half of the wavelength at 0.5 GHz. The inclusion of the reflector enhances the gain in almost all frequencies, especially at the lower frequencies ranging from 0.5 GHz to 0.7 GHz. Moreover, the reflector increases the front-to-back lobe ratio by 2.94 dB and 3.83 dB at 1.3 GHz and 2.5 GHz, respectively, demonstrating the suppression of the back lobe.

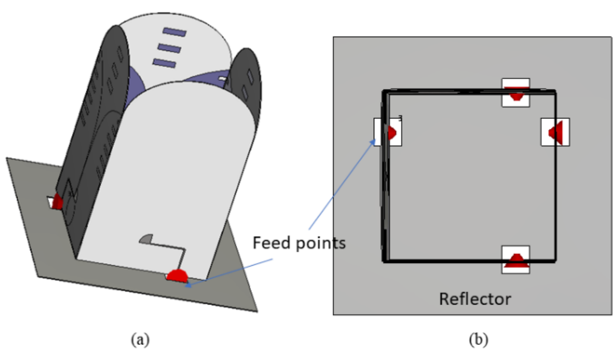

Figure 3. Configuration of the compact dual-polarized antenna system; (a) perspective view and (b) top view.

IV. Overall Antenna Performance

The reflection coefficients and port isolations of the designed compact dual-polarized Vivaldi antenna system are shown in Fig. 4. The reflection coefficients of horizontal (port 1) and vertical (port 2) elements are always smaller than -10 dB, showing the operating band of the designed system from 0.5 GHz to 3 GHz. Additionally, port isolation is achieved as more than 35 dB throughout the band. Fig. 5 shows the radiation patterns of the E- and H-planes. All cross-polarized components are negligible compared to the co-polarized components; the XPD is larger than 30 dB. In addition, the realized gain of the final dual-polarized system varies from 5.56 dBi to 15.6 dBi.

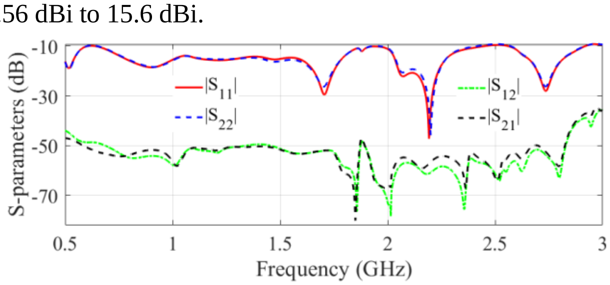

Figure 4. The S-parameters of the dual-polarized Vivaldi antenna.

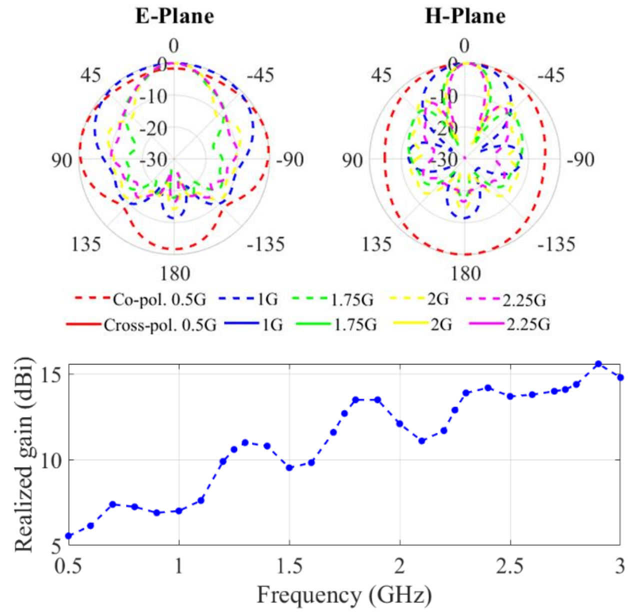

Figure 5. The radiation pattern of the dual-polarized Vivaldi antenna on the E- and H-planes and its realized gain.

V. Conclusion

A compact, portable, wideband, and dual-polarized Vivaldi antenna system was proposed. The directors, edge slots, and a reflector were used to improve the radiation performance of the antenna system. The final antenna system has a compact size of 0.29 × 0.29× 0.48 λ^3 with a high gain ranging from 5.56 to 15.6 dBi.

Acknowledgment

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