Linear to Circular Polarization Transformation of Vivaldi Antennas and Its Use in GPR Detection

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***Abstract*—An antipodal Vivaldi antenna is designed for use in the ground penetrating radar (GPR) detection of landmines. Two such antennas, one transmitting and one receiving, are connected to an ultra-wideband GPR to record the responses of exact models of certain types of landmines. Later, a periodic structure converter is used to transform the antennas' linear polarization into circular polarization. The responses obtained from the same landmine models upon making the linear to circular polarization transformation show more information, and as a result are better fit for employment with signal processing algorithms aiming at detecting and classifying buried landmines. The results for the antenna design, polarization conversion, and GPR responses with both linear and circular polarization are reported.**

Keywords; Antipodal Vivaldi antenna, Ground Penetrating Radar (GPR), Periodic Structure Polarization Converter.

I. INTRODUCTION

The problem of landmine contamination affects many countries around the world, and this problem is worsening due to the continuing armed conflicts taking placed around the globe. The landmine clearance methods include the use of metal detectors, ground penetrating radar (GPR), trained dogs and rats, and infrared imaging [1]. Among these, metal detectors and GPR are the mostly used ones. This work focuses on the GPR method.

Two types of GPR exist: narrow band (NB) and ultra-wideband (UWB). The advantages of UWB GPR include low design complexity, low cost and higher time domain resolution [2]. To use UWB GPR, UWB antennas are required to properly radiate the GPR pulses. Most available UWB antennas are omnidirectional [3–5]. The GPR application prefers the use of directional antennas to radiate solely towards the soil surface. The antipodal Vivaldi Antenna is UWB and directional at the same time, and that is why it is famously employed in GPR. However, it has the disadvantage of being linearly polarized, whereas a circular polarization (CP) is preferred in GPR as the polarization of the signals reflected from the underground targets cannot be expected, and this could lead to losing or weakening parts of the received reflected pulses.

In this paper we present the design of a periodic structure converter to transform the polarization of an antipodal Vivaldi antenna from linear to circular, and show that the pulses received with the CP version contain more information compared to the earlier linear polarization (LP) version, and this improves the landmine detection process by decreasing the landmine detection errors.

II. ANTIPODAL VIVALDI ANTENNA DESIGN

Vivaldi antennas are preferred in several applications, including GPR, due to their wideband properties, directional pattern, high gain, simple structure and easy fabrication [6, 7].

An antipodal Vivaldi antenna is designed, simulated, and fabricated. The design model is shown in Fig. 1, and a photo of the given prototype is given in Fig. 2. The dimensions and substrate data of the antenna are listed in Table I.

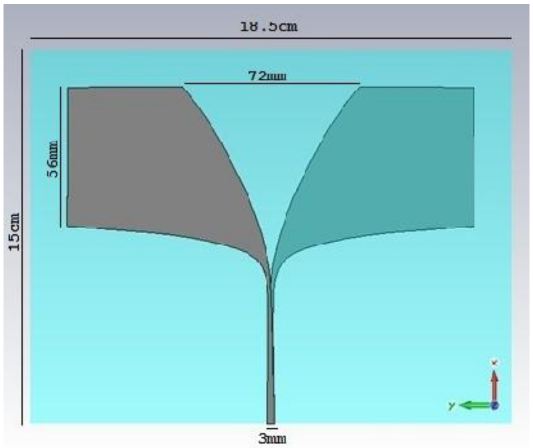


Fig. 1. The model of the antipodal Vivaldi antenna design

The simulated and measured reflection coefficient plots are given in Fig. 3. They show satisfactory resemblance and prove the ultrawideband operation of the Vivaldi antenna.

III. POLARIZATION TRANSFORMER

Antipodal Vivaldi antennas are inherently linearly polarized. This could be a disadvantage in the GPR detection of underground targets as the polarization of the reflected signal is hard to guess and might not be aligned with the receiver antenna's

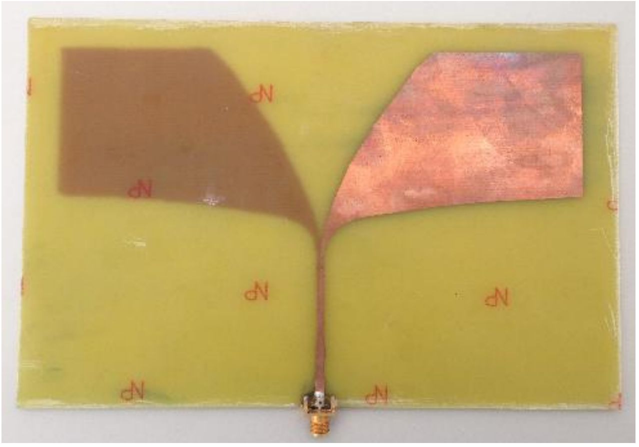


Fig. 2. Photo of the fabricated prototype

TABLE I
ANTENNA DIMENSIONS AND DATA

`Substrate`	FR4
`Thickness`	1.6 mm
`Permittivity`	4.4
`Dimensions`	$18.5 * 15$ cm^2
`Metal Thickness`	35 μm

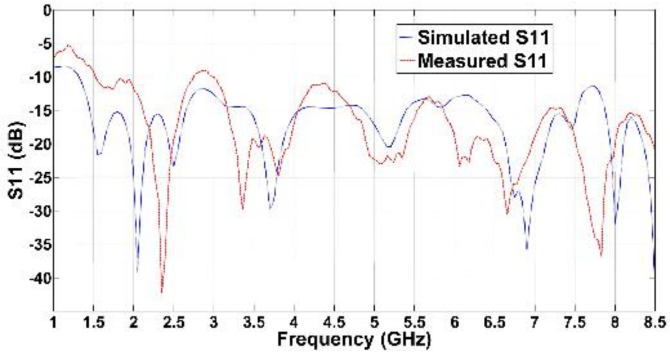
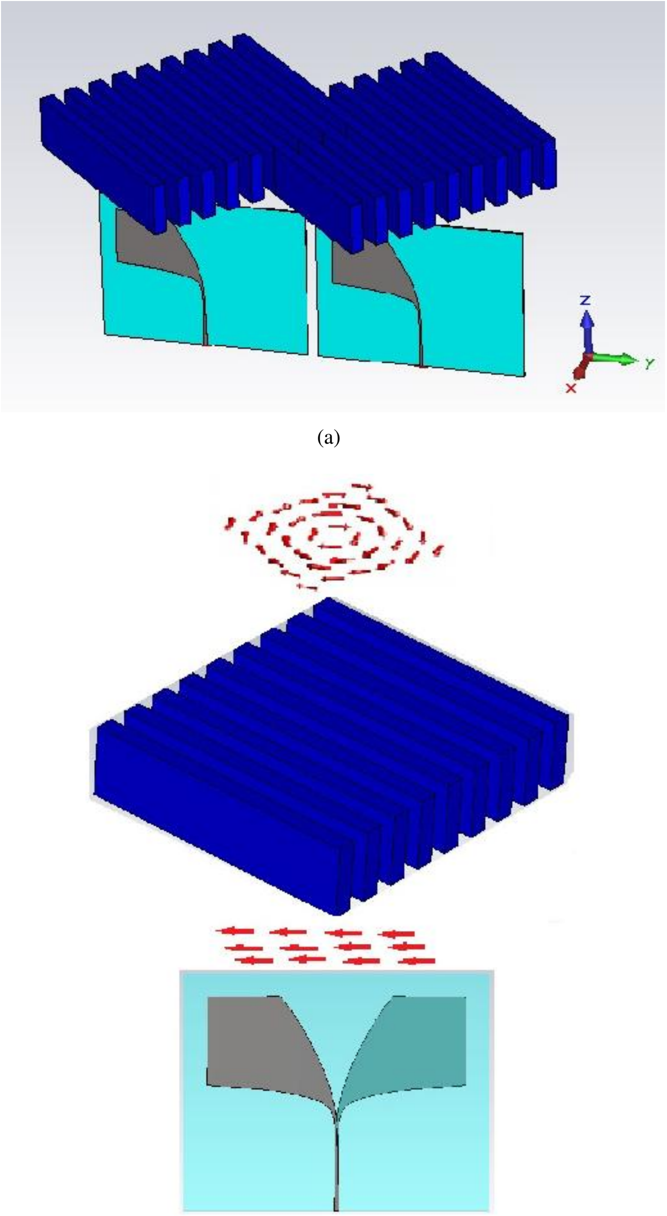


Fig. 3. The simulated and measured reflection coefficient results of the antennas

polarization. This might lead to data loss, and as a result to an increased detection error.

To counter this disadvantage, a linear to circular polarization transformer is designed and used with the two GPR antennas. The transformer is based on a periodic structure of dielectric slabs with a permittivity of 11.9. The slabs are rotated by 45° compared to the plane of the two antennas, as shown in Fig. 4. With this configuration, the signal emitted by the transmit antenna will be divided into two orthogonal components, where one of them, going through the slabs, gets delayed by 90° compared to the second component. This phase difference is directly related to the height (dimension in the Z direction) of the slabs. The same phenomenon happens to the reflected signal that passes through the transformer before reaching the receive antenna. This produces a circular polarization of the antennas' original linear polarization [8].



(a)

(b)

Fig. 4. (a) The GPR system with the polarization transformer structure. (b) The linear to circular polarizer operation

For a height of the slabs of 50 mm, the axial ratio results, computed in CST STUDIO and ANSYS HFSS, are given in Fig. 5. A 3 dB axial ratio is achieved from 1.39 GHz to 2.12 GHz.

IV. GPR RESULTS

The electrical model of common landmines are produced and used in CST Studio to record the GPR data. Below we report some of the results obtained with the No.4 AP Mine and the Gyata landmine. The GPR system including the two Antipodal Vivaldi antennas is placed above the tesbed containing soil and the landmine model. One of the antennas

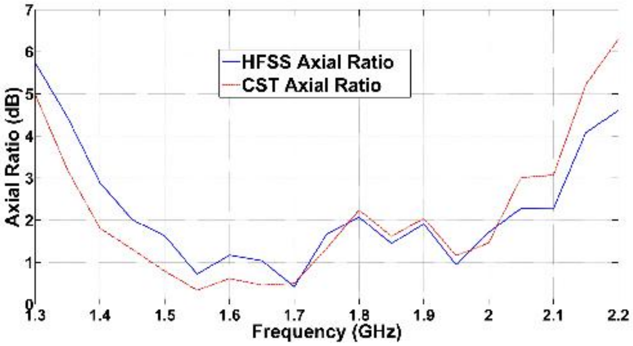


Fig. 5. Axial ratio results with the use of the polarization transformer

is used to transmit a Gaussian pulse, while the other antenna receives the response from the soil and the landmine buried in it at a depth of 5 cm. The responses are different for different types of soil, landmine types, landmine position with respect to the GPR, and its depth in the soil.

To assess the effect of the polarization transformer on the GPR results, we generate and present the responses of the No.4 AP Mine and the Gyata landmine with and without the converter for three different positions along the soil surface, given by the x and y values shown on Figs. 6–11.

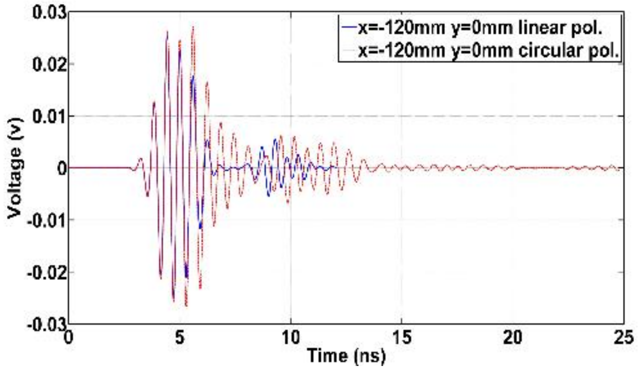


Fig. 6. No.4 AP mine responses for the linear and circular polarization cases at $x = -120$ mm

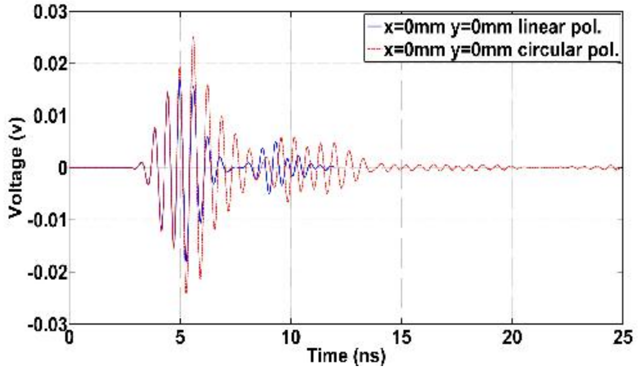


Fig. 7. No.4 AP mine responses for the linear and circular polarization cases at $x = 0$ mm

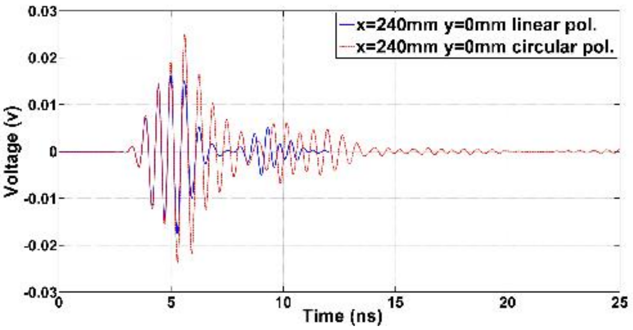


Fig. 8. No.4 AP mine responses for the linear and circular polarization cases at $x = 240$ mm

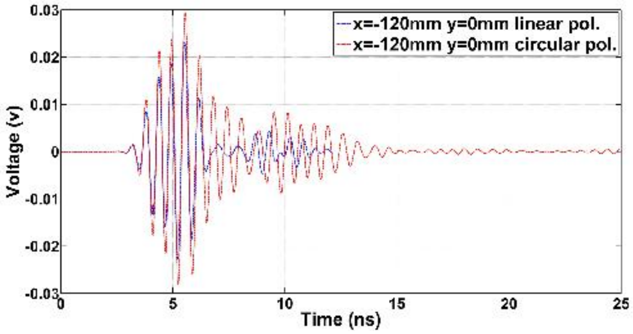


Fig. 9. Gyata landmine responses for the linear and circular polarization cases at $x = -120$ mm

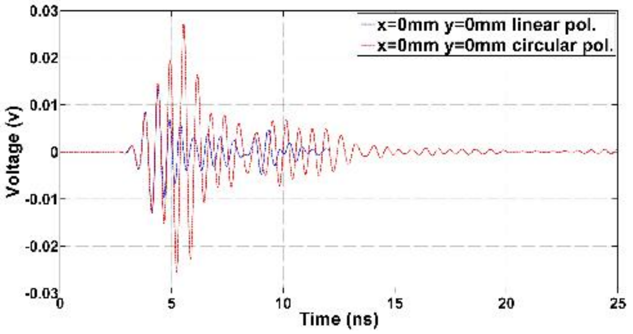


Fig. 10. Gyata landmine responses for the linear and circular polarization cases at $x = 0$ mm

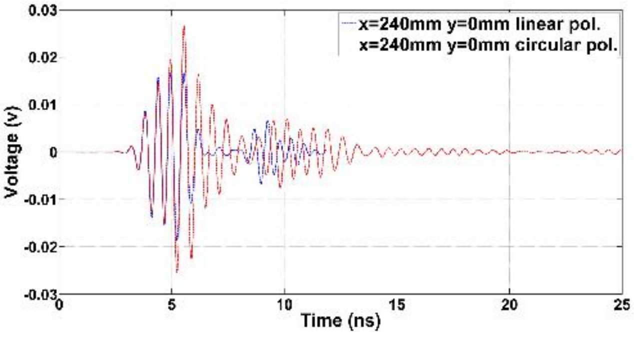


Fig. 11. Gyata landmine responses for the linear and circular polarization cases at $x = 240$ mm

The received pulses for the two landmine types and in both polarization cases are clearly different. Mainly, the pulse received in the linear polarization case is shorter in time (only up to 12 ns), whereas with the polarization converter, it continues with more ripples up to 25 ns. These extra ripples are slightly different between landmine types and for the two polarizations, although it could be difficult to inspect that visually. They hold additional information on the target characteristics and can be used by a detection algorithm to tell more about the nature of the target, its properties and location, and hence the detection errors, whether the false alarms or the false negatives, and the target classification errors can be decreased.

V. Conclusion

An ultra-wideband antipodal Vivaldi antenna has been designed and fabricated. It is meant for use in the GPR detection and classification of buried landmines. The linear polarization of this antenna could hurt the GPR results. Hence, a linear to circular polarization transformer has also been designed. The GPR responses with circular polarization show a longer pulse holding more data, which can be used to decrease the GPR detection and classification errors.

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