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Vivaldi Antenna for Ground Penetrating Radar Applications

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Abstract: The Ground Penetrating Radar (GPR) is an advanced technique used for identifying and detecting objects beneath the surface. Ultra Wideband (UWB) antennas are utilized as a part of GPR system for transmission and reception of short electromagnetic pulses. The fundamental source of difficulty lies in the performance of GPR for detecting the subsurface objects is the reflection from the antenna itself. These reflections cause late time ringing; which makes problem in the recognition of the underground object. Reflections in the antenna itself can be examined by studying transient behavior of the antenna. This paper focuses on the theoretical investigation of the design of UWB Vivaldi antenna (1GHz - 2.6GHz) for GPR applications. Vivaldi antenna has been designed, optimized and simulated in the CST Microwave Studios. The optimized Vivaldi antenna has a lower return loss and VSWR at a center frequency (1.8 GHz) of -35dB and around 1.0, respectively. Vivaldi antenna is also modeled with the GPR environment (i.e. with earth and scatterer inside the earth). Hence, the optimized Vivaldi antenna is presented to use for GPR applications.

Keywords: Vivaldi Antenna; Ground Penetrating Radar; VSWR; Antenna Design

1. INTRODUCTION

A ground penetrating radar (GPR) system uses short electromagnetic pulses to examine a subsurface structure and properties of an earth (or ground) (Jamali, *et a.l*, 2011). GPR is among the most important technologies being investigated for the detection and recognition of subsurface structures and in homogeneity of ground. There are three main components of the GPR system, i.e. ultra wideband (UWB) antenna, control unit and the power supply. GPR system mainly uses UWB antennas for the broadcast and reception of the electromagnetic pulses. The antenna transmits a short pulse of an electromagnetic wave in to the ground. The part of the wave is transmitted into the ground and the other part is reflected from the interface of ground and air. The part of the wave, which is entered into the ground, is then reflected from the hidden object or medium with different dielectric properties. The reflected signal is sensed by the receiving antenna and is displayed on the screen in real time. From the information of the reflected signal, the hidden objects or the materials can be identified (or imaged) after post processing. The reflected data can also be stored in the memory for later processing and interpretation (Daniels, 2007). GPR profiles are also used to judge the position and intensity of hidden materials and to search attributes of the natural underground (Vignesh, *et al.*, 2014).

The development in radar technology plays a vital role in many important applications including medical imaging, flight, and civil (Perdana, *et al.*, 2017). GPR is a type of radar that offers various applications within the field of industrial and medical sciences, military and civil from which most of the applications necessitate the finding of hidden artifacts. It is used in the science of Archaeology, where systems can be utilized to identify and map the subsurface objects such as archaeological artifacts, features, and patterning (Masini, *et al.*, 2010). With this feature, scientist can use it as a map utility and discover both metallic and a nonmetallic anomaly before any digging is needed or involved. Military applications of GPR include detection of unexploded ordnance buried under the subsurface. To find tunnels for border protection and terrorist activities (Cornick, *et al.*, 2016) and various other field of science can utilize this technology to look for under-ground problems and to resolve them.

The working mechanism of generic GPR system can be seen in **(Fig-1)**, where transmitting antenna accepts the signal pulse created by the control unit; it amplifies the signal pulse and sends it into the earth with a particular frequency. The frequency of signal is one main aspect in finding the hidden object. If the frequency of the signal is higher, it will penetrate deep

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into the ground. Thus, the antenna designed to work on a higher frequency will also be able to 'detect' targets, which are resided deep in to the ground.

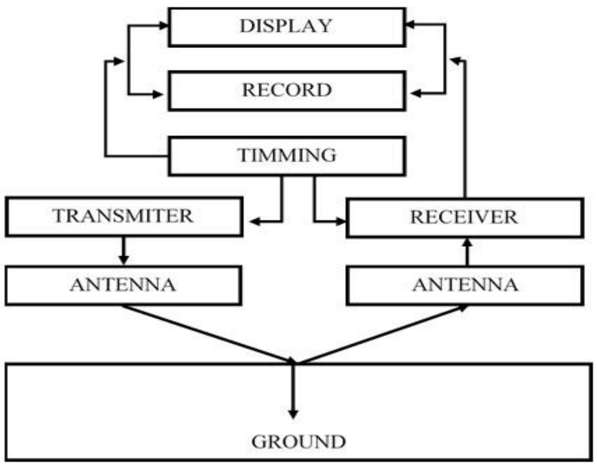


Fig.1: Flow Chart of Typical GPR System

In order to produce different frequencies, which can penetrate in ground, various antenna types can be used such as Spiral, Horn, Dipole or Vivaldi antenna (Daniels, 2007).

2. DESIGN METHODOLOGY

The main aim of this research work is to design an UWB Vivaldi antenna with a frequency range of (1-2.6GHz). To create simulation environment, electromagnetic simulation software such as CST Microwave (MW) Studio is used. It has special tools for designing high frequency components and can perform 3D simulations in time and frequency domain. To gether with the design and modeling of Vivaldi antenna, an earth ground is also modeled in CST MW, to mimic the real environment of earth, so that reflection can be observed as from real earth.

3. DESIGN OF VIVALDI ANTENNA

3.1 Profile of Vivaldi Antenna

Gibson introduced the first Vivaldi antenna in 1979, Vivaldi antenna is represented by an exponential flare shape. This radiating flare shape structure is exponentially tapered which can be made in one, two or three layers (Elsheakh, *et al.*, 2013). The one-layer structure is known as Tapered Slot Vivaldi antenna that provides sufficient reflection and has smaller dimension (Elsheakh, *et al.*, 2013). The different size of Taper opening such as width or/and length can bring effects on the Voltage Standing Wave Ratio (VSWR) and Return loss of the antenna. The one layered structure has relatively planar structure, low profile, high directivity, and both E and H-plane symmetrical radiation pattern. It is simple to integrate and economical to fabricate (Elsheakh, *et al.*, 2013).

The Vivaldi antenna consists of the design of two main sections on the sandwiched substrate, on top of the substrate a conductive flared slot and on the back side of the substrate a ground plane. A discrete port is used for feeding the antenna.

3.2 Substrate Material Parameter used for Designing

The selection of the substrate material plays an essential role in the design of antenna. The two types of losses that occur in Vivaldi antenna are the conductor and dielectric losses and both of which increases with increase in frequency (Ali, *et al.,* 2017). Thus, to keep the dielectric losses at minimum (in the frequency of operation), FR4 material is used. Table **(Table-1)** gives specifications and values of the materials used for the design of antenna.

Table 1. Major properties of the material

#	Characteristics	Values
1.	**Dielectric thickness**	**10mm**
2.	**Thermal coefficient**	**7.0×10−5 K−1**
3.	**Thermal conductivity**	**0.29 W/(m·K)**
4.	**Conductor thickness**	**10mm**

3.3 Design of Flare Slot Section

The bottom layer is the ground plane and the top layer is the exponential tapered profile of PEC Layer. The upper frequencies of the band can be explained by initial width of the flare and the lower frequencies of the band can be explained by the ending width of the flare (mouth of the flare) (Fisher, 2000). In this paper, the slot is tapered exponentially from feeding port along its axial direction 'x' as shown in **(Fig-2)**.

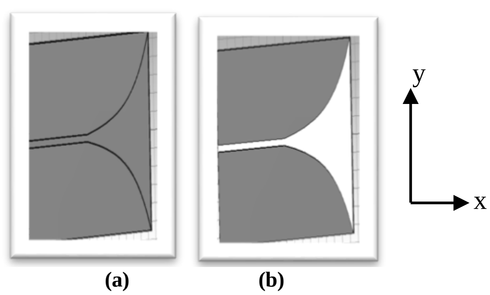


Fig.2: Flared antenna Slot: (a) FR-4 plane; (b) Taper forming.

The flare section is defined by equation 1 (Fang *et al.*),

$$z(y) = \pm A e^{py} \quad \textbf{(equation 1)}$$

Where 'x' and 'y' are in same unit, 'x' is the substrate axial direction and 'y' is the vertical direction of the substrate, as shown in **(Fig-2)**.

The propagation of EM waves through Vivaldi antenna in free space is characterized by input impedance, slot measurement in correspondence with position of discrete port placed. By modifying the position of discrete port, resonance frequency can be improved. Characteristic impedance of the antenna is given by equation2.

$$Z_c = \eta \frac{a}{w} \quad \textbf{(equation2)}$$

Whereas intrinsic impedance of free space (η) is taken as 120Ω, characteristic impedance of antenna (Zc) is 50Ω and length of antenna (L) is chosen to be 80mm, width (w) be 10mm and slot distance (a) be 4.16mm, as shown in **(Fig-3)**.

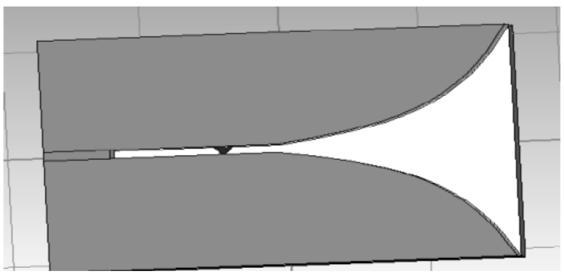
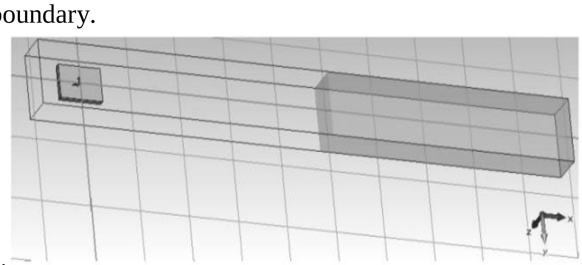


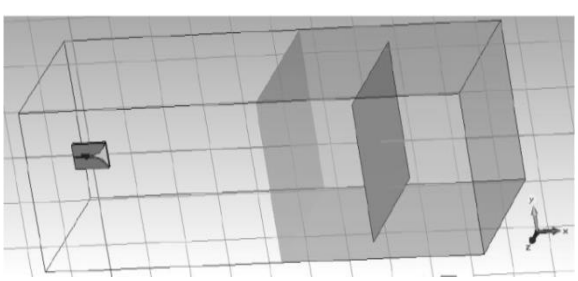
Fig. 3: Vivaldi antenna with discrete port connection on the PEC material.

4. SIMULATION MODEL WITH EARTH

The earth is modeled in CST MWS having the relative permittivity (εr) = 5 and relative permeability (μr) = 1.0. The antenna is placed at a distance of 3λo (999mm), as shown in **(Fig. 4a)**. Inside the earth, a Perfect Electric Conductor (PEC) scatterer is located with a depth of 3λe. The modeling is done to identify the scatterer which is kept inside the earth. The modeling of GPR environment is shown in **(Fig. 4b)**. In all the different directions of computational domain, open (add space) boundary conditions are applied, so that there would not be any reflection from the boundary.



(a)



(b)

Fig. 4: GPR environment, i.e. Modeling of Vivaldi antenna: (a) with Earth; (b) with PEC Scatterer inside earth.

5. SIMULATION RESULTS

The designed Vivaldi antenna is excited with a short pulse having frequency band between 1GHz to 2.6GHz with a center frequency of 1.8GHz. It is observed from the simulation result **(Fig. 5)** that the designed Vivaldi antenna could be suitably operated in two frequency ranges, where the return loss and VSWR are below -10dB and 2.0, respectively. The first frequency range is in between 1.1-1.37 GHz; and the second frequency range is 1.62-2.1 GHz. **(Fig.5a)** shows the computed results that this antenna is suitable for 1.8GHz with the VSWR remains less than 1.1. The return loss value is about -35 dB at 1.8GHz **(Fig. 5b)**.

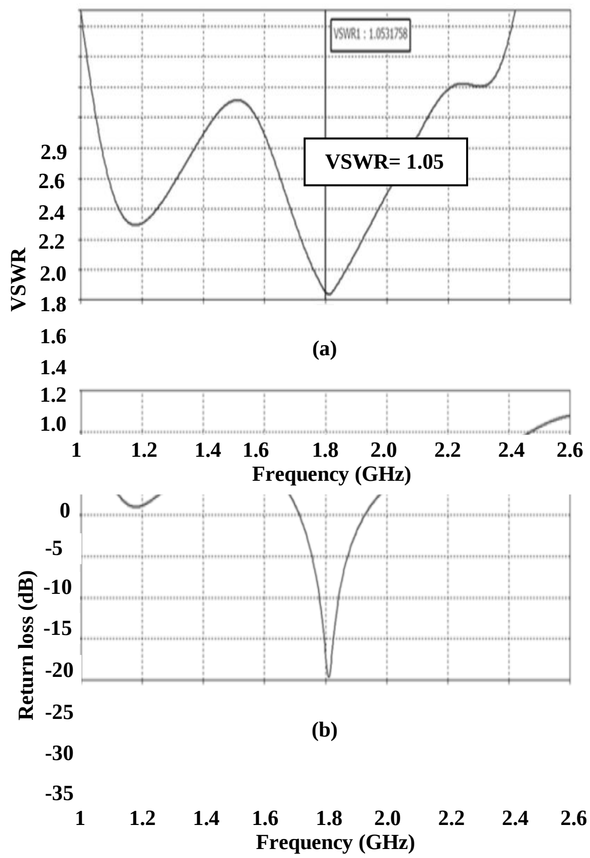
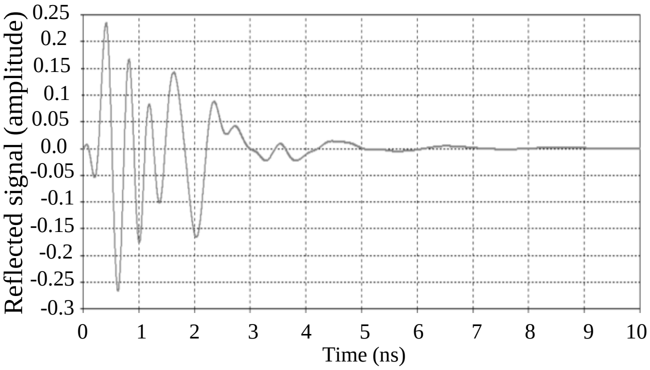


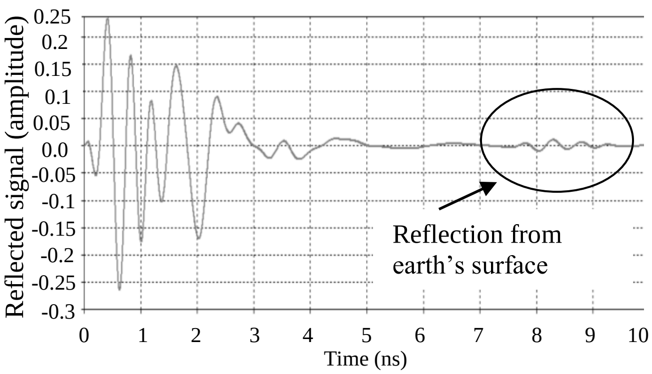
Fig. 5: Simulated result of proposed antenna :(a) VSWR; (b) Return loss (dB).

The speed of the signal that is being transmitted within the earth is lower than signal that travels in free space and this is caused due to the properties of the earth.

The transient behavior of the proposed antenna is simulated with an amplitude modulated raised cosine pulse (RC2). This input signal of 1.1nsec width was chosen, to observe reflections from the earth, scatterer, and antenna itself. This can be seen that Vivaldi antenna has low reflection and ringing **(Fig-6a)**. The reflected signal of earth is found by subtracting antenna reflections from reflected signal of antenna and earth. From the reflected signal, it is clear that Vivaldi antenna is affected less by the internal reflection from itself. The maximum amplitude of the reflection from earth is obtained, as shown in **(Fig-6c)**.



(a)



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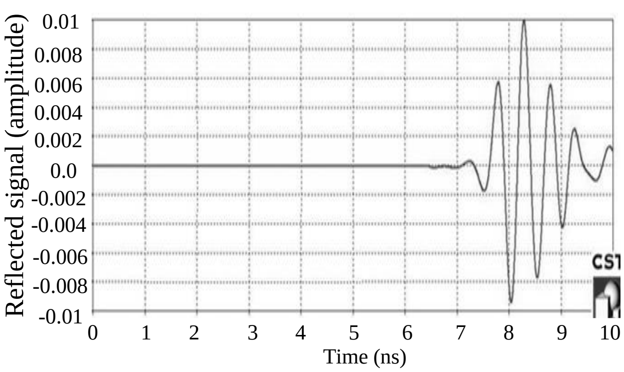
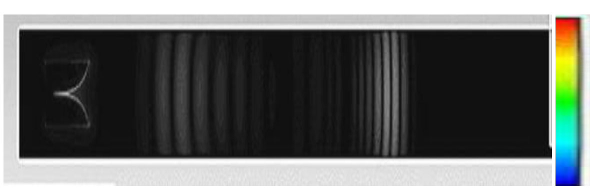


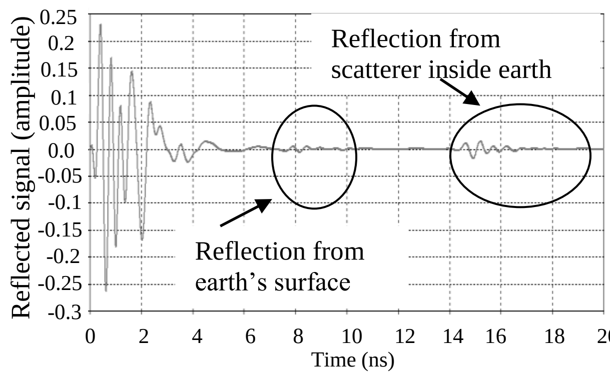
(c)



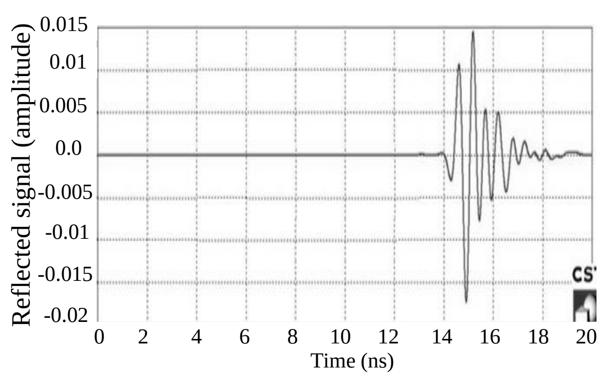
(d)

Fig. 6: GPR Scenarios: (a) Reflections from Vivaldi antenna only; (b) Reflected signal from antenna and earth; (c) Reflection from earth only; (c) Snapshot of reflected signal from the surface of earth.

The main objective is to discover the buried objects in the layers of the earth with the help of Vivaldi antenna, therefore a perfect electric conductor (PEC) scatterer is kept inside the earth at a distance of $3\lambda e$ from the surface of earth. In both cases antenna is located over the earth in free space at the height of $3\lambda o$. The signal radiated by the antenna towards the earth is bounced back from earth and scatterer. The signal that is reflected from the scatterer and the earth are received by the Vivaldi antenna and are saved on the discrete port. The reflected signal of the hidden PEC scatterer is computed by subtracting antenna and earth reflection signal's from reflected signals of antenna, earth and scatterer. **(Fig-7c)** gives the radiation's snapshot of the electric field from the antenna to the scatterer within the earth.



(a)



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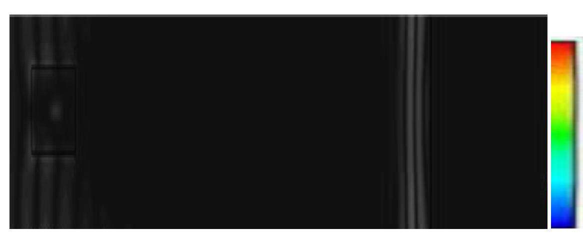

(c)

Fig.7 :(a) Reflected signal from antenna, earth and scatterer; (b) Reflected signal from scatterer only; (c) Snapshot of reflected signal from scatterer.

6. CONCLUSION

This paper focuses on the design and investigation of Vivaldi antenna for GPR applications. The Vivaldi antenna is designed for a frequency range of 1GHz to 2.6 GHz; and simulated by using 3D electromagnetic simulation software tool i.e. CST MWS. The Vivaldi antenna is optimized at the center frequency of 1.8GHz. At this frequency, the designed antenna provides a return loss of -35 dB and VSWR of around 1.0. From the transient analysis, it is demonstrated that it has short ringing of 8ns duration. The reflected signal of the antenna itself has normalized reflected amplitude of less than 23%. The Vivaldi antenna is also demonstrated in GPR environment with earth and buried scatterer. In GPR environment of earth and scatterer, the reflection from scatterer (only) is achieved by subtracting antenna's reflection signal from the reflected signals of earth and scatterer together. The results show that the proposed antenna proves to be an effective candidate detection of subsurface objects in GPR environments.

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