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# Design of Ground Penetrating [GP] Antenna

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**Abstract:** GPR is an advanced, non-invasive sub-surface imaging technique that typically uses short pulses of electromagnetic energy to detect the buried object in the ground. UWB antennas are used in GPR for transmission and reception of electromagnetic pulses. the main performance originate in the performance of GPR for finding the buried objects is the reflection from the antenna itself; which furthered the problem in identification of the object. reflections in the antenna itself can be analyzed by studying time-domain behavior of the antenna.

This paper present the theoretical studies of the design of lower ultra wideband Vivaldi Antenna (1G - 2.6G) for GPR applications, As a standard Vivaldi Antenna has been designed and simulated by CST Microwave Studios then Vivaldi Antenna is modelled with the GPR environment (i.e with scattered inside the earth). Therefore, reflected signals are analyzed in GPR Environment for Time domain Characteristic, it offers less ringing in GPR environment.

Keywords: Antenna Design, Ground Penetrating, CST Microwave

## 1. Introduction

Ground Penetrating Radar (GPR) is a highly developed geophysical imaging system that uses short electromagnetic pulses to detect buried (or hidden) objects [1]. There are three main components of the GPR system, i.e, ultra wideband (UWB) antenna, control unit and the power supply [1]. The UWB antenna of the GPR system transmits a short pulse of an electromagnetic wave in to the ground. The part of the wave is transmitted in to the ground and the other part is reflected from the interface of ground and air. The part of the wave which is entered in to the ground is then reflected from the hidden object or medium with different dielectric properties. The reflected signal is then sensed by the receiving antenna and is display 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 [2]. Ground penetrating radar (GPR) profiles are used for judge the position and intensity of hidden materials and to search the occurrence and stability of natural subsurface environment and features [3]. The GPR is among the most important technologies being investigated for the detection and recognition of subsurface human arts and structures. UWB antennas are used in the GPR system for the broadcast and reception of the electromagnetic pulses. In the performance of the GPR system, the main problem for the detection of the materials is the reflection from the antenna itself. These reflections produces late-time ringing in the GPR antenna, which make issue in the recognition of the material. Reflections in the antenna itself can be examined by studying time-domain behaviour of the antenna.

Therefore, the main focus of this work to optimize the selected UWB antenna for GPR applications. In the first step, Modelling of UWB antenna will be carried out and the second step, Analysis of time-domain characteristic of UWB antenna will be performed. The application of the

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proposed are discussed as GPR has found its applications in the science of Archaeology, where GPR can be used to detect and map surface archaeological artifacts, features, and pattering [14]. Utility mapping to locate the map utilities before any excavation is a concern to involve. GPR is a beneficial tool due to its capability to locate both metallic and nonmetallic utilities [15]. Military application of GPR include detection of unexploded ordnance and detecting. Tunnel, using this technology borders are protected and kept away from terrorist activities [17].

## 2. Design of Vivaldi Antenna

A wideband Vivaldi antenna for Ground Penetrating Radar is designed. Compared with other wideband antennas, the TSAs have relatively high directivity, planar structure, low profile, and symmetric beam in both E- and H-plane. Also, it is economical to fabricate and simple to integrate. Components includes an exponentially tapered slot, which radiates the signal by traveling wave principle as well as slot line. This antenna can be designed in one layered structure which is called as tapered slot Vivaldi antenna that provides sufficient reflection and small dimensions. The different size of Taper opening width and length can bring effects on the VSWR and S11. Vivaldi Antenna is designed using one layered structure, which is further explained. In theory, tapered slot antennas normally have broad bandwidth, high directivity and are able to create symmetrical radiation pattern.[19] The designed optimized Vivaldi antenna consist of two main sections a conductive flared slot and on the reverse side there is formed a plane of the conductor and a discrete port for feeding the following antenna.

## 3. Design of Substrate Material

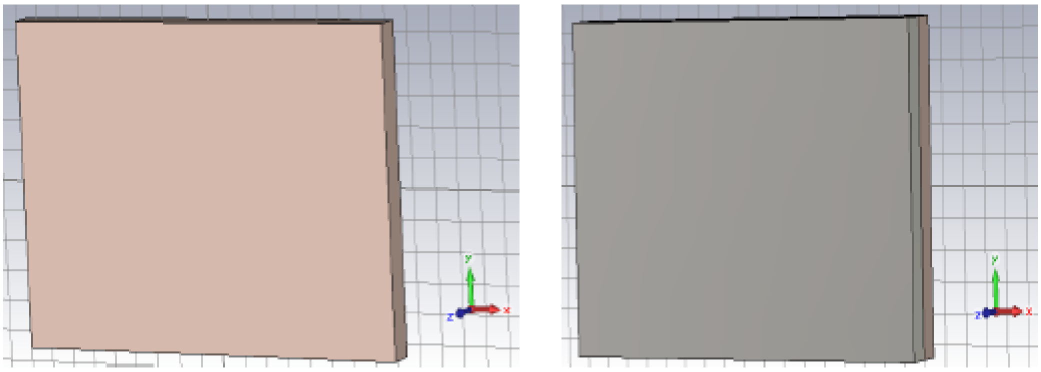
The selection of dielectric substrate plays a vital role in the design and simulation of transmission lines as well as antennas. Some essential features of the dielectric substrate are, in no specific order:

· Dielectric constant.
· Dielectric loss tangent that sets the dielectric loss.
· Thickness of the copper surface.
· Thermal expansion and conductivity.
· Manufacturability and cost.

The designing of the antenna we can use several types of substrates. They often have different properties and their dielectric constants generally provide improved efficiency and a wider bandwidth. However, in accordance to get the smaller antenna size by means of using thin substrate with high dielectric constant. But this also results negatively on the efficiency and bandwidth as shown in Fig. 1. Therefore, there must be a design trade-off between antenna size and good antenna performance. [20]. Dielectric loss is associated to the fact that all dielectrics contain polarized molecules that move in the presence of EM fields. High frequency fields oscillate very rapidly and as the polar molecules move in sync with the field, they begin to heat the dielectric material. There's only one possible source for the heat; the energy of the signal itself. It turns out that dielectric loss increases relentlessly with higher frequencies and in direct proportion to signal frequency. Hence, Fr4 material is used, Table 1 gives a gist of the major properties of the material.

**Table 1**. Major properties of the material Characteristic

| Characteristic | Value |
|---|---|
| Dielectric thickness | 10mm |
| Thermal Coefficient | $7.0\times10^{-5}$ $K^{-1}$ |
| Thermal Conductivity | 0.29 W/(m·K) |



(a) (b)

**Fig. 1** Substrate material (a) Fr4 plane (b) PEC layer on the top of Fr4 layer.

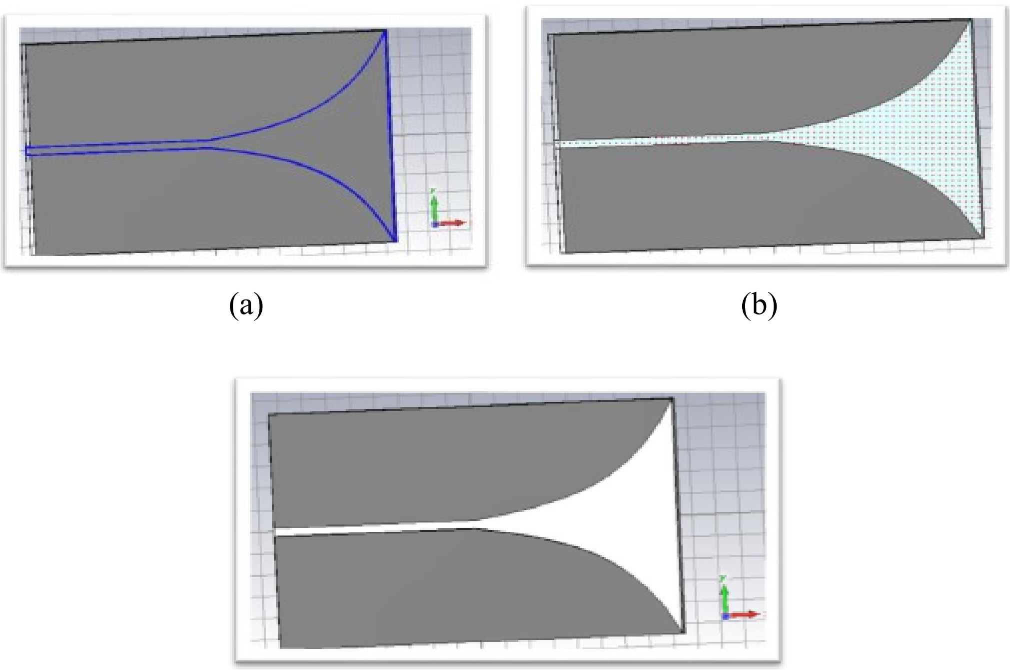
## 4. Design of Flared Slot Section

The Vivaldi antenna is a tapered slot antenna characterized by an exponential flare shape. At the start of the flare the width defines the upper frequency and at the mouth of the flare the width defines the lower frequency [21]. The conventional form of Vivaldi antenna is fed from a slot line and to feed the slot line of the Vivaldi antenna a stripline, discrete port or microstrip circuit is required, in this design we have used a discrete port for energizing the slot.

The flare section is defined by the equation (1):

$$Z(y) = \pm \text{Aepy} \tag{1}$$

where y and z are in same unit, z is in the substrate axial direction and y is in the horizontal direction as shown in Fig. 2



(a) (b)

(c)

**Fig. 2** Flare Slot design (a) Exponential flare on the PEC (b) Front view of antenna when the flare material is changed to vacuum (c) Top view of the final tapered slot.

For the propagation of Electromagnetic waves in free space by optimized Vivaldi antenna, the slot measurement, characteristic Impedance variance in correspondence with position of discrete port should be appropriately selected. the Characteristic Impedance of the given antenna is calculated by equation (1):

$$Zc = \eta\,(a/\omega) \tag{2}$$

L = length of antenna = 80 mm Zo = characteristic Impedance of antenna = 50 = intrinsic Impedance of free space = 120 a = distance of the slot = 4.16 w = width of antenna = 10. Fig. 3 shows the Flared Antenna Slot (a) Front-view (b) 3D view (c) left view.

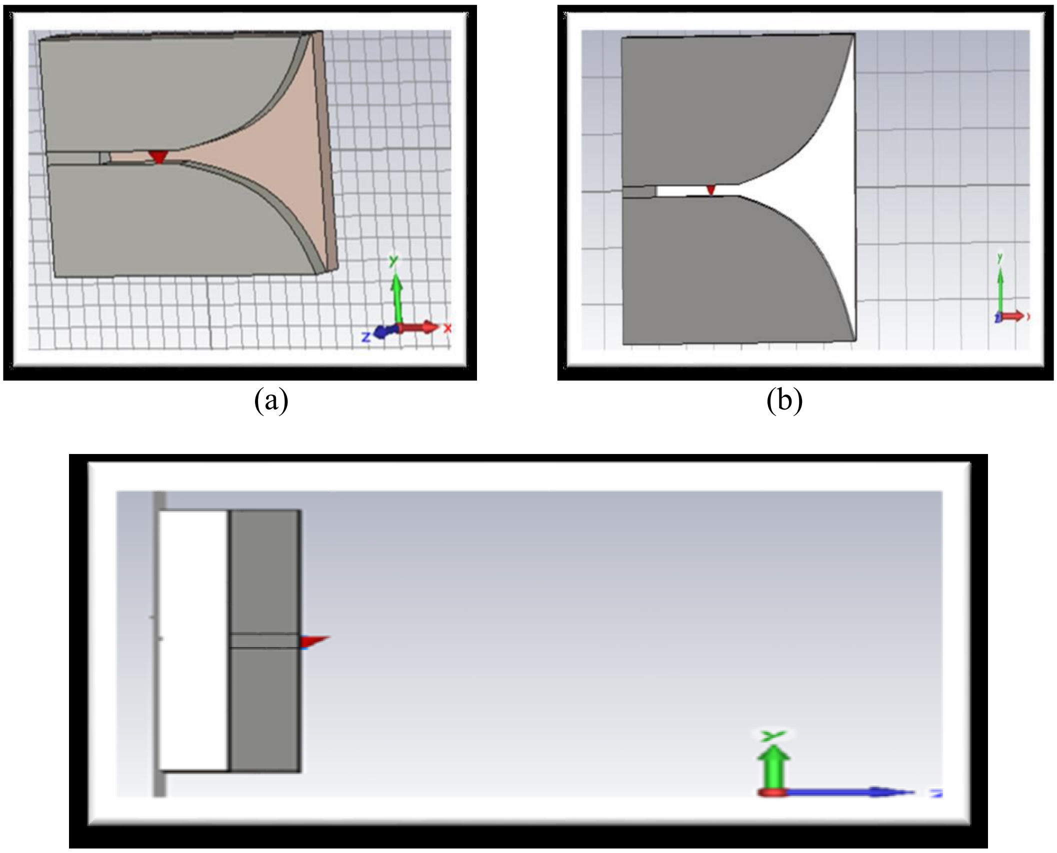



**Fig. 3** Flared Antenna Slot (a) Front-view (b) 3D view (c) left view.

## 5. Modification to Vivaldi Antenna

The most important side to be considered for the GPR application is the time domain characteristics of antenna. It is essential that the reflection from antenna and ringing ought to be minimum. Vivaldi antenna is optimized so as to reduce the reflection and ringing from antenna assembly. We can modify Vivaldi antenna by changing the position of discrete port to increase the frequency of the resonance. The discrete port of optimized Vivaldi antenna is shown in Fig. 4.

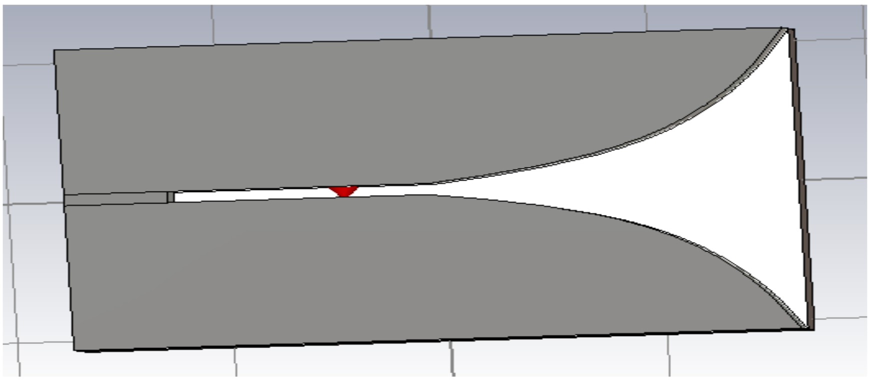


**Fig. 4** Discrete port of Vivaldi antenna

## 6. Results and Discussion

The below graph shows that the internal reflection of optimized Vivaldi antenna is at lower side which we desired. Due to low level of internal reflection, the detailed information of object inside the land is possible with optimized Vivaldi antenna as shown in Fig. 5

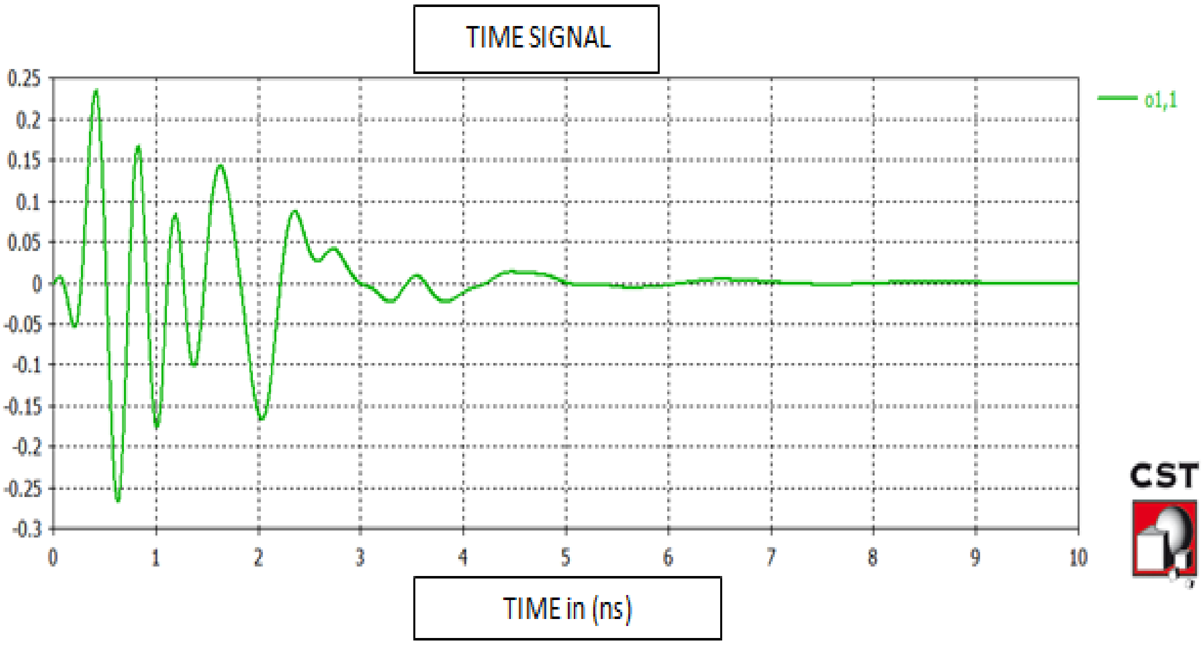



**Fig. 5** Reflection signal of Vivaldi Antenna

## 7. Voltage Standing Wave Ratio

It is measure of how well the source and load impedance are matched, so that maximum power can be radiated in case of antenna. Ideally this ratio should be less than 1. VSWR is the ratio of maximum to minimum voltage for standing wave as shown in Fig. 6.

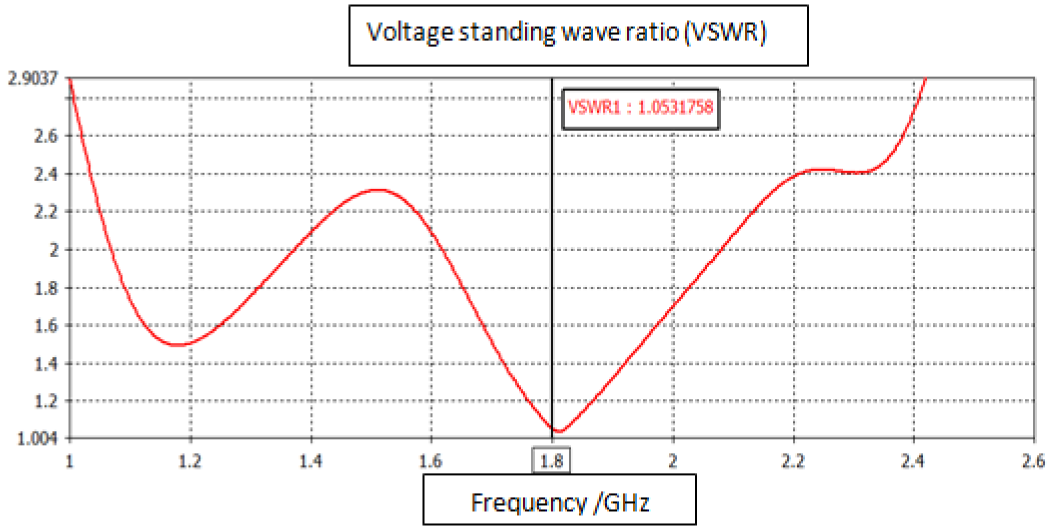



**Fig. 6** VSWR of Vivaldi antenna

From the above graph the VSWR of the optimized Vivaldi antenna at 1.2GHz, 1.8GHz and 2GHz are 1.5, 1.05 and 1.7 respectively. The graph of the VSWR shows that this antenna is suitable for 1.8GHz which having the ratio remain less than 1.1.

## 8. S - Parameters:

The scattering matrix (S-Parameters or S-Matrix) is a mathematical representation which quantifies low RF energy propagation takes place through a multiport network as shown in Fig. 7.

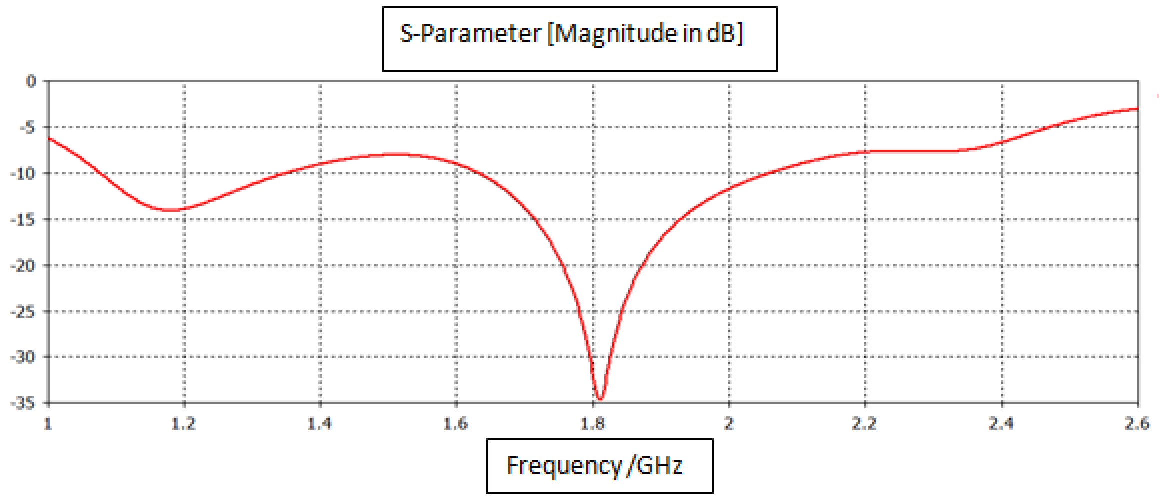



**Fig. 7** S-Parameters of Vivaldi antenna

In S-Parameter graph it can be shown that the value is about -31.73 at 1.8GHz, which show less reflection.

## 9. Vivaldi Antenna

Optimized Vivaldi antenna designed in CST Microwave studio 2014 software. As an input signal an RC2 pulse having 1.1nsec width is used for the time domain simulation.

The output signal at the port shows reflection from the antenna itself. The optimized Vivaldi antenna has low reflection and ringing a shown in Fig. 8. In Fig. 9, the Reflected signal of Vivaldi antenna are shown. Fig. 10 shows the Reflection of signal in 2D/3D view of Vivaldi antenna.

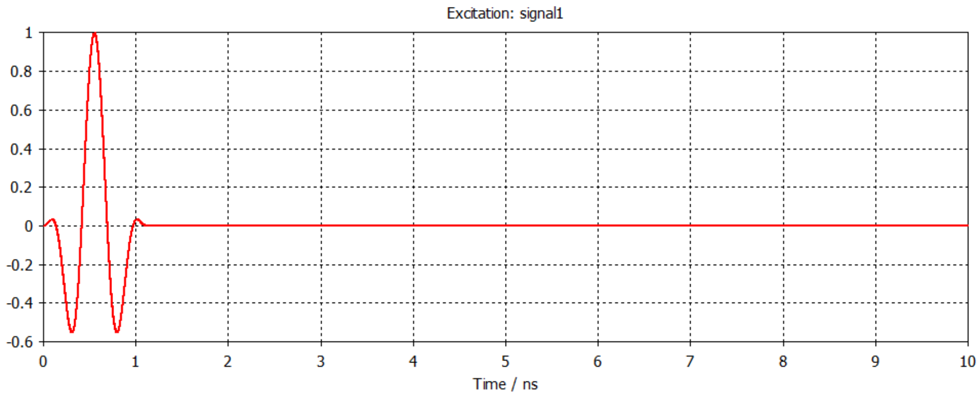



**Fig. 8** Input signal

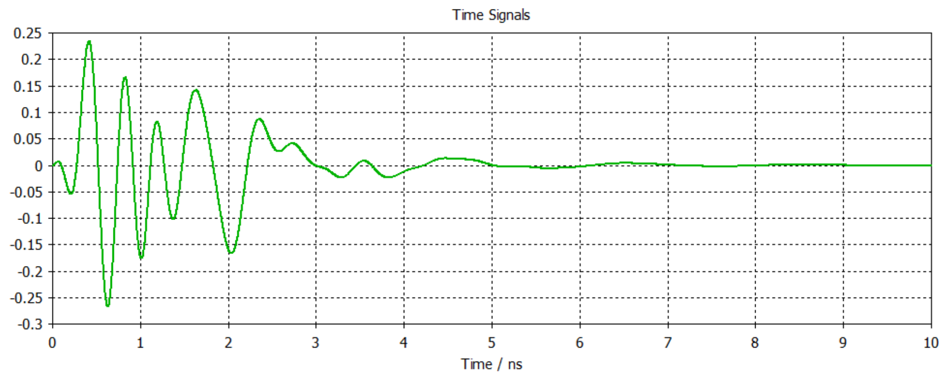



**Fig. 9** Reflected signal of Vivaldi antenna

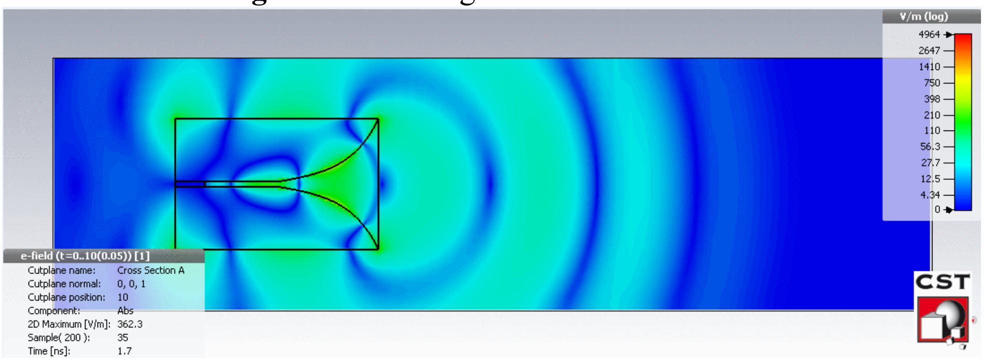



**Fig. 10.** Reflection of signal in 2D/3D view of Vivaldi antenna

## 10. Conclusion

This work targets the analysis of Vivaldi antenna for GPR application. Vivaldi antenna is optimized at the center frequency of 1.8GHz. As discussed in the previous section, a lot of improvements / modifications could be done to the design so that better S11 and pattern characteristics could be obtained. The Vivaldi is a member of a class of aperiodic continuously scaled traveling-wave antenna structures. Besides being efficient and lightweight, the more attractive features of this antenna are that it can work over a large frequency bandwidth and produce a symmetrical end-fire beam with appreciable gain and low side lobes. The design of the antenna is very simple and could be completed in the lab with limited resources and labor. This antenna design hence costs less than the horn antenna. These were the basic reasons that led us to investigate the use of the Vivaldi antenna in this particular application. Software tool which is used for designing and simulation of antenna is Microwave Studio 2014. In this research work we conclude that the reflection from antenna itself found to be sufficient and its normalized amplitude is 0.23V/m. The vivaldi antenna also modelled in GPR environment with earth and scattererinside the earth. In GPR environment scenario of earth and scatterer, the reflection from scatterer is achieved by subtracting earth signal from scatterer inside the earth. In order to view this work, vivaldi antenna is much effective in detecting subsurface objects due to small reflection and short ringing of antenna itself.

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