Design and Optimization of Ultra-Wideband TEM Horn Antennas for GPR Applications

Abdul Aleem Jamali and *René Marklein*
Computational Electronics and Photonics, Department of Electrical Engineering and Computer Science,
University of Kassel, D-34109 Kassel, Germany.
Email: jamali@uni-kassel.de, marklein@uni-kassel.de

Abstract

This paper presents the design and optimization of ultra-wideband (UWB) transverse electromagnetic (TEM) horn antennas for ground penetrating radar (GPR) applications. The numerical simulations of electromagnetic wave propagation are performed in the time domain for a preliminary and modified TEM horn antenna. The TEM horn antennas have some reflections and ringing which are not suitable for GPR applications. These effects are reduced by optimization of the antenna structure. The time domain characteristic and voltage standing wave ratio (VSWR) of the antennas are computed. The optimized TEM horn antenna is then modeled with the typical GPR environment with earth, and the hidden object inside the earth. The presented antenna can be used in the GPR systems to detect and image buried objects, and for the characterization of the non-homogeneous layered structure.

1 Introduction

A ground penetrating radar (GPR) system uses radar wavefields to investigate and evaluate a subsurface structure and properties of a ground. The propagated waves are reflected by a target or material inhomogeneity and these reflections are recorded. The GPR system uses the received information to detect or/and to image a hidden object and or to examine the interior composition of the underlying structures. It can be used in different grounds, which includes ground with soil, water, concrete, pavements and floors with multiple layers. The GPR is a dominant tool in different applications such as in archeology, forensics, non-destructive testing (NDT), location of anti-personal land mines, and utilities [1]. Several ultra-wide band antennas are used GPR applications including cone antenna, circular disc monopole antenna, bow-tie antenna, Vivaldi antenna, frequency independent antennas, and TEM double-ridged horn antenna; the latter provides best solution for GPR applications [2].

In this paper, the TEM horn antennas are designed for the frequency range of 2-19 GHz followed by [3,4]. The transient behavior of the antennas is computed by utilizing the commercial software CST Microwave Studio 2010 [5]. The simulation results show that there are some reflections occur due to the antenna structure. These reflections are reduced by optimizing the horn section of the antenna. For each designed TEM horn antenna the VSWR is computed and compared, which are mainly less then 2 in the frequency band of operation. The optimized antenna is then applied and tested in a typical GPR environment.

2 Design and Optimization of TEM Horn Antenna

The TEM horn antenna and the modified TEM horn antenna are designed according to the design parameters given in [3]. TEM horn antenna with double-ridged waveguide transition, is consists of exponential horn section, TEM double-ridged waveguide, and an elliptical shaped cavity located at the back of the waveguide. Double-ridged waveguide is used for the smooth transition of waves from coaxial cable to the horn section. An elliptical shaped cavity is added to the structure to couple the energy in direction of the horn opening. This antenna is designed in such a way that it provides impedance matching from coaxial cable to the free space.

In [3], the radiation pattern of the TEM horn antenna is analyzed and it has been found that the main

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lobe is divided into the two side lobes because of the destructive interference at the end of the horn section. By modification of the horn section of the antenna it was possible to mitigate this disadvantage, i.e., by carving the horn section from the end of the two exponentially tapered plates in form of an arc. This changed the field distribution at the horn section and presents a constructive interference on the main axis.

The study of the transient behavior of the antenna is very important for GPR applications. We have simulated the time domain characteristics of the above antennas with an amplitude modulated raised cosine pulse of two cycles (RC2). The pulse has a time duration of 190 ps and is stimulated at a waveguide port which is placed at the end of the coaxial cable. The port is also used for reception and absorption of reflected waves. From the analysis of the time domain simulation, we have found that there are some reflections and ringing coming from different parts of the antenna structure itself. These effects were seen in both antennas at the waveguide port. In order to reduce the prohibited effects, the shape of TEM horn antenna is optimized according the following steps:

1. Perpendicular plates are placed at the lower ends of the exponential tapered plates. The perpendicular plates have the same height as the ridges of the waveguide.
2. The upper ends of the exponential tapered plates and the perpendicular plates are connected with the another plates.
3. Cover the remaining sides of the exponential tapered plates.
4. Finally, an elliptical cylinder and spheres of radius 5 mm are placed at the upper end of exponential tapered plates to reduce the corner effects.

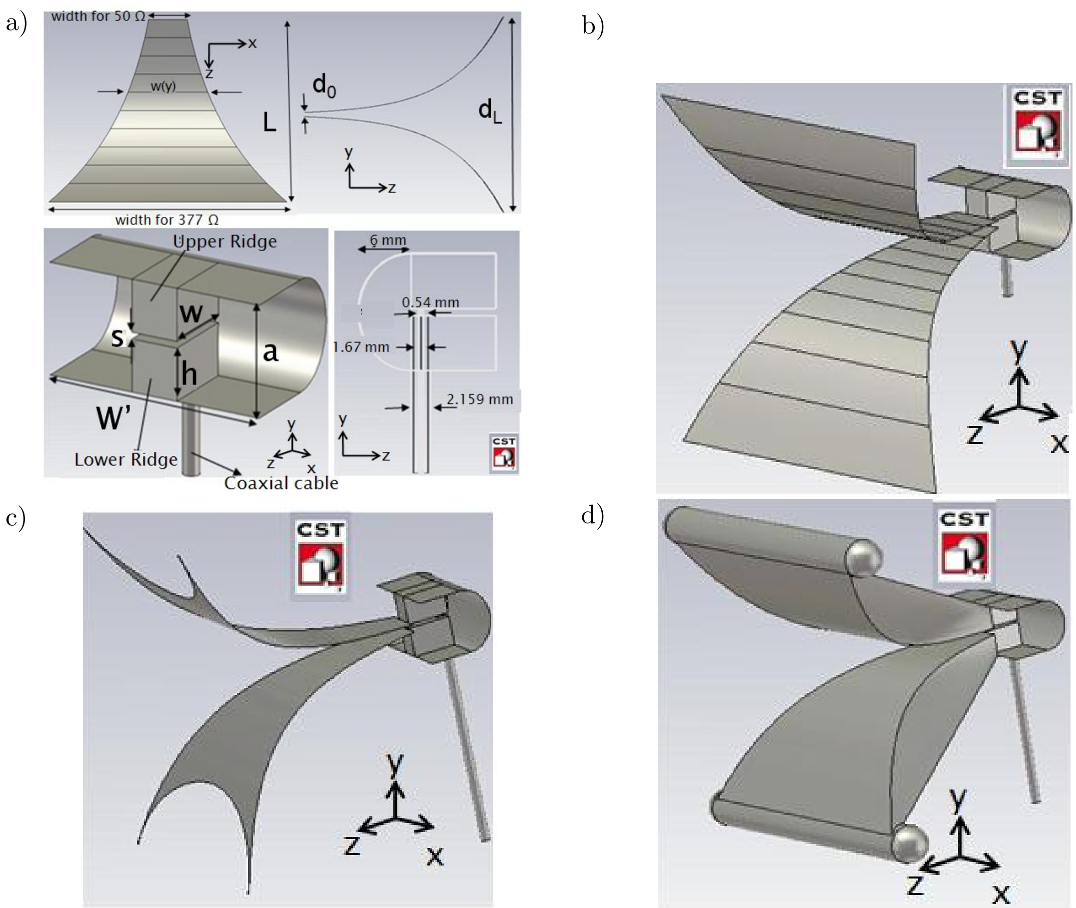

Figure 1: TEM horn antenna: (a) design paramters; (b) original, (c) modified, and (d) optimzed geoemtry

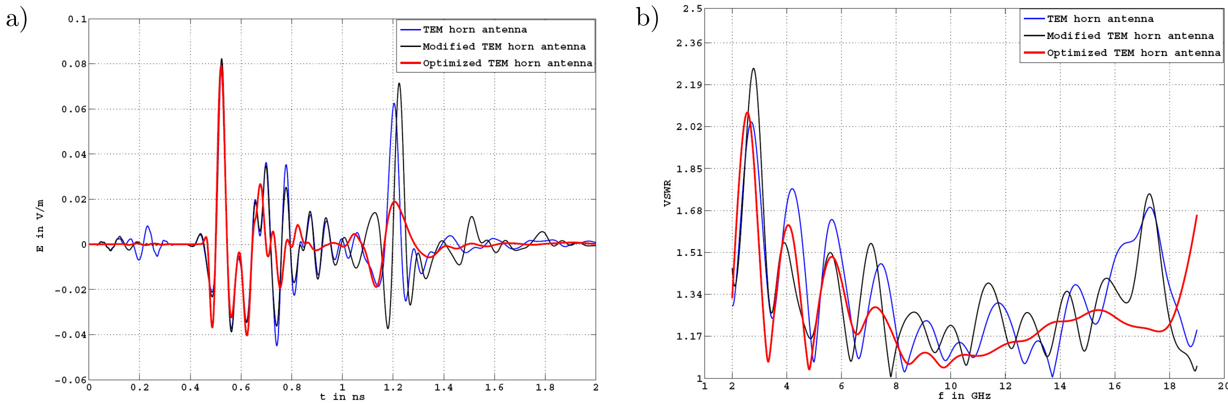

Figure 2: Comparison of different TEM horn antennas: (a) time domain characteristics; (b) VSWRs

The Figure 1 shows the configuration of the original, modified, and optimized TEM horn antenna structure. The time domain characteristics and VSWRs of the antennas are shown in Figure 2.

3 Modeling of GPR Scenarios

As an example, we consider an earth half-space with a relative permittivity of $\varepsilon_r = 5$ and a relative permeability of $\mu_r = 1$ (see Fig. 3a). The antenna is placed in the air above the earth half-space in a distance of 28.57 mm. The antenna is first simulated without the scatterer. The radiated wave is reflected and transmitted at the interface. The received time domain signal is shown in Fig. 4a. In a second GPR

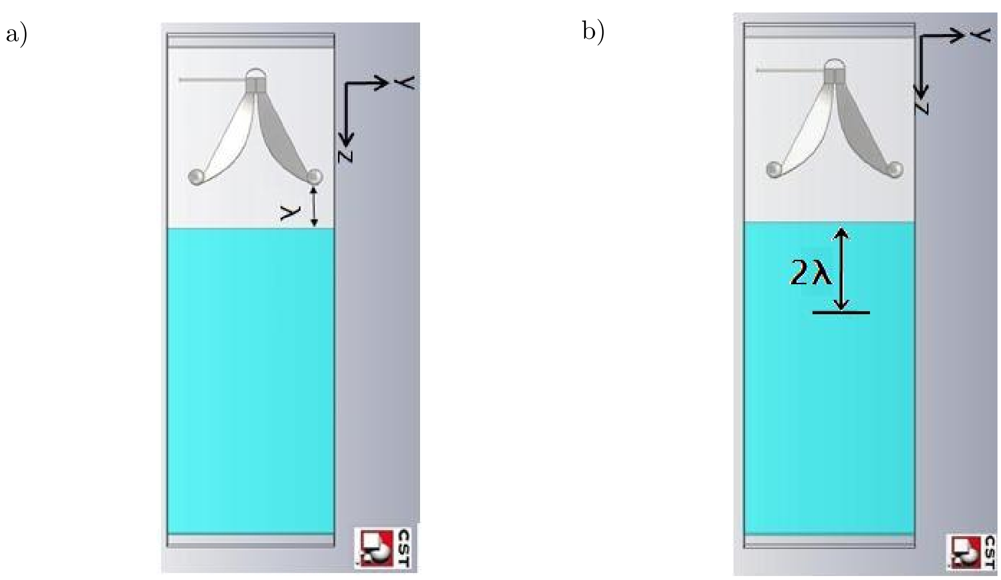

Figure 3: GPR scenarios: (a) empty earth half-space; (b) a scatterer embedded in the earth half-space

simulation we place a scatterer in form of a PEC plate with a size of $1\lambda_C \times 1\lambda_C$ parallel oriented to the interface in a distance of $2\lambda_C$ inside the earth half-space (see Fig. 3b). Additionally to the reflections in Fig. 4a the main reflection from the scatterer is clearly visible in Fig. 4b. Substration of both signals yields the reflection from the scatterer only as given in Fig. 4c.

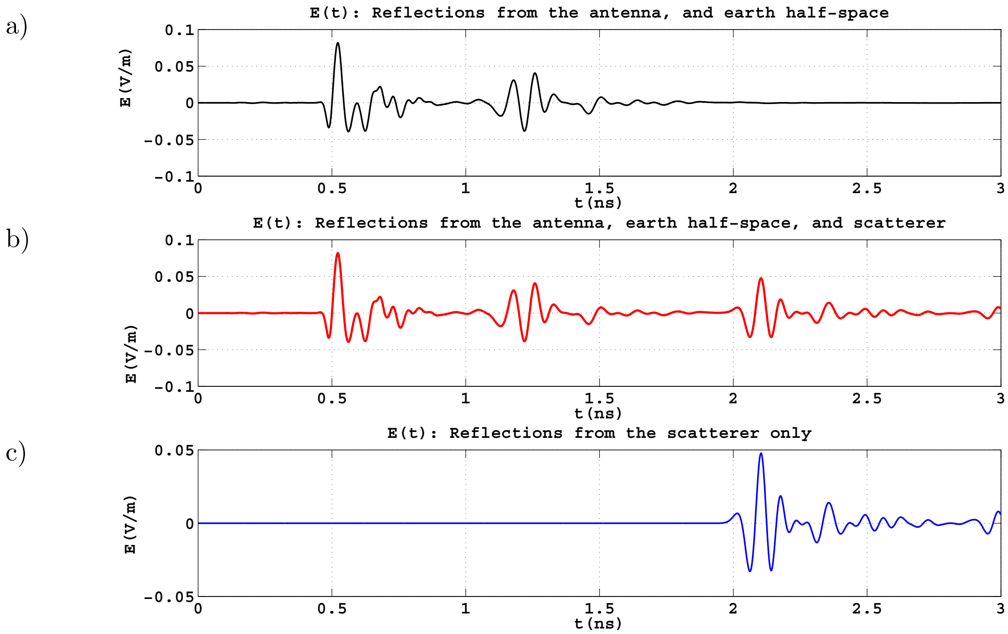

Figure 4: Computed reflections: (a) empty earth half-space; (b) earth half-space with scatterer; (c) scattered field

4 Conclusion

The design and optimization of UWB TEM horn antennas for GPR applications have been studied in terms of the transient behavior and VSWR. The optimized TEM horn antenna was found to be optimal for GPR applications, because of its low reflections and ringing. GPR scenarios have been modeled and simulated including the antenna, earth environment, and simple scatterer. The scattered signal from the buried object was found by signal substraction and it can be further used for inverse scattering and profiling.

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