Design and Analysis of Wideband Antenna with An Application to Ground Penetrating System

G. E. Atteia[1] , K. F. A. Hussein[2] and A. A. Shaalan[1]

Abstract- **In this paper, a wide band antenna is proposed for Ground-Penetrating Radar (GPR) system. This antenna consists of a dipole antenna housed in a rectangular conducting reflector whose inner walls are coated with an absorbing material. The capability of buried target detection by the proposed antenna is examined by investigating the coupling between the transmitting and receiving antennas in the presence and absence of buried targets. The operating bandwidth of the antenna is shown to be about 50%. The GPR system with the proposed antenna is shown to be capable of detecting the existence of buried targets.**

Keywords**- Ground-Penetrating Radar, GPR, FDTD, Wideband antenna**

I. INTRODUCTION

Ground-Penetrating Radar (GPR) systems are used for the subsurface investigation of earth. They are used in the detection of objects buried beneath the earth surface such as pipes, cables, land mines, and hidden tunnels. GPR system consists of transmitting and receiving antennas. The efficiency of a certain GPR system depends on its capability of the true detection of buried objects. This capability depends mainly on the characteristics of the signal used for the detection. In order to enhance these characteristics, it is required to develop efficient GPR antennas to satisfy a number of demands. A GPR system should have low and short coupling between transmitting and receiving antennas to avoid false detection. Since it operates very close to ground, its characteristics should not be affected strongly with ground properties. In addition it should have light weight and should be economic. Due to the great importance of GPR antenna performance, various types of GPR antennas have received considerable attention in the literature. For example, modeling of GPR antennas with shields and simulated absorbers is discussed in [1]. In [2], a separated-aperture sensor which consists of two dipoles housed in corner reflectors that are separated by a metallic septum is discussed and simulated using the FDTD method. In [3], an efficient bow-tie antenna for GPR system is developed to exhibit good efficiency in ultra-wide band using a combination of a tapered capacitive and resistive loading [4].

This paper proposes a design for new GPR antenna composed of a linear dipole housed in a conducting rectangular reflector whose inner walls are coated with absorbing layers to optimize the antenna performance. The GPR system uses two units of such an antenna; one for transmission and the other for reception.

The FDTD method is used for electromagnetic simulation of the complete GPR system to study the characteristics of the proposed antenna and to evaluate the coupling between the transmitting and receiving antennas during the operation of target detection. FDTD method has been widely used to model wave propagation, scattering, radiation, and simulations of GPR problems [5] since it was first introduced by Yee in 1966 [6]. A major reason for using the FDTD method is that it proved its efficiency in simulating complex geometries and its capability of modeling wide range of realistic mediums and soils [7-8].

The remaining of the paper falls into three parts, the first of which is concerned with describing the construction of the proposed antenna as well as the complete GPR system, the second part describes the electromagnetic simulation of the GPR system using FDTD and the third part presents the results showing the antenna characteristics and the system performance.

II. DESCRIPTIONS OF THE DESIGN OF THE PROPOSED GPR SYSTEM

As shown in Fig.1, two units of the proposed antenna are used to construct the GPR system. This antenna is composed of a linear dipole housed inside a rectangular conducting reflector. The purpose of the reflector is to eliminate direct coupling between the transmitting and receiving antennas. To improve the antenna characteristics and to diminish the internal resonance of the rectangular cavity, the inner walls of the reflector are coated with a lossy absorbing material.

During the operation of buried target detection, and when the GPR system is placed over the ground with the apertures of the reflectors close to the ground surface, the antenna characteristics are significantly affected. The impact of the ground on the antenna characteristics depends on the electric properties of the ground soil. Thus the design of the antenna should take into account the electric properties of a practical soil.

The coating on the inner walls of the conducting reflectors is composed of many layers of lossy materials, which are chosen to achieve a conductivity profile that optimizes the antenna performances for the common types of ground soils.

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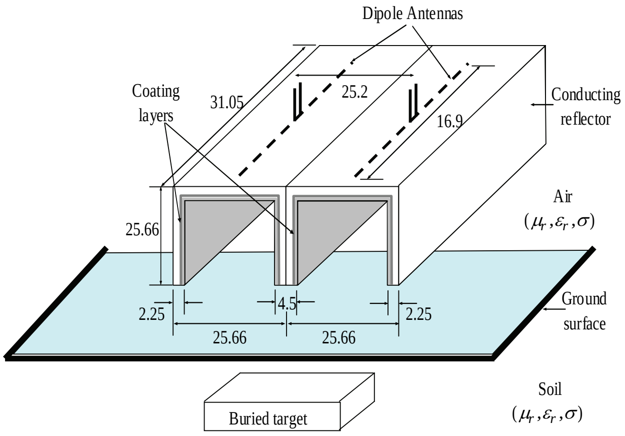

Fig. 1. Geometry of GPR antenna above ground surface (all dimensions in cm) .

III. ELECTROMAGNETIC MODELING OF THE GPR SYSTEM USING FDTD

The FDTD method as described in [9] is applied here to provide electromagnetic simulation for the complete three-dimensional model of the GPR system including the system antenna, soil, and buried target. The entire space is divided into a number of cubic cells with the appropriate resolution. The boundaries of the FDTD volume are terminated using the uniaxial perfectly matched layer (UPML) absorbing boundary conditions. The PML is composed of a number of cells with a specific profile of the electric and magnetic properties and is backed by perfectly conducting walls [9].

A thin-wire model is used to present the transmitting dipole antenna, which is excited with a sinusoidal voltage source applied across an infinitesimal gap at its center [10]. The receiving dipole antenna is also modeled as a thin wire with an infinitesimal gap at its center. The received voltage signal is measured across this gap.

The input impedance of the dipole antenna is a frequency-domain quantity that is measured by, first calculating the current flowing in the antenna arms at the feed point and then dividing the applied voltage on the calculated current, both in the frequency domain. The current is calculated using Ampere's law as described in [9].

The transmission coefficient S_{21} is another frequency-domain quantity whose magnitude expresses the amount of coupling between the transmitting and receiving antennas. This coefficient is defined as the ratio of the voltage measured at the receiving dipole antenna port to the voltage applied at the transmitting dipole antenna port.

IV. RESULTS AND DISCUSSION

In this section, the results for the input impedance, VSWR of the GPR antenna as well as the coefficient S_{21} are presented in the entire frequency band of the GPR system operation.

The type of soil selected for the present study is the most practical one and has properties : $\varepsilon_r = 2.9$, $\mu_r = 1.0$ and $\sigma = 0.02\ S/m$ [2]. The ground is assumed to be homogenous.

The simulation space is a volume of size ($40.05 \times 59.85 \times 58.95$ cm), which is divided into cubic cells, each of dimensions 0.45×0.45×0.45 cm. The field components are updated every $\Delta t = 8.66$ ps. This time step satisfies the condition of numerical stability [9]. The dipole is modeled as a perfect electric conductor. The dipole length is 16.9 cm. Its radius is 0.002 of its length, and the thin-wire approximation described in [10] is used. The transmitting dipole antenna is excited with a sinusoidal voltage source of the form : $V(t) = A_0 \sin(2\pi f t)$, where $A_0 = 100$ V.

The coating on the inner walls of the reflectors has a thickness of 2.25 cm and is composed of 6 layers with the conductivity profile: $\sigma = 0.0001 \times 10^{2n}$, where n=0,1,2,3,4,5 is the layer number and n=0 is number of the layer just touching the air region of the reflector cavity. The walls of the reflectors are modeled as a perfect conductor.

*4.a. Frequency Response of Dipole Antenna inside Rectangular Reflector***.**

To investigate the proposed antenna performance as regards the optimal band width of operation without being limited by the properties of the ground, the GPR system here is placed in free space. However, the effect of the ground is taken into consideration later on.

Figures (2) and (3) show the frequency response of the antenna impedance and VSWR respectively, while the inner walls of the reflectors are left without coating. The source impedance is taken as 180Ω. It is clear that the antenna is suitable for operation over the band 700-1000 MHz, i.e. about 35% bandwidth.

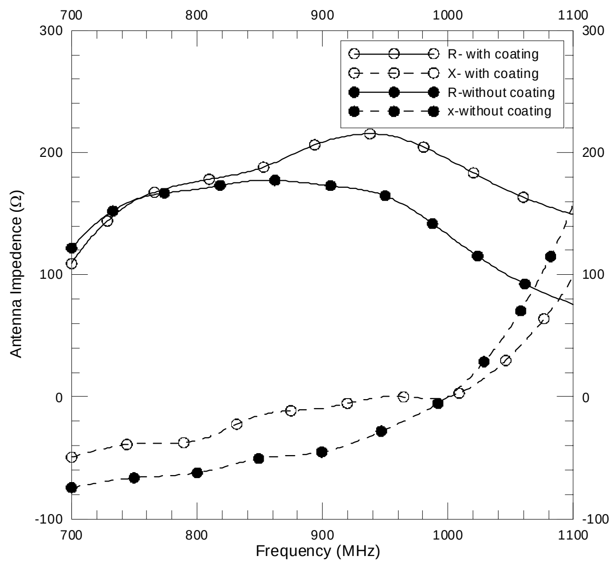

Fig. 2. Input impedance for the antenna with coating and without coating.

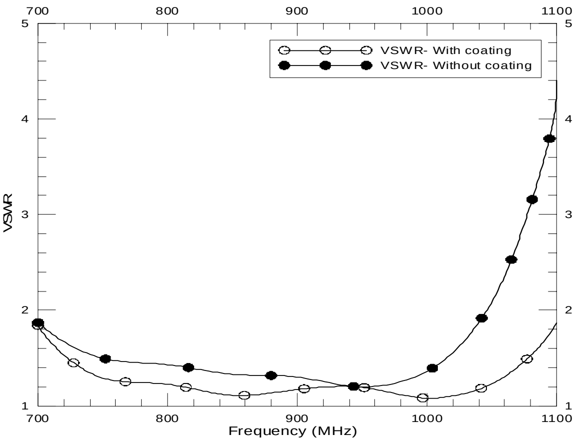

Fig. 3. VSWR for the antenna with coating and without coating.

4.b. Improvement of Antenna Characteristics by Coating the Internal Walls of the Rectangular Reflectors.

To improve the performance of the antenna as regards the proper band width of operation the inner walls of the reflectors are covered by the 6-layer coating with the conductivity profile described above. As shown in Figures (4) and (5), and by comparison with antenna characteristics in the absence of the coating absorber, the addition of this coating results in a significant reduction of reactive part of the antenna impedance and, hence, the VSWR, with respect to 180Ω source impedance, is maintained below 2.0 in the entire band of operation (700-1100 MHz), i.e. the band-width is improved to be about 50%.

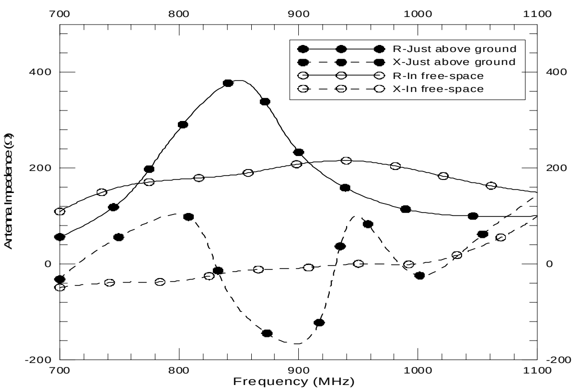

Fig. 4. Input impedance of the GPR antenna against the frequency

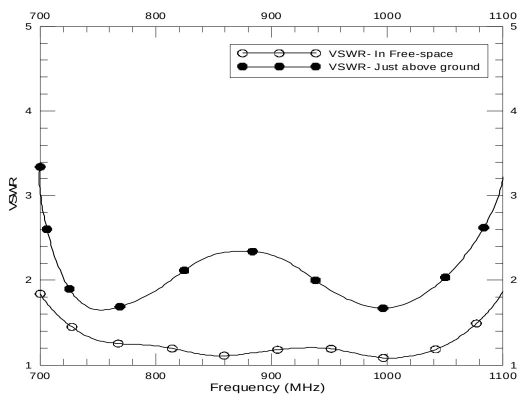

Fig..5. VSWR of the GPR antenna against the frequency.

4.c. Effect of the Ground on the GPR Antenna Characteristics.

The effect of the ground on the characteristics of the GPR antenna should be studied as the antenna is placed very close to the ground during the buried target detection operation. Figures (6) and (7) show the frequency response of the antenna impedance and the corresponding VSWR with respect to 180Ω source impedance when the antenna is placed at different heights over the ground surface. Compared with the characteristics of the same antenna in free-space, the ground soil has a bad effect on the antenna impedance and hence, on the VSWR. The higher the antenna position is above the ground, the less the effect of the ground on the antenna performance. As clear in Fig.(7), the VSWR of the GPR antenna can still be accepted even when the reflector aperture is just touching the ground surface.

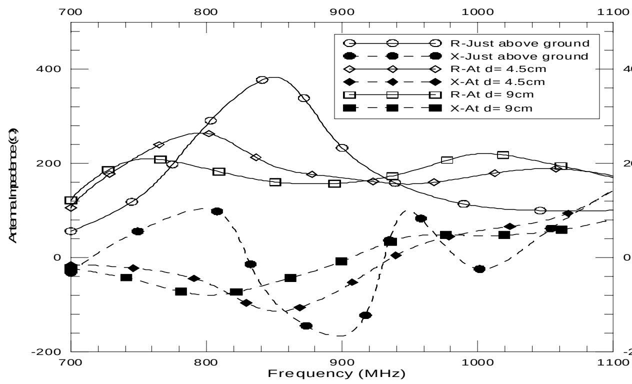

Fig. 6. Input impedance of the GPR antenna against the frequency when it is placed over the ground.

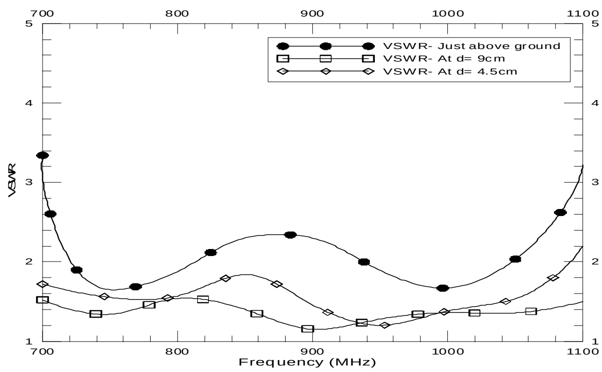

Fig. 7. VSWR of the GPR antenna against the frequency when it is placed over the ground.

4.d. Capability of Buried Target Detection using the Coated-Reflector Antenna.

The capability of target detection by such antenna as GPR system can be measured by change of the electromagnetic coupling ($|S_{21}|$) between the transmitting and receiving antennas due to the presence of a buried target.

In the present investigation, the used target is a dielectric block ($31.05\times49.5\times9$) cm with the properties: $\varepsilon_r = 8$, $\mu_r = 1.0$, $\sigma = 0.0 \;\; S/m$. The target is buried in ground at a depth of 6.75 cm.

Figures (8), (9) and (10) show the coupling coefficient $|S_{21}|$ between the transmitting and the receiving antennas in the presence and absence of a buried dielectric target when the GPR system is placed at different heights over the ground. It is clear that the maximum detection is obtained when the GPR system is placed with the reflector aperture touching the ground surface.

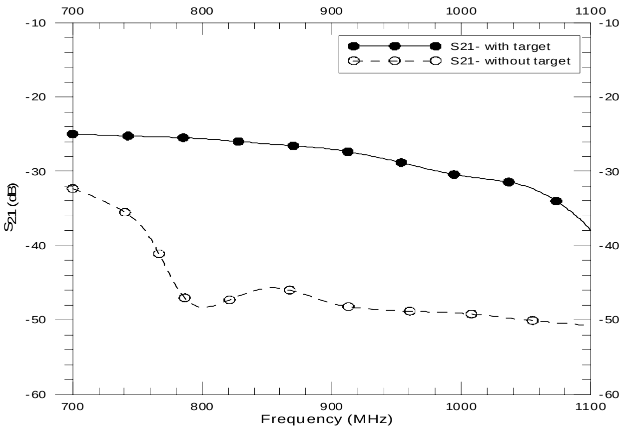

Fig. 8. The coupling coefficient 0$|S_{21}|$ for the GPR system when placed touching the ground surface in the absence and presence of a buried target.

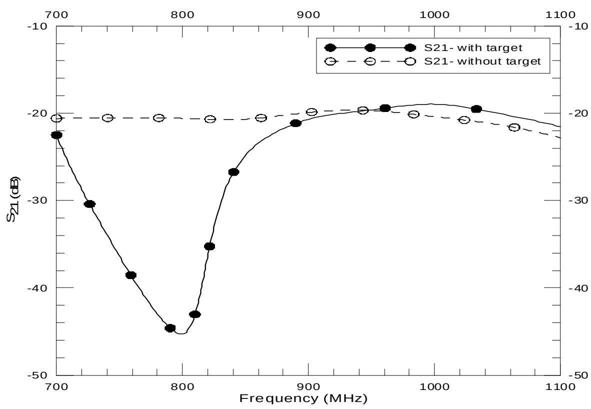

Fig. 9. The coupling coefficient $|S_{21}|$ for the GPR system when placed at a height of 4.5 cm over the ground in the absence and presence of a buried target.

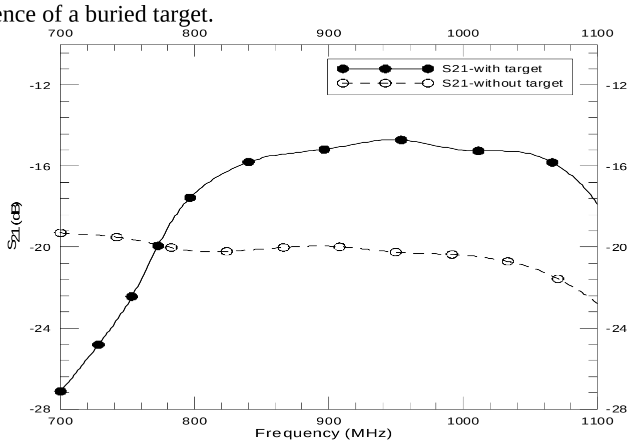

Fig. 10. The coupling coefficient $|S_{21}|$ for the GPR system when placed at a height of 9 cm over the ground in the absence and presence of a buried target

V. CONCLUSION

A wide band antenna designed for Ground-Penetrating Radar (GPR) system is introduced and examined. This antenna consists of dipole antenna housed in a rectangular conducting reflector whose inner walls are coated by an absorbing material. The coating is composed of a number of layers with a conductivity profile designed to achieve the minimum voltage standing wave ratio (VSWR) of the dipole antenna over the frequency band of operation. The antenna impedance and VSWR are calculated using the Finite-Difference Time-Domain (FDTD) method. The antenna impedance and VSWR are presented over a wide-band of frequency. The capability of buried target detection by the proposed antenna is confirmed by investigating the coupling between the transmitting and receiving antennas in the presence and absence of buried targets. The operating bandwidth of the antenna is shown to be about 50%. The effect of the ground soil on the antenna characteristics is studied when the GPR system is placed at different heights above such a soil. The GPR system with the proposed antenna is shown to be capable of detecting the existence of buried targets even when it is placed at different heights above the ground.

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