*Progress In Electromagnetics Research, PIER 71, 211–226, 2007*

# WIDEBAND PARTIALLY-COVERED BOWTIE ANTENNA FOR GROUND-PENETRATING-RADARS

**G. E. Atteia and A. A. Shaalan**

Communications and Electronics Department
Faculty of Engineering
Zagazig University
Egypt

**K. F. A. Hussein**

Electronics Research Institute (ERI)
Dokki, Cairo, Egypt

**Abstract**—In this paper, wide band transmitting and receiving antennas; each composed of a bowtie partially covered by an open conducting box; are proposed for ground-penetrating-radar (GPR) system. The inner walls of the conducting box are covered by a lossy coating which is composed of a number of layers with a conductivity profile designed to achieve better characteristics of the bowtie antenna. The Finite-Difference Time-Domain (FDTD) method is applied to simulate the radiating and receiving antennas, the buried target and the wave propagation in the lossy ground soil over the frequency band of operation. The performance of the proposed system is examined as regards the antenna characteristics and the buried target detectability. The impedance and voltage standing wave ratio (VSWR) of the partially covered bowtie antenna are presented over a wide frequency range. The capability of the proposed GPR system to detect targets buried in a ground soil is examined by investigating the change of the coupling between the transmitting and receiving antennas due to the presence of a buried target. The effect of the ground soil on the antenna characteristics is studied for some common types of real soils when the GPR system is placed at different heights above the ground surface.

## 1. INTRODUCTION

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. A GPR system consists of a transmitting antenna and a receiving antenna. The transmitting antenna is connected to a source and the receiving antenna is connected to a suitable signal processing device. 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.

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, 4, 10, 12], an efficient bowtie antenna for GPR system is developed to exhibit good efficiency in ultra-wide band using a combination of a tapered capacitive and resistive loading.

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. 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 media and soils [5, 6, 11].

This paper proposes a design for a new GPR antenna composed of a bowtie antenna housed in a conducting rectangular reflector whose inner walls are coated by 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 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.

## 2. PROPOSED DESIGN OF THE 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 bowtie housed in a rectangular conducting reflector with inner coating. The function of this reflector is to eliminate direct coupling between the transmitting and receiving antennas and to improve the characteristics of the bowtie antenna over a wide frequency band. For the latter purpose, and to diminish the internal resonances of the rectangular cavity, the inner walls of the rectangular reflector are coated with a lossy absorbing material.

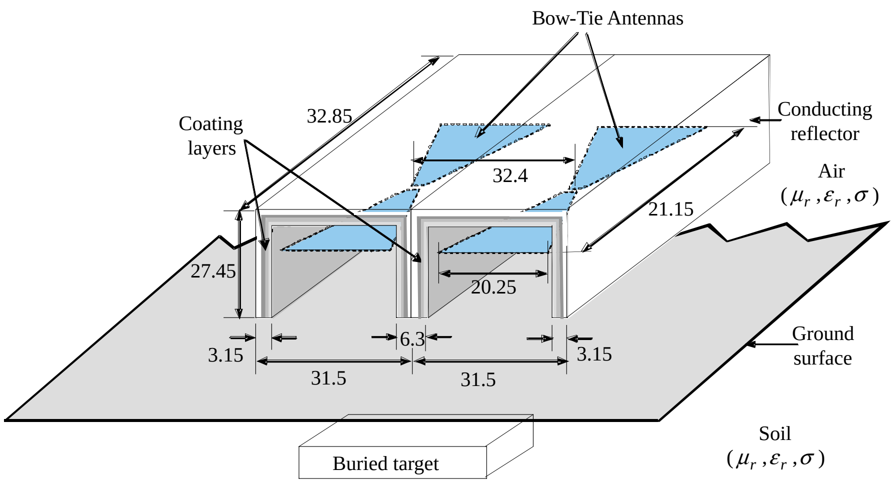



**Figure 1.** The GPR system placed above the ground surface with the proposed bowtie antennas housed in rectangular reflectors (all indicated dimensions are in cm).

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 performance for the common types of ground soils.

## 3. ELECTROMAGNETIC MODELING OF THE GPR SYSTEM USING FDTD

The FDTD method, as described in [7], is applied here to provide electromagnetic simulation for the complete three-dimensional model of the GPR system including the antennas, soil, and buried target. The entire space is divided to 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 UPML is composed of a number of cells with a specific profile of the electric and magnetic properties and is backed by perfectly conducting walls [8].

The input impedance of the bowtie 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 antenna port to the voltage applied at the transmitting antenna port.

## 4. RESULTS AND DISCUSSION

This section is concerned with presenting the results for the input impedance and the VSWR of the bowtie antenna in free-space, when it is housed in a rectangular conducting reflector whose inner walls are coated with an absorbing material, and finally, when this antenna is housed in such a coated enclosure while being placed above a lossy ground. The results concerning the effects of practical types of ground soils on the antenna and, hence, the GPR system performance are presented and discussed. The coefficient of coupling between the receiving and transmitting antennas, $|S_{21}|$, is presented in the entire frequency band of operation considering practical types of ground soils and buried targets.

Two practical types of soil are selected for investigating the performance of the proposed GPR antenna system. The first is known as fairly dry soil that has the properties: $\varepsilon_r = 2.9$, $\mu_r = 1.0$ and $\sigma = 0.02\,\mathrm{S/m}$ [2], and the other type is the red clay soil that has the properties: $\varepsilon_r = 8.1$, $\mu_r = 1.0$ and $\sigma = 0.038\,\mathrm{S/m}$ [2]. Both types of ground soil can be assumed homogenous and non-dispersive over the frequency band of operation [2].

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 $0.45 \times 0.45 \times 0.45$ cm. The field components are updated every $\Delta t = 8.66$ ps. This time step satisfies the condition of numerical stability [7].

It should be noted that, in the following presentations, the proposed bowtie antenna is modeled as a perfect electric conductor of one cell thickness. Its length is 21.15 cm, its width is 20.25 cm, and its flaring angle is 90°. A staircase approximation is used to model the antenna edges.

The coating on the inner walls of the reflectors has a thickness of 3.15 cm and is composed of 7 layers with the conductivity profile: $\sigma = 10^{n-4}$, where $n = 0, 1, 2, 3, 4, 5, 6$ is the layer number and $n = 0$ is number of the layer just touching the air region inside the reflector. The walls of the reflectors are modeled as conductors of $\sigma = 10^{16}$ S/m.

### 4.1. Frequency Response of a Bowtie Antenna in Free Space

The bowtie 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. Fig. 2 shows a time-domain snap-shot of the electric field intensity distribution in the near region around the antenna when it is left in free-space at 800 MHz. The field intensity distribution indicates the staircase model used for the bowtie antenna.

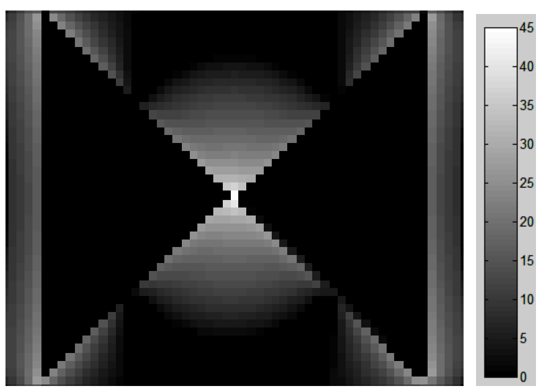
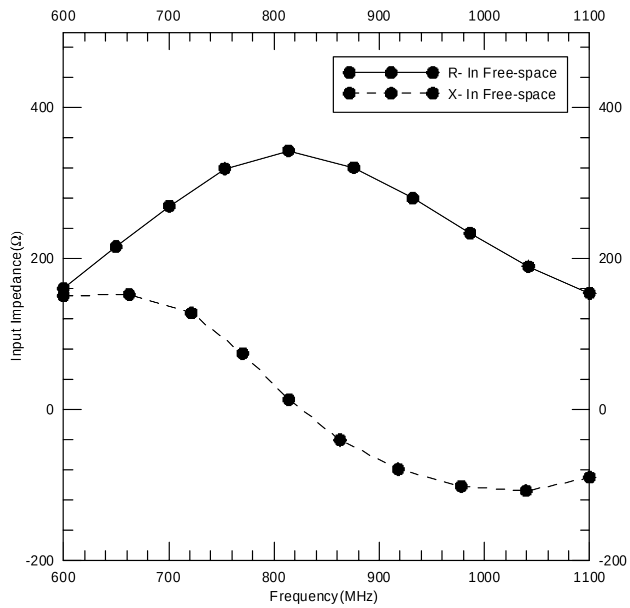
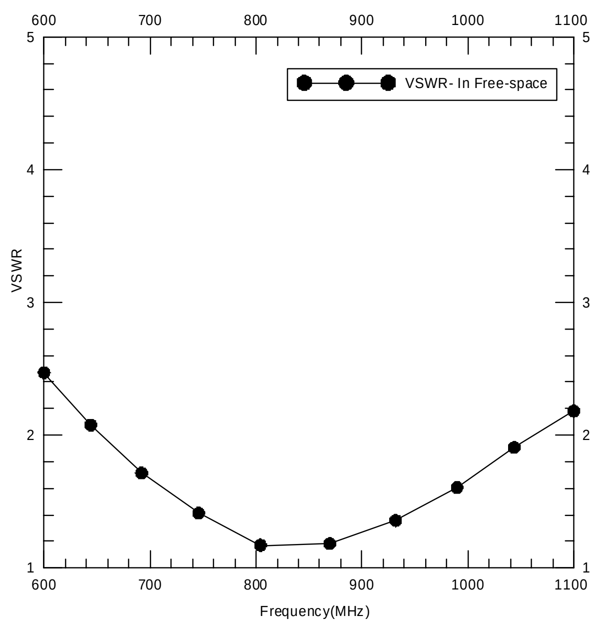



**Figure 2.** Distribution of the electric field intensity in the near region around a bowtie antenna in free space at 800 MHz.

Figure 3 shows the frequency response of the antenna impedance and the VSWR with respect to a source impedance of 300 Ω. It is clear that the antenna is suitable for operation over the frequency band 700–1050 MHz, i.e., about 40% bandwidth.




(a)




(b)

**Figure 3.** Frequency response of the bowtie antenna in free space, (a) input impedance, (b) VSWR with respect to $300\,\Omega$.

### 4.2. Frequency Response of a Bowtie Antenna inside a Coated Reflector

To investigate the performance of the proposed antenna 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.

For a bowtie antenna housed in a rectangular reflector whose inner walls are covered by the 7-layer coating with the conductivity profile described above, Fig. 4 shows the frequency response of the antenna impedance and VSWR, respectively, over a wide frequency band. In this case it is more appropriate to take the source impedance as $170\,\Omega$. It is clear, in Fig. 4(b), that as regards the VSWR, this antenna is suitable for operation over the band 600–1200 MHz, i.e., its bandwidth is about 66%.

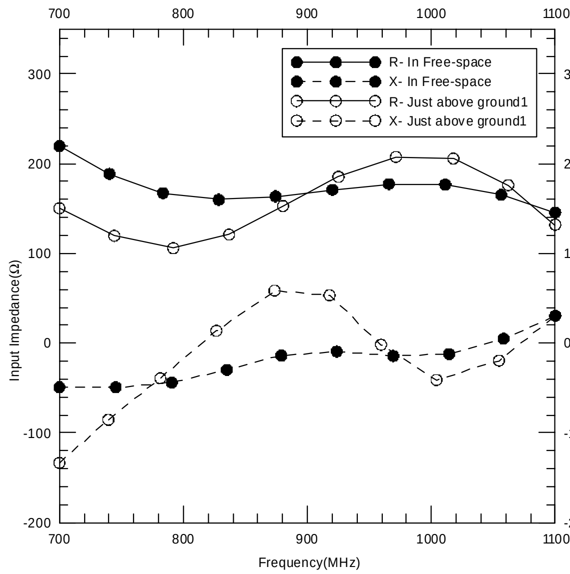
Comparing the characteristics of the bowtie antenna in free space presented in Fig. 3 to those of the same antenna when housed inside the coated reflector which are presented in Fig. 4, it becomes clear that housing the bowtie antenna in such a reflector results in a significant reduction in the reactive part of the antenna impedance and, at the same time, keeps the resistive part of the antenna impedance more stable over a wide frequency range. This results in improving the VSWR and, thereby, increasing the antenna bandwidth from 40% to 66%.

### 4.3. Effect of the Ground Soil on the GPR Antenna Characteristics

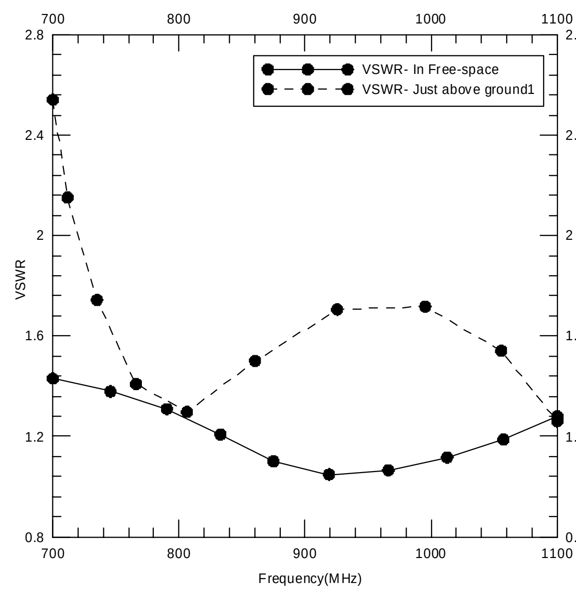
During the operation of buried target detection, the bowtie antenna is placed very close to the ground surface. For this reason, the effect of the ground soil on the characteristics of the GPR antenna should be studied. In this section, the effect of the ground on antenna performance is examined for the fairly dry and red clay soils described above.

For the fairly dry soil ($\varepsilon_r = 2.9$, $\mu_r = 1.0$ and $\sigma = 0.02\,\mathrm{S/m}$), Fig. 5 shows the frequency response of the antenna impedance and the corresponding VSWR with respect to $130\,\Omega$ source impedance when the GPR is placed with the reflectors apertures touching the ground surface. Compared with the characteristics of the same antenna in free-space, it becomes clear that the ground soil has a bad effect on the antenna impedance and hence, the VSWR.

When the GPR system is raised above the ground so that the reflectors apertures are kept at a height of 4.5 cm over the ground surface instead of being touching it, the antenna performance is

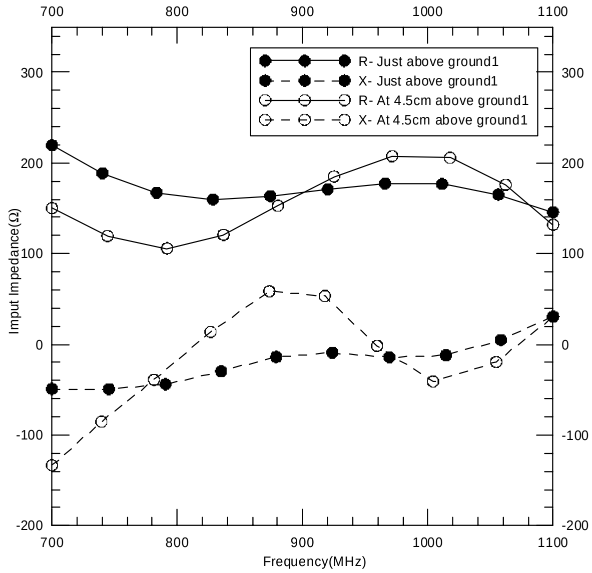



(a)

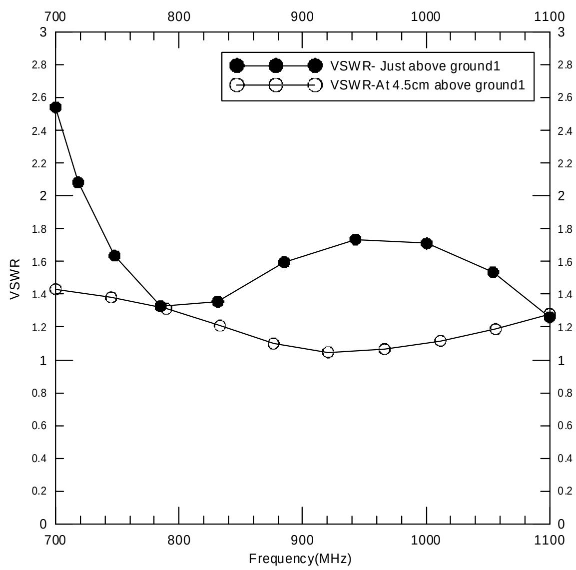



(b)

**Figure 4.** Comparison between the frequency responses of bowtie antenna housed in a rectangular reflector when left in free space and when placed touching the surface of a fairly dry soil (ground-1), (a) input impedance, (b) VSWR with respect to 170 Ω.




(a)




(b)

**Figure 5.** Comparison between the frequency responses of a bowtie antenna housed in a rectangular reflector when placed touching the surface of a fairly dry soil (ground-1) and when it is placed at a height of 4.5 cm above the same soil, (a) input impedance, (b) VSWR with respect to 170 Ω.

improved as shown in Fig. 5. It may be concluded, from this, that the higher the antenna position above the ground, the less the effect of the ground on its performance.

For the red clay soil ($\varepsilon_r = 8.1$, $\mu_r = 1.0$ and $\sigma = 0.038\,\mathrm{S/m}$), Fig. 6 shows the frequency response of the antenna impedance and the corresponding VSWR with respect to $170\,\Omega$ source impedance when the antenna is placed with the apertures of the reflectors touching the ground surface. Comparing the GPR antenna characteristics in this case with those of the same antenna in free-space, Fig. 4, it becomes evident that the ground soil has a bad effect on the antenna impedance and, hence, the VSWR.

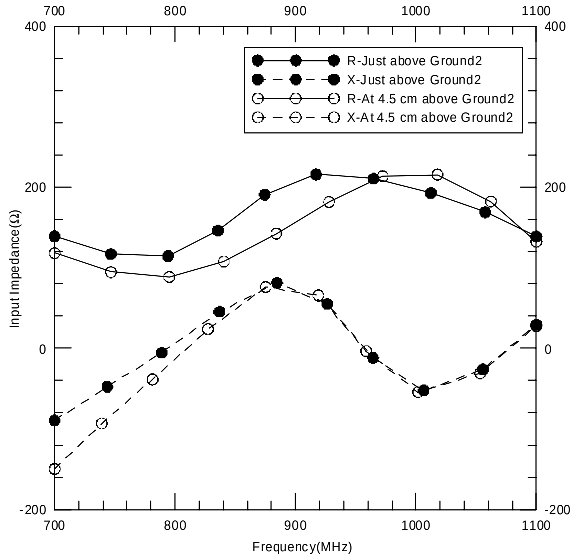
When the GPR system is raised above the ground so that the reflectors apertures are kept at a height of 4.5 cm over the ground surface instead of being touching it, the antenna performance is improved as shown in Fig. 6. This ensures that the higher the antenna position above the ground, the less the effect of the ground on its performance.

Figure 7 shows a comparison between the effects of the two types of soil on the GPR antenna impedance and VSWR when the GPR system is placed so that the reflectors apertures are touching the ground surface. It is clear that the red clay soil has worse effects on the antenna performance than those of the fairly dry soil.

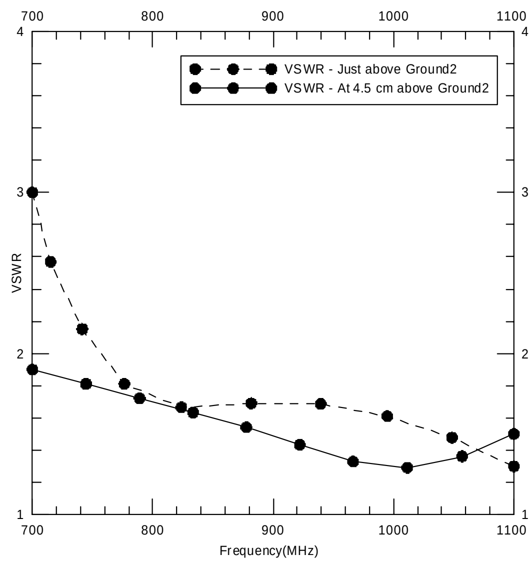
### 4.4. Capability of the GPR System to Detect Buried Targets

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

To examine the ability of the GPR system it is used to detect a buried dielectric block of dimensions $31.15 \times 58.95 \times 6.75\,\mathrm{cm}$ with the electric properties: $\varepsilon_r = 8$, $\mu_r = 1.0$, $\sigma = 0.0\,\mathrm{S/m}$. This dielectric block is buried at a depth of 6.75 cm below the surface of a fairly dry soil of the electric properties given above. Fig. 8 shows the coupling coefficient $|S_{21}|$ between the transmitting and the receiving antennas of the GPR system when it is placed touching the surface of an empty ground and when the dielectric block described above is buried at a depth of 6.75 cm under the ground surface. The comparisons are presented over a wide range of frequency for the fairly dry and red clay soils as shown in the figure. Considerable increase in $|S_{21}|$ occurs due to the presence of the target over most of the operating frequency band, which indicates the capability of the proposed system to detect buried targets.

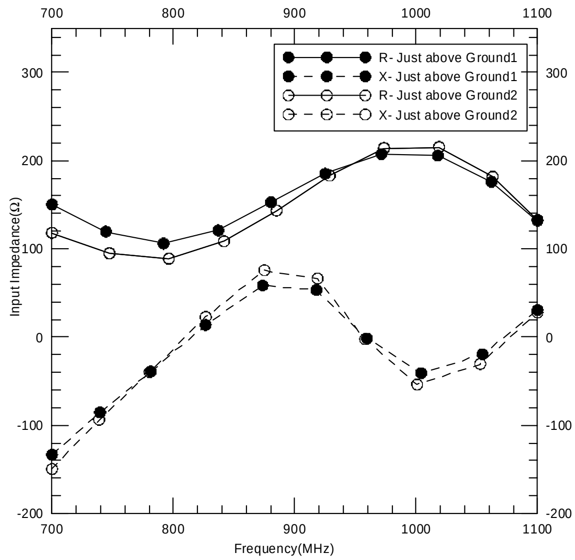



(a)

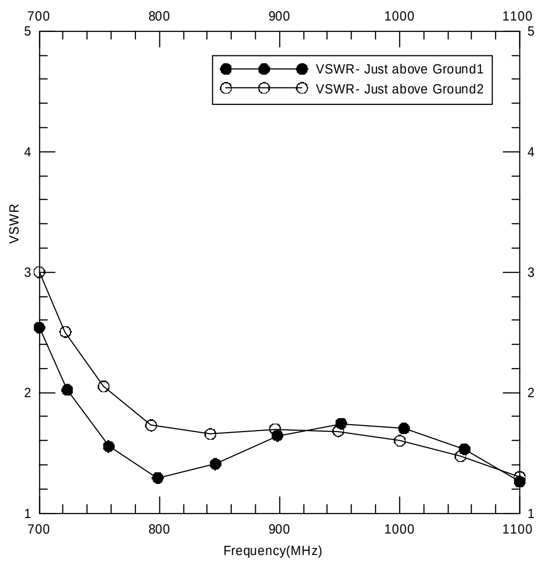



(b)

**Figure 6.** Comparison between the frequency responses of a bowtie antenna housed in a rectangular reflector when placed touching the surface of a red clay soil (ground-2) and when it is placed at a height of 4.5 cm above the same soil, (a) input impedance, (b) VSWR with respect to 170 Ω.

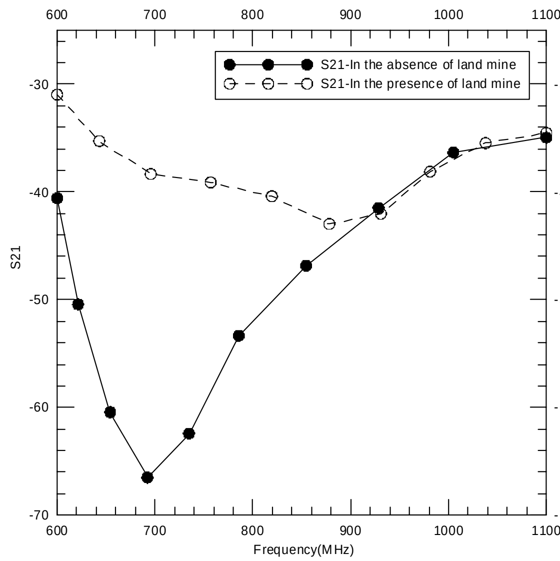



(a)

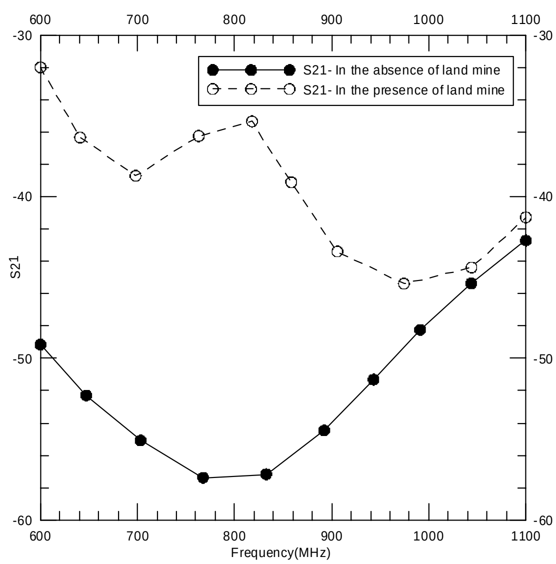



(b)

**Figure 7.** Comparison between the frequency responses of a bowtie antenna housed in a rectangular reflector when placed touching the surface of a fairly dry soil (ground-1) and when placed touching the surface of a red clay soil (ground-2). (a) input impedance, (b) VSWR with respect to $170\,\Omega$.



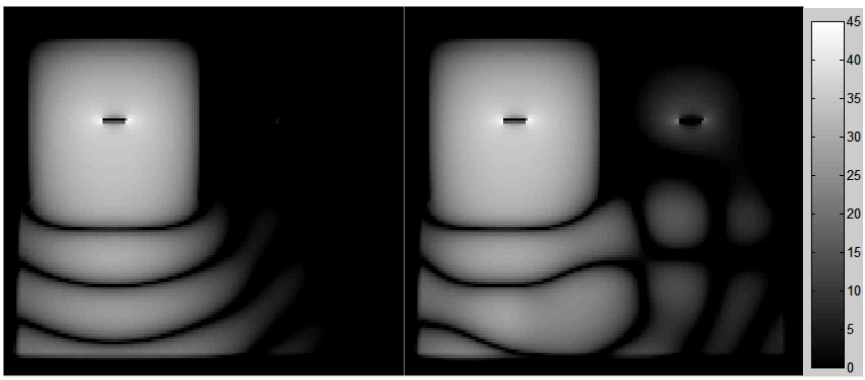

(a)




(b)

**Figure 8.** The coupling coefficient $|S_{21}|$ between the transmitting and receiving antennas in the presence and absence of the buried dielectric target, (a) the GPR system is placed touching the surface of a fairly dry soil (ground-1), (b) the GPR system is placed touching the surface of a red clay soil (ground-2).

Figure 9 shows a time-domain snap-shot for the electric field intensity distribution in the ground soil and inside the reflectors of the GPR system. It should be noted that, in each of the two Figures 9(a) and 9(b), the transmitting antenna is to the left and the receiving antenna is to the right. It is clear, in the figure, that the buried target causes a significant increase in the intensity of the field arriving at the receiving antenna in comparison with the intensity of the field arriving at this antenna when there is no target buried in the ground.




(a) (b)

**Figure 9.** Electric field intensity distribution in the ground and inside the reflectors when the GPR is placed touching the surface of an empty red clay soil at 600 MHz, (a) the ground is empty, (b) a dielectric block is buried at a depth of 6.75 cm under the soil surface.

## 5. CONCLUSION

A wideband antenna composed of a bowtie partially covered by an open conducting box is proposed to operate as transmitting and receiving antennas for GPR system. The inner walls of the conducting box are covered by a lossy coating which is composed of a number of layers with a conductivity profile designed to achieve better characteristics of the bowtie antenna. The performance of the proposed system is examined considering the antenna characteristics and the buried target detectability. The impedance and the VSWR of the partially covered bowtie antenna are presented over a wide frequency range. The capability of proposed GPR system to detect targets buried in a ground soil is examined by investigating the change of the coupling between the transmitting and receiving antennas due to the presence of buried targets of practical dimensions. The bandwidth of the antenna is shown to be about 66%. The effect of the ground soil on the antenna characteristics is studied for two common types of real soils when the GPR system is placed at different heights above the ground surface.

## REFERENCES

1. Oguz, U. and L. Gurel, "Modeling of ground-penetrating radar antennas with shields and simulated absorbers," *IEEE Trans. Antennas Propagat.*, Vol. 49, No. 11, November 2001.
2. Bourgeois, J. M. and G. S. Smith, "A complete electromagnetic simulation of the separated-aperture sensor for detecting buried land mines," *IEEE Trans. Antennas Propagat.*, Vol. 46, No. 10, October 1998.
3. Lestari, A. A., A. G. Yarovoky, and L. P. Ligthart, "Ground influence on the input impedance of transient dipole and bowtie antennas," *IEEE Trans. Antennas Propagat.*, Vol. 52, No. 8, 1970–1975, Aug. 2004.
4. Nishioka, Y., O. Maeshima, T. Uno, and S. Adachi, "FDTD analysis of resistor-loaded bowtie antenna covered with ferrite-coated conducting cavity for subsurface radar," *IEEE Trans. Antennas Propagat.*, Vol. 47, No. 6, June 1999.
5. Bourgeois, J. M. and G. S, Smith, "A fully three-dimensional simulation of ground- penetrating radar: FDTD theory compared with experiment," *IEEE Trans. on Geosciences and Remote Sensing*, Vol. 34, No. 4, January 1996.
6. Yee, K. S., "Numerical solution of initial boundary value problem using maxwell's equations in isotropic media," *IEEE Trans. Antennas Propagat.*, Vol. AP-14, May 1966.
7. Teixeira, F. L. and W. C. Chew, "Finite-Difference-Time-Domain method simulation of ground-penetrating radar on dispersive in homogeneous and conductive soils," *IEEE Trans. on Geosciences and Remote Sensing*, Vol. 36, No. 6, November 1998.
8. Lestari, A. A., A. G. Yarovoy, and L. P. Lightar, "Ground influence on the input impedance of transient dipole and Bow-Tie antennas," *IEEE Trans. Antennas Propagat.*, Vol. 52, No. 8, August 2004.
9. Taflove, A., *Computational Electrodynamics: The Finite-Difference-Time-Domain Method*, Artech House, Boston, MA, 1995.
10. Qu, S. and C. Ruan, "Effect of round corners on bowtie antennas," *Progress In Electromagnetics Research*, PIER 57, 179–195, 2006.

11. Chen, X., K. Huang, and X.-B. Xu, "Microwave imaging of buried inhomogeneous objects using parallel genetic algorithm combined with FDTD method," *Progress In Electromagnetics Research*, PIER 53, 283–298, 2005.
12. Uduwawala, D, M. Norgren, P. Fuks, and A. Gunawardena, "A complete FDTD simulation of a real GPR antenna system operating above lossy and dispersive grounds," *Progress In Electromagnetics Research*, PIER 50, 209–229, 2005.