International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:11, No:7, 2017

Investigation of Utilizing L-Band Horn Antenna in Landmine Detection

Ahmad H. Abdelgwad, Ahmed A. Nashat

Abstract**—**Landmine detection is an important and yet challenging problem remains to be solved. Ground Penetrating Radar (GPR) is a powerful and rapidly maturing technology for subsurface threat identification. The detection methodology of GPR depends mainly on the contrast of the dielectric properties of the searched target and its surrounding soil. This contrast produces a partial reflection of the electromagnetic pulses that are being transmitted into the soil and then being collected by the GPR. One of the most critical hardware components for the performance of GPR is the antenna system. The current paper explores the design and simulation of a pyramidal horn antenna operating at L-band frequencies (1- 2 GHz) to detect a landmine. A prototype model of the GPR system setup is developed to simulate full wave analysis of the electromagnetic fields in different soil types. The contrast in the dielectric permittivity of the landmine and the sandy soil is the most important parameter to be considered for detecting the presence of landmine. L-band horn antenna is proved to be well-versed in the investigation of landmine detection.

Keywords—Full wave analysis, ground penetrating radar, horn antenna design, landmine detection.

I. Introduction

RESEARCH and development in the domain of radar technologies especially in the target data collection, precision locating and tracking applications have been gaining interest among researchers. GPR is one of the radar systems that are used for subsurface investigation, such as the detection of objects buried beneath the earth's surface, hidden tunnels, cables, pipes, and landmines [1], [2]. The detection of a landmine has been a popular research area over the past few years. The intensive research is driven by the need in military operations and humanitarian purposes to clear up mine fields left after wars which cause large numbers of deaths and injuries every year. One of the most important components in a GPR system is the transmitting and receiving antennas. The need to obtain a fine resolution and good penetration depth for a portable GPR requires the antenna to have desired features such as ultra wide bandwidth, good impedance matching, unidirectional radiation pattern and be small or compact in size [2].

GPR is a non-destructive tool for non-invasive investigation [3]. GPR is a geophysical technique that can be used to investigate and map the dielectric properties of the subsurface [4], [5]. It is based on measuring the electromagnetic pulses that being transmitted into the medium and then being collected by the receiver. The performance of GPR and related detecting techniques relies mainly on the high contrast of the searched target and its surroundings.

GPR systems usually operate in the vicinity of the soil. Hence, the dielectric characteristics of soil determine the GPR system parameters like the operating frequency and the power levels. The optimal antenna design must provide steady performance for different soil types and weather conditions. Dry soils are favourable for the GPR application, since higher radio-frequencies can be used for a given depth of investigation [6]. The success of GPR in detecting the landmine depends on the penetration depth as well as frequency of the GPR signal. The frequency of the radar signal is a trade-off. Low frequencies give better penetration, but low resolution so that soil contamination may not be detected. Contamination may be better detected utilizing higher frequencies, but the depth of penetration may be limited to only a couple of centimetres particularly in moist soil.

The current paper is organized as follows. Section II describes the prototype model. It is introduced to investigate the effectiveness of L-band horn antenna in landmine detection. The situation incorporates a box which is filled with sandy soil. Two scenarios are studied, the first is where the soil does not contain the landmine, and the second one is where the landmine is buried on the soil to investigate that microwave sensing is precisely able to discriminate between the two scenarios. On the basis of such a description, two identical wideband pyramidal horn antennas that operate at L-band frequencies are designed. Section III illustrates the design of the antennas. In section IV, the design is tested and the results are discussed. Section V offers the conclusions.

II. Prototype Model

The primary objective of this work is to research the potential of using bi-static architecture of the GPR as a tool for landmine detection. Bi-static radar architecture employs two sites, which separated by a considerable distance. A transmitter is placed at one site, and the associated receiver is placed at the other site. To achieve this objective, a prototype model is precisely designed. This model essentially comprised of a wooden box loaded with sandy soil where a piece of mine is incorporated in soil for simulation. The geometry of the prototype model is shown in Fig. 1 and the optimized dimensions, searched for modelling, are tabulated in Table I.

A. H. Abdelgwad is with the Department of Electrical Engineering, Faculty of Engineering, Fayoum University, Fayoum, 63514 Egypt (corresponding author, phone: +201007665621; e-mail: aha05@fayoum.edu.eg).

A. A. Nashat is with the Department of Electrical Engineering, Faculty of Engineering, Fayoum University, Fayoum, 63514 Egypt (e-mail: aan01@fayoum.edu.eg).

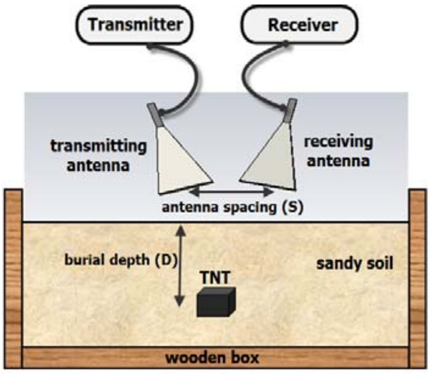

Fig. 1 Landmine detection prototype model

TABLE I
OPTIMIZED DIMENSIONS OF THE PROTOTYPE MODEL

Parameter	value (cm)
wooden box length	200
wooden box width	100
wooden box height	100
antenna height from ground surface (H)	10
antenna spacing (S)	50
TNT burial depth (D)	40
antenna tilting from vertical	20˚

The prototype model for the situation outlined in Fig. 1 is simulated by dielectric modelling of mediums of interest. Propagation of microwave signals in materials is dictated by their electrical properties, chief amongst these is the dielectric permittivity. Permittivity portrays the interaction of a material with the electric field and it can be seen as a capacity to store electric energy due to changes in the relative positions of electric charge displacements shaped by internal positive and negative charges.

III. HORN ANTENNA DESIGN

The primary part of a GPR system is comprised of the antenna design. In order to get reasonable penetration depth and fine resolution for GPR, the antenna should have certain features like high directivity and efficiency, wide operational bandwidth, good impedance matching, and directional radiation pattern [7]. Horn antennas are the most popular antennas in the microwave band (above 1 GHz) because of their advantages. Horn antennas are cheap and simple to be manufactured; they provide wide bandwidth, high directivity and gain, and low voltage standing wave ratio with waveguide feeders. Hence, they are the best choice for many GPR applications. The rectangular waveguide feeders are typically suitable for the rectangular horn antennas and the antenna's horn can be considered as a transition stage between the waveguide mode and the free-space mode of the microwave signal [8].

For GPR applications, the higher the frequency, the less the signal is able to pass through the medium. However, higher frequency antennas will provide better image resolution with more data detail for interpretation. This trade-off exists across all GPR antennas. L-band frequencies are the most appropriate band to obtain the optimum results for the proposed model. A pyramidal horn antenna operating at L-band (from 1 GHz to 2 GHz) is designed using Computer Simulation Technology (CST) software program for landmine detection model. The material used for designing the pyramidal horn and the waveguide is assumed to be perfect electric conductor (PEC) with thickness of 2mm. This guarantees that the microwave signals transmitted in the waveguide is appropriately reflected and the surface current on the waveguide does not produce much Ohmic loss. Fig. 2 depicts the structure of the proposed pyramidal horn antenna. The antenna is associated with a coaxial adapter which provides match between the waveguide and a 50 ohm coaxial to be connected to the vector network analyzer (VNA) where the power flow can be in either direction. The overall optimized dimensions of the designed antenna, obtained utilizing the mathematical relationships of the pyramidal horn antennas dimensions in [7], are organized in Table II.

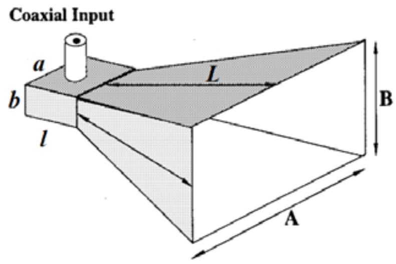

Fig. 2 Geometry of the proposed GPR horn antenna

TABLE II
OPTIMIZED DIMENSIONS OF THE ANTENNA

Antenna dimension	Unit (cm)
aperture width, *A*	41
aperture height, *B*	30
aperture length, L	60
waveguide width, *a*	24
waveguide height, *b*	12
waveguide length, *l*	20

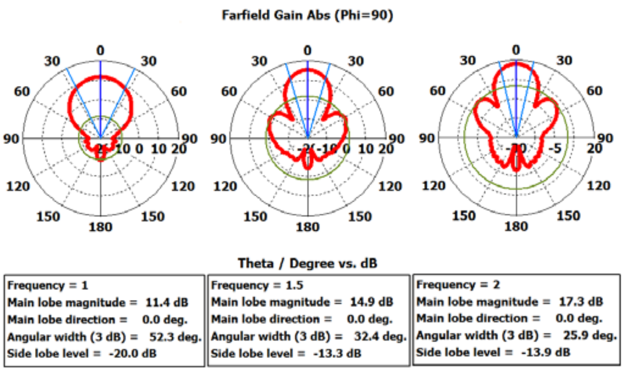

Fig. 3 Radiation pattern of the designed antenna at 1, 1.5 and 2 GHz

The simulated 2D polar radiation pattern of the antenna at 1 GHz, 1.5 GHz and 2 GHz is portrayed in Fig. 3. Interestingly, the designed horn antenna provides directive radiation pattern with gain up to11.4 dB, 14.9 dB, and 17.3 dB at 1 GHz, 1.5 GHz, and 2 GHz, respectively; this high gain helps the microwave signals to penetrate the soil deeper beneath the ground surface. Furthermore, the very low side lobe level and the narrow beam width of the antenna diminish the coupling between the transmitting and receiving antennas. This in turn enhances the landmine detection.

IV. Results and Discussion

GPR system is an electromagnetic geophysical method that utilizes microwave signals to gain subsurface information by detecting the reflected signals of subsurface structures. At the point when the radiated wave hits a boundary or a buried object with different dielectric constants, the receiving antenna senses the variations in the reflected return signal. There are three GPR architectures: mono-static, bi-static and multi-static architectures. In a mono-static architecture, only single antenna is used for transmitting and receiving of GPR signals, while in bi-static architecture, two separated antennas are used for the transmitting and the receiving parts. In multi-static radar system, the signal is transmitted by an antenna, while the multiple receiving antennas in an array configuration are utilized for receiving of the reflected signals. In the current study, a bi-static radar system is introduced.

The capability of the GPR system to detect landmine can be measured by the change of the electromagnetic coupling, $|S_{21}|$, between the transmitting and receiving antennas due to the presence of landmine. The coupling coefficient, $|S_{21}|$, is simulated at L-band frequencies. A simulation setup is realistically implemented in the CST Microwave Studio. Two models are presented; the first one is where landmine is placed on the soil, as portrayed in Fig. 1, while the second one is where there is no landmine buried on the soil. The coupling coefficients, $|S_{21}|$, for both models are compared in Fig. 4, with the dimensions listed in Table I. The results indicate a significant increase in the reflected signal coefficient of the model with landmine buried in soil compared to the model without landmine. The coupling coefficient, $|S_{21}|$, is further investigated for the case of the increase of moisture content of soil, the burial depth at which the landmine is buried, and the change of spacing between the Tx and Rx antennas.

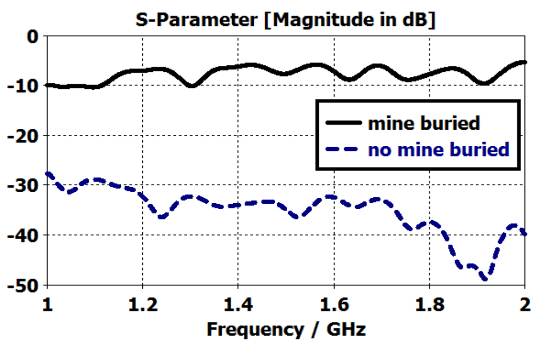

Fig. 4 Simulated S_{21} coefficient for landmine models with and without landmine buried in soil

A. Effect of Soil Moisture

The depth range of the GPR system is restricted by the electrical conductivity of the soil, the operating frequency band and the radiated power. As soil conductivity increases, the penetration depth decreases. This is because the electromagnetic energy is more immediately dissipated into heat, causing signal strength loss at depth. Moist soils usually have high electrical conductivity due to water content in the soil, so penetration is sometimes only a couple of centimeters. The dry sandy soil model results discussed previously indicate significant contrast in the $|S_{21}|$ of the model with landmine vs. the model without buried landmine.

By supplanting the dry sandy soil with moist sandy soil with dielectric constant of 13 and dielectric loss tangent of 0.29 [9], this contrast becomes insignificant at L-band frequencies due to the high attenuation of moist soil which reduces the amount of power that path through to the landmine. In Fig. 5, the simulated $|S_{21}|$ coefficient is plotted for moist soils. It is observed that $|S_{21}|$ is reduced compared with the dry soil model due to the high conductivity of moist soil which increases the attenuation. The results clarify, as expected, that landmines are effectively detected in dry sandy soil, but detection becomes infeasible in moist soils.

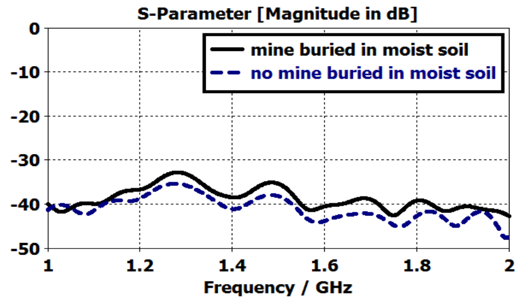

Fig. 5 Simulated S_{21} coefficient for landmine buried in moist sandy soil at L-band

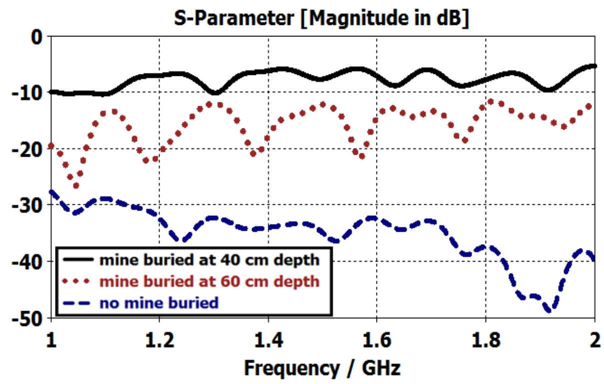

Fig. 6 Simulated S_{21} coefficient of landmine models for two different landmine burial depths (D)

B. Effect of Landmine Burial Depth (D)

Fig. 6 demonstrates the effect of increasing the depth (D) at which the landmine is buried from 40 cm to 60 cm on the coupling coefficient, $|S_{21}|$, while all other dimensions listed in

Table I are the same. The results indicate that while the landmine burial depth increases, the coupling coefficient $|S_{21}|$ shows a slight decrease. This indicates that if the landmine is buried near to the surface of the ground, it becomes easier to be detected. If the landmine is buried at deeper depth, the backscattered power becomes weaker due to the increased attenuation. Hence, it is more challenging to detect deeper landmines.

C. Effect of Antenna Spacing(S)

The determination of spacing between the transmitting and receiving antennas (*S*) and the tilting (orientation) of the antennas are very critical as they control the direct coupling between the transmitting and receiving antennas. In order to achieve the best landmine detection, this direct coupling should be minimized. As the antennas spacing increases, the direct coupling between the transmitting and receiving antennas decreases. However, the received reflected signals from the landmine likewise become weaker. The optimized spacing between the Tx and Rx antennas is 50 cm at which the direct coupling is minimized and in meanwhile the received reflected signal from landmine is significantly notable. Fig. 7 illustrates the effect of increasing the direct coupling between the transmitting and receiving antennas by decreasing of the antenna spacing (*S*) from 50 cm to 40 cm while keeping all other dimensions as in Table I. The comparison is presented over the L-band frequencies for the two models with and without landmine buried in soil. The results indicate that as the antenna spacing decrease, considerable increase occurs in $|S_{21}|$ due to the increase of the direct coupling between the two antennas, so low side lobe level of the antenna is a preferable property of the GPR antennas, where lower side lobe level is very useful to reduce the direct coupling between the transmitting and receiving antennas in the bi-static GPR architecture.

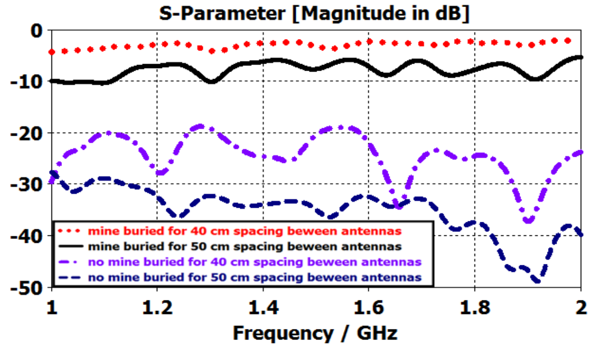

Fig. 7 Simulated S_{21} coefficient for landmine models for two different antenna spacing (*S*)

V. CONCLUSIONS

The present paper discusses the validity and effectiveness of using L-band horn antenna as a tool for detecting landmines. Supported by full-wave electromagnetic simulations, we have discussed simulation aspects and design considerations of a prototype model of a landmine buried in a sandy soil. Two identical horn antennas operating at L-band frequencies have been designed and exploited for bi-static GPR system. The obtained results show that there are notable contrasts in the reflected signal of the two models with and without buried landmine. Many situations are investigated like the use of moist soil, increasing the landmine burial depth, and changing of the antennas spacing. The primary conclusion of this research is that the GPR technique with L-band horn antenna could be used for landmine detection.

REFERENCES

[1] L. Li, A.E Choon Tan, K. Jhamb and K. Rambabu, " Buried object characterization using ultra-wideband ground penetrating radar" *IEEE Transaction on Microwave and Techniques*, vol.60, no. 8, Aug. 2012.

[2] Ahmad H. Abdelgwad, Tarek M. Said and Amr M. Gody, "A Non-destructive Electromagnetic-based Model for Detecting Water Pollution in Underground Pipelines," *Al-Azhar University Engineering Journal, JAUES*, Vol. 9, No. 3, pp.1-8, Dec. 2014.

[3] Ahmad H. Abdelgwad, Tarek M. Said, Amr M. Gody, "Microwave Detection of Water Pollution in Underground Pipelines," *International Journal of Wireless and Microwave Technologies, IJWMT*, vol.4, no.3, pp.1-15, Oct. 2014.

[4] J. Francke, "Applications of GPR in mineral resource evaluations," in *13th Int. Ground Penetrating Radar Conf.*, Lecce, Italy, 21–25, pp. 1–5, June 2010.

[5] Ahmad H. Abdelgwad, Tarek M. Said, "Measured Dielectric Permittivity of Contaminated Sandy Soil at Microwave Frequency," *Journal of Microwaves, Optoelectronics and Electromagnetic Applications, JMOe*, vol.15, no.2, pp. 51-58, June 2016.

[6] Ahmad H. Abdelgwad, Tarek M. Said, and Amr M. Gody, "Developing of A Ground Penetrating Radar Antenna for Detecting Water Pollution in Underground Pipelines," *International Journal of Microwaves Applications*, vol. 4, no. 1, Feb. 2015.

[7] C. A. Balanis, "Antenna Theory: Analysis and Design," John Wiley and Sons Inc., Hoboken, New Jersey, 2005.

[8] V. Ohri, O. Amin, H. Gebremariam, B. Dubois, "Microwave Horn Antenna Design and Test System," Senior Design Project II, San Jose State University, 2003.

[9] H. Trang, "Simulation of mine detection over dry soil, snow, ice and water," *Proc. SPIE*, vol. 2765, pp. 430-440, 1996.