

PAPER • OPEN ACCESS

Design and Simulation of Horn Antenna Using CST Software for GPR System

To cite this article: Ariffuddin Joret *et al* 2018 *J. Phys.: Conf. Ser.* **995** 012080

View the [article online](#) for updates and enhancements.

You may also like

- [A full-polarimetric GPR system and its application in ice crack detection](#)
Xiaotian Li, Xuan Feng, Wenjing Liang et al.
- [Measuring soil layer thickness in land rearrangement with GPR data](#)
Xianlei Xu, Suping Peng, Wu Xiao et al.
- [Acquiring underground infrastructure's as-built information for cities' sustainability](#)
S W Jaw



IOP | ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

Design and Simulation of Horn Antenna Using CST Software for GPR System

Ariffuddin Joret^{1,3}, M S Sulong^{1,3}, M F L Abdullah¹, Aziman Madun², and Samsul Haimi Dahlan^{1,4}

¹Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia

²Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia

³Microelectronics and Nanotechnology Centre, Universiti Tun Hussein Onn Malaysia

⁴Research Centre for Applied Electromagnetic, Universiti Tun Hussein Onn Malaysia

Abstract. Detection of underground object can be made using a GPR system. This system is classified as a non-destructive technique (NDT) where the ground areas need not to be excavated. The technique used by the GPR system is by measuring the reflection of electromagnetic wave signal produced and detected by antenna which is known as the transmitter and the receiver antenna. In this study, a GPR system was studied by means of simulation using a Horn antenna as a transceiver antenna. The electromagnetic wave signal in this simulation is produced by current signal of an antenna which having a shape of modulation of Gaussian pulse which is having spectrum from 8 GHz until 12 GHz. CST and MATLAB Software are used in this GPR system simulation. A model of a Horn antenna has been designed using the CST software before the GPR's system simulation modeled by adding a model of background in front of the Horn antenna. The simulation results show that the output signal of the Horn antenna can be used in detecting embedded object which are made from material of wood and iron. In addition, the simulation result has successfully developed a 3D model image of the GPR system using output signal of the Horn antenna. The embedded iron object in the GPR system simulation can be seen clearly by using this 3D image.

1. Introduction

Ground Penetrating Radar (GPR) system is a radar system that can be used in searching of a buried object in soil. The principle of GPR in detecting an underground object was by using the scattering principle of electromagnetic waves [1]. Three types of GPR system that are often used by researchers of the GPR system are Impulse GPR [2], Step Frequency Continuous Wave (SFCW) GPR [3, 4, and 5] and Frequency Modulated Continuous Wave (FMCW) GPR [6].

In the Impulse GPR system, antenna is used to transmit and receive a pulse signal into and from ground. Measurement of this pulse signal, which was the electromagnetic wave that was reflected by the ground, can provide information about the buried object and the structure of the ground [2]. Theoretically, the depth of objects buried under the ground that can be detected by the GPR system depends on the formula (1) given [7, 8, and 9].

$$d = \frac{vt}{2\sqrt{\epsilon_r}} \quad (1)$$



Where d is the depth in meters, v is the speed of electromagnetic waves in air, measured as 3×10^8 m/s, t is the time of propagation of electromagnetic waves from GPR system equipment to the surface of the object, measured in seconds and ϵ_r is medium permittivity.

In the GPR system, antenna plays an important role and need to be chosen wisely. The characteristics of the GPR antenna should have a unidirectional radiation pattern with high gain. Several types of antenna that normally used in the GPR system are the Dipole antenna, the Horn antenna and the Vivaldi antenna of the micro strip types [8, 10, and 11]. In the development of the GPR system equipment, a model of GPR system can be developed using the Computer Simulation Technology (CST) software, in order to avoid many measurement problems that will occurs in the GPR system equipment that to be developed, and also to obtain the best radar's parameters of this GPR equipment [12].

In this paper, two types of GPR system simulation are conducted. The first simulation is carried out to verify the capability of the GPR system using a Horn antenna to detect an object buried in sandy soil. In the second simulation, a scanning procedure of a GPR system model is conducted to detect an iron bar that buried in sandy soil. Here, the result is displayed as an image view of common GPR system.

2. Materials and Methods

In this study, the GPR system simulation has been developed using CST Studio Suite software in order to get output of current signal of the antenna. This output signal will then be extracted into MATLAB software to be analyzed and produce an image of the GPR system in form of 2D and 3D. Based on the CST Studio Suite software, the material of the ground used in the development of this GPR system simulation was the sandy soil while the embedded object's material used were the wood and iron.

2.1. GPR system simulation using CST

The development of the GPR system simulation using CST software in this study was started with the design of a Horn antenna. This antenna has been designed using PEC material as shown in figure 1 [11].

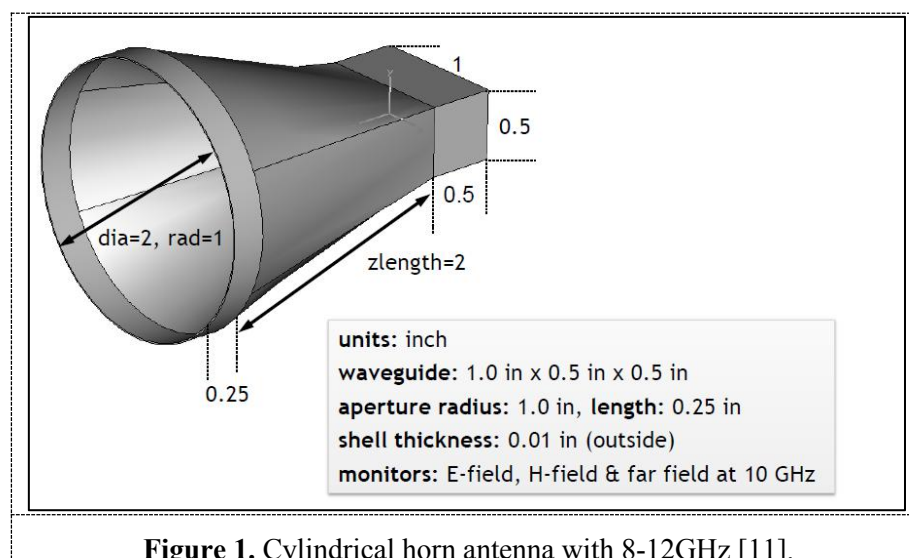


Figure 1. Cylindrical horn antenna with 8-12GHz [11].

After gaining suitable design of a Horn antenna, the GPR system simulation was developed by adding models of a ground and an embedded object to the Horn antenna model in the CST software as shown in figure 2.

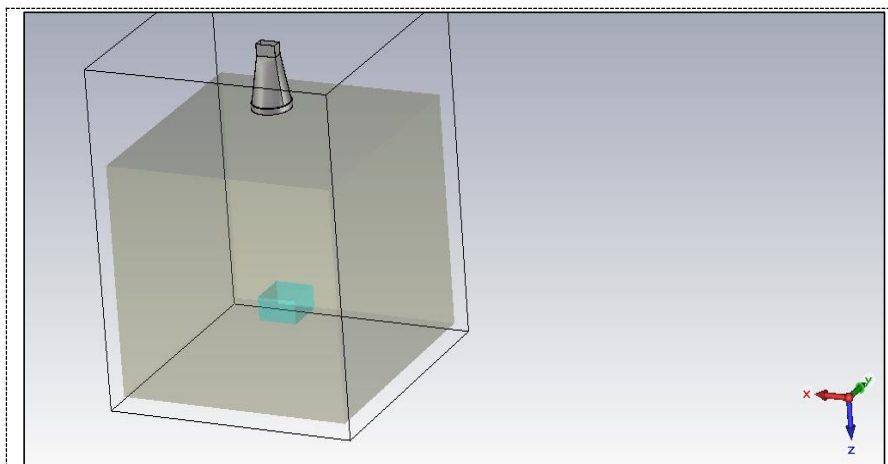


Figure 2. GPR system simulation by using CST software.

In this study, there were two types of simulation (A and B) that has been conducted using an image of 2D and 3D as output of GPR system. The simulation on GPR system A is to estimate the embedded object's position based on the output of current signal which are the wood and iron, while the simulation on GPR system B is to detect the embedded iron object.

2.1.1. Simulation on GPR System part A

This type of simulation was done in order to determine the GPR system's capability in detecting and estimating an embedded object in sandy soil such as wood object and iron object. The position of the embedded object in this simulation has been made based on three positions: 2 inches, 4 inches and 8 inches. The model size of the ground object in this simulation was made as 10 inches wide, 10 inches length and 9.75 inches thick. Meanwhile the model size of the embedded object in this simulation was set to 2 inches x 2 inches x 1 inch for wide, length and thick respectively. In this simulation the position of a Horn antenna as referring to the ground object has been set to 0 inch and situated in the middle of the ground object.

2.1.2. Simulation on GPR System part B

In this simulation on GPR system of part B, the position of the embedded object has been set at 4 inches from the surface of the ground model, which was the sandy soil. The size of the ground model in this simulation has been set to 10 inches wide, 10 inches length and 9 inches thick. On the other hand, the size of the embedded object in this simulation which was iron object has been set to 4 inches x 4 inches x 2 inches for wide, length and thick respectively. The position of the Horn antenna in this simulation has been set to 1 inch from the ground model. In this simulation, the antenna has been moved in order to simulate the scanning procedure of the GPR system equipment on the sandy soil area. The movement of the antenna has been made based on figure 3 where the distance between the two antenna's positions was set to 1 inch.

1	→							9
18	←							10
.								.
.								.
73	→							81

Figure 3. Scanning grid of simulation on GPR system 2.

2.2. Output signal of GPR system simulation processing using MATLAB

In this simulation, output signal from the CST Studio Suite software will be extracted and imported to the MATLAB software. In the CST Studio Suite software, the frequency range of the simulation was set from 8 GHz until 12 GHz. This setting will automatically produce a modulated Gaussian pulse signal as a default input signal of the software with carrier frequency at 10 GHz. In MATLAB software, the output signal calculated by CST Studio Suite will be demodulated in order to obtain the pulse of output signal, and then to produce an output image of the GPR system in form of 2D and 3D.

In this simulation, in order to produce an output signal without modulation, an envelope detection technique known as the Asynchronous half-wave [12] has been used. This detection technique is based on threshold technique and low pass filter technique as shown in Figure 4. The low pass filter used in this envelope detector system is the Finite Impulse Response (FIR) filter which has been designed using windowing technique, where the window chosen is Hamming window [13]. The threshold technique of the envelope detector system used in this simulation system is:

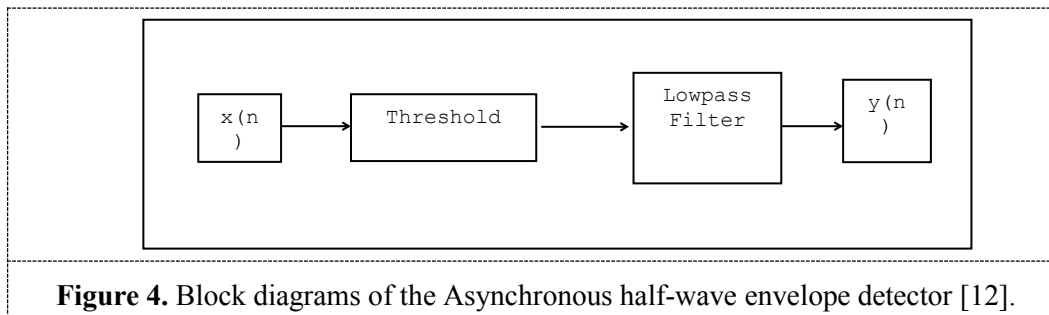
$$\text{if } x(n+1) > V_c(n) ; V_c(n+1) = x(n+1)$$

else

$$V_c(n+1) = V_c(n) - gV_c(n) \quad (2)$$

where, x is the signal value, V_c is the threshold signal and n is the sample number.

In equation (2), the limit value g needs to be determined to get the best threshold signal. In this study, the limit value of g that has been chosen is 0.013, as a result of parametric study on the threshold signal produced by this threshold operation.



The production of 2D image of the GPR system in this simulation was done by arranging the output signal of the antenna calculated by the CST Studio Suite software for each of antenna position based on a rows arrangement of Figure 3. This mean that the first 2D image of the GPR system in this study has been produced using the output signal of antenna at position from 1 until 9. Next, the second 2D image of the GPR system in this simulation was produced using a combination of the output signal of the antenna's position between 10 and 18. Furthermore, the 2D image of GPR system have been produced using output signal of the antenna's position at 19 until 27 for the third 2D image, 28 until 36 for the fourth 2D image, 37 until 45 for the fifth 2D image, 46 until 54 for the sixth 2D image, 55 until 63 for the seventh 2D image, 64 until 72 for eighth 2D image and 73 until 81 for the ninth 2D image.

In producing the 3D image of the GPR system in this simulation, the output signal of the antenna has been arranged based on the antenna's position in Figure 3. This position is referred as the x axis and y axis of the 3D image while the z axis has been chosen as the time samples position of the output signal between 18,000 and 44,000 with the distance of the time samples used was 1000. Next in generating

this 3D image all the output signal data need to be transformed as the 'isosurface' data for the 3D image using MATLAB function.

The output signal of the Horn antenna in the simulation of the GPR system which was calculated by the CST software has several value of sampling time. In order to produce the proper GPR system's image in 2D and 3D shapes, all the output signal need to be resampled at one fix value. In this study, the new sampling value of the output signal is 0.0001 ns. The technique of the re-sampling used in this study is a technique known as the linear interpolation [13].

3. Results and Discussion

3.1. Design of Horn Antenna

By using CST Studio Suite software, the calculation of the reflection signal ratio S11 of the Horn antenna which was designed in this study has produced results as shown in figure 5. The radiation pattern of this Horn antenna is as shown in figure 6. Referring to Figure 5, this Horn antenna is estimated can transmit an electromagnetic wave signal at operating frequency of 10 GHz with the signal's reflection ratio which is less than -10 dB. This result shows that this Horn antenna is suitable to be used as a transmitter antenna that able to transmit an electromagnetic wave signal produced by antenna current signal in shape of a modulated Gaussian pulse with carrier of 10 GHz. In this figure, S11 value of the Horn antenna in the frequency range of 8 GHz until 12 GHz is less than -6 dB.

Figure 6 shows the input and output signal of the Horn antenna simulation using CST. According to figure 6, it can be seen that the default signal used in this simulation is the modulated Gaussian pulse signal.

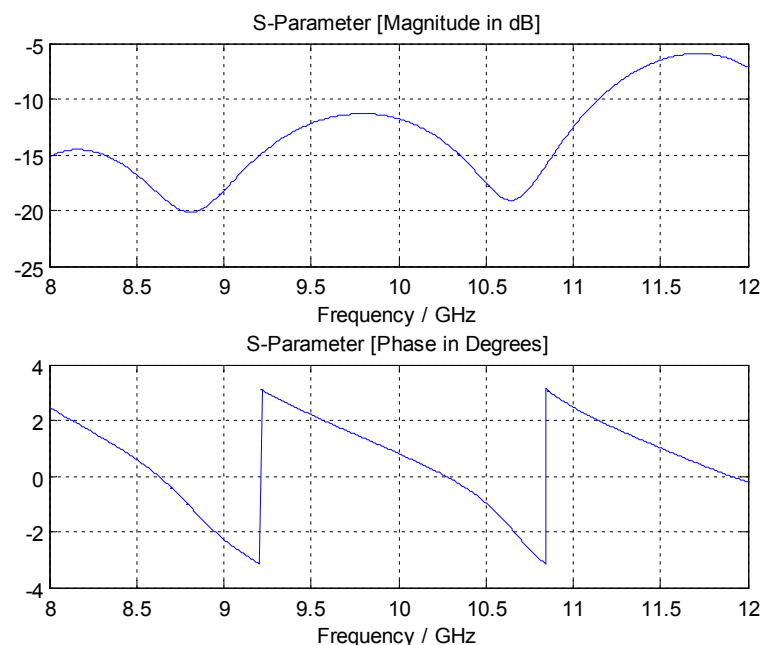


Figure 5. S11 of Horn antenna

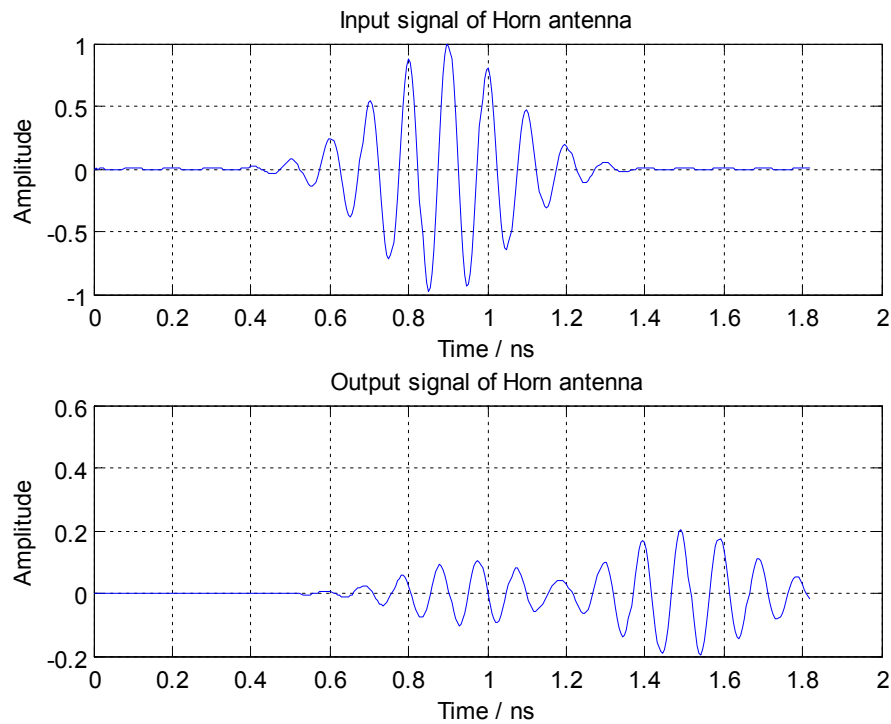


Figure 6. Horn antenna signal

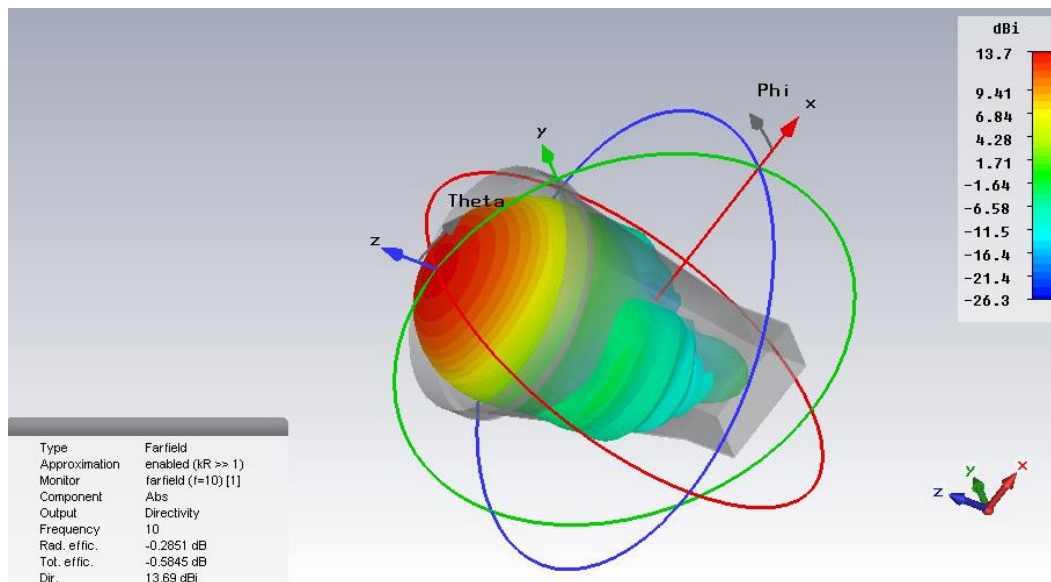


Figure 7. Farfield of Horn antenna

Referring to figure 7, the radiation pattern of the designed Horn antenna is pointing forward which show that this Horn antenna is having a unidirectional radiation pattern which is suitable to be used as the antenna of GPR system.

3.2. Simulation Result on GPR System A

Figure 8 and Figure 9 show the output signal of the GPR system simulation of part A in detecting embedded object of iron and wood in sandy soil. Referring to figure 8 and figure 9, the last pulse of the output signal is the reflection pulse of the electromagnetic wave in the simulation by the embedded object while the first pulse is the reflection pulse of electromagnetic wave between the antenna and air. In Figure 9, the reflection pulse of the electromagnetic wave by the embedded wood object at depth of 8 inches in sandy soil could not be seen. This result leads to the estimation process of depth of the embedded wood object at depth of 8 inches in sandy soil could not be done.

In figure 8a, the position of the iron object as referring to the reflection pulse of the electromagnetic wave can be estimated using formula (1) as:

The position of the last pulse and the first pulse of the output signal of the electromagnetic wave of the simulation,

$$t = 2.216 \times 10^{-9} - 1.644 \times 10^{-9} = 0.5720 \times 10^{-9}$$

The depth of the object in meter,

$$d = \frac{(3 \times 10^8)(0.5720 \times 10^{-9})}{2 \times \sqrt{2.53}} = 0.0539m$$

The depth of the object in inches,

$$d = 0.0539 \times 39.37 = 2.12 \text{ inches}$$

The simplified results of the embedded object estimation in this GPR system simulation of part A is shown in table 1.

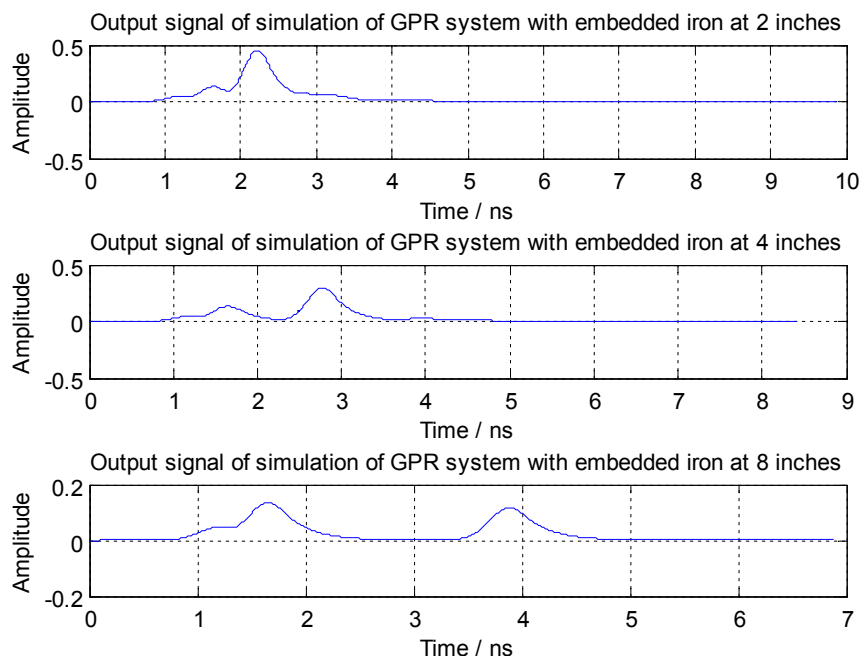


Figure 8. Output signal of GPR system simulation of part A in detecting embedded object, (a) iron at 2 inches, (b) iron at 4 inches, and (c) iron at 8 inches.

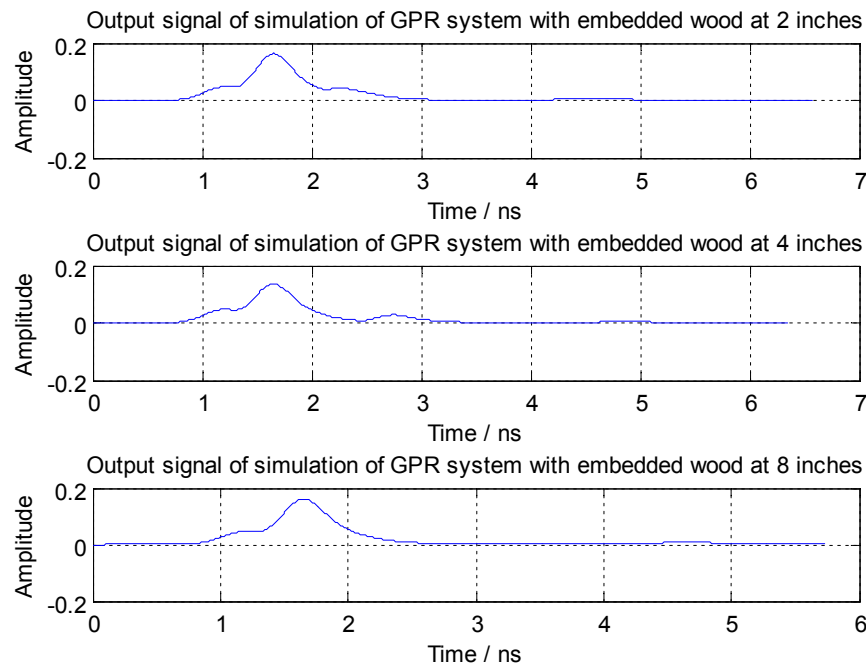


Figure 9. Output signal of GPR system simulation of part A in detecting embedded object, (a) wood at 2 inches, (b) wood at 4 inches, and (c) wood at 8 inches.

Table 1. Estimation of depth of the embedded object of the GPR system simulation of part A

Embedded object	Pulse position (object)	Pulse position (antenna)	Depth of object in inches	Depth of object in meter
Iron at 2 inches	2.216	1.644	0.0539	2.1220
Iron at 4 inches	2.782	1.66	0.1058	4.1653
Iron at 8 inches	3.897	1.66	0.2110	8.3071
Wood at 2 inches	2.25	1.657	0.0559	2.2008
Wood at 4 inches	2.759	1.66	0.1036	4.0787
Wood at 8 inches	NA	1.66	NA	NA

Based on table 1, the estimation of the embedded object in sandy soil in the simulation of GPR system A can be done correctly except for the embedded wood object at depth of 8 inches.

3.3. Simulation Result on GPR System B

In the second simulation, a GPR system simulation of part B is conducted by scanning the sandy soil buried with iron object. Results of simulation are as shown in figures 10 until 18.

Referring to Figure 10 and Figure 18, the image of the GPR system produced in this simulation which involving the simulation of the scanning of the sandy soil's model at antenna position of 1 until 9 and 73 until 81, there was two line of yellow and red exist. The lines show the reflection of the electromagnetic wave by the ground model in this simulation. The position of these lines can be estimated at about 10000 until 20000 of time samples position. Besides, in these images there are two spots of blue color has existed at time samples position between 40000 until 50000 and scanning position of 2 and 8 that can be considered as the reflection of electromagnetic wave produced by the edges of the embedded object. In these two images, there are also two light blue lines existed at time samples position at about 25000 until 30000.

The simulation of the scanning of the ground model of the sandy soil in this study for antenna position at 10 until 18 and 64 until 72 are shown in the image of figure 11 and figure 17. In both of the images, there are two lines of yellow and red existed at time samples position between 10000 until 20000 which show the reflection of electromagnetic wave produced by the model of ground. In these images, there are also two spots of yellow has existed at scanning position at 2 and 8, and time samples position at about 40000 until 50000. These images also show a blue line has existed at scanning position at 4 until 6, and time samples at about 25000 until 30000 which can be considered as the reflection of the electromagnetic wave from the edge of the embedded object.

Referring to the simulation results of the scanning of the ground model for antenna position at 19 until 27 in figure 12, 28 until 36 in figure 13, 37 until 45 in figure 14, 46 until 54 in Figure 15 and 55 until 63 in figure 16, there is a red plus blue line in the image at scanning position from 3 until 7. Referring to the development of the model of the GPR system simulation B in CST software, this line can be considered occurs as results of the reflection of electromagnetic wave by the embedded iron object.

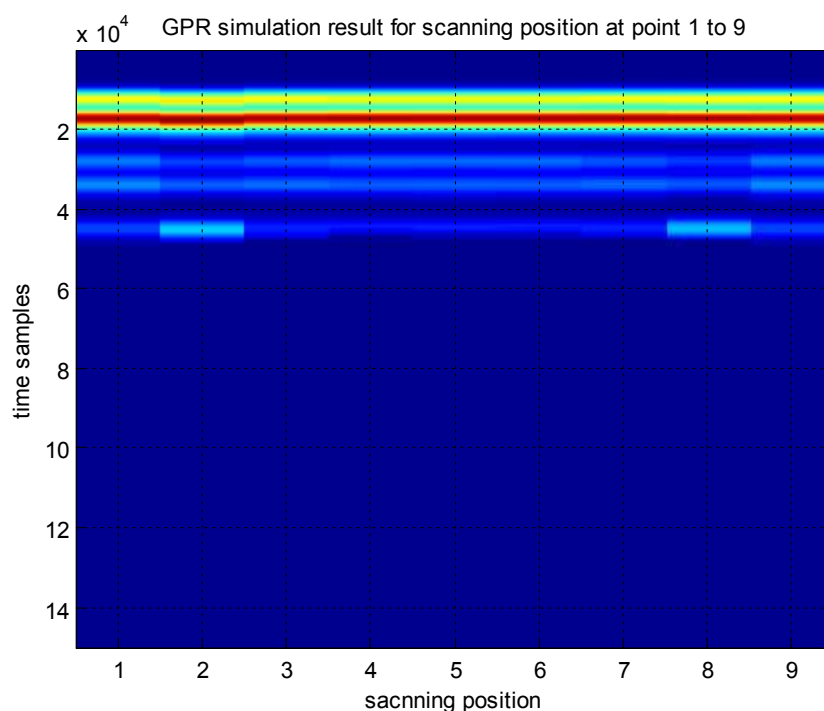


Figure 10. Scanning position from point 1 until 9.

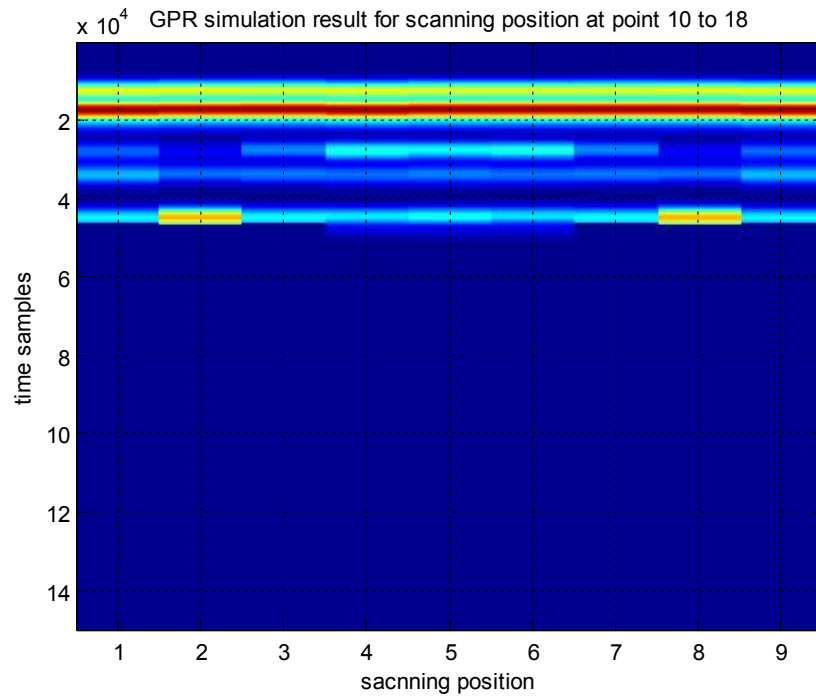


Figure 11. Scanning position from point 10 until 18.

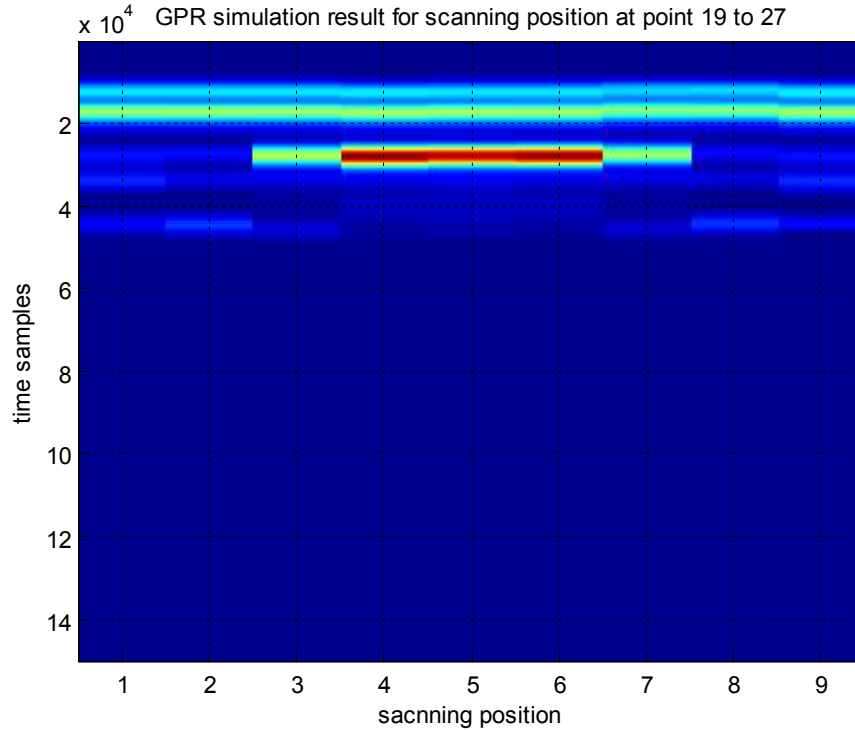


Figure 12. Scanning position from point 19 until 27.

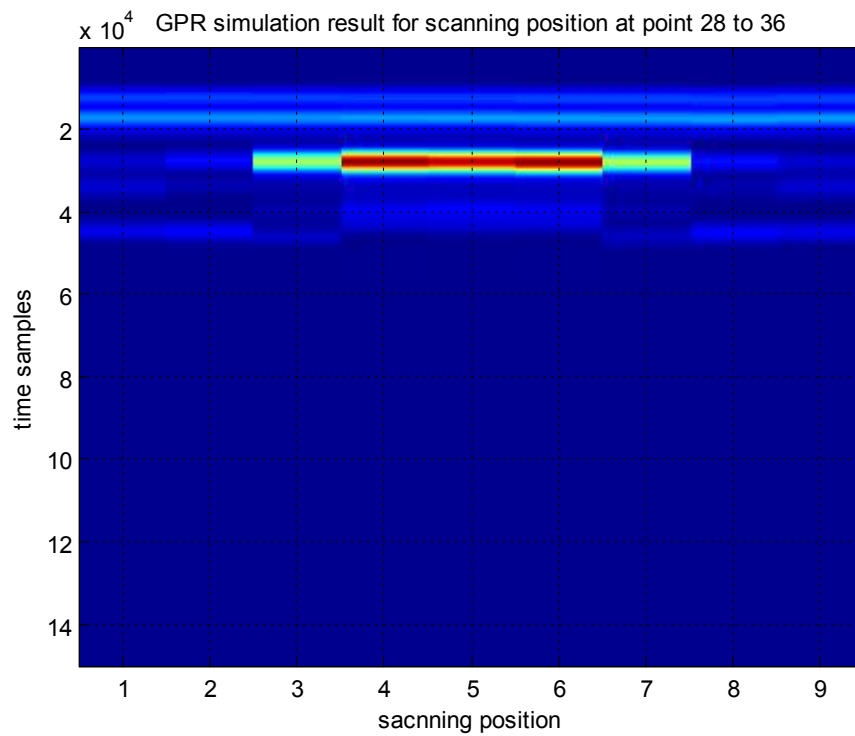


Figure 13. Scanning position from point 28 until 36.

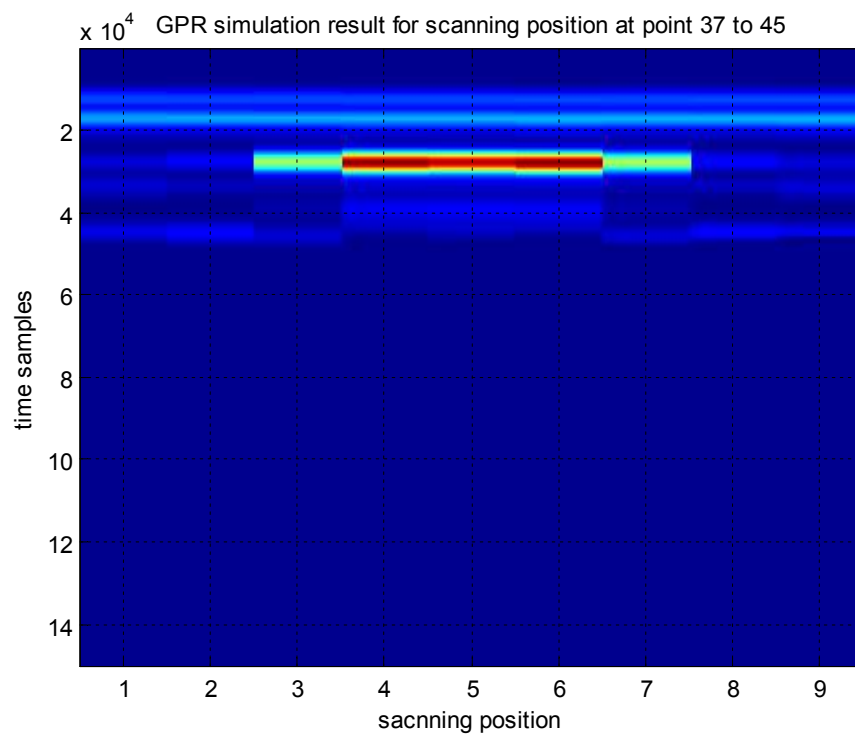


Figure 14. Scanning position from point 37 until 45.

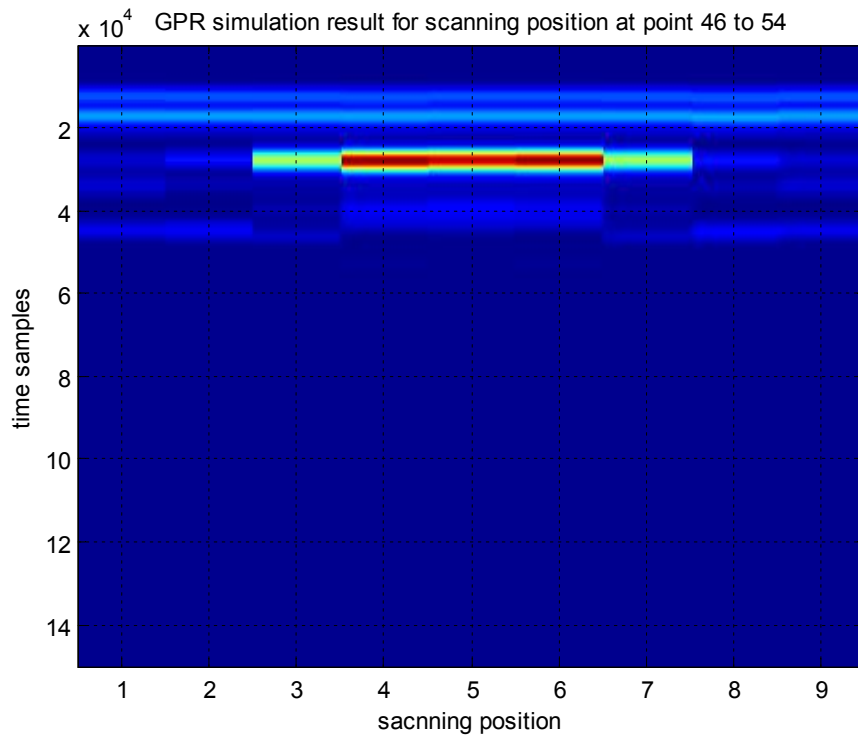


Figure 15. Scanning position from point 46 until 54.

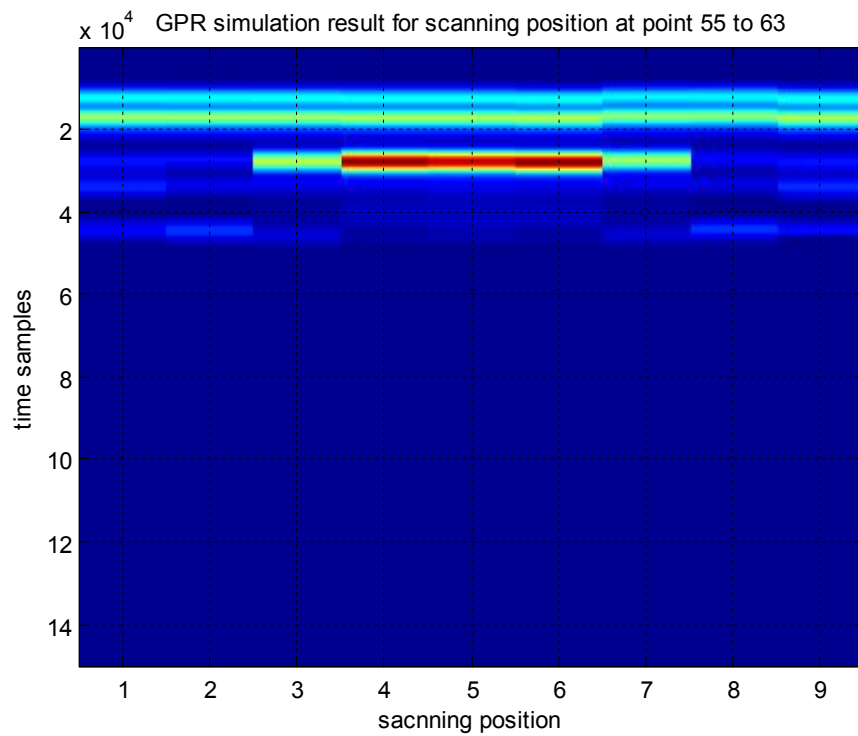


Figure 16. Scanning position from point 55 until 63.

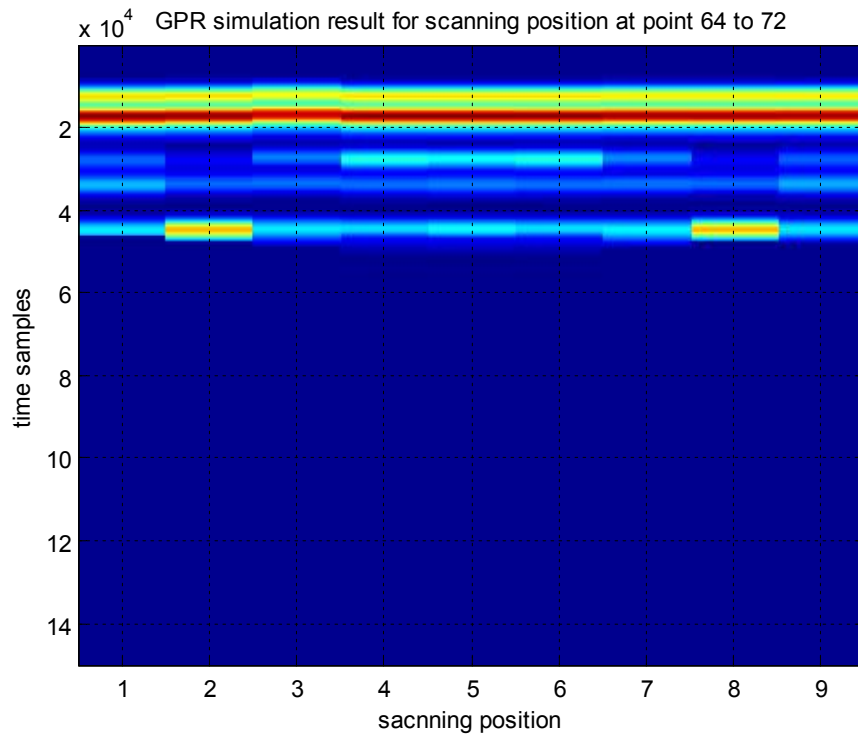


Figure 17. Scanning position from point 64 until 72.

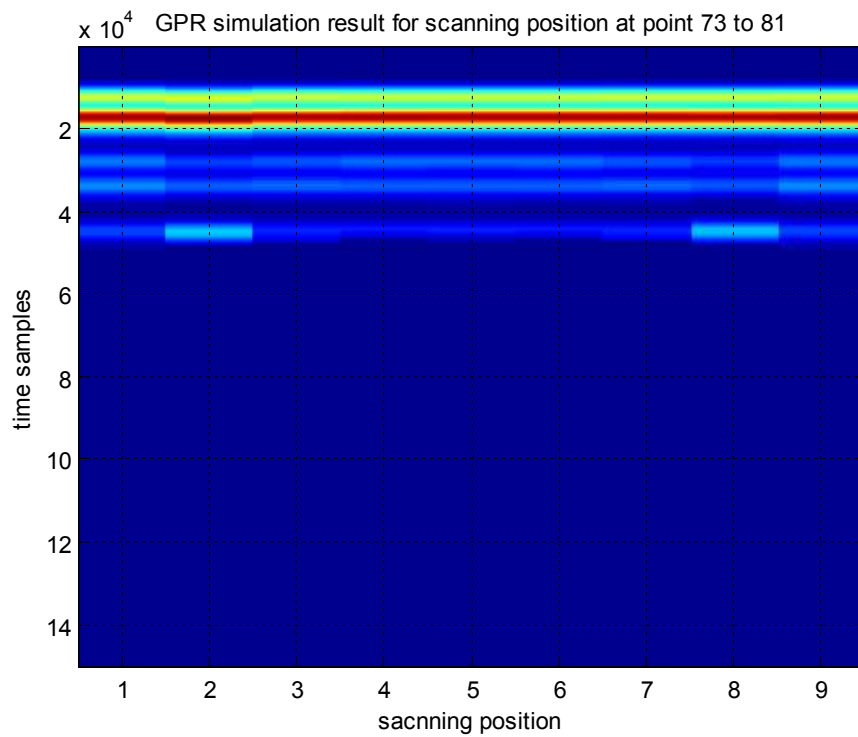


Figure 18. Scanning position from point 73 until 81.

Figure 19 shows the result of the GPR system simulation of part B made in this study in detecting an embedded iron object in sandy soil ground at depth of 4 inches as the 3D image. Referring to this image, the embedded iron object in the GPR system simulation of part B can be seen clearly.

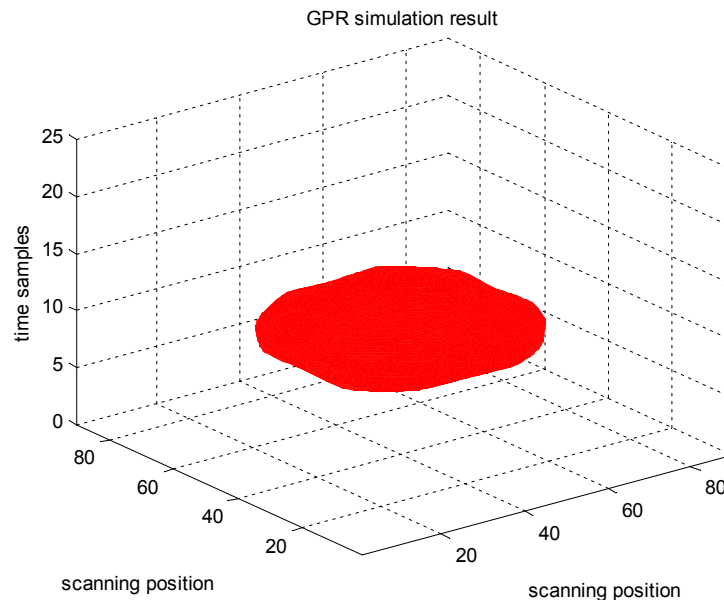


Figure 19. GPR simulation 3D image.

4. Conclusion

The design of a Horn antenna for GPR system application has been presented. The analysis of output signal of the Horn antenna by using CST Studio Suite software has been performed and indicates good results of detecting buried object such as iron and wood. Next, the simulation of GPR system in the real scenario through scanning procedure has been done and able to detect the embedded iron. These results show that the simulation of the GPR system using CST Studio Suite software is capable and reliable in detecting a buried object in sandy soil. Further investigation will focus on the capability of the GPR system in estimating the depth and shape of the buried object in sandy soil using the S11 parameter by simulation and real systems.

References

- [1] Daniels J J 2000 Ground penetrating radar fundamentals *US EPA report* region V p 1-21
- [2] Li L, Tan A C, Jhamb K, Rambabu K 2012 Buried object characterization using ultra-wideband ground penetrating radar *IEEE Transactions on Microwave Theory and Techniques* vol 60(8) p 2654-2664
- [3] Feng X, Li L L, Liu L M and Liu C 2009 Developing polarimetric GPR system *Proceedings of the Progress in Electromagnetics Research Symposium* p 800-803
- [4] Oyan M J, Hamran S E, Hanssen L, Berger T and Plettemeier D 2012 Ultrawideband gated step frequency ground penetrating radar *IEEE Transactions on Geoscience and Remote Sensing* vol 50(1) p 212-220
- [5] Duc A N and Phu B H 2014 A detail design and evaluation of stepped frequency continuous wave ground penetrating radar systems *International Journal of Research in Wireless Systems* vol 3(1) p 1-8

- [6] Liang H and He Z 2009 Study on signal processing of FMCW ground penetrating radar *Proceedings of the IEEE International Conference on Measuring Technology and Mechatronics Automation* p 528-531
- [7] Daniels D J 2004 *Ground Penetrating Radar* (London: The Institution of Electrical Engineers)
- [8] Poley H G 2010 GPR antennas design and experimental evaluation [Master thesis] (Netherlands: Delft University of Technology)
- [9] Sato M 2009 Principles of Mine Detection by Ground-penetrating Radar *Anti-personnel Landmine Detection for Humanitarian Demining: The Current Situation and Future Direction for Japanese Research and Development* ed Furuta K and Ishikawa J (London: Springer) p 19-26
- [10] Sharma S 2014 Design and analysis of pyramidal horn antenna at 8 GHz frequency *International Journal of Advanced Research in Electronics and Communication Engineering* vol 3(2) p 231-234
- [11] Wang Y and Fathy A E 2008 Design of a compact tapered slot Vivaldi antenna array for see through concrete wall UWB applications *Proceedings of the XXIXth URSI General Assembly in Chicago* p 1-4
- [12] Zych M 2013 Ground penetrating radar simulations of non-homogeneous soil with CST Studio Suite *Przegląd Elektrotechniczny* R 89 NR 7/2013
- [13] Workflow Example Horn Antenna. Download from: <https://webapps.jyu.fi/wiki/download/attachments/13894852/Workflow+example+-+horn+antenna.pdf?version=1&modificationDate=1304930418000>
- [14] Lyons R 2016 *Digital Envelope Detection: The Good, the Bad, and the Ugly* (Cited on November 1, 2016 from: <https://www.dsprelated.com/showarticle/938.php>)
- [15] Ambardar A 1999 *Analog and Digital Signal Processing* (USA: Brooks/Cole Publishing Company)

Acknowledgments

The authors wish to thank Universiti Tun Hussein Onn Malaysia and the Government of Malaysia for technical and financial support for the experiment.