SIMULATION OF GPR SYSTEM OPERATION USING DIPOLE ANTENNA AND AFW ENVELOPE DETECTOR TECHNIQUE FOR UNDERGROUND OBJECT DETECTION APPLICATION

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To my beloved family, especially for my parents, whom I love the most

Razali bin Hashim and Timah binti Samah

And my lovable husband

Muhammad Roziamy Asraf bin Mohd Ram

Thank you for your endless prayers, supports and always be by my side during my hard times and also never give up on me.

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ABSTRACT

Underground object detection requires a lot of time and energy and may damage the study surface area. Therefore, the use of electromagnetic wave reflection techniques emitted by GPR system to detect the embedded object is very useful. Beside wideband antenna, a narrowband antenna can be used in designing a GPR system using CST software. However, this type of GPR system produces blurry radargram image due to high ripple signal that occur in the antenna input signal. In this study, the design of GPR system simulations using CST software have been made using four frequency ranges which are from 0 – 0.13 GHz, 0.06 GHz – 0.08 GHz, 0 – 0.5 GHz and 0 – 1 GHz. The simulations also have been designed based on four depth of embedded object. Referring to the radargram image displayed by the design GPR system using frequency range 0 – 0.13 GHz, the embedded object has been clearly displayed in the radargram image which include the position of the object at 7 cm depth. On the other hand, by using frequency ranges 0 – 0.5 GHz and 0 – 1 GHz, the design GPR system has able to produce a clear radargram image showing embedded object position up to 20 cm depth. Furthermore, the design GPR system using frequency range 0.06 GHz – 0.08 GHz has produced a blurry radargram, but can be solved by applying the AFW envelope detector technique and produce a clear radargram image in detecting an embedded object position up to 7 cm depth. The results achieved through this study indicate that the use of narrowband antenna in GPR system is still able to detect an embedded object by applying an envelope detector technique which suggest an effective GPR system.

ABSTRAK

Pengesanan objek terbenam dalam perut bumi melibatkan penggunaan masa dan tenaga yang banyak serta mengakibatkan kerosakan pada kawasan permukaan bumi yang dikaji. Oleh itu, penggunaan teknik pantulan gelombang elektromagnetik yang dipancarkan oleh sistem GPR untuk mengesan objek terbenam sangat berguna. Sebuah antena berjalur sempit untuk sistem GPR telah direka bentuk dengan menggunakan perisian CST. Penggunaan antena ini akan menghasilkan paparan imej radargram yang kabur akibat daripada kewujudan isyarat riak yang berlaku pada isyarat masukan antena. Kajian berkenaan sistem GPR yang dilakukan dalam kajian ini melibatkan pembangunan simulasi sistem GPR menggunakan empat julat frekuensi serta empat kedalaman objek terbenam yang berbeza untuk dikesan oleh sistem GPR dan dinilai. Empat julat frekuensi tersebut adalah 0 – 0.13 GHz, 0.06 GHz – 0.08 GHz, 0 – 0.5 GHz dan 0 – 1 GHz. Imej radargram yang dipaparkan oleh sistem GPR menggunakan julat frekuensi 0 – 0.13 GHz menunjukkan paparan imej radargram yang jelas sehingga kedalaman 7 cm manakala bagi julat frekuensi 0 – 0.5 GHz dan 0 – 1 GHz telah menghasilkan imej radargram yang jelas sehingga kedalaman 20 cm. Namun begitu, perkara sebaliknya berlaku pada julat frekuensi 0.06 GHz – 0.08 GHz menghasilkan imej radargram yang kabur hasil daripada keberadaan isyarat riak pada isyarat masukan. Akan tetapi, masalah ini boleh diselesaikan dengan menggunakan teknik pengesan sampul AFW pada isyarat masukan antena yang membolehkan ia menghasilkan imej radargram yang jelas sehingga kedalaman 7 cm. Keputusan yang dicapai melalui kajian ini menunjukkan bahawa penggunaan antenna berjalur sempit dalam sistem GPR masih mampu untuk mengesan objek terbenam dengan penggunaan teknik pengesan sampul yang menghasilkan sistem GPR yang berkesan.

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LIST OF SYMBOLS AND ABBREVIATIONS

v	–	Velocity
λ	–	Wavelength
2D	–	2 Dimension
3D	–	3 Dimension
AFW	–	Asynchronous Full Wave
AHW	–	Asynchronous Half Wave
ARSL	–	Asynchronous Real Square Law
BAVA	–	Balance Antipodal Vivaldi Antenna
CST	–	Computer Simulation Technology
cm	–	centimeter
dB	–	decibels
dBi	–	decibels relative to isotropic
EM	–	Electromagnetic
F_H	–	Frequency high
F_L	–	Frequency low
FFT	–	Fast Fourier Transform
FIR	–	Finite Impulse Response

GHz	–	Giga Hertz
GPR	–	Ground Penetrating Radar
Hz	–	Hertz
MHz	–	Mega Hertz
mm	–	millimeter
ns	–	nano seconds
NDT	–	Non-Destructive Technique
PEC	–	Perfect Electric Conductor
PM	–	Pulse Modulation
RADAR	–	Radio Detection and Ranging
S_{11}	–	Reflection Coefficient
SVD	–	Singular Value Decomposition
TSE	–	Tapered Slot Edge
UWB	–	Ultra-Wide Band
VNA	–	Vector Network Analyzer

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Ground Penetrating Radar (GPR) is a system that is capable of detecting unforeseen objects under the ground effectively at a certain depth by using a selected range of frequencies (Ferrara *et. al*., 2016), (Aziz, 2016), (Ariffuddin; Joret, 2018) from the obtained electromagnetic wave (Jin & Duan, 2020). The first appearance of this system was in 1926 (Annan, 2002), where at the beginning of its appearance, the echo radio has been used, which was produced by glaciers and pieces of ice sheets followed by permafrost analysis. The system is said to be able to detect embedded object that is not only consists of metal objects, but also non-metal objects have been studied by many GPR system researchers (Giannakis *et. al*., 2016), (Shweta B. & Roy, 2017), (Lai & Xavier, 2018), (Rojhani *et. al*., 2018), (Jalil *et. al*., 2019), (Jazayeri *et. al*., 2019), (Bai & Sin, 2020) and (Bugarinović *et. al*., 2020). The researchers believe this GPR system is a high resolution electromagnetic technique (Bugarinović *et. al*., 2020) and (Jin & Duan, 2020) based on RADAR (Radio Detection and Ranging) concept that can be used to detect the existence of embedded object underground. Nowadays, GPR system is a well-known method due to its high resolution characteristics (Yilmaz *et. al*., 2016), (Donno *et. al*., 2017) and (Cui *et. al*., 2020) and its ability to detect the presence of objects underground where it cannot be done by human using human eyes (Jalil *et. al.*, 2019) and (Mint *et. al*., 2018).

Other than that, one of the methods that makes this system recognized by geological researchers is this system using an object detection technique called Non-

Destructive Technique (NDT). By using this technique the area of the ground and also the embedded objects underneath would not be harmed. This technique has been studied by a few scholars such as Bianchini *et. al.* (Bianchini *et. al*., 2019), Ferrera *et. al.* (Ferrara *et. al*., 2016), Comite *et.al.* (Comite *et. al*., 2017), Ariffuddin (Ariffuddin; Joret, 2018), Lai and Xavier (Lai & Xavier, 2018), Park *et. al*. (Park *et. al*., 2018) and Jazayeri *et. al.* (Jazayeri *et. al*., 2019). Lai and Xavier (Lai & Xavier, 2018) said that this GPR system is able to give precise information regarding to the depth and also the position of the embedded objects underground. The differences between the permittivity value of the embedded objects and the background will cause the electromagnetic wave either to be reflected or refracted, through this reflection and refraction, there would be a set of data that can be processed to form complete information about the embedded object to the GPR system. However, Xu *et. al*. and Jazayeri are not agreeing with the researcher. According to them, the accurate location of the embedded object detection by using this GPR system is still under development (Xu *et. al*., 2018) and (Jazayeri *et. al*., 2019).

Figure 1.1 shows an image result from Cintra *et. al*. (Cintra *et. al.,* 2020) research. It shows the electromagnetic wave radiation reflection produced by an embedded object towards the GPR system. The reflection of this electromagnetic radiation happened when the electromagnetic wave scattered from air medium to the ground medium and from ground medium to the target medium that had a different permittivity value with each other (Baek *et. al*., 2017), (Xu *et. al*., 2018) and (Arifianto *et. al*., 2019). By referring to the electromagnetic wave that can penetrate into the ground medium, only low frequency electromagnetic waves can penetrate deeper in the ground rather than the high frequency of electromagnetic waves (Bernatek-Jakiel & Kondracka, 2019), (Jalil *et. al*., 2019), (Tilley *et. al*., 2019) and (Tronca *et. al*., 2018).

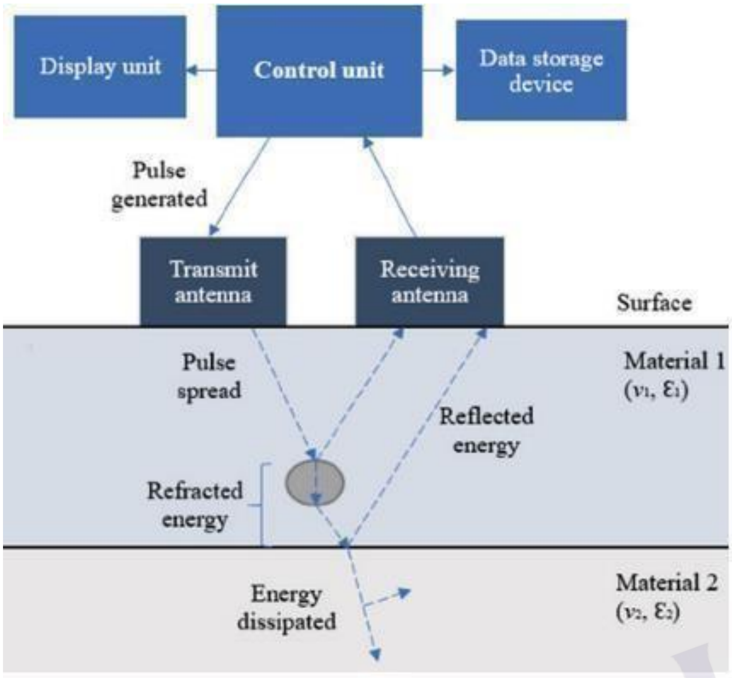

Figure 1.1: The propagation of electromagnetic wave in GPR system (Cintra *et. al*., 2020).

The basic equipment developed for the GPR system requires an involvement of electromagnetic wave signal transmission system and an electromagnetic wave receiving system as per attached in Figure 1.2. By referring to this GPR system, alternating current generators have been used as the transmitting system and the oscilloscope as the receiving system. The GPR system shown is known as a bistatic GPR system where it uses two identical antennas as the transmitter and detector of the electromagnetic wave signal.

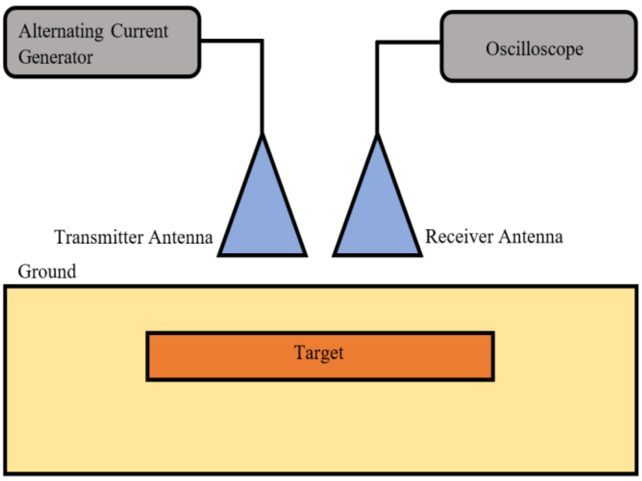

Figure 1.2: GPR system basic equipment.

There are several types of antennas used in the GPR system to detect the existence of embedded objects such as Vivaldi antenna, microstrip patch antenna, horn antenna, frame antenna, monopole antenna, bowtie antenna dan circular disc antenna (Markov *et. al*., 2020), (Shebalkova *et. al*., 2018) and (Ariffuddin; Joret, 2018) and (Ali *et. al*., 2017). These antennas have been used in GPR system as they have the characteristics of broadband antennas. These researchers stated, to obtain a clearer radargram image of underground objects, a wideband antenna is ideal to be used as a GPR system antenna (Singh & Singh, 2019). The downside of this wideband antenna is its design, which is intricate.

Travassos *et. al*. (Xisto Lucas Travassos *et. al*., 2018), Mint *et. al*. (Mint *et. al*., 2018) and Tronca *et. al*. (Tronca *et. al*., 2018) stated that to obtain a high resolution radargram image, a wideband antenna is needed. However, to detect the presence of underground objects with deeper depth, the GPR system needs to use an antenna that can produce electromagnetic radiation at low frequency. According to Xu *et. al*. studies, the narrowband antenna that they designed can operate at frequency center of 200 MHz (Xu *et. al*., 2018).

An antenna input signal needs a pulse signal as shown in Figure 1.3. The input signal of a wideband antenna with fractional bandwidth of 1 is shown in Figure 1.3(a) while Figure 1.3(b) shows the input signal of a wideband antenna with fractional bandwidth of 0.4. The ripple signal in both Figure 1.3(b) and Figure 1.3 (a) shows a significant difference. This proves that the fractional bandwidth value greatly affects the antenna input signal. Through this figure, it is also proved that the ripple signal will rise if the fractional bandwidth value of the antenna decreases. Based on this figure, the narrowband antenna can be said to be affected by input signal ripple as its fractional bandwidth value is less than 0.2 (Ariffuddin; Joret, 2018). Therefore, the narrowband antenna will have more ripple signal at the input signal than the wideband antenna.

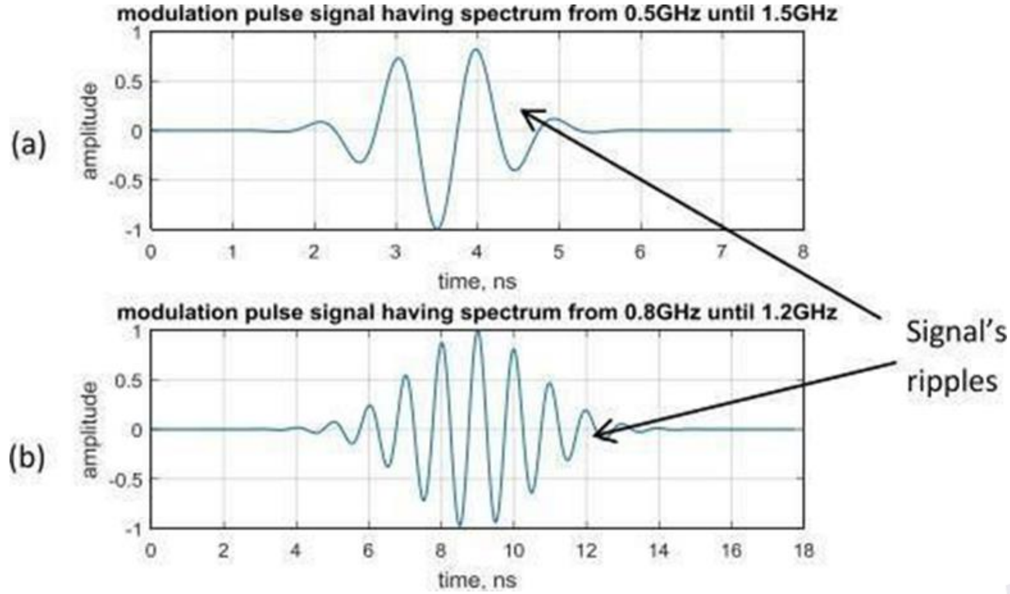

Figure 1.3: Antenna input signal (a) Wideband antenna input signal with fractional bandwidth value of 1. (b) Wideband antenna input signal with fractional bandwidth value of 0.4.

The narrowband antenna was studied by Plati *et. al*. because this antenna is easy to design. However, there is a drawback when using this type of antenna. The radargram image displayed by this antenna will be blurry due to the high ripple existence at the input or output signal of the antenna (Plati *et. al*., 2018). Nevertheless, this issue can be overcome by reprocessing the narrowband antenna input signal and this will make the system display a clearer radargram image. Dipole antenna (Xu *et. al*., 2018), loop antenna, dish antenna and Yagi-Uda antenna are some of the examples of narrowband antenna.

Referring to the fractional bandwidth of the GPR system, as in narrowband GPR system, the reprocessing of the antenna input signal needs to be performed as the radargram produced by the system without the reprocessing technique will be very blurry. Furthermore, as in narrowband GPR system with fractional bandwidth less than 0.2, the reprocessing technique should also be applied in order to produce a clearer radargram image. The fractional bandwidth value of GPR system as well as antenna can be calculated by using equation (1.1) (Ariffuddin; Joret, 2018).

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APPENDIX A

LIST OF PUBLICATIONS

1. M. Razali, A. Joret, M. F. L. Abdullah, E. Baharudin, A. Ponniran, M. S. Sulong, C. K. N. A. H. C. K. Melor, N. A. Shairi, "Pulse Modulation (PM) Ground Penetrating Radar (GPR) System Development by Using Envelope Detector Technique," Proceedings of the 11th National Technical Seminar on Unmanned System Technology 2019, Lecture Notes in Electrical Engineering 666, pp 381 – 397, 2019.

2. M. Razali, A. Joret, C. K. N. A. H. C. K. Melor, M. F. L. Abdullah, E. Baharudin, "Simulation Study for Underground Object Detection Using Pulse Ground-Penetrating Radar (GPR) System," 2020 IEEE Student Conference on Research and Development (SCOReD), 2020.

3. Maryanti Razali, Ariffuddin Joret, Muhammad Suhaimi Sulong, Mohammad Faiz Liew Abdullah, Elfarizanis Baharudin, Che Ku Nor Azie Hailma Che Ku Melor, Nur Izzati Zulkefli, Noor Azwan Shairi, "Embedded iron object detection using asynchronous full wave envelope detector technique in ground penetrating radar system," International Journal of Electrical and Computer Engineering (IJECE) Vol. 12, No. 6, December 2022, pp. 6187~6195, 2022.

4. Che Ku Nor Azie Hailma Che Ku Melor, Ariffuddin Joret, Maryanti Razali, Asmarashid Ponniran, Muhammad Suhaimi Sulong, Rosli Omar, "Frequency based signal processing technique for pulse modulation ground penetrating radar system," International Journal of Electrical and Computer Engineering (IJECE) Vol. 11, No. 5, October 2021, pp. 4104~4112, 2021.

5. C. K. N. A. H. C. K. Melor A. Joret, M. S. Sulong, A. Ponniran R. Omar M. Razali, "Signal Processing Technique for Pulse Modulation (PM) Ground Penetrating Radar (GPR) System Based on Phase and Envelope Detector Technique," Proceedings of the 11th National Technical Seminar on Unmanned System Technology 2019, Lecture Notes in Electrical Engineering 666, pp 659 – 669, 2019.

APPENDIX B

VITA

The author was born in Melaka on June 25th, 1992. She finished her early education at Sekolah Menengah Teknik Sepang, Selangor. In 2013, she finished her Diploma in Electronics Engineering (Communication) and got her Bachelor Degree in Electronics Engineering with Hons at Universiti Tun Hussein Onn Malaysia (UTHM) on 2018. She was hired by M&E Consultant Company at Melaka right after she finished her Bachelor Degree.