DEVELOPMENT OF GPR SYSTEM USING HIGH GAIN WIDEBAND ANTENNA AND MICROWAVE IMAGING TECHNIQUE FOR BURIED OBJECT DETECTION

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Specially dedicated to my beloved wife, my children, parents, brothers, sisters and my friends

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LIST OF SYMBOLS

λ	Wavelength
c	Speed of light
dB	Decibel
ε_r	Relative permittivity
ε'_r	Real part complex permittivity
ε''_r	Imaginary part complex permittivity
ε_{eff}	Effective permittivity
f	Frequency
GHz	Giga Hertz
mm	Millimetre
t	Thickness
σ	Electrical conductivity
ρ	Density
S_{11}	Reflection coefficient
Π	Pi
C	Celcius

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LIST OF ABBREVIATIONS

AUT	Antenna Under Test
CST	Computer Simulation Technology
DGS	Defected Ground Structure
dB	Decibel
GHz	Giga Hertz
GPR	Ground Penetrating Radar
MHz	Mega Hertz
MUT	Material Under Test
NCP	Notch Circular Patch
RADAR	Radio Detection and Ranging
SBA	Slotted Bowtie Antenna
UV	Ultra Violet
UWB	Ultra Wide Band

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Membangunkan Sistem GPR Menggunakan Antena Jalur Lebar Gandaan Tinggi dan Teknik Pengimejan Gelombang Mikro untuk Pengesanan Object Tertanam

ABSTRAK

Radar Penetrasi Bumi *(GPR)* adalah salah satu kaedah bukan pemusnah yang menggunakan frekuensi gelombang elektromagnet antara beberapa puluhan MHz hingga GHz untuk memetakan ciri-ciri objek di dalam tanah atau struktur buatan manusia. Dalam aspek alat pemancar dan penerima *GPR* , permintaan untuk gandaan yang tinggi, jalur lebar dan saiz antenna yang kecil semakin meningkat, kerana manfaatnya seperti penembusan isyarat lebih dalam, keupayaan untuk membawa kadar data yang lebih tinggi dan mudah untuk dikendalikan terutamanya apabila ruang menjadi masalah. Selain antena, aspek geologi seperti jenis tanah, kelembapan dan suhu tanah perlu dipertimbangkan kerana ia mempunyai kesan yang besar kepada prestasi pengukuran *GPR* . Keputusan pengukuran *GPR* adalah banyak bergantung kepada aspek geologi, contohnya, keadaan tanah kawasan yang berbeza mempunyai ciri-ciri yang berbeza. Parameter lain yang penting dalam sistem *GPR* adalah teknik pengimejan gelombang mikro. Teknik ini diperlukan untuk memetakan objek tertanam ke dalam bentuk grafik 2- dimensinal dan akhirnya memberikan prestasi keseluruhan sistem GPR. Bagi memenuhi keperluan ini, kaedah di dalam tesis ini dibahagikan kepada tiga fasa. Dalam Fasa I, rekabentuk *slotted bowtie antenna (SBA)* dan *notch circular patch (NCP)* yang mempunyai gandaan tinggi, ringan dan jalur lebar masing-masing antara 1.25 GHz hingga 3.0 GHz dan 0.5 GHz hingga 3.0GHz, dicadangkan. Dalam usaha untuk mendapatkan gandaan yang lebih tinggi, pemantul logam telah dietakkan di belakang antena dan prestasi antena yang dicadangkan dalam bentuk parameter-S, corak sinaran dan gandaan diperhatikan. Antena difrabrikasi menggunakan Taconic TLY-5 dan prestasi diukur, dibanding dan dianalisis. Kedua-dua antena mempunyai persamaan yang baik bagi keputusan simulasi dan pengukuran seperti jalur lebar iaitu lebih daripada 60% untuk SBA dan 150% untuk NCP, gandaan yang melebihi 8 dB dan corak sinaran yang terarah. Dalam Fasa ke II, aspek geologi, lapan (8) jenis sampel tanah di kawasan tempatan (Perlis) telah dikumpulkan untuk diukur sifat pemalar dielektriknya dalam tiga (3) keadaan yang berbeza iaitu keadaan biasa (ambient), basah (10% air) dan kering (50^oC). Eksperimen ini dijalankan menggunakan pengukur pemalar dielektrik Agilent dan data yang dikumpul bagi pemalar dielektrik dan factor kehilangan diplotkan dan dijadualkan. Pemalar dielektrik seperti tar dan pasir adalah serupa dibandingkan dengan kajian lepas dalam literasi. Dalam fasa terakhir, Fasa III, *SBA* dan *NCP* yang dicadangkan dan telah diintegrasikan dengan pelbagai jenis tanah serta objek tertanam dilaksanakan. Analisis objek tertanam yang berbeza saiz, perbezaan lokasi objek dan perbezaan jenis objek telah dijalankan. Simulasi menunjukkan minimum saiz objek adalah 30mm x 30mm bagi membolehkan imej dikesan dan sesetengahnya tidak dapat dikesan disebabkan sifat objek itu sendiri seperti batu, konkrit dan kayu. Semua imej dari hasil simulasi dibentangkan dalam jadual dan dibincangkan dalam tesis ini. Pelaksanaan eksperimen menggunakan *Network Analyzer (E8362B)* dengan dan tanpa objek logam tertanam telah dijalankan. Data untuk kedua-dua simulasi dan pengukuran diekstrak dan teknik pengimejan microwave dilakukan. Teknik penyingkiran hingar *(clutter)* diaplikasi dalam algoritma (aturcara) dalam usaha untuk menghapuskan isyarat yang tidak diingini atau hingar. Akhir sekali, imej yang dibina bagi keputusan pengukuran sebelum dan selepas penyingkiran isyarat hingar dibentangkan.

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Development of GPR System Using High Gain Wideband Antenna and Microwave Imaging Technique for Buried Object Detection

ABSTRACT

Ground Penetrating Radar (GPR) is one of the non-destructive methods which employ electromagnetic waves of frequency that ranges from few MHz to tens of GHz to map the buried features inside the ground or man-made structures. In transmitter and receiver parts of GPR, the demand for high gain, wideband and small antenna is increasing, owing to its benefits such as deeper signal penetration, ability to carry higher data rate and easy to handle particularly when space is a constraint. Instead of antenna, geological aspects such as soil types, humidity and soil temperature need to be considered as well since it has a significant effect to the GPR measurement performance. The GPR measurement results are much dependent on the geological aspects, for example, soil condition of different areas has different properties. The other important parameter of GPR system is the microwave imaging technique. This technique is required to map the buried object into 2-dimensinal graphical form and finally shows the overall performances of the GPR system. In order to fulfil these requirements, the methodology in this thesis is divided into three phases. In Phase I, the design of the Slotted Bowtie Antenna (SBA) and Notch Circular Patch (NCP) which have low ringing field, light weight and wideband characteristic frequency that ranges from 1.25 GHz to 3.0 GHz and 0.5 GHz to 3.0GHz respectively, is proposed. In order to obtain higher gain, a metallic reflector has been located at the back of the antennas and the performances of the proposed antenna in term of S-parameter, radiation pattern and gain is observed. The antennas are fabricated using Taconic TLY-5 and the measured performances are compared and analysed. Both antennas have a good agreement for simulated and measured results such as wide bandwidth which are higher than 60% for SBA and 150% for NCP antennas, higher gain more than 8 dB and have a directional radiation pattern. In Phase II the geological aspect, Eight (8) types of soil samples in local region (Perlis) have been collected to measure the dielectric properties in three (3) different condition which are normal (ambience), wet (10% water content) and dry (50^{o}C). The experiment was conducted using Agilent dielectric probe and the data collected for the dielectric constant and loss factor are plotted in graph and tabulated in a table. The dielectric properties such as asphalt and sand are very similar as compared to the previous work in literatures. In the final phase i.e., Phase III, the proposed SBA and NCP were incorporated with different types of soil with buried object is carried out. The analysis of the different buried object size, differences in object location and differences in object materials have been conducted. From the simulation, its shows that the minimum object size is 30mm x 30 mm in order to detect the buried features and some buried object cannot be detected due to their properties such as stone, concrete and wood. The constructed image from the simulated result are presented in table and discussed in this thesis. Then, the experimental setup using Performance Network Analyzer (PNA E8362B) with and without buried metal object has been conducted. The data for both simulated and measured results was extracted and microwave imaging technique is performed. The clutter removal technique is applied to the algorithm in order to remove the unwanted signal or clutter. Finally, the constructed image for measured results before and after clutter removal is presented and analysed.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Ground Penetrating Radar (GPR) is a class of RADAR which employ radio waves, typically in the 10 MHz until 10 GHz frequency range, to map structures and features buried in the ground (or in man-made structures). The specific category that GPR falls into being in primary radar where there is no dedicated or specific frequency for transmitting and receiving part. The GPR is differ from conventional navigation radar, which usually has range of tens or hundreds of kilometres, whereas GPR has a range typically limited to tens of metres. GPR's limited range is due to the attenuation characteristics of the material or soil properties that varies with frequency. GPR is generally moved along the surface of the material, where conventional radar is fixed. The signals reflected from various objects give an indication of the depth and shape of the object.

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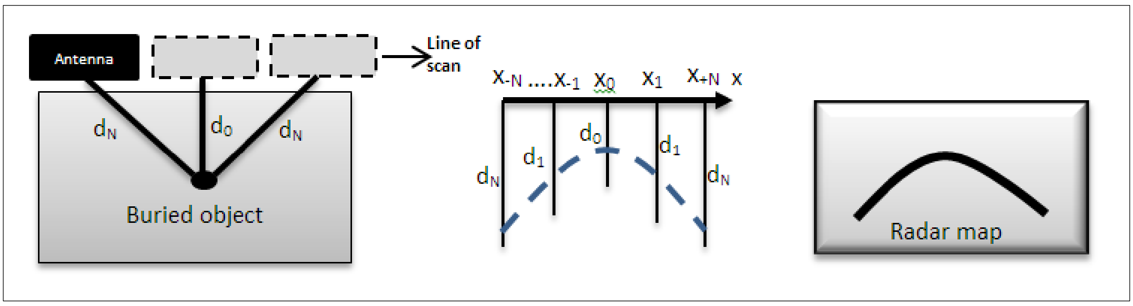

Figure 1.1: Target detected by GPR.

Figure 1.1 shows the acquisition data of scattering and reflection and the constructed image shows the received signal being process resulting 2D image (Arnison, 2009).

GPR provides high-resolution images of the subsurface and structures through wideband electromagnetic waves. It operates in wide range of frequencies, from 10 MHz to 5 GHz for impulse systems and from 1 to 8 GHz for stepped-frequency systems (Lara Pajewski, 2014). The electromagnetic field emitted by the radar interacts with the investigated parameters such as reflection, transmission and scattering phenomena occur at any interface subject to a change in dielectric properties. The reflected signals are detected by the radar receiver.

The history of GPR begins in 1904 where the foundation for radar systems in general was laid by Christian Hülsmeyer when he obtained the worldwide first patent in radar technology on April 30, 1904 (Annan, 2003; Daniels, 2004; Jol, 2009). Then, Gotthelf Leimbach and Heinrich Löwy applied for a patent to use radar technology to locate buried objects with radar technology six years later. This system used surface antennas together with a continuous-wave radar. In 1926, a pulse radar system was introduced and filed for a patent by Dr. Hülsenbeck. The particular invention improved the depth resolution and is still widely used until today (Obonic.de).

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One of the first worldwide ground penetrating radar survey was performed in Austria in 1929 by W. Stern when he measured the depth of a glacier. Thereafter GPR technology was not used anymore although some patents were filed in the field of “subsurface radar”. This changed after the Second World War. Different scientific teams began to work on radar systems for viewing into the ground in the early 1970’s. In the beginning, these radars were developed for military applications such as locating tunnels in the demilitarized zone between North and South Korea. Soon thereafter public utility and construction companies were interested in such radars as a practical tool to map pipes and utility lines under city streets as reported by R. M. Morey.

There are three main parts which are the backbone in the development of GPR system such as control unit, transmitting and receiving part, and processing part or display. In transmitting and receiving part, the antennas are the component of radar system which brings much interest among the researchers since its play a big role to the successful of the GPR system. The needs for higher gain, wide bandwidth and small in size become advantages to the antenna characteristics. Moreover, some of the research works in the GPR area currently more focus on the use of this imaging technique in a many of different applications, such as on its combination with other non-destructive methods, improvement of modelling technique, and imaging techniques for GPR.

The GPR system can be divided into three main category which are monostatic, bi-static and multi static radar system. In monostatic radar system, same antenna reacts as transmitting and the reflected signals are detected by the same antenna. Unlike bi-static radar system, where the transmitting and receiving antenna work as single function with a certain distance in order to avoid the coupling effect. Besides, in multi-static radar systems, there are at least three antennas for example, one receiving and two transmitting, or two receiving and one transmitting, or else multiple receiving and transmitting antennas. In most cases, the GPR are bi-static radar system and there are often housed in a single module and their orientation and spacing cannot be changed. Meanwhile, separate antenna modules represent a significant advantage in the applications where transmitter and receiver can be placed on the two opposite sides of the investigated structure, thus halving propagation and attenuation losses.

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The reflectivity of the planar targets much depending on the antenna spacing; the larger the spacing increases the reflectivity which can be advantageous in some application such as reducing the depth of penetration. However, this factor is small until the spacing approaches half the target depth.

Another advantage by having transmitting and receiving antennas in separated modules is the possibility to change their orientation and polarisation. For instant, if the sought target has a dominant size over the others, the electric field of both antennas should be polarised parallel to the long axis of the target, in order to maximise reflections and increase detectability. Meanwhile, an orientation of the electric field perpendicular to a long object will allow revealing targets buried deeper. For an equidimensional target there is not an optimal orientation. As far as the mutual orientation of the transmitting and receiving antennas is regarded, they can be arranged as parallel or orthogonal to one another. Parallel orientation of antennas allow maximising the polarisation match between them; in this case, the antennas can be arranged in broadside or end fire configuration with respect to the survey line direction, i.e., with an orientation parallel or perpendicular to the line. On the contrary, when the transmitting and receiving antennas are arranged with orthogonal orientations, they are cross-polarised and target information can be extracted based on the coupling angle. GPR antennas operate in a strongly demanding environment and should satisfy a number of requirements, somehow unique and very different than in conventional radar antennas. First of them is an ultra-wide frequency band: the radar has to transmit and receive short-duration time-domain waveforms, in the order of a few nanoseconds, the time-duration of the emitted pulses being a trade-off between the desired radar resolution and penetration depth. The fractional bandwidth of a GPR antenna can be as high as 160 % (Lara Pajewski, 2014).

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Furthermore, there are other factors that influence or give significant results to the GPR performances. For instant, the depth of penetration, the selection of frequency, the materials or soil properties which effect the signal propagation and the challenges in performing the GPR system itself are still enticing among researcher to investigate since the potential of GPR application become more popular.

Other than that, microwave imaging technique has been used in variety of applications such as in medical application, civil application, communication and other application (E.Rufus & Alex, 2012; Sattar, 2012). In (Francesco Soldovieri, Lopera, & Lambot, 2011), the microwave imaging has been applied to construct image for determining the buried target in sand. Recently, microwave imaging has shown great potential to be used for structural health monitoring. Electromagnetic waves in low frequency (e.g., <10 GHz) can easily penetrate inside concrete and reach to object of interest which is usually rebar.

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1.2 Problem Statement

Research and development related to GPR technology has become much interest to researcher all over the world since this non-destructive method have their own advantages. There are many companies involves in the research and work in the field of ground radar applications such as MALA, GSSI, Radarteam, 3D radar and so forth. Nevertheless, the researches in this area are still getting updated since the needs in a certain application are differ to another application. In the field of antenna design and its applications, the design and its characteristic are the main factors which determine the suitability of the antenna been used for particular application. In GPR applications, the needs for high gain and wideband antenna become popular due to its capabilities to propagate deeper (depend on soil properties) and able to carry high data rate (wideband) in order to cater with image construction (Lara Pajewski, 2014).

Besides, bigger antenna size especially in the lower frequency range sometime brings some difficulties to conduct the experiment or searching work especially when space becomes constraint. While, at the higher frequency range, the antenna size become smaller but have some drawback in term of penetration depth. In order to have combination between lower frequency and higher frequency range, some technique could be applied to the antenna design. Therefore, the needs for small in size, wider bandwidth and higher antenna gain become one of the main scopes in this thesis. By having these characteristic, the antenna is more versatile and easy to handle during the experimental or other technical works (Bellett & Leat, 2003).

On the other hand, geological aspect such as types of soil, humidity and temperature of soil need to be considered as well since it gives a significant effect to the GPR measurement performance because the difference location will have difference soil characteristic (H. Liu & Sato, 2014; Rhebergen et al., 2004). Basically, the provided data on dielectric properties of soil by GPR provider sometimes is not suitable to use because the condition of soil as compared to the local (Malaysia) condition is different due to weather and geological aspect. The different of soil properties will have different permittivity and loss factor which influence the signal penetration as well (Gurbuz, 2012). The soils which have higher moisture content or high dielectric constant will absorb more signals and reduce the performance of imaging. Therefore, the early hypothesis or to characterize the soil properties is needed in order to ensure that the whole process in collecting data during the measurement process is promising (Sensoft, 2009).

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Furthermore, reconstruction of the imaging on GPR system is one of the important parts since the overall performances of the system much rely on the constructed image. There are many methods have been used to perform the image for GPR such as B-scan radar, C-scan radar, object mapper, FDTD and most of the software are available in the market and costly (F Soldovieri, Crocco, Brancaccio, Solimene, & Persico, 2011). Some of them are using post processing method which means the analysis is carried out after the experimental works or collecting the data. Hence, needs for alternative; which will be readily available, cost less and easier to operate and still be efficient in detecting and localising buried object with great potential is microwave imaging technique and its feasibility of detection buried object under the ground surface is proposed in this thesis. Besides, the clutter removal technique is applied to the constructed algorithm and the performance are observed and analysed.

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1.3 Objectives

There are three main objectives in this thesis:

1) To design, fabricate and test the proposed Slotted Bowtie Antenna (1.25GHz until 3.0GHz) and Notch Circular Patch (0.5GHz until 3.0GHz) for GPR applications and compare the performances of the proposed antenna in term of return loss, radiation pattern and gain for both simulated and measured results.
2) To characterise the dielectric properties of differences types of soil (heterogeneous) with difference humidity which are normal (ambience), dried (50^{o}C) and wet condition (10 % water content).

3) To construct image using confocal microwave imaging technique (algorithm) with clutter removal for both simulated and measured results using propose antennas.

1.4 Scope of Work

One of the structures of this thesis is to design antenna for GPR applications using planar substrate which have small size, wider bandwidth and higher gain (dB). Two differences types of antenna which are Slotted Bowtie Antenna (SBA) and Notch Circular Patch (NCP) are proposed and it was designed using Computer Simulation Technology (CST) 2014 and fabricated using wet etching technique on Taconic (TLY-5) substrate. The fabricated antennas performances are verified in term of return loss, gain and radiation pattern using Agilent Network Analyzer and Aten lab anechoic chamber.

Measuring the properties of soils are carried out in this thesis as well. Thus, few samples of soil have been collected in few regions in Perlis, Malaysia. For that purpose, permittivity and loss factor of sample are measured using Agilent High Temperature Dielectric probe in the range from 0.5 GHz until 10.0 GHz with three (3) differences condition which is hot (heated up to 50^{o}Celsius), normal condition (ambience) and wet condition (10% water content). All data are recorded and discussed in this thesis.

The combinations of proposed antennas (SBA and NCP) are incorporated with difference types of soil with buried object are carried out. The analysis of difference buried object size, difference object location and difference object materials are observed. The experimental setup using Performance Network Analyzer (PNA E8362B)

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