ULTRA-WIDEBAND ANTENNA ARRAY DESIGN AND DEVELOPMENT FOR MICROWAVE IMAGING

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I hereby declare that this thesis entitled "*Ultra-WideBand Antenna Array Design and Development for Microwave Imaging*" is based on my original work except for the excerpts and summaries which have been duly acknowledged. I also declared that it has not been previously or concurrently submitted for any degree at UTeM or other institution.

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Dedicated to my beloved family, for your love and supports.
To my friends, for your wits, intelligence and guidance in life.

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ABSTRACT

Microwave imaging has been one step forward among the biomedical imaging techniques such as X-ray, Magnetic Resource Imaging (MRI) and ultrasound imaging. By projecting non-invasive high frequency electromagnetic (EM) waves across the human body parts, the signals across the body tissues of different dielectric constants will reflect on discrepancy which then to be processed with algorithm in order to reconstruct the 3D image. Antenna plays an important role as the transmitting and receiving elements whereby the reflection coefficient of the antenna itself should be extreme low to ensure optimal operation of antenna. An Ultra-WideBand (UWB) antenna operating from 3.1 GHz to 10 GHz with the microstrip patch design is proposed at which its return loss is targeted to below -10 dB. Return loss of -10 dB indicates 90% of the signals are being transmitted successfully across the matching terminals to the antenna radiating elements with only 10% of them being reflected back to the system. This project presented an optimized microstrip patch UWB antenna of dimension 20 mm X 18.5 mm with return loss of below -10 dB at bandwidth 3.1 GHz to 10 GHz. Substrate of Flame Retardant 4 (FR4) with dielectrics constant of 4.4 of thickness 1.6 mm is being used in conjunction with the application of partial ground plane and added circular slot on conducting patch. The antenna design is well simulated using CST Simulation Software for its return loss of -20 dB from 3.1 GHz to 10 GHz with 180° phase shift on Far-Field radiation pattern. Validation of the antenna is conducted with the fabricated prototype to perform measurement process with the aid of Vector Network Analyzer (VNA) in the far-field region. The measurement and simulation results are compared and analyzed for its performances.

ABSTRAK

Pengimejan gelombang mikro telah mencecah langkah besar dalam kalangan teknik pengimejan bioperubatan seperti X-ray, Pengimejan Resonans Magnet (MRI) dan ultrasound. Dengan mengunjurkan gelombang electromagnet berfrekuensi tinggi melalui bahagian tubuh badan, isyarat yang merentas tisu badan terdiri daripada pemalar dielektrik berlainan akan menggambarkan perbezaan antaranya dimana ia akan diproses dengan algoritma untuk membina imej 3D. Antenna memainkan peranan penting sebagai element pemancar dan penerima dimana pekali pantulan antenna perlu rendah supaya operasi optimum antenna terjamin. Antenna jalur ultra luas (UWB) beroperasi dari 3.1 GHz hingga 10 GHz dengan berbentuk patch mikrostrip diusulkan dengan sasaran kehilangan balikan dibawah -10 dB. Kehilangan balikan dibawah -10 dB menunjukkan bahawa 90% daripada isyarat yang disalurkan melalui terminal sepadan ke element pemancar antenna dengan hanya 10% daripadanya akan dipantul balik ke system. Project ini membentangkan UWB patch microstrip yang berdimensi 20 mm X 18.5 mm dengan kehilangan balikan dibawah -10 dB pada jalur lebar 3.1 GHz hingga 10 GHz. Substrat FR4 dengan pemalar dielektrik 4.4 berketebalan 1.6mm akan digunakan bersama teknik *partial ground plane* dan potongan alur bulatan pada patch konduktor. Antenna disimulasikan dengan perisian CST dan didapati kehilangan balikannya pada -20 dB dari 3.1 GHz hingga 10 GHz dengan anjakan fasa 180° semasa radiasi dalam kawasan far-field. Pengesahan antenna prototaip dijalankan menggunakan *Vector Network Analyzer* (VNA). Keputusan simulasi dan pengukuran akan dibandingkan dan dianalisa prestasinya.

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LIST OF ABBREVIATIONS

UWB	Ultra-WideBand Antenna
VNA	Vector Network Analyzer
CT	Computerized Tomography
MRI	Magnetic Resource Imaging
MSI	Microwave Sensing and Imaging
FCC	Federal Communications Commission
PPE	Personal Protective Equipment
DUT	Device Under Test
FSPL	Free Space Path Loss
EM	Electromagnetic
FR4	Flame Retardant 4

CHAPTER I

INTRODUCTION

1.1 Project Background

Human body health is the most important assets for continually development of human civilization. Ancestors started to develop greater understanding on human body since 15^{th} Century and the study of oncology has been first puzzled out as the growth of tumors or ulcers in body part uncontrollably. Following the evolution of biological studies since then, the understanding on human body has been improved tremendously with the development of apparatus as aiding tools. X-ray was first invented in 1895 as the first outcomes of biological imaging evolving. Followed by the development of ultrasound scan, Computerized Tomography (CT) scan and Magnetic Resource Imaging (MRI), human body screening has become a vital issue in prescribe the entire body condition for prompt treatments. Yet in recent years, microwave technologies[1] had been a popular research for its enhancement on MRI performance in terms of portability as well as functional imaging.

Antenna application is the crucial part in wireless communication as well as the imaging process. IEEE Standard for Definitions of Terms for Antennas [2] has defined antenna as the part of a transmitting and receiving system which radiates or accepts electromagnetics wave. In another word, can be prescribed as the element used in converting the radio frequency signals into alternating current, allowing the transmitting of the signal across the transmission line into the free space as electromagnetic wave. Antenna do exist in different characteristics such as hi-directivity, semi-directional and omni-directional of respective operating frequency band. Antenna may appears in various structures such as parabolic, monopole, dipole, horn, Yagi Uda and etc. for different field of applications.

Microstrip antenna appears to be prominent among various types of antenna due to its feasibility of fabrication and analysis. Microstrip patch antenna may takes up different configurations yet it is basically a metallic patch of conducting material placed on a ground plane separated by a dielectric sheet namely substrate[3]. Microstrip antenna is versatile in terms of polarization, pattern and resonant frequency. In case which the application require more than a single antenna for full implementation, a combination of electrically and geometrically arranged sets of antennas may produce the desired radiation characteristics.

For a wearable aligned microwave imaging device, it is expected to have more than one single antenna perform as the transmitting and receiving point of the microwaves. An array of 3pairs of antenna acting as transmitting and receiving is proposed in order to have implement the full imaging area for the scanning purpose. This project is mainly focusing on design, simulate, fabricate and validate an ultra-wide band antenna array of microwave imaging that can operate at frequency range from 3.1 GHz to 10 GHz and achieve optimized return loss, S_{11} by using CST Studio Suite software.

1.2 Problem Statement

X-mammography, ultrasound scan, magnetic resource imaging (MRI) and computerized tomography (CT) are the common techniques used in creating images for diagnostic and therapeutic purpose. These techniques utilize either the ionization radiation or magnetic field to project the radio waves accessing the entire body and visualize the current condition of the organs or tissues in within. The unusual condition of the human body parts can therefore be determined and treatment can be prescribed for higher recovery possibilities. However, based on [4], it is believed that these techniques do contributed to biologically tissue change within the body which may lead to false negative mammogram results and high missed rate of cancer detection. In view of this, microwave imaging has appeared with excellent diagnostic capabilities by visualizing human entire body part with the projection of microwaves across it. The ability of differentiating the malignant tissues with the normal ones is highly manifested by microwave techniques with its harmless effect to biological tissues. Besides, the nature of the microwave the tissues water content in human tissues by which the greater the water content the smaller the penetration depth of microwave into it [5]. This has somehow expedite the applications of microwave in biomedical applications since then.

Due to the properties of higher frequency produces better resolution, smaller sized antenna with higher number of antennas is proposed to enhance the resolution of imaging. Microstrip patch antenna with its low profile characteristics meets the specification of low cost and weight with performance guaranteed. However, the challenges that microstrip antenna must first be overcame are its narrow bandwidth and low efficiency. Wide bandwidth assures higher data transmission for signal capturing while high efficiency performs full transmission rate throughout the distance. Ultra-wide band antenna operating from 3.1GHz to 10GHz is proposed to fulfil the basic design requirement of the system.

1.3 Objectives

The project is focused on achieving the following objectives:

1. To design a high frequency oriented ultra-wideband antenna operating from 3.1GHz to 10GHz with wearable properties.
2. To analyse the performance of the antenna using CST simulation tools in determining its gain, directivity and return loss.
3. To fabricate and validate the simulation results with practical laboratory measurements.

1.4 Scope of Project

This project includes the scopes such as below:

i. The ultra-wideband antenna is designed to operate under projection of microwaves as from 3.1GHz up to 10GHz of bandwidth 7.1GHz with return loss of -10dB.
ii. The design of antenna must be simulated using Computer Simulation Technology (CST) Microwave Studio as main simulation tools to determine the return loss, gain and directivity of the antenna.
iii. The fabrication technique of this antenna is by using chemical etching. The substrate FR4 with dielectric constant of 4.4 is used for the middle layer of microstrip patch antenna design.
iv. The validation of the antenna fabricated is tested and measured with Vector Network Analyzer (VNA) and is further analyzed in anechoic chamber in order to obtain the operating performance.

1.5 Thesis Outline

This thesis comprises of five chapters.

Chapter 1 describes an introduction of the microwave imaging and the problem that faced by current biomedical imaging field that could be overcome with this project. Also, the objective and the scope of work for this project was set in order to achieve in the end of project.

Chapter 2 describes the literature review on basic antenna parameter, ultra-wide band antenna design techniques, microwave imaging, on-body parameters and tissues scanning.

Chapter 3 explains the methodology of the project with the use of flow chart, design specification, and the ultra-wide band antenna design.

Chapter 4 depicts the result and discussion of the project and also analysis on the finding and problem faced in this project.

Chapter 5 concluded the finding of the project and suggestions for future work.

CHAPTER II

LITERATURE REVIEW

Research and studies on the microwave imaging techniques with the aid of ultra-wide band antenna of microstrip design have been conducted. In this chapter, the theoretical background of antenna as well as the parameters of antenna will be discussed thoroughly. Besides, the design specifications from previous journal papers, articles, books and electronic resources are discussed.

2.1 Biomedical Imaging Techniques

Previously, the screening technique such as x-ray mammography uses the concept of ionization radiation in order to project the machine generated portion of electromagnetic wave of sufficient energy across the human body. As soon as the interaction with human tissues, the electrons are dislodged to form ions and in turn produced biological changes with the tissues[6]. Meanwhile, ultrasound reveals the usage of high frequency sound waves and the reflection from the hitting of tissues boundary as the image generating technique. MRI aligns the nuclei atoms in the human body with varying magnetic field forming condition of magnetic resonance. From then, the waves absorbed will be emitted as in signal for generating image by the computerized tools. Emerging technology in wireless communication system has become essential for all these screening techniques for the transmitting and receiving of signals across human body. For current technology there are researchers proposed microwave imaging as promising techniques of body monitoring applications whereby it offers no invasion or any biological impact to human body. Currently there are two main applications of microwave imaging that are screening of healthy patient for malignant cells growth detection and post-diagnosis during the treatment process for cancerous patients[7].

2.2 Microwave Imaging

Microwave technology is the technique whereby the wave ranges from 300MHz to 300GHz is projected across the desired objects. Microwave imaging is basically comprises of two approaches which are radar based and tomography based. Discrepancy of dielectric constants between the normal and malignant tissues are the main referrals for both the methods of imaging. Anyhow, radar based imaging extracts the information from the backscattered energy after the signal has been transmitted across the human body parts based on the location of strong scatters and vice versa. Meanwhile, tomography based imaging performs the inverse scattering solving on the dielectric constants spatial distributions in order to take measure of the scattered field generated.

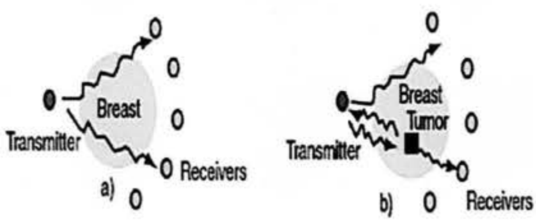

Figure 2.1 Radar-based microwave imaging on human breast cancer detection.

For the radar based microwave imaging, signals of short pulses will be transmitted to the scanning body part via the antenna and any back scattered waves will be received by the same antenna which this process is repeated for different positioning of the set of antenna array on the particular body part. Different intensity of energy will be reflected back as due to the malignant tissues where the travel time for all the signal reflection at all locations will be computed and producing an algorithm of image information[8].

According to Bahramiabarghouei[9], larger amount of information could be provided by a multi-static system due to wider band of signals are collected for given sets of sensor. Size of the antenna would directly affect the positioning of the antennas around the scanning body parts and thus influence the radiation coverage over the scanning tissues. Consequently the errors and accuracy of the system would be drastically increased. In view of this, the resolution of the imaging is dependent on the number and efficiency of the receivers, synthetic aperture of the antenna array as well as the bandwidth of the broadband antenna. Hence, ultra-wide band antenna array with characteristics on wide impedance bandwidth of physically small sized and cost effective are proposed as the main antenna array structure of microwave imaging.

2.3 Microwave Imaging – Bone Sensing and Imaging

Microwave sensing and imaging (MSI) has become trendy in biomedical applications due to its non-invasive and low cost technologies. The fundamental notion of MSI is the acquiring of tissue-dependent dielectric contrast in order to reconstruct the images via the radar-based or tomographic techniques. Connected to this, the difference between the dielectric properties being acquired is due to the variation of the water content in the cell itself which subsequently caused the variation in scattered field of particular tissues[10].

Sara [10] proposed the imaging of knee joint focusing on meniscal tears detection using microwave imaging techniques. Tendons and ligaments are anisotropic in structure in which its physical values is in variation with respect to direction of measurement. In the research measurement, the specimen or specifically the tendons are rotated to obtain the different orientations between its major axis and antenna aperture. Two types of abrasions are considered during the research that are regions of tendons and ligaments are being modeled as dielectric properties increment and decrement with respect to healthy tissue. The numerical and experimental results are presented whereby the lesion is imaged at the correct position yet the increment intensity of bottom part of tendon has been invalidating the measurement due to the closely located with bone causing the domination of reflections rather than useful signals. In Figure 2.2 it is shown that the green frames indicating the correct position of lesions.

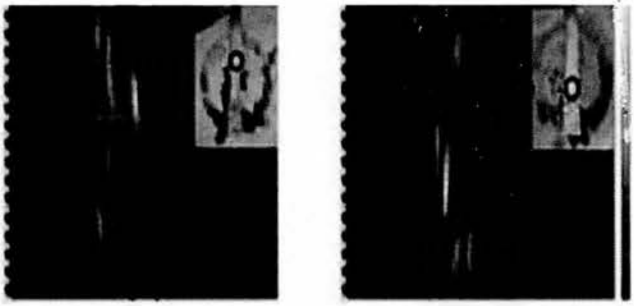

Figure 2.2 Maps obtained for 2 different locations of lesions.

A research conducted by Meaney et al. [11] proposed the imaging system of calcaneus bone as a parameter of monitoring bone health progression regarding the disease like osteoporosis. The existing breast tomographic system is used to construct leg-rest fixture in order to locate the calcaneus bone in illumination chamber.

Figure 2.3 Leg-rest fixture for calcaneus bone positioning.

The imaging system differs from the human breast cancerous cells detection due to the uttermost property variation. There are large concentrations of high water content tissue or mainly muscle and the large structure of low water content calcaneus tissue. This would be a key element which eventually the dielectric properties has become the presaging parameters.