SIZE REDUCTION OF VIVALDI ANTENNA ARRAY FOR MICROWAVE IMAGING

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Sincerely dedicated to my beloved Parents and brothers….

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In the name of Allah, Most Gracious, Most Merciful. All praises be to Allah for blessing me and giving me the strength to complete this project.

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ABSTRACT

UWB antennas with compact size, stable patterns of end-fire radiation and high gain find many of applications such as radar, microwave imaging, remote sensing. To achieve these goals, a compact-sized end-fire slot antenna (TSA) is a good candidate as it offers broad impedance bandwidth and stable radiation patterns, and high gain characteristics In this project, Vivaldi antenna array is designed, one antenna element is designed using FR-4 substrate which has relative permittivity of 4.3. and thickness of 1.6 mm. Furthermore, the single element is investigated to cover an ultra-wideband from 3.1 to 10.6 GHz by using Computer based Simulation Technology for Microwave studio (CST MWS) reducing the size of antenna will lead to gain reduction as well. Therefore, it is crucial to obtain a compact antenna with an acceptable return loss and radiation pattern. Hence, a single element antenna of size (36×42.8 mm^2) was designed, afterward an antenna array 2×1 was placed adjacent to each other on top of a plate made of copper. Though the simulation results have shown that the return loss is better that -10dB within the required frequency range. Therefore, the designed antenna will be useful for ultra-wideband application.

ABSTRAK

Antena UWB dengan saiz padat, corak radiasi akhir stabil, dan gandaan tinggi banyak digunahan dalam aplihagi seperti radar, pengimejan gelombang mikro, penderiaan jauh, dan sistem komunikasi UWB. Untuk mencapai matlamat tersebut, antena slot tirus akhir (TSA) dengan saiz padat adalah calon yang baik kerana ia menyediakan jalur lebar goilangan, corak radiasi yang stabil, dan ciri-ciri keuntungan yang tinggi. Dalam projek ini, array antena Vivaldi direka bentuk dengan, satu elemen antena direka menggunakan substrat FR-4 yang mempunyai ketelusan relatif 4.3. dan ketebalan 1.6 mm. Selain itu, elemen tunggal dikaji bagi meliputi ultra-wideband dari 3.1 hingga 10.6 GHz dengan menggunakan perisian Simulasi berasaskan komputer untuk Studio Microwave (CST MWS) yang mengurangkan saiz antena akan membawa kepada pengurangan gandaan. Oleh itu, adalah penting untuk mendapatkan antena padat dengan corak kehilangan dan corak sinaran yang boleh diterima. Oleh itu, satu elemen antena saiz (36 ×42.8 mm^2) telah direka, selepas itu sebuah antena array 2 × 1 diletakkan berdekatan satu sama lain di atas plat yang diperbuat daripada tembaga. Walaupun keputusan simulasi menunjukkan bahawa kehilangan kembali adalah lebih baik iaitu -10dB dalam julat frekuensi yang diperlukan. Oleh itu, antena yang direka akan berguna untuk aplikasi ultra wideband.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

c	Speed of Light
CPW	Coplanar Waveguide
CST	Advanced Design System
CST	Computer Simulation Technology
dB	Decibel
DC	Direct Current
Ext	Extra Metallization
f	Frequency
FR	Flame Retardant-4
GHz	Gigahertz
I	Current
L	Inductor
m/s	meters per second
mm	millimeter
PCB	Printed Circuit Board
Q	Quality factor
RF	Radio Frequency
RF	MEMS - Radio Frequency Microelectromechanical System
S_{11}	Input Port Voltage Reflection Coefficient
S_{21}	Reverse Voltage Gain
S_{12}	Output Port Voltage Reflection Coefficient
S_{22}	Forward Voltage Gain
US	United States
UV	Ultraviolet
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio

CHAPTER 1

INTRODUCTION

1.1 Background Study

The rapid growth of satellite, cellular, remote sensing and radar technology has contributed to the ultra-wideband (UWB) electronic system. Any radio technology that uses signals with bandwidth more than 20% of the center frequency or bandwidth exceeding 500 MHz is called Ultra-wide band technology [1]. Ultra-wide band technology needs broad-bandwidth antennas and minimal distortion of pulses transmitted and received. In addition, a severe requirement is needed by ultra-wide band airborne applications regarding the scale of antenna arrays to be used because of the limited space available. Due to its simple structure and small size, the Vivaldi antenna is the most common directive antenna for commercial UWB applications. Gibson first introduced the Vivaldi antenna in "The Vivaldi aerial," which comes under the Tapered Slot Antenna (TSA) with an exponentially tapered profile formed on a thin metallization. It has since been commonly used in various applications such as microwave sensing, wireless communication and ground penetration radars [2]. Furthermore, according to the U.S, UWB refers to radio technology with a bandwidth exceeding 500 MHz or 20 percent of the frequency of the arithmetic core. Commission for Federal Communications (FCC). FCC allocated the frequency ranges from 3.1 to 10.6GHz for a 7.5GHz wide UWB network. TSAs have been of great interest to Ultrawideband applications since the implementation of Lewis et al. Vivaldi antenna is a type of streamlined slot antenna that works on the principle of traveling wave antennas with an exponential streamlined profile, providing broad bandwidth and end-fire radiation patterns. Vivaldi antenna was first introduced by P. J. Gibson in 1979.

Many applications are used in the Ultra-wide band Vivaldi antennas and end-fire radiation patterns are needed such in tissue imaging to detect cancer cells, detecting concealed weapons on the body, seeing wall applications that are used where it is difficult to go beyond the wall or for safety purposes, high-range radar systems and many other applications [3].

Vivaldi antennas belong to the surface wave class of moving wave antennas (leaking wave antennas are another type of travelling wave antenna). To illustrate the theory of operation, surface wave antennas can be divided into two parts: the radiation part and the propagating part. The gap width (the distance between the conductors) is less than half the wavelength of free space, and the wave in the segment that launches the curved band along the antenna is very close to the conductor. The connection eventually decreases and the energy is dispersed into the air at a wide area from the antenna width, indicating that the slot width increases more than half the wavelength [4]. The wave travels along the surface of the antenna to the speed limit is equal to the speed of light in the free space (c = 3x10 ^ 8). Boundary boxes are dielectric for antennas. This means that the radiation from low dielectric substrates is higher and is very important for antenna function. As a member of the TSA class, Vivaldi antennas are most effective on slotted cables. The switch is used to incorporate signals from the Vivaldi transmitter or receiver circuit to control the antenna. In order not to reduce the width of the operating band, the transitions must have low losses over various frequencies. It should be compact and easy to build.

One of the engineering challenges is to design a satisfactory antenna device with both small dimensions and large bandwidth. The size of the element must be small enough to hold the required number of elements in the imaging system. In the meantime, high resolution defects and well-managed beam paths require wide bandwidth. In the past, several small UWB antennas have been studied, such as stacked patch antennas, leaked lens antennas, conventional case antennas, and resistance-supported pyramid horn antennas. Among the existing designs, the Vivaldi antenna is one of the best candidates with outstanding advantages such as high gain, easy and light construction. The Vivaldi antenna is a tapered slot cut onto a thin metal film. As an antenna with special shaped housing, it functions as a portable fire wave antenna with very large impedances and a broad bandwidth. As a result, Vivaldi antipodal antennas were selected as the basis for the generation of UWB image network antenna elements [5].

1.2 Problem Statement

Ultra-Wide band antennas with compact size, directive radiation patterns and high gain find many applications such as radar, microwave imaging, remote sensing, and Ultra-Wide band communication systems. But the main drawback is the size of the Vivaldi antenna. While Vivaldi antennas were widely used in many applications, especially in ultra-wideband systems, the original architecture suffered from several design problems, mainly due to poor and inconsistent gain, restricted operating bandwidth and large dimensions. In order to overcome these problems, a compact Vivaldi array antenna will be proposed that is operational at the UWB. To achieve these goals, Since the compact Vivaldi antenna array offers a broad impedance bandwidth, directive radiation pattern and high gain it is considered as a good candidate for such features. In addition, the analysis of different geometrics definition is one of the aims of this project as a method to reduce the antenna size. It will investigate the impact of material properties on the efficiency of the Vivaldi antenna's gain and bandwidth.

1.3 Objectives

The objectives of this research are:

i. To design a compact Vivaldi antenna array for microwave imaging.
ii. To develop the antenna configuration in order to maximize the bandwidth and directivity.
iii. To validate simulated result and measured result of the antenna introduced.

1.4 Scope of Study

1. Using CST Technology, the antenna will be designed for low-cost FR4 substrates operating in the UWB from 3.1 to 10.6 GHz.
2. 2×1 antenna array will be designed in this project
3. To observe how these parameters, affect the performance of the antenna by comparing the designed antenna through simulated and measured results.
4. Fabricate and measure the parameters such as S-parameters, radiation pattern and gain after simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review on the type of antenna being used will be presented in this chapter and the modification of what was proposed in the past will be discussed as well as the results of each paper relevant to the Vivaldi antenna.

2.2 Ultra-Wideband

UWB is now becoming in business and science with special interests and hot topics. UWB technology provides comfort and freedom of movement for wireless broadband networking in home and office devices designed for short distances and personal wireless networks (WPANs), Ultra-wide band is the most recent technology to free individuals from cables and connect multiple wireless video, audio and other high-bandwidth data, Wireless remote technology from UWB complements other remote wireless technologies such as WIFI, WiMAX and mobile phones. It is used in the following media (up to 10 m) to transfer data from the main device to another device. UWB systems with acceptable technical standards can work without interfering with the frequency spectrum of existing wireless services, making it possible to use the limited resources more efficiently. UWB is either a new communication age or the culmination of old technology and maybe both will endure. UWB devices have been defined by the Federal Communications Commission in the United States (FCC) as any device with a fractional bandwidth of -10 dB, covering at least 20% Most narrow band systems cover less than 10% of the central frequency band and are delivered at much higher power rates. For instance, if the radio system uses the entire UWB spectrum from 3.1 to 10.6 GHz and centers almost all frequencies in the band, the frequency bandwidth used must surpass 100%. All frequencies of UWB [6].

After engineers started using microwaves for medical applications, their attention has been drawn to the search for a suitable antenna. Balance antipodal Vivaldi antenna (BAVA) is one of the most commonly known and appropriate antennas used in microwave imaging. It is a compact and flexible type of antenna design characterized by the potential benefits of wide bandwidth properties, high gain efficiency, low cross-polarization, good directivity, Relatively small size, easy manufacturing and light weight. Compared to the tapered slot antenna, it also has better input impedance matching structure. It can also support the transmission of low distortion sub-nanosecond pulse signals and can achieve high accuracy imagery during detection. The main objective of one study was to design and implement two BAVA operating in two different frequency bands: one operating in the 0.75-3.32 GHz range and the other operating in the UWB range (allocated by FCC) to detect breast cancer [4].

Although the design was older than this, In the late 1960s, ultra-wide band technology became popular because of its use in the form of military-impulse radar. Even after FCC approved the commercial-use UWB technology in 2002, its development accelerated. UWB technologies have increasingly been used for wireless high-speed RF communication, High-power RF jamming and high-resolution impulse radar systems as they have a number of advantages over conventional narrowband systems such as low-complexity, low-cost. Clearly Ultra-wide band antennas are a vital part of these systems because they are closely linked to system performance. Certain antenna characteristics can be considered as specific.st application and improved performance in detection, range and target resolution [5].

2.2.1 Ultra-wideband GPR Antennas

The most commonly used UWB radar at the moment is GPR, which has been marketed by more than a dozen firms worldwide due to the widespread proliferation of electromagnetic products., The radio spectrum has become a limited resource, so that the ' large intrusion ' of GPR signals into an already crowded spectrum has recently led to legislation laying down rules and regulations on the use and characteristics of these devices The main advantage of using UWB surface radar technology is the need for high vertical resolution, which is closely related to the operating bandwidth of radar [7]. GPR systems generally rely on ultra-wideband (UWB) pulse radar technology in which antennas transmit and receive wireless radio frequency electromagnetic waves. Based on the amplitude of the reflected signals, the properties of the subsurface structures can be defined. GPR systems are historically ground-connected to the ground-connected antenna because it eliminates losses at the air-ground interface and allows for a deeper investigation. These systems are impractical for the mandate of an in-traffic GPR, and an air-coupled system is a necessity [8].

The transmitting and receiving antennas must be compact and lightweight for portability for the See-Through-Wall (STW) application. The pattern of antenna radiation needs to be accounted for as significant distortion of the picture could be seen due to the angle dependence of the radiation pattern. Here we use Vivaldi antennas for STW applications because of their favourable characteristics and especially because of their relatively simple structure., Light weight, small lateral measurements, big band, high efficiency and high gain features are excellent applications for the series. Theoretical and experimental analysis of the characteristics of the Vivaldi antenna can be found in Variants of the Vivaldi feature [6].

2.2.2 Ultra-Wideband Radar Systems

An ultra-wide-band radar (UWB) is an ultra-wide-band waveform radar system that differs from the conventional radar system that transmits constant wave frequencies with a fixed carrier frequency. At all transmission times An Ultra-wide band signal must have a bandwidth exceeding 500 MHz or a bandwidth exceeding 20%. The bandwidth is called non-zero energy, or the spectrum of frequencies that ranges over a limited threshold. The UWB radar transmits pulses with a pulse repetition frequency (PRF) and detects the return signal of each pulse. The pulse repetition frequency is typically in the range from 1 to 50 MHz. PRF is limited by area uncertainties. It is assumed that the reflected signal is received before the next pulse propagates [9].

Ultra-wideband radar is promising for various applications today. The UWB scanner detects aggressive heart movements. The resistance spectrum for Radar and Broadband Imaging (UWB) offers great potential for medicine, earth-radar systems, emergency services, UWB sensor networks, and other applications. One or more antennas are a key component of the UWB radar system. The Ultra-wide band antenna for wall measurements, depending on the application. One of the basic requirements for a UWB antenna used in a radar system is minimal noise. Other requirements include high operating frequencies, UWB devices that exceed 500 MHz full bandwidth or over 0.2 MHz bandwidth. Depending on the Vivaldi frequency center, additional features are required for the UWB radar antenna: Linear polarization changes at fmin = 1 GHz at least 90, small, surprising, simple and at least small profile. Small flap width. This antenna is selected from a set of UWB antennas and has a specific directional function for its intended use. Ignored deviation refers to the delay in a stable group that is relatively stable with the frequency of activities. This image shows the antenna usage rating [7].

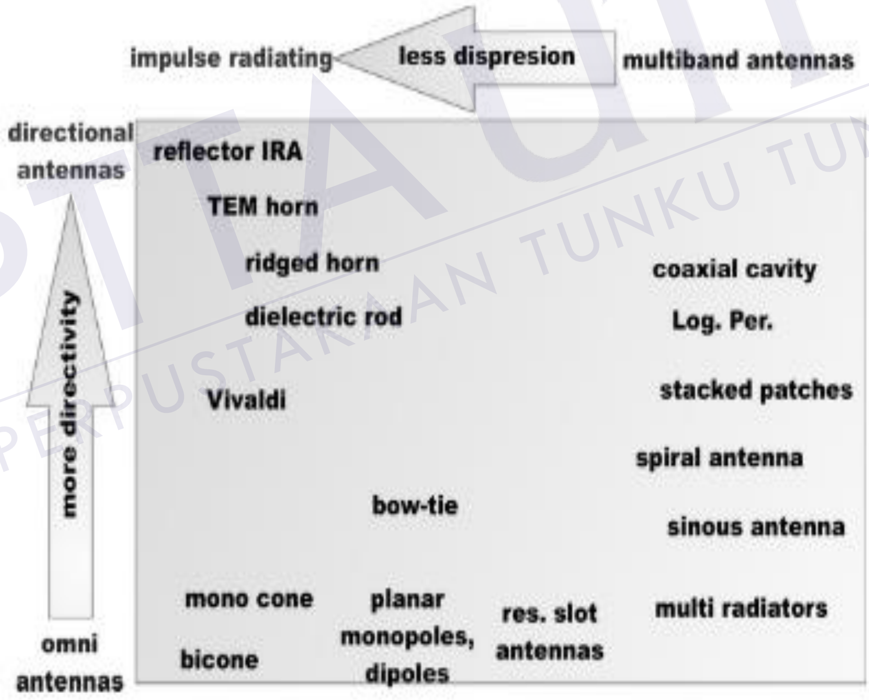

Figure 2.1: Application classification of antenna

A radar sensor is a non-contact sensor that can detect walls. This makes it ideal for a variety of applications, e.g. B. for fall detection for 3D tracking of older people. Among the frequencies at which a radar sensor can be used, ultra-wideband (UWB) is a good choice for the application due to its broad spectrum and its precisely defined properties. An important part of a radar sensor is the antenna. In previous studies, four types of antennas were generally used for UWB Richtradar: microstrip disk, conical, curved housing and Yagi - Uda. The microstrip disc antenna produces not only one but two main lobes, which makes it a bidirectional rather than a unidirectional antenna, such as a conical socket, curved antennas or Yagi-Uda. Various designs have been developed to unilaterally transform the bi-directional nature of the microstrip disk antenna by strategically placing a bottom plate to absorb the unwanted main lobe. These designs successfully removed unwanted main lobes; However, side effects have been detected along the path, so that the direction of the remaining main lobe depends on the frequency. On the other hand, the building of the curved antenna is very complex compared to the conical housing antenna (TSA) and comprises several curves and angles. Although the construction of the Yagi-Uda antenna is less complex than the winding (ie only taking into account the shape of the segments and the distance between the segments), it is still more complex than some segments and the conical slot antenna [8].

2.2.3 Ultra-wide band Microwave Antennas

The generation, transmission, detection and processing of EM waves require frequencies within a certain range, called the EM spectrum. Microwaves (MW) are part of this spectrum covering bands between 1 GHz and 300 GHz. Sending and receiving information by microwave is called microwave transmission and can consist of audio, data, television, telephone, or radio signals. Microwaves are also emitted by natural objects and space. Since microwaves cover a large part of the electromagnetic spectrum, they can be used in many different applications. An antenna for transmitting and receiving microwave frequencies is called a microwave antenna. In addition, microwave transmission is exposed to environmental and atmospheric variables. Depending on its location, an antenna may be exposed to rain, hail, snow, fog, extreme temperatures and strong winds without mentioning lightning. Poor environmental conditions can affect microwave connections, since signal reflection or break can significantly reduce the power level of received signals. This is especially true for high frequency transmissions, which are more susceptible to weather effects. In addition, adjacent-link interference can be a problem if there is not sufficient LOS clearance [10].

Microwave imaging in non-destructive experiments had a major and decisive impact on military and civilian applications. The app also finds continuous and potential suitability for various medical applications, such as breast cancer imaging applications. Breast cancer is a disease caused by the presence of malignant cells in the breast tissue. This is the main cause of unwanted deaths among women in the world. Every eighth woman in England is diagnosed. In order to cause several thousand deaths a year, it is essential to recognize this early. Early diagnosis and treatment can result in a survival rate of almost 97%, which underlines the serious need for a reliable, effective and efficient method of early detection of breast cancer. Medical imaging is currently based on various techniques such as X-ray mammography, magnetic resonance imaging (MRI) and ultrasound. However, these techniques face some obstacles, which is why more effective and efficient approaches are desirable. The use of microwave radar (MWR) as a medical imaging technique for breast cancer screening offers several advantages over other imaging techniques. Imaging by microwave is non-ionizing and non-invasive, and inexpensive, and does not require breast compression compared to X-ray mammography. Microwave imaging, MRI, is very large and expensive. Microwave imaging techniques also have advantages such as high data rates, low complexity and low spectral power density. In microwave imaging, the antenna is used as a transceiver to send and receive microwave signals in breast tissue. This principle is based on the variation of the electrical properties of different tissues, such as. B. the relative permeability and conductivity. The scatter signal reflected by the antenna is used to detect the contrast of the dielectric properties between normal tissue and tumor tissue more efficiently, more effectively, more reliably and more precisely. This technique uses the difference in water content between cancerous and non-cancerous tissue. In contrast to abnormal tissue, normal tissue is permeable to microwaves. The high-water content is collected in cancer cell colonies and serves as a strong diffusion point that causes a different response to tumor detection. In this way, microwave images can be used as a screening tool at an early stage and save many of life [9].

2.2.4 Applications of UWB Antennas

Ultra-wideband (UWB) antennas have had many applications in broadband and spread spectrum communication systems in radar systems for many years. UWB antenna performance is based on stimulating pulses or non-sinusoidal signals with rapidly changing powers. A new symmetrical antipodal Vivaldi antenna has been proposed for UWB applications with ultra-wide bandwidth (1.3 to 20 GHz) based on an impedance of 10 dB. A new version of the ultra-wideband single-cone antenna for measuring UWB channels has recently been developed, and the transient reactions of a periodic logarithmic dipole and a Vivaldi antenna to characterize a UWB antenna.
Ultra-wideband (UWB) technologies have paid particular attention to the advantages of high-speed wireless communication, microwave-microwave imaging and data output on ground radar (GPR). High speed, low power consumption, high precision telemetry and low cost. This leads to the need for broadband printed antennas for ultra-wideband (UWB) applications. Various UWB antennas have been proposed and investigated. Some printed UWB antennas are well known for their compact size, small size and easy integration into other RF circuits. The Vivaldi antenna has been extensively studied in UWB antenna research due to its low profile, wide impedance bandwidth, moderately high gain and good directivity advantages. Antenna always needs big size for good performance [10]. Microwave imaging for biomedical applications is very interesting today and offers the possibility of providing information on the physiological state and anatomical structures of human tissues. Microwave imaging allows for non-destructive evaluation of biological tissue due to the non-ionizing nature of microwaves, since changes in the dielectric properties of the tissue may be related to their physiological state. One of the most promising applications is the detection of breast tumours. This is particularly useful due to the anatomy of the breast, in which the adipose tissue (low loss) has little attenuation effect on the signal, as well as a simple approach to imaging. Contrast permeability for various tissues in vivo (fats, glands, malignant tumours, vascular tissue, etc.) is higher in microwaves. It has been reported that there is a high contrast in the dielectric properties between fibro-glandular tissue and tumour tissue in the breast, and that it is likely to be a non-ionizing method which will be quite inexpensive. Therefore, microwave imaging has been developed, which may be a supplement to standard mammography. However, there remains an area with many undiscovered areas and

microwave imaging techniques need to be overcome and improved. This includes both the development of more sophisticated hardware (antennas, electromechanical parts and RF design) and software (imaging algorithms), which will be considered a reliable method for biomedical application [11].

2.3 Antennas for Microwave Imaging

The rapid development of sectors using microwaves and radio frequencies brought huge changes in our daily life today, particular in telecommunications and medical applications. Microwave imaging is one of the most illustrating examples for both industries, military and medical applications whereas monitoring, tracking and screening are needed. However, it cannot be utilized without the use of antenna. So, antenna is considered as key element in microwave imaging systems where electromagnetic energy is transmitted and / or received.

Cancer deaths are expected to continue rising worldwide. Various techniques of cancer treatment have been used including: surgery, chemotherapy, and radiotherapy. Success of the clinical therapy depends on early detection of the tumour. Three main techniques were proposed for cancer detection including: X-ray mammography, magnetic resonance imaging (MRI), and ultrasound technique. However, microwave imaging has received considerable attention in recent years. Microwave systems are simple, and of low costs compared to other modalities. Microwave imaging systems can thus provide a tool for early diagnosis, provided their performance would become accepted clinically. The working principle is based on the high dielectric difference between the tumour and healthy tissue. The tumour can thus be detected from the back-scattered signals. Two methods of microwave imaging for cancer detection have been using; tomography, and radar techniques. The radar techniques are based on the use of ultra-wideband (UWB) antennas, in which a short pulse is transmitted into the body; then the reflected signals are detected by one or more receiver antennas placed in different locations [12]. Currently, many research groups have shown great interest in the detection of microwave cancer. The large dielectric difference between cancer and healthy body tissue suggests that microwave imaging may be a possible method for finding the tumour. There are two main microwave imaging methods that can be used to detect cancer. An imaging method is called microwave tomography. This method

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