DEVELOPMENT OF WIDEBAND PHASED ARRAY ANTENNA

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DEDICATION

Special dedicated to my caring and loving mother, Sado Ali Farah and to my beloved father Mohamed Abdi Yuosuf, as well as my siblings for their support, encouragement and constant love throughout my life. Thank you so much to all of you for tireless and continued support.

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ABSTRACT

Wideband communication system covering the range from 4 to 8 GHz requires compact antenna to provide desirable characteristic over whole operating band. This project consists of two designs; first design is presented with optimum geometry of an ultra wideband circular patch antenna. To achieve an UWB characteristic, a patch antenna is designed before proceeding to the bandwidth optimization techniques for the proposed antenna which generates (3.1 – 10.6 GHz). While the second design wideband phased array antenna was realized by adding one element and meander line T-divider, partial ground plane and two slots at ground plane. The antenna was designed and optimized using CST Microwave studio (CSTMWS). The proposed antenna's parameters were optimized with various options such as differing the ground plane length, different slot position, and the distance between the elements, and found to operate satisfactorily. An optimized bandwidth has been noticed in this design. Moreover, the antennas structure offers great advantages due to its simple designs and small dimensions working with c-band application. The antenna has been fabricated using FR-4 substrate and tested using network analyzer which has range between 3GHz to 9GHz at the radio frequency (RF) laboratory. Simulation result for wideband 4-8 GHz while the measurement result drops at 7.8 - 4.2 GHz, and the gain is 3.65 dB, and directivity 5.35 dBi. As well as the phase difference between the port 1 to port 2 is -154° and the phase from port 1 to port 3 is 66.8°.The antenna performance showed good agreement between both simulation and measurement results with only some small deviation and this observed deviation is due to the different numerical modeling and meshing techniques.

ABSTRAK

Sistem komunikasi wideband meliputi rangkaian dari empat (4) hingga lapan (8) GHz yang memerlukan antena padat untuk membekalkan ciri yang wajar ke atas semua operasi jejalur. Projek ini merangkumi dua reka bentuk: Reka bentuk pertama adalah dikemukakan dengan geometri optimum dari antena tampalan pusingan wideband ultra. Untuk memenuhi ciri-ciri UWB, antena tampalan direka sebelum memulakan teknik pengoptimuman jalur lebar bagi antena yang dicadangkan yang di mana ia menjana (3.1-10.6GHz). Sementara itu, reka bentuk kedua fasa pelbagai antena wideband disiapkan dengan menambah satu elemen dan garis berliku-liku pembahagi-T, satah tanah separa dan dua slot pada satah tanah. Antena direka dan dioptimumkan menggunakan studio CST gelombang mikro (CSTMWS). Parameter antena yang dicadangkan dioptimumkan dengan pelbagai pilihan,contohnya perbezaan panjang satah tanah, kedudukan slot yang berlainan, dan jarak antara elemen-elemen, dan ia didapati berfungsi dengan baik. Jalur lebar yang dioptimumkan telah diperhatikan dalam reka bentuk ini. Selain itu, struktur antena menawarkan kelebihan yang besar disebabkan oleh reka bentuknya mudah dan dimensinya kecil yang berfungsi dengan aplikasi c-penjalur. Antena telah direka dengan menggunakan substrat FR-4 dan diuji menggunakan penganalisis rangkaian yang mempunyai jarak antara 3GHz hingga 9GHz di makmal frekuensi radio (RF). Hasil simulasi untuk wideband bagi 4-8 GHz semasa hasil pengukuran telah turun pada 7.8-4.2 GHz, dan faedahnya ialah 3.65 dB, dan berarah 5.35 dBi. Begitu jugadengan perbezaan fasa antara port 1 hingga port 2 ialah -154° dan fasa dari port 1 hingga port 3 ialah 66.8°. Prestasi antena menunjukkan persetujuan yang baik di antara kedua-dua simulasi dan hasil pengukuran dengan hanya beberapa sisihan kecil dan sisihan yang diperhatikan adalah kerana model pemodelan dan teknik berangka yang berlainan.

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LIST OF SYMBOLS AND ABBREVIATIONS

GPR	-	Ground Penetration Radar
UWB	-	Ultra-wideband
RF	-	Radio frequency
RFID	-	Radio Frequency Indentified
SLL	-	Side Lobe Level
CPW	-	Coplanar Wave Guide
DS	-	Direct Sequence
MB	-	Multi-band
OFDM	-	Orthogonal frequency-division multiplexing
FCC	-	Federal Communication Commission
WPAN	-	Wireless Personal Area Network
TMDA	-	Time Division Multiple Access
GPS	-	Global Positioning System
EPLRS	-	Enhanced Position Location and Reporting System
FPR	-	Fabry–Perot Resonator
RCS	-	Radar Cross-Section
RVSM	-	Remote Vital Sign Monitoring
EMC	-	Electromagnetic Compatibility
IR	-	Impulse Radio
CST	-	Computer Simulation Technology
MWS	-	Microwave Studio
dB	-	Decibels
dBi	-	Decibels Isotropic
BW	-	Bandwidth
SMA	-	Sub-miniature A
UV	-	Ultraviolet
GP	-	Ground plane

PCB	-	Printed Circuit Board
VSWR	-	Voltage Standing Wave Ratio
GHz	-	Giga Hertz
Mm	-	Millimeter
FR-4	-	Flame Retardant 4
ε_r	-	Dielectric Constant Of The Substrate
h	-	Height of dielectric substrate
λ	-	Free space wavelength
F_c	-	Center Frequency
c	-	Speed Of Light
Δh	-	Changing Of Height of the Partial Ground Plane
L_{eff}	-	Effective length
SWR	-	Standing Wave Ratio
RL	-	Return Loss
S_{11}	-	Return loss or Reflection Coefficient (dB)
Γ	-	Reflection Coefficient
F_H	-	Upper Frequency
F_L	-	Lower Frequency

CHAPTER 1

INTRODUCTION

1.1 Project background

Wideband communication system covering the range from 4 to 8 GHz requires a compact antenna to provide desirable characteristic over the whole operating band. Due to the of the simple structures of the wideband antennas, and their offering of attractive features such as wide band, and Omni-directional radiation patterns, they have been studied for wideband communication systems. Wideband technology has been regarded as one of the most promising wireless technologies, which promises to revolutionize high data rate transmission. It is also used in medical imaging, ground-penetrating radar (GPR), position location and tracking. Since an antenna acts like a filter for the generated ultra short pulse, one of the key issues is the design of a compact antenna with an wideband characteristic wideband communication systems. There are a huge number of wideband single antenna constructions [1].

The existing wideband antennas lack high gains and usually satisfy omni-directional radiation patterns. However, applications such as target detections, 3D microwave imaging, sensor networks and RFID readers need high gains and narrow beam widths [2]. Wideband arrays can be good choices for the purpose of achieving directional radiation patterns. Much research has been investigated on this topic a wideband array of 2-5 antennas is investigated by simulation. Each antenna is designed for 6-8.5 GHz European wideband band with an elliptical-shaped radiator and is excited through a two-step stripline.

Employed four identical compact planar circular slot microstrip antennas to compose 1x2 array with uniform amplitude distribution. Actually, the single element used in an Ultra-wideband array, plays a crucial role to meet the requirements of an approximately constant directive radiation pattern [3].Another important parameter in an antenna array is the mutual coupling between the elements, which influences the performance of an antenna array. In addition, it may lead to the changes in array gain, side lobe level, array polarization, and its size [4]. Initially, it addresses linear dipoles (narrow band) to approximate the coupling effects for wideband linear antenna array [5]. Investigating on the mutual coupling effect for 2-element and 4-element wideband linear arrays. It is assumed that both antenna arrays are fed independently by uniform amplitude distributions.

In this project, we propose a novel wideband phased array antenna (2 elements) with a semi-elliptical radiating patch. Indeed, it is a combination of two semi-circular patches and a rectangular patch. As mentioned above, the single element of an antenna array is of paramount importance. There would be many microstrip antennas designed for wideband applications. However, the lack of suffice effective designs for satisfying array demands while keeping wideband characteristics directed us toward the design of this novel single element. This structure has been utilized to construct a 1×2 linear antenna array in order to achieve a better result and a more directive pattern than the previous designs as confirmed by the simulation results presented and discussed in detail in the project.

1.2 Motivation

The wideband technology has undergone remarkable achievements during the past few years. In spite of all the promising prospects featured by wideband, there are still challenges in making this technology fulfill its full potential. One particular challenge is the wideband antenna. In recent years, many varieties of wideband antennas have been proposed and investigated.

They present a simple structure and wideband characteristics with nearly omni-directional radiation patterns. However, for some space-limited applications, wideband antennas need to feature a compact size while maintaining wideband characteristics. Therefore, miniaturization of wideband antennas becomes an interesting research topic and deserves a comprehensive investigation and analysis. In this thesis, three different miniaturisation approaches are applied to wideband antennas and all the miniaturised wideband antennas are investigated in detail in order to understand their operations. In addition, a competent wideband antenna should also have good time domain characteristics. Unlike traditional narrow band systems, wideband systems usually employ short pulses to convey information. In other words, a huge bandwidth is occupied. In this case the antenna parameters will have to be treated as functions of frequency and will impose more significant impacts on the input signal. Moreover, successful transmission and reception of wideband signals entails minimization of ringing, spreading and distortion of the pulses in the time domain. Therefore, it is indispensable and important to study antenna characteristics in the time domain. In this thesis, a Coplanar Waveguide (CPW)-Fed disc monopole antenna is exemplified to evaluate its time domain behavior.

1.3 Problem Statement

One of the critical issues in this wideband antenna design is the size of the antenna for portable devices, because the size affects the gain and bandwidth greatly [6]. Therefore, to miniaturize the antennas capable of providing wideband bandwidth for impedance matching and acceptable gain will be a challenging task. Planar monopole is used to reduce the size of the proposed antennas. Some novelty wideband planar monopole antennas are investigated in detail in order to understand their operations; find out the mechanism that leads to wideband characteristics and to obtain some quantitative guidelines for designing of this type of antennas. In order to obtain the wideband bandwidth and Omni-directional radiation pattern, four matching techniques are applied to the proposed wideband antennas, such as the use of slots, the use of bevels and notches at the bottom of patch, the truncation ground plane, and the slotted ground plane[7].

All these techniques are applied to the small wideband antenna without degrading the required wideband antenna's performance. The size of slots, bevels and notches are critically affect to the impedance bandwidth. The distance between truncation ground plane to the bottom of the patch is as matching point, where it determines the resonance frequency.

To ensure the broad bandwidth can be obtained, the proper designs on those parameters are required. The theory characteristic modes are used to design and optimize the proposed wideband antennas as well as some new designs are studied. From the study of the behavior of characteristic modes, important information about the resonant frequency and the bandwidth of an antenna can be obtained. The current behaviors of the antenna are investigated in order to obtain several new slotted wideband antennas. High radiation efficiency and linear phase are also required.

1.4 Objectives

The objectives of this project are:

i. To design a wideband phased array antenna for C band application.
ii. To design a wideband T-divider for the wideband antenna.
iii. To validate the simulation results by fabrication and measurement.

1.5 Scope of Project

i. Design the antenna and t-divider for frequency 4-8 GHz using CST Microwave software.
ii. Fabricate the designed antenna.
iii. Conduct a measurement using Vector Network Analyzer for S-parameter and Phase.

1.6 Thesis Organization

This thesis is composed of five chapters. That will explain in details all the work carried out during my research project progress is given below:

Chapter one is summarized the introduction to the project background, objectives, problem statement, scope of project and issues related wideband application system.

Chapter two introduces the history of wideband and antenna description. It also discusses structure of a wideband antenna miniaturized techniques, like meander line, fractal and more including the antenna basic parameters, feeding methods, methods of analysis, advantage and disadvantage of wideband antennas.

Chapter three is mainly consists of project methodology and explanation about the design and fabrication process for wideband phased array antenna as well as flow chart that shows the process of the design.

Chapter four will explain in detail all the results such as simulations results, parameter studies, fabrication method, compared the results of simulation and fabrication.

Chapter five consists of conclusion and recommendation of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses about the theoretical of wideband antenna that is related to the project such as the basics of wideband antenna and the general phased array antenna, and we talk about others that can use a very low energy level for short-range, high-bandwidth communications over a large portion of the radio spectrum. These sections of the thesis also review a number of papers, which have formed the basis for the research component of this paper. This thesis provides an approaching into the background of wideband phased array antenna. Many papers have been studied in order to gain required knowledge that is needed in the design process. There are also many references from source such as books, publications and articles and so on.

2.2 Antenna History for UWB and Array Antenna

Array antennas and printed antennas have become important after the World War 2. For the last 40 to 50 years, the focus has been on the development of printed antennas. Microstrip printed antennas received an extensive attention due to advantages such as low profile, light weight, low cost and small size. However, conventional microstrip antennas are narrowband and measures for substantially increasing their operational bandwidth were needed; examples of antennas with increased bandwidth are the stacked structures and those with parasitic patches [8].

After the adoption of the First Report and Order by the Federal Communication Commission, that permitted the commercial operation of UWB technology, UWB research and development has evolved very fast from theoretical study to engineering design as well as from general concepts to specific prototypes [9]. Looking through the history of UWB antennas, it can be noticed that before 1990's all proposed UWB antennas were based on general volumetric structures, such as Schelkunoff's spheroidal antenna (1941), Lodge's & Carter's biconical antenna (1898, 1939), Lindenblad's coaxial horn element (1941), Brillouin's omnidirectional and directional coaxial horn antenna (1948), King's conical horn antenna (1942), Katzin's rectangular horn antenna (1946), Stohr's ellipsoidal monopole and dipole antenna (1968) and Harmuth's large current radiator (1985). As explained previously, from 1992 onwards, several microstrip, slot and planar monopole antennas with simple structures such as circular, elliptical or trapezoidal shapes have been proposed. Today the state of the art of UWB antennas focuses on these microstrip, slot and planar monopole antennas with different matching techniques [10]. In this dissertation, the research is directed towards planar UWB antennas that are also suitable for array environments. In the following section the basic concepts concerning the antenna elements will be reviewed.

2.3 Requirements for Wideband Antennas

According to the FCC definition [11], a wideband antenna has a fractional bandwidth of 20%, while it has 25% fractional bandwidth in radar domain [12]. Hence, first of all an antenna should have more than a certain value of fractional bandwidth to be called an wideband antenna. Secondly the performance, both the reflection and radiation characteristic of the antenna, should be stable over the entire operational bandwidth of the antenna. Another requirement of the wideband antenna comes from the size of its which should be small enough to be compatible with the wideband unit.

Mechanically, they should be low-profile, embeddable and easily integrated for portable devices. For example, the antennas that are required to have omni-directional radiation patterns and to be used in mobile devices should be small enough to fit in the mobile terminal. Finally the robustness and the low cost are also key requirements. After these general requirements, some antenna design parameters are strongly dependent on the modulation schemes that are used by the wideband systems. The multi-band orthogonal frequency division multiplexing (MBOFDM) based wireless communication systems require antenna systems with extremely wide band width covering all operating sub-bands. Similarly pulse based systems, referred to as direct sequence UWB (DS-UWB), require wide impedance bandwidth covering that part of the spectrum where the major pulse energy falls in. A linear phase response of the antenna is also an important parameter in the pulsed-based systems [13].

2.4 Advantages of Wideband

Due to its wideband nature, wideband communication systems present unique benefits that are attractive for radar and wireless communication applications. The primary advantages of UWB can be summarized as follows [14].

i. Potential for high data rate
ii. Multipath immunity
iii. Potential small size and low equipment cost
iv. High-precision ranging and localization at the centimeter level

The extremely large bandwidth occupancy of wideband provides the potential of very high theoretical capacity, yielding very high data rates. This can be demonstrated by considering Shannon's capacity equation [15].

$$C = B\log_2 (1+\frac{S}{N}) \tag{2.1}$$

Where

C Is the Maximum Channel Capacity,

B The Signal Bandwidth,

S The Signal Power

N The Noise Power.

2.5 Application of Wideband

Wideband is the leading technology for freeing people from wires, enabling wireless connection of multiple devices for transmission of video, audio and other high bandwidth data. Designed for short range, WPAN, it is used to relay data from a host device to other devices in the immediate area (up to 10 m or 30 feet).

Recent years, rapid developments have been experimented on the technology using wideband signals. Wideband technology offer major enhancements in three wireless application areas: communications, radar and positioning or ranging.

2.5.1 Communication System

Using wideband techniques and the available large RF bandwidths, ultra wideband communication links has become feasible. The exceptionally large available bandwidth is used as the basis for a short-range wireless local area network with data rates approaching gigabits per second.

This bandwidth is available at relatively low frequencies thus the attenuation due to building materials is significantly lower for wideband transmissions than for millimeter wave high bandwidth solutions. By operating at lower frequencies, path losses are minimized and the required emitted power is also reduced to achieve better performance [16].

Wideband radios operate in the presence of high levels of interference by trading data rate for processing gain. The attributes of low emitted power and wide signal bandwidth result in a very low spectral power density of the wideband signal. This means that wideband radios operate in the same spectrum space as narrowband radios on a non-interfering basis. Computer peripherals offer another fitting use of wideband, especially when mobility is important and numerous wireless devices are utilized in a shared space. A mouse, keyboard, printer, monitor, audio speakers, microphone, joystick, and PDA are in wireless, all sending messages to the same computer from anywhere in the given range [17].

Wideband also is used as the communication link in a sensor network. A wideband sensor network frees the patient from the tangle of wired sensors. Sensors are being used in medical situation to determine pulse rate, temperature, and other critical life signs. Wideband is used to transport the sensor information without wires, but also function as a sensor of respiration, heartbeat, and in some instance for medical imaging.

Wideband pulses are used to provide extremely high data rate performance in multi-user network applications. These short duration waveforms are relatively immune to multipath cancellation effects as observed in mobile and in-building environments. Multipath cancellation occurs when a strong reflected wave arrives partially or totally out of phase with the direct path signal, causing a reduced amplitude response in the receiver. With very short pulses, the direct path has come and gone before the reflected path arrives and no cancellation occurs. As a consequence, wideband systems are particularly well suited for high-speed multimedia, mobile wireless applications. In addition, because of the extremely short duration waveforms, packet burst and time division multiple access (TDMA) protocols for multi-user communications are readily implemented [18].

2.5.2 Radar Systems

For radar applications, these short pulses provide very fine range resolution and precision distance and positioning measurement capabilities. The very large bandwidth translates into superb radar resolution, which has the ability to differentiate between closely spaced targets. This high resolution is obtained even through lossy media such as foliage, soil and wall and floor of the buildings. Other advantages of wideband short pulses are immunity to passive interference (rain, fog, clutter, aerosols, etc) and ability to detect very slowly moving or stationary targets [19].wideband antennas arrays are especially important, to have both fine range and angular resolution in radars.

In radar cross-section (RCS) range, a single wideband antenna replaces a large set of narrow band antennas that are normally used to cover the whole frequency band of interest. Wideband signals enable inexpensive high definition radar. Radar will be used in areas currently unthinkable such as, automotive sensors, smart airbags, intelligent highway initiatives, personal security sensors, precision surveying, and through-the wall public safety application.

Operation of vehicular radar in the 22 to 29 GHz band is permitted under the wideband rules using directional antennas on automobiles. These devices are able to detect the location and movement of the objects near a vehicle, enabling features such as near collision avoidance, improved air bag activation, and suspension systems that better respond to road conditions.

2.5.3 Positioning Systems

For global positioning system (GPS), location and positioning require the use of time to resolve signals that allow position determination to within ten of meters. Greater accuracy is enhanced with special techniques used. Since there is a direct relationship between bandwidth and precision, therefore increasing bandwidth will also increase positional measurement precision, with wideband techniques extremely fine positioning becomes feasible, e.g. sub-centimeter and even sub-millimeter. In satellite communications where wide band feeds save space and weight by supporting many communication channels with just one antenna.

The architectures for UWB position-determination systems would resemble traditional systems, e.g. multi-alterations like GPS or radio ranging like the military's enhanced position location and reporting system (EPLRS). Having relatively low frequency of operation, this type of system has the potential to work within buildings with minimal attenuation of the signal.

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