BANDWIDTH OPTIMIZATION OF ULTRA-WIDEBAND (UWB) ANTENNA

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ABSTRACT

This project presents the design with optimum geometry of an UWB rectangular patch antenna. To achieve an UWB characteristic, a patch antenna is designed before proceeding to the bandwidth optimization technique for the proposed antenna. The configuration of patch antenna has a partial ground and addition of two steps in the bottom edge of the patch and one slot in the middle of the patch. 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, differing the width of feed line, with different slot positions and different slot widths, 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. The antenna has been fabricated using FR-4 substrate and tested using the network analyzer which has range between to 3GHz to 13GHz at the Radio Frequency (RF) Laboratory. The antenna performance showed 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.

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LIST OF ABBREVIATIONS

UWB	Ultra-wideband
RF	Radio frequency
MB	Multi-band
OFDM	Orthogonal frequency-division multiplexing
FCC	Federal Communication Commission
IR	Impulse Radio
CST	Computer Simulation Technology
MIT	Massachusetts Institute of Technology
MWS	Microwave Studio
dB	Decibels
BW	Bandwidth
SMA	Sub-miniature A
UV	Ultraviolet
WP	Width of patch antenna
GP	Ground plane
PCB	Printed Circuit Board
FL	Length of the feed
FW	Width of the feed
LP	Length of patch antenna
FBW	The fractional bandwidth
VSWR	Voltage Standing Wave Ratio

GHz	Giga Hertz
Mm	Millimeter
LG	Length of the ground plane
FR4	Flame Retardant 4
ε_r	dielectric constant of the substrate
h	Height of dielectric substrate
WG	Width of the ground plane
λ	Free space wavelength
F_c	Center frequency
c	Speed of light
W	Width
L	Length
LS	Length of substrate
ΔL	Extended length due to fringing field effect
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

WS	Width of substrate
LST1	Length of step 1
WST1	Width of step 1
LST2	Length of step 2
WST2	Width of step 2
FL	Length of the feed
FW	width of the feed

CHAPTER 1

INTRODUCTION

1.1 Introduction

An antenna is a transducer between an electromagnetic wave propagating in an unbounded medium, air for example and a guided wave propagating in a transmission line [1]. All wireless systems have a transmitting and receiving antenna. The transmitting antenna obtains the signal from the source while the receiving antenna is the antenna that outputs the desired signal to a receiver. For example in radio applications, the receiving antenna on a car collects the signal from the radio station and outputs the signal into the receiver.

Ultra-wideband antenna is defined as an antenna that has a bandwidth greater than 500 megahertz (MHz) and ranges from 3.1 GHz to 10.6 GHz. Instead of sinusoidal waveforms compressed in frequency, ultra-wideband signals are pulse-based waveforms compressed in time. UWB technology has been regarded as one of the most promising wireless technologies for high data rate transmission, higher bandwidth and low power requirements. The difference between a narrowband signal and a UWB signal is that the bandwidth of the UWB signal is much larger than the narrowband, which means UWB signals can operate over wider frequencies [2].

Within this operating range of frequency (3.1 GHz to 10.6 GHz), the antenna should have stable response in terms of impedance matching, gain, radiation pattern polarization, and at the same time it should be of small size, conformal, low cost and should be easily integrated into the RF circuits. The difference between a narrowband signal and a UWB signal is that the bandwidth of the UWB signal is much larger than the narrowband, which means UWB signals can operate over wider frequencies [3].

A variety of ultra-wideband antennas existed for many years such as log periodic antenna and spiral antenna. But all these antennas tend to be unsuitable for short pulse applications, because log-periodic antenna and spiral antenna radiate different frequency components from different sections of the antenna; this distorts and stretches out the radiated waveform for ultra-wideband communications applications. Some prototypes have been reported for this purpose [4] [5]. So the shape or the structure of the design of the antenna can be different so that it can be a bow-tie antenna, the wide-slot antenna, fractal antennas, a planar monopole with the modified shape.

1.2 Background of research

Ultra-wideband antenna systems have been based historically on impulse radio, because of its very high data transmission rates data it sends pulses of energy rather than using a narrowband frequency carrier, the pulses have very short durations, typically a few nanoseconds which results in an ultra wideband frequency spectrum [6].

In the 1900s, the concept of impulse radio was initially originated with Marconi when spark gap (consists of an arrangement of two conducting electrodes separated by a gap usually filled with a gas such as air and designed to allow an electric spark to pass between the conductors) transmitters induced pulsed signals having very wide bandwidths [7]. In that moment, the wideband energy emitted by a spark gap transmitter or discriminate among many such wideband signals in a receiver could not be effectively recovered which caused the wideband signals to have too much interference with one another. So the communications world abandoned wideband communication in favour of narrowband radio transmitter that was easy to regulate and coordinate.

Even though UWB is recommended by the FCC of United States (U.S) to operate with maximum in-band effective incident radiated power of -41.3 dBm/MHz within the band from 3.1 GHz to 10.6 GHz, there have been a lot complaints lodged against UWB deployment so far [8]. Evaluation of interference between Multiband Orthogonal Frequency Division Multiplexing (MB-OFDM) UWB and Wireless Local Area Network (WLAN) systems using a Gigahertz Transverse Electromagnetic (GTEM) cell has been proposed in [9]. As a result, when the frequencies of the MB-OFDM UWB corresponded to out-of-band radiation for the 11a (Band #3), MB-OFDM UWM did not interfere with the WLAN system. In the other hand, when frequencies of the MB-OFDM UWB corresponded to in-band radiation for 11a (Band #4), although the interference power of MB-OFDM UWB was less than receiver noise, the MB-OFDM UWB systems interfered with the WLAN.

In February, 2002 as a part their work towards the likes of broadband spectrum, the Federal Communications Commission (FCC) which is an independent agency of the United States government amended, the Part 15 rules which govern unlicensed radio devices to include the operation of ultra-wideband devices [10]. The FCC also allocated a bandwidth of 7.5GHz, i.e. from 3.1GHz to 10.6GHz to ultra-wideband applications [11], by far the largest spectrum allocation for unlicensed use the FCC has ever granted. According to the FCC's ruling, any signal that occupies at least 500MHz spectrum can be used in UWB systems. That means UWB is not restricted to impulse radio any more, it also applies to any technology that uses 500MHz spectrum and complies with all other requirements for ultra-wideband.

1.3 Problem statement

The ultra wide-band technology has experienced many significant developments in recent years. However, there are still challenges in making this technology live up to its full potential. One of the critical issues in this UWB antenna design is the size of the antenna for portable devices, because the size affects the bandwidth. In order to obtain the ultra wide bandwidth three matching techniques are applied to the proposed UWB antennas, such the use of slot, the use of steps at the bottom of patch and the use of reduced ground plane. All these techniques are applied to the small UWB antenna without degrading the required UWB antenna’s performance. The slot size and position, and the steps are critically affected to the impedance bandwidth. To ensure the broad bandwidth can be obtained, the proper designs on those parameters are required.

1.4 Objectives of research

The objectives of this research are as follows

i) To design ultra-wideband (UWB) antenna with a frequency range from 3.1 GHz to 10.6 GHz using FR4 substrate.

ii) To propose a small UWB patch antenna which is capable to operate on a UWB bandwidth (3.1GHz - 10.6 GHz) and beyond.

iii) To simulate the antenna using Computer Simulated Software CST and then fabricate on a PCB board.

1.5 Project scopes

The scope of the project focuses the design of a rectangular structured patch antenna to provide an ultra-wideband bandwidth. Inserting a slot, addition of steps at the bottom of patch and the use of reduced ground plane are introduced to improve the impedance bandwidth. Optimum bandwidths are achieved by varying the width of the slot and its position, step lengths and widths as well as feed width. To achieve the objective of the project, a number of activities have been identified below:

i) Study the characteristics of UWB antennas by means of calculation and simulation.

ii) Simulate the UWB antenna design model using antenna simulation software before fabrication.

iii) Investigate the effects of slot, step width and length as well as feed width into the proposed antenna to optimize and evaluate the bandwidth of the antenna.

CHAPTER 2

LITERATURE REVIEW

Ultra-wideband communication technologies provide a different approach to wireless technologies. One of the promising potential application areas is in medicine because of some unique features of ultra- wideband make it very suitable for medical areas. Ultra-wideband (UWB) has many applications in many different areas such as wireless communications, radar, military, weather and many other areas but in this chapter, we will discuss the features and its current major applications in medical areas such as medical monitoring and screening.

2.1 Introduction

In the past, the idea of an ultra-wideband antenna that would allow stable pattern control over many frequency decades seemed elusive at the best. The phase centre and voltage standing wave ratio (VSWR) of ultra-wideband antennas are required to be constant across the whole bandwidth of operation. A change in phase centre may cause distortion on the transmitted pulse and worse performance at the receiver therefore any distortion (filtering) of the signal in the frequency domain will cause distortion of the transmitted pulse shape. This will increase the complexity of the detection mechanism at the receiver [12].

Many techniques to broaden the impedance bandwidth of small antennas and to optimize the characteristics of broadband antennas have been widely investigated. In terms of size, any reduction to antenna size presents various problems due to the performance penalties in antenna characteristics, such as impedance, efficiency, and bandwidth. Small antennas with smallness sizes in terms of size, wavelength, and function are defined as small antennas and are divided into four categories.

i) Electrically small antennas, which have a very small size compared to the wavelength.

ii) Physically constrained small antennas, which are not necessary electrically small, but are shaped in such a way that considerable size reduction is achieved in one plane.

iii) Physically small antennas, which have dimensions regarded as small in a relative sense.

iv) Functionally small antennas, which are antenna systems that achieved additional functions without increasing size [13].

So to understand the challenges that ultra-wideband provides to antenna we need to analyse and understand several important parameters of antennas.

2.2 Ultra-wideband antenna fundamental parameters

Antenna design are based on the fundamental principles of electromagnetic field theories and the antenna working conditions depend on the antenna parameters which will affect the selection of an antenna. The most fundamental parameters of an antenna are impedance bandwidth, radiation pattern, efficiency, gain, directivity and with some other important parameters such as field region, polarization and dispersion. In order to determine whether an antenna is optimized for a certain application, the above mentioned parameters are to be fully characterized.

2.2.1 Radiation pattern

Radiation pattern is one of the most common characteristics of an antenna. Radiation pattern can indicate the application in which an antenna will be used. The case of cell phone usage for instance, the antenna would nearly be an omnidirectional antenna, because of the user's location which is not known. So, in the case like this the radiation power should be spread out uniformly around the user for optimal reception. However, for satellite applications, the majority of radiated power is directed to a specific, known location because a highly directive antenna would be desired. Antenna pattern or radiation pattern is a graphical representation of the radiation (far field) properties of an antenna.

Three dimensional radiation patterns are measured on a spherical coordinate system; the x-z plane with ($\boldsymbol{\theta}$ = 0°) usually indicates the plane, while the x-y plane ($\boldsymbol{\theta}$= 90°) indicates the azimuth plane. Normally, the elevation plane will contain the electric-field vector (E-plane) and the direction of maximum radiation, and the azimuth plane will contain the magnetic-field vector (H-Plane) and the direction of maximum radiation [14].

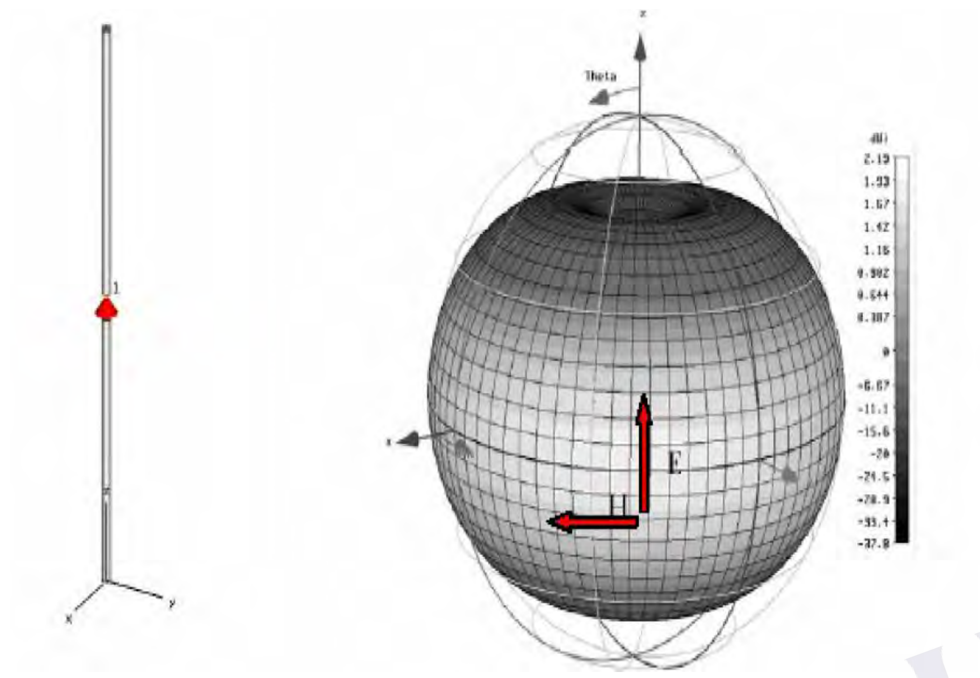

Figure 2.1: Dipole model for simulation and simulated 3D radiation pattern

Figure 2.1 illustrates a half wave dipole and its three dimensional radiation pattern. And the gain is expressed in dBi, which means that the gain is referred to an isotropic radiator. At the same time it can be seen clearly that the maximum radiation power occurs along the θ = 90° plane, or for any varying in the azimuth plane. The nulls in the radiation pattern occur at the ends of the dipole along the z axis (or at **θ** = 0° and 180°). The position of the receiving antenna with respect to the transmitting antenna will determine the received power at point.

The received power graph is at a constant radius from the transmitting antenna and it is called the power pattern of the antenna and hence it is the spatial pattern. The spatial pattern of the electric or magnetic field is called the field pattern. So the cross section of this field pattern in any particular plane is called the radiation pattern in that plane [15]. A typical antenna power plot is shown in the figure 2.2

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