Reactive-Loaded Antenna Designs for Ultra-Wideband (UWB) Applications

by

Siti Zubaidah Bte Aziz
1340810920

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School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS

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LIST OF SYMBOLS

Ω	Resistance (ohm)
c	Free Space Velocity
f_r	Resonant Frequency
ε_r	Dielectric Constant
ε_{re}	Effective dielectric constant
η	Efficiency
μ	Permeability
S_{11}	Reflection Coefficient
S_{21}	Transmission Coefficient
λ	Wavelength
$\lambda_\circ$	Wavelength in free space
G	Gain (electromagnetic)
h	Height
K	Impedance scaling factor
w	Width
γ	Propagation constant
α	Attenuation constant
σ	Relative spacing constant
β	Phase constant
ξ	Fringing field effect

LIST OF ABBREVIATIONS

2G	Second Generation
3G	Third Generation
4G	Fourth Generation
APT	Asia-Pacific Telecommunity
AUT	Antenna Under Test
BPF	Band-pass Filter
CEPT	Conference of Postal & Telecommunications Administrations
CPW	Co-planar Waveguide
CST	Computer System Technology
dB	Decibel
dBi	Decibel Isotropic
DOD	Department of Defense
DGS	Defective Ground Structures
DS-UWB	Direct Sequence Ultra-Wideband
EM	Electromagnetic
ERS	Elliptical Ring Slot
ETRI	Electronics and Telecommunications Research Institute
FCC	Federal Communications Commission
FDTD	Finite-difference Time-domain
FEM	Finite Element Method

GPR	Ground Penetrating Radar
GPS	Global Positioning System
HDR	High Data Rate
HFSS	High Frequency Structure Simulator
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
LDR	Low Data Rate
MB-OFDM	Multiband Orthogonal Frequency Division Multiplexing
MIC	Ministry of Internal Affairs & Communications
MoM	Method of Moment
NA	Network Analyzer
OFDM	Orthogonal Frequency Division Multiplexing
PCB	Printed Circuit Board
RF	Radio Frequency
Rx	Receiver
SCSA	Self-complementary Spiral Antenna
TSA	Tapered Slot Antenna
Tx	Transmitter
UFZ	UWB Friendly Zone
UV	Ultra-violet
UWB	Ultra-Wideband
VSWR	Voltage Sin Wave Ratio

Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access
WBAN	Wireless Body Area Network
WLAN	Wireless Local Area Network
WPAN	Wireless Personal Area Network

REKAAN ANTENA DENGAN PENAMBAHAN BEBAN REAKTIF UNTUK APLIKASI JALUR LEBAR ULTRA

Teknologi jalur lebar Ultra telah mendapat perhatian penyelidikan yang sangat mengagumkan dari institusi penyelidikan dan industri disebabkan oleh ciri-ciri eksklusif teknologi tersebut. Keperluan terhadap antena jalur lebar Ultra untuk pelbagai aplikasi jalur lebar Ultra semakin cepat berkembang. Cabaran-cabaran untuk mereka bentuk antena jalur lebar Ultra adalah untuk menghasilkan operasi jalur lebar yang diperlukan, dapatan yang bersesuaian dengan corak radiasi yang stabil, dan antena yang bersaiz padat. Dalam tesis ini, penyelidikan yang dilakukan tertumpu kepada reka bentuk antena, perkembangannya, dan penghasilan antena-antena jalur lebar Ultra mengikut kriteria-kriteria untuk aplikasi jalur lebar Ultra. Teknik pengisian reaktif telah dipilih sebagai teknik untuk menyediakan kriteria-kriteria menarik tersebut. Teknik tersebut termasuklah perlubangan, takuk, dan torehan. Teknik yang dipilih tersebut mempunyai ciri-ciri yang boleh menyediakan antena jalur lebar Ultra dengan jalur lebar operasi yang diperlukan, kepadatan, corak radiasi stabil, dan dapatan yang bersesuaian. Lima antena jalur lebar Ultra telah direka bentuk, difabrikasi, dan pencapaian antena tersebut telah diselidiki secara meyeluruh. Antena pertama yang difabrikasi di atas substrat FR4 mempunyai elemen terpancar tak seragam dengan lubang-lubang, separuh satah bawahan dengan torehan dan lubang seragam. Antena kedua mempunyai pelbagai lubang di dalam elemen terpancar berbentuk bulat, separuh satah bawahan, dan satah bawahan yang berada di atas dengan torehan-torehan yang difabrikasi di atas substrat FR4. Antena ketiga mempunyai lubang-lubang di dalam elemen terpancar, lubang dalam garisan kaki, satah konduktor-belakang di bawah substrat FR4, dan dua separa satah bawahan. Antena keempat mempunyai lubang di dalam elemen terpancar, lubang-lubang di atas satah bawahan, satah konduktor-belakang dibawah substrat dan torehan di atas satah bawahan berada di atas. Antena keempat itu difabrikasi di atas substrat FR4. Antena kelima telah direka bentuk dengan konfigurasi yang sama seperti antena keempat tetapi menggunakan substrat yang berlainan iaitu Taconic (TLY-5A). Semua antena jalur lebar Ultra telah difabrikasi dan di ukur di dalam ruang tanpa gema untuk diperhatikan pencapaian-pencapaiannya. Daripada pemerhatian, semua antena mencapai jalur lebar separuh lebih daripada 100 % yang meliputi seluruh operasi jalur lebar untuk jalur lebar Ultra daripada 3.1 GHz sehingga 10.6 GHz, menunjukkan corak radiasi menghampiri arah 'omni' yang stabil dan dapatan bersesuaian setinggi 7.35 dBi. Keadaan ini membuktikan bahawa kesemua antenna tersebut mempunyai potensi yang tinggi untuk digunakan dalam aplikasi jalur lebar Ultra termasuk radar, gambaran, sensor, komunikasi, dan lain-lain. Berdasarkan penyelidikan ini, antena kedua mencapai operasi jalur lebar yang sangat lebar sehingga 32 GHz. Oleh hal yang demikian, antena kedua boleh diaplikasikan untuk aplikasi masa depan seperti aplikasi 5G dan lain-lain.

REACTIVE-LOADED ANTENNA DESIGNS FOR ULTRA-WIDEBAND (UWB) APPLICATIONS

Ultra wideband (UWB) technology have attracted incredible research attention from research institution and industry due to its exclusive characteristics. The need of UWB antenna is speedily growth for many types of UWB applications. The challenges on designing UWB antenna are to produce the required operating bandwidth, an adequate gain with stable radiation pattern, and compact size of antenna. In this thesis, the research study is focused on the antenna design, development, and prototyping the UWB antennas for UWB application that fulfil the characteristics. Reactively loading technique is chosen as the method to provide those appealing characteristics. This technique includes slots, notches, and slits. The selected technique has features that can provide UWB antenna with requires operating bandwidth, compactness, stable radiation pattern, and acceptable gain. Five UWB antennas have been designed, fabricated and their performances are investigated comprehensively. The first antenna is designed on FR4 substrate which comprises of unsymmetrical rectangular radiating element with slots, and symmetrical slots with slit on the ground plane. The second antenna has multi-slots circular radiating element, a partial ground plane, and a ground plane on top with slits that is fabricated on FR4 substrate. The design of third antenna has multi-slots in the radiating element, slot in the feed line, conductor-backed planes under the FR4 substrate, and two partial ground planes. The fourth antenna consists of slot in the radiating element, multi-slots on the ground plane, a conductor-backed plane under the substrate and slits on the ground plane on top. The fourth antenna is fabricated on the FR4 substrate. The fifth antenna is designed with same configuration as the fourth antenna but using a different substrate which is Taconic (TLY-5A). The UWB antennas have been fabricated and measured in an anechoic chamber in order to observe their performances. From observation, all antennas achieved fractional bandwidth more than 100 % that covered the entire UWB operating bandwidth from 3.1 GHz to 10.6 GHz, exhibit stable nearly omni-directional radiation pattern and appropriate maximum gain of 7.35 dBi. These behaviours prove that those antennas have high potential for being used in UWB applications includes radar, imaging, sensor, communication, and others. Based on this research, the second antenna achieved a very wideband operating bandwidth up to 32 GHz. Therefore, the second antenna can be applied for future application such as 5G application and others.

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Last few years, various communication technologies have been created to errand every field of human life. A revolution has been created in wireless communication with the help of numerous communication systems such as Wi-Fi, Wireless Local Area Network (WLAN), Bluetooth, global position systems (GPS), WiMAX, second generation (2G), third generation (3G), fourth generation (4G), and ultra-wideband (UWB) systems. Ultra Wideband (UWB) technology is the cutting edge technology for wireless communications with a wide range of applications. The demands of UWB communication systems are speedily growing to deliver data with higher rates while supporting more users at one time.

UWB communication systems can be classified as any communication system which instantaneous bandwidth is many times greater than the minimum required to deliver particular information. In 2002, United States Federal Communications Commission (FCC) has approves UWB technology for commercial use. An UWB system has been found to be used in short-distance wireless communication systems comprehensively because of the attractive properties. For a communication system, UWB is a worthy choice because of its low complexity, low spectral power density, low interferences, and extremely high data rates with a low cost. UWB is considered as fast developing and very promising low cost technology with outstanding attractive features.

This advance of technology is applied in wireless communication, sensor network, positioning system, radar, detector, wireless body area network, and wireless personal area network. Various designs with compact size of antenna for UWB application have been designed, developed, and fabricated in this thesis. All these antennas are investigated extensively with their performances.

1.2 MOTIVATION

In this thesis, all structures of antenna are explained and discussed thoroughly in order to improve the fundamental characteristics of UWB antennas. Important characteristics of antennas that need to be studied are wide operating bandwidth with compact size, low cost, ease of integration and fabrication, and operate independently in desired application.

1.3 PROBLEM STATEMENT

Even though UWB antennas are favourable among researchers of academic and developer in industry, it facing several challenges and trade-off between size (Guo Ping Gao, Bin Hu, and Jin-Sheng Zhang, 2013), gain (Nader Behdad et al., 2013), and radiation pattern stability (Li Li et al., 2012).

In 2010, the smallest size of UWB antenna with gain of 1.02 to 3.78 dBi is produced which is 12.8 x 12.8 mm^2 (Raj Kumar and K. K. Sawant, 2010). Such gain is considered low for UWB application such as high rate data (HDR) transmission for Wireless Local Area Network (WLAN), medical imaging (Botao Feng et al., 2014) and other application that required antenna with high gain (G. K. Pandey et al., 2015).