UNIVERSITI PUTRA MALAYSIA

FRACTAL DIELECTRIC RESONATOR ANTENNA FOR ULTRA WIDEBAND WIRELESS COMMUNICATION SYSTEMS

ABOLFAZL AZARI

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By

ABOLFAZL AZARI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Master of Science

May 2015

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DEDICATION

To my ever-loving parents…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

FRACTAL DIELECTRIC RESONATOR ANTENNA FOR ULTRA WIDEBAND WIRELESS COMMUNICATION SYSTEMS

By

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May 2015

Chairman: Alyani Binti Ismail, PhD

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Recently, the integration of multiple wireless technologies has enforced the modern communication systems to operate in multiple frequency bands. In addition, the high demand for faster and reliable services in these systems leads to the necessity of a large data transmission capacity and therefore a wide operational bandwidth. Beside this, advanced wireless devices face with some strict features concerning the size and weight. A major component of modern wireless devices is the antenna which should meet the mentioned requirements. Hence, a small physical size and multi band performance are the major design requirements for antennas in wireless communication systems.

Fractals are recognized by their self similarity and space filling properties. Applying fractal geometries to antenna design donates a good solution for addressing the proper miniaturization and multi band performances. On the other hand, using dielectric materials in antenna design leads to dielectric resonator antennas (DRAs) which are characterized by compact size, a wide operational bandwidth and a high radiation efficiency.

The thesis initially discusses and evaluates recent and past developments taken place in fractal antenna and DRA areas through a review of literature. In the beginning of the design, the popular Koch fractal geometry and its monopole configurations are discussed. Then, a new fractal geometry that looks like Koch is chosen as a candidate geometry, primarily because its similarity dimension is more than the similarity dimension of Koch geometry. In addition, various DRA structures reported in the literature are considered in order to extract the suitable guidelines for design procedure. Extensive numerical simulations are presented to obtain an efficient design. As a result, the conic is chosen as an optimized dielectric resonator shape for superimposing to the proposed fractal monopole antenna.

Accordingly, an ultra wideband monopole antenna based on the combination of a new fractal geometry and a new dielectric resonator configuration is presented. The numerical and experimental results confirm that, this novel design is an ultra

wideband antenna with a usable bandwidth of 2 – 40 GHz. This huge bandwidth is the major advantage of the proposed antenna amongst conventional ultra wideband antenna types. Radiation patterns are studied at different frequencies, and the gain is found to be reasonable across the entire operating bandwidth. The most popular applications of this antenna are for wireless LAN IEEE 802.11 a/b/g and body area network (BAN). Also, the possible applications in X and Ku bands are broadband satellite communication and military applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master of Sains

ANTENA PENYALUN DIELEKTRIK FRAKTAL UNTUK SISTEM KOMUNIKASI WAYARLES JALUR LEBAR ULTRA

Oleh

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Baru-baru ini, integrasi pelbagai teknologi wayarles telah menguatkuasakan sistem komunikasi moden untuk beroperasi dalam jalur frekuensi yang berganda. Di samping itu, permintaan yang tinggi untuk lebih cepat dan perkhidmatan yang boleh dipercayai dalam sistem ini membawa kepada keperluan kapasiti penghantaran data yang besar dan oleh itu lebar jalur operasi lebar. Di samping itu, alat-alat wayarles maju muka dengan beberapa ciri-ciri yang ketat berkaitan dengan saiz dan berat badan. Komponen utama peranti wayarles moden adalah antena yang harus memenuhi syarat-syarat yang dinyatakan. Oleh itu, saiz fizikal yang kompak dan prestasi pelbagai-jalur adalah keperluan reka bentuk yang paling penting untuk antena dalam sistem komunikasi wayarles.

Fraktal diiktiraf oleh persamaan diri mereka dan ruang mengisi hartanah. Penggunaan geometri fraktal dalam reka bentuk antena menyediakan kaedah yang baik untuk menangani pengecilan saiz yang dikehendaki dan persembahan pelbagai-jalur. Sebaliknya, dengan menggunakan bahan-bahan dielektrik dalam reka bentuk antena membawa kepada antena penyalun dielektrik (DRAs) yang ditandai dengan saiz kompak, lebar jalur operasi yang luas dan kecekapan sinaran yang tinggi.

Tesis ini pada mulanya membincangkan dan menilai perkembangan baru-baru ini dan masa lalu berlaku di antena fraktal dan kawasan DRA melalui kajian literatur. Pada awal reka bentuk, Koch geometri fraktal yang popular dan konfigurasi monopole yang dibincangkan. Kemudian, geometri fraktal baru yang kelihatan seperti Koch dipilih sebagai calon geometri, terutamanya kerana dimensi persamaan adalah lebih dari dimensi persamaan dari geometri Koch. Di samping itu, pelbagai struktur DRA dilaporkan dalam kesusasteraan dianggap untuk mengekstrak garis panduan yang sesuai untuk prosedur reka bentuk. Simulasi berangka luas dibentangkan untuk mendapatkan reka bentuk yang cekap. Akibatnya, berbentuk kerucut yang dipilih sebagai bentuk resonator dielektrik dioptimumkan untuk menindih ke antena Monopole fraktal yang dicadangkan.

Oleh itu, Monopole antena jalur lebar ultra berdasarkan kombinasi dari geometri fraktal baru dan konfigurasi resonator dielektrik baru dibentangkan. Keputusan berangka dan eksperimen menunjukkan bahawa reka bentuk yang dicadangkan ialah antena jalur lebar ultra dengan lebar jalur yang boleh digunakan dari 2 - 40 GHz. Ini lebar jalur yang besar adalah kelebihan utama antena yang dicadangkan atas jenis antena jalur lebar ultra konvensional. Pola radiasi yang dipelajari pada frekuensi yang berbeza, dan keuntungan yang didapati tidak wajar di lebar jalur operasi keseluruhan. Aplikasi yang paling popular antena ini adalah untuk LAN wayarles IEEE 802.11 a / b / g dan rangkaian kawasan badan (BAN). Selain itu, aplikasi dalam bidang X dan Ku band adalah komunikasi satelit jalur lebar dan aplikasi ketenteraan.

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APPROVAL

I certify that a Thesis Examination Committee has met on 26th May 2015 to conduct the final examination of Abolfazl Azari on his thesis entitled "Fractal Dielectric Resonator Antenna for Ultra Wideband Wireless Communication Systems" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

3D	Three Dimensional
AUT	Antenna Under Test
BAN	Body Area Network
BW	Bandwidth
CNC	Computer Numerical Control
CST	Computer Simulation Technology
dB	Decibel
DR	Dielectric Resonator
DRA	Dielectric Resonator Antenna
DRR	Dielectric Resonator Ring
EM	Electromagnetic
FDTD	Finite Difference Time Domain
FEM	Finite Element Method
GA	Genetic Algorithm
GUI	Graphic User Interface
HEM	Hybrid Electromagnetic
HFSS	High Frequency Structure Simulator
IEEE	Institute for Electrical and Electronic Engineers
IFS	Iterated Function System
LAN	Local Area Network
MoM	Method of Moments
NEC	Numerical Electromagnetics Code
TE	Transverse Electric
TM	Transverse Magnetic
UWB	Ultra Wideband
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio

CHAPTER 1

INTRODUCTION

1.1 Background

Modern communication systems are required to operate in wideband frequencies. Ultra wideband (UWB) antennas are the main constituents of modern wireless communication systems. UWB antennas need to further bandwidths and smaller dimensions than conventional antennas. There is an important role which states: the antenna size, smaller than a quarter of wavelength leads to inefficient antenna performance because radiation resistance and gain are reduced. In addition, A wideband antenna usually requires different elements for different frequency bands. These challenges have propelled antenna engineers in different directions, one of which is by utilizing fractal shapes. Fractal shapes are identified by their self similarity and space filling properties. These properties have motivated antenna engineers to approve fractal shapes as a viable solution to meet UWB applications.

On the other side, dielectric resonators (DR's) are good candidates for antenna applications due to inherent merits of high radiation efficiency, wide bandwidth, small size and light weight structures. The high degree of versatility over a wide frequency range makes dielectric resonator antennas (DRAs) suitable for UWB applications. The designers can control the operating bandwidth of a DRA by choosing the dimension and dielectric constant of the resonator material appropriately.

Antenna design can exploit from studying fractal geometries and DRs. Various classes of fractal antennas can be designed for various frequency bands. Also, DRAs can be configured to enhance the bandwidth and radiation efficiency. In this project, a hybrid configuration of fractal and DRA is developed for ultra wideband applications.

1.2 Problem Statement and Motivation

In this modern world, there is a fast growing demand for fast data services. This demand tends to need for higher bandwidth specially in higher frequencies. On the other side, the integration of multiple technologies with different frequency bands in one device impels the communication systems to operate in multi-band frequencies. Accordingly, the modern wireless communication systems request small size and low profile antennas capable to operate in multiple frequency bands. Thus, ultra wideband (UWB) antennas are highly desirable. Multi band applications and compact size are the most important characteristics of UWB antennas. The motivation for this work has been inspired by the need for wideband, compact and high efficient antenna to satisfy these challenging demands.

Traditional antennas are unable to meet these requirements because they need different antenna elements for different frequency bands and this leads to a large size antenna. Therefore, alternative approaches are required. Recent UWB antenna developments have applied fractal geometries to antenna design, resulting in new fractal antennas with multi band behavior. Fractals have self similar shapes such that each part is a small version of the whole shape. The self similarity of fractals causes wideband and multi band behavior. Also, due to space filling property of fractal geometries, a long length can be spaced into a small area and this causes compactness of fractal antennas. On the other hand, many investigations have been performed on DRAs with wideband operation in recent years. Applying DRs to antenna elements increases the bandwidth due to resonances of DR shapes. There are various DR shapes that can be applied for UWB antennas such as cylindrical, hemispherical and conical. Therefore, these two solutions can be used for achieving a compact antenna with UWB applications.

This thesis work is a study of fractal geometry and dielectric resonator and effectiveness of their combination in UWB antennas. Fractal geometry offers a good scheme to obtain the demanded miniaturization and multi band performances while, using dielectric resonator improves bandwidth and radiation characteristics. The most UWB antenna bandwidth in literature is around 10 GHz, while recent UWB DRAs based on conical shape and its stack configuration report around 20 GHz bandwidth but this work offers an interesting bandwidth between 2 – 40 GHz. The most challenge is satisfying the result for whole frequency band which is very critical.

In fractal section, a new fractal geometry exhibiting better performance than Koch is applied to a monopole due to its simplicity and low profile structure. At this stage, the bandwidth is not desirable for whole frequency range and should be improved using a DR shape. Cylinder is selected as a base shape and a comprehensive parametric study is conducted on its various parameters in order to meet the mentioned challenge. As a result, the conic is used since of its better performance in bandwidth. Another work of study is using stack configuration with the same length that leads to further resonant frequency. Thus, stack configuration is used and shows a better result. Finally, the targeted bandwidth is achieved successfully.

1.3 Research Aim and Objectives

The goal of this project is to study, design and analyze fractal antennas and DRAs capable of facing modern wireless communication systems. Various structures of fractal geometry and dielectric resonator shapes are discussed in order to achieve maximum possible bandwidth.

The main objective of this research work is to design an ultra wideband antenna utilizing both fractal geometry and dielectric resonator properties. A combination of these methods as a novel technique into UWB antenna design is undertaken to achieve this goal. The proposed design is a hybrid configuration of a new DRA excited by a new fractal monopole antenna operating in 2- 40 GHz frequency range. Following objectives can be defined for achieving the main objective of this work.

- **Designing:** In order to exploiting fractal and dielectric resonator properties, a good reviewing the literature is necessary. Firstly, the characteristics of well known Koch fractal and its application in antenna are investigated. Next, the properties of dielectric resonator shapes and their application in UWB antennas are considered. In consequence, the useful guidelines can be extracted for employing in design section.The operating frequency of interest is started from 2.4 GHz, which is used considerably for networking wireless applications. As the most common applications of wireless communication systems are in 1 – 40 GHz frequency range, the interest operational bandwidth of this work is 2 – 40 GHz. It is evident that, achieving to an acceptable result in this huge bandwidth is very difficult and needs the analysis and optimization of various fractal DRA configurations. The first approach is introducing a new fractal geometry exhibiting better bandwidth performance than well know Koch geometry. Then, the targeted bandwidth (2 – 40 GHz) is going to be improved using dielectric resonator by a comprehensive parametric study. The simplest shape, cylindrical is used as a base shape for parametric study. Then, the performance of conical shape and its stack configuration are studied for achieving the maximum bandwidth.
- **Simulation and Analyzing:** This research work depends a great scope on the parametric studies based on simulation using electromagnetic simulation softwares. The SuperNEC and Ansoft HFSS are used for performing simulation processes. The simulation results are adequately discussed in order to indicate the effect of design parameters on targeted bandwidth.
- **Fabrication and Measurement:** The final design is fabricated and measured in order to confirm the simulated results. A good agreement between the simulated and measured results are presented and the possible applications of the proposed antenna are introduced. A performance comparison is also presented in order to recognize the privilege of the proposed fractal DRA.

1.4 Brief Methodology

The brief methodology employed in this thesis is as follow:

- Study the theory of fractals and characteristics of well known monopole fractal antennas as well as various developed DRAs.
- Study the fundamentals of antenna parameters, modelling and characterization techniques.
- Design a novel hybrid DRA excited by a new fractal monopole antenna.
- Implementation of proposed antenna
- Comparison between simulation and measurement results.

1.5 Thesis Organization

The thesis is organized into six chapters of which the first chapter introduces general information, the problem statement and motivation, research aim and objectives and contribution of the thesis and the proposed solutions. The other chapters outlined below will address the core issues of the targeted project.

Chapter 2: An understanding of the fundamental characteristics of fractal antennas and dielectric resonator antennas (DRAs) is essential to utilize the benefits of their advantages in efficient antenna design. This chapter deals with the review of the evolution of fractal antenna and DRA technologies and the major progress in their research. The suitable design guidelines are provided for the generalization of the design procedure.

Chapter 3: The basic parameters of the antennas are discussed to aid subsequent design process. Conventional analytical models and the characterization techniques are also presented. Then, the design procedure of the proposed antenna is discussed. Firstly, a new fractal shape is introduced and considered for the targeted design. Secondly, a new DRA configuration is proposed to improve the antenna performances. Several comprehensive parametric studies have been presented to examine the influence of different physical parameters of the antenna on its performances in order to achieve an optimized antenna. The final design structure and its fabrication process are also described in this chapter.

Chapter 4: Measurements and characterization of the proposed antenna simulated in Chapter 3, as well as the comparison between simulated and measured results are presented in this chapter. Finally, the antenna usage to a number of suitable applications is investigated.

Chapter 5: An overall conclusion drawn from this thesis research work is presented in this chapter. Some directions for future work to consider further combinations of fractal and dielectric resonator antennas are also mentioned in this chapter.

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