HYBRID DIELECTRIC RESONATOR ANTENNA FOR ULTRA HIGH FREQUENCY BAND

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A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

OCTOBER 2015

This thesis is dedicated to my beloved father and mother, Abdul Sukur Bin Ismail and Norjan Bee Binti Daud, my siblings, my families and my friends for their support, morally and financially.

ACKNOWLEDGEMENT

In the Name of Allah, Most Gracious, Most Merciful,

Alhamdulillah, thank you Allah, for your blessing and guidance to complete my study. First and foremost, my highest gratitude goes to my project supervisor, **Professor Dr. Mohamad Kamal A. Rahim** for his support and guidance. I am also very thankful for the presence and knowledge of my co-supervisor, **Dr. Noor Asniza Binti Murad.** Without these two pillars of support, I will not be able to finish this thesis.

I warmly thank the entire Advanced Microwave and Antenna Laboratory (AMAL - P18) members especially Dr. Huda, Dr. Bashir, Raimi, Hazmi, Nasrun, Syazwan, Ezwan, Osman and Izni, for their help in multiple situations and the beneficial discussions during the progress presentation meetings.

Finally, I am very grateful to my **beloved parents**, for their endless prayers, love and encouragement. I wish to express my love and gratitude to other members of my family, my brother and lovely sisters, for their supports and endless love, through the duration of my studies.

ABSTRACT

A hybrid Dielectric Resonator Antenna (DRA) design using the concept of the Dielectric-Resonator-on-Patch (DRoP) is presented in this thesis. This design is introduced to overcome the narrow bandwidth and big size drawbacks experienced by the antennas in the UHF band applications. The hybrid DRA has the ability to provide wide bandwidth while maintaining its compact structure. Firstly, two antenna designs which are the aperture-coupled square microstrip patch antenna (RMPA) and dielectric resonator antenna (RDRA) are presented to investigate the characteristic of the antennas individually. Two different aperture shapes, rectangular and circular are used to clarify the difference between them. Then, both antennas are combined together into the hybrid DRA structure. All three antennas are designed and optimized using Computer Simulation Technology (CST) microwave studio software and the Taconic RF-35 is used as the substrate for the prototype fabrication. The antenna performances such as the reflection coefficient magnitude (S_{11}), bandwidth, radiation pattern and gain are measured. In the RMPA design, both configurations managed to obtain a compact size, with a reduction of more than 25% compared to the reference antenna. On the other hand, by maintaining the size of the DRA at 7cm × 7cm × 1.4cm, a wide bandwidth of around 30% is recorded using the circular aperture in the RDRA design. The hybrid DRA combined both RMPA and RDRA, resulting in wider bandwidth of 60%, from 0.77 to 1.43GHz with an average gain of 3.4dBi. The dimension of the dielectric resonator antenna is compact, which is $0.257\lambda_o$ and also low-profile with a height of $0.051\lambda_o$.

ABSTRAK

Sebuah reka bentuk antena penyalun dielektrik (DRA) hibrid yang menggunakan konsep penyalun-dielektrik-atas-tampalan (DRoP) dikemukakan dalam tesis ini. Reka bentuk ini diperkenalkan untuk mengatasi masalah lebar jalur yang sempit dan saiz yang besar yang dialami oleh antena-antena di dalam aplikasi-aplikasi jalur UHF. Antena DRA hibrid dapat menghasilkan lebar jalur yang luas di samping mengekalkan saiz strukturnya yang kompak. Pertama, dua reka bentuk antena iaitu antena mikrojalur tampalan segi empat sama (RMPA) dan antena penyalun dielektrik segi empat sama (RDRA) yang disuap-alur dibentangkan untuk mengkaji ciri antena secara individu. Dua bentuk alur yang berbeza iaitu segi empat dan bulat digunakan untuk menerangkan perbezaan yang wujud. Kemudian, kedua-dua antena digabungkan membentuk struktur antena DRA hibrid. Ketiga-tiga antena direka bentuk dan dioptimumkan menggunakan perisian CST Microwave Studio dan Taconic RF-35 digunakan sebagai substratum di dalam pembikinan prototaip. Prestasi-prestasi antena yang penting seperti S_{11}, lebar jalur, corak sinaran dan gandaan diukur. Di dalam reka bentuk RMPA, kedua-dua konfigurasi berjaya menghasilkan saiz yang kompak, dengan pengurangan saiz lebih dari 25% berbanding antena rujukan. Sebaliknya, dengan mengekalkan saiz DRA pada 7cm × 7cm × 1.4cm, penambahan lebar jalur sebanyak lebih kurang 30% dicatat apabila alur bulat digunakan di dalam reka bentuk RDRA. Antena hibrid menggabungkan RMPA dan RDRA, menghasilkan lebar jalur yang lebih baik iaitu 60%, dari 0.77 hingga 1.43GHz dengan purata gandaan sebanyak 3.4dBi. Antena penyalun dielektrik mempunyai saiz yang kompak, iaitu $0.257\lambda_o$ dan juga berprofil rendah dengan ketinggian $0.051\lambda_o$.

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LIST OF ABBREVIATIONS

UHF	-	Ultra-High Frequency
RFID	-	Radio Frequency Identification
DRA	-	Dielectric Resonator Antenna
DRoP	-	Dielectric-Resonator-on-Patch
CST	-	Computer Simulation Technology
UV	-	Ultra Violet
DR	-	Dielectric Resonator
RDRA	-	Rectangular Dielectric Resonator Antenna
CDRA	-	Cylindrical Dielectric Resonator Antenna
HDRA	-	Hybrid Dielectric Resonator Antenna
MPA	-	Microstrip Patch Antenna
RMPA	-	Rectangular Microstrip Patch Antenna
CPW	-	Coplanar Waveguide
FR-4	-	Fire Retardant Type 4
VSWR	-	Voltage Standing Wave Ratio
CP	-	Circular Polarization
RHCP	-	Right Hand Circular Polarization
LHCP	-	Left Hand Circular Polarization
DWM	-	Dielectric Waveguide Model
FDTD	-	Finite Difference Time Domain
TE	-	Transverse Electric
SMA	-	Sub Miniature version A
PVA	-	Poly-Vinyl Acetate

LIST OF SYMBOLS

E	-	Electric Field
H	-	Magnetic Field
ε_r	-	Relative Permittivity
ε_{reff}	-	Effective Relative Permittivity
ε_o	-	Free-space Permittivity (8.85×10^{-12} F/m)
λ_o	-	Free-space Wavelength
λ_g	-	Guided Wavelength
f_o	-	Operating Frequency
ΔL	-	Extended Incremental Length of the Patch
c	-	Speed of Light (3×10^8 m/s)
k_x	-	Wave Number along x-axis
k_y	-	Wave Number along y-axis
k_z	-	Wave Number along z-axis
K_o	-	Wave Number in Free-space
h, d	-	Height
W, b	-	Width
r	-	Radius
L, a	-	Length

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

The Ultra-High Frequency (UHF) band is being used in various applications such as television transceiver systems, walkie-talkies, and radio frequency identifications (RFIDs). Ranging from 300 Megahertz up to 3 Gigahertz, this particular band mostly used in two-ways radio and public safety communications. They do not interfere other local transmissions since they are transmitted in a limited range, and relied on a line-of-sight distance. The conventional antennas used in these applications are patch, monopole and dipole antennas.

The dielectrics were first used in oscillator or filter designs, whereby they were enclosed in metal cavities to prevent radiation and maintaining high quality factor (Q-factor). In order to create an efficient radiator, the shield was removed, causing the Q-factor to be reduced and dependant on the permittivity of the dielectric, and the dielectric was properly fed to excite suitable mode. The dielectric resonator antennas have a long history of development, almost three decades, which started in 1983 when Long, McAllister and Shen introduced a cylindrical dielectric cavity antenna [1].

The dielectric resonator antenna (DRA) has several advantages over the conventional radiating antenna such as small size, low cost and good temperature stability [2]. In 1981, Birand and Gelsthorpe used the DRs as antenna elements by proposing the linearly polarized array dielectric radiators structure [3]. The DRA is normally fabricated using a material with a high dielectric constant. It can be incorporated with multiple feeding mechanisms such as the coaxial probe, the microstrip feed line, the aperture coupling source, and the coplanar waveguide (CPW) [4].

Furthermore, the DRA consists of various geometries such as rectangular, cylindrical, hemispherical, circular, and triangular. The resonant frequency of the DRA is highly dependent on the dimension and the shape of the DRA, as well as the permittivity of the material. Numbers of works were carried out on the types of DRAs such as the compact DRAs, the wideband DRAs, the DRA arrays and the hybrid DRAs. The dielectric-resonator-on-patch (DRoP) is one of the existing concept of the hybrid DRAs introduced by Esselle in 2001 [5] before it is experimentally carried out in 2005 [6]. DRoP is a structure with a dielectric resonator placed symmetrically on top of a patch antenna. In other words, DRoP is a combination of two different antennas with less space consuming yet providing a wider bandwidth.

1.2 Problem Statement

Nowadays, the communication applications at UHF bands developing rapidly, especially at the lower region of the UHF band. These ranges of frequencies are used for several applications such as walkies-talkies, digital television, UHF RFIDs and two-ways radio. The signal can travel farther by operating at lower frequencies but its obstacle penetration level is low, which is suitable for terrestrial applications as mentioned before where signal penetration is not critical.

Antennas such as patch, monopole and dipole antennas are normally used in UHF band applications. The main drawbacks of these antennas are having a huge size of a half-wavelength or quarter-wavelength, in regards of their operating frequencies. For example, at 0.9 GHz, the conventional patch antennas and the dipole antennas have a dimension of 166.7 milimeters (half-wavelength) and the monopole antennas have a dimension of 83.8 milimeters (quarter-wavelength). Monopole antennas are more desirable since it halved the dimension of its counterparts, the patch and dipole antennas. In addition, the bandwidth of these antennas is narrow, which is less than 1% for the patch antennas and less than 10% for the dipole and monopole antennas.

The Dielectric Resonator Antenna (DRA) can obtain wide bandwidth while maintaining its compact size. The dimension of the structure is highly dependent on the dielectric constant of the material, with a wide range between 4 and 100. However, by using the materials with high dielectric constant, it will result in a narrower bandwidth of the DRA. So, in order to achieve both features, the DRA is combined with other radiating elements such as slot and patch antennas. Thus, a hybrid design which offers wider bandwidth and miniaturization can be developed. A quarter-wavelength hybrid DRA is proposed in [5] and [6] which operate at 5 GHz. The design achieved a wide bandwidth of 23.5%. By doing some modification, this structure can maintain its size eventhough it operates at lower frequency and its bandwidth can be enhanced.

Wider bandwidth will lead to a cost reduction in the antenna design since a single wideband antenna can be used instead of multiple narrowband antennas. Most of the antennas in the UHF bands cannot achieve wide bandwidth due to the usage of the material with high dielectric constant without the addition of the bandwidth enhancement technique.

1.3 Research Objective

The objectives of this research are:

1. To develop a compact aperture-coupled rectangular microstrip patch antenna (RMPA) using the rectangular and circular slots.
2. To develop a wideband aperture-coupled rectangular dielectric resonator antenna (RDRA) using the rectangular and circular slots.
3. To integrate the aperture-coupled RDRA and RMPA into a compact and wideband hybrid dielectric resonator antenna for UHF band.

1.4 Scope of Work

The scope began with the information gathering process through the literature review on the related topics. The ultra-high frequncy (UHF) band is from 300 MHz up to 3 GHz, and the applications at the middle range of this band (800 MHz to 1.4 GHz) is aimed in this work. The previous published design of the rectangular microstrip patch antennas, rectangular DRAs, compact DRAs, wideband DRAs and the hybrid DRAs are reviewed to obtain the best solution to achieve the objectives. It is crucial to find out the basic information on the antenna designs, and identifying the limitations and the expected results of the proposed designs. The main objective is to design a hybrid DRA consists of the DRA and microstrip patch antenna to obtain wide bandwidth without increasing the dimension of the antenna unnecessarily, and the dielectric-resonator-on-patch (DRoP) concept is found to be the most suitable solution. In order to fully understand this concept, the aperture-coupled MPAs and DRAs are reviewed and studied. The theoretical dimensions of the antennas were also obtained from the literature review.

Computer Simulation Technology (CST) Microwave Studio is used to design and simulate the proposed antenna. Simulation results are analyzed in term of the reflection coefficient magnitude (S_{11}), the bandwidth, the gain, and the radiation pattern and optimum dimensions are obtained by doing optimization and parametric studies. The effect of changing the dimensions towards the resonance frequency are observed during the process. The final design with the optimum dimensions were fabricated by using photolitography process.

Once the prototypes are fabricated, measurement is carried out using vector network analyzer setup. The parameters such as the reflection coefficient magnitude (S_{11}), the bandwidth, the gain, the radiation pattern were measured using the vector network analyzer and anechoic chamber. The differences that occured between the simulated and the measured results were compared and discussed.

1.5 Thesis Outlines

There are seven chapters in this thesis. Chapter 1 introduces the overview of the project, the problem statements, the objectives and the scope of the project. Two main problems were identified, where the antennas employed in the ultra-high frequency band applications have narrow bandwidth and excessive dimensions. The scope of work is briefly explained.

Chapter 2 provides critical explanations on the different feeding techniques for the MPA designs, the RDRA antennas, and useful equations to calculate the dimensions of the RMPA and RDRA. In addition, the different methods to enhance the bandwidth of DRA and to achieve DRAs miniaturisation are presented. Hybrid DRAs with radiating elements are also reviewed.

Chapter 3 discusses on methodology and project designs implemented in this work. In this chapter, the simulation, fabrication and measurement process are illustrated. The methods and techniques used are explained to show the technical flow of the project. Besides that, the design specifications of the proposed designs and the limitations during the whole period of this project are also stated.

Chapter 4 presents the configuration and the design of the compact rectangular microstrip patch antenna, coupled by a slot. Two different shapes of the slot, the rectangular slot and the circular slot are used and the differences that occurred in the important paremeters such as the reflection coefficient magnitude (S_{11}), gain and radiation patterns between the two configurations are discussed.

Chapter 5 explains the wideband rectangular dielectric resonator antenna design, using the rectangular and the circular slot. The differences that occurred in the important parameters such as the reflection coefficient magnitude (S_{11}), gain and radiation patterns between the two configurations are discussed.

Chapter 6 describes the design process of the proposed wideband and compact hybrid dielectric resonator with patch antenna, consists of the rectangular microstrip patch antenna and rectangular dielectric resonator antenna. In this chapter, the simulated and fabricated results such as the reflection coefficient magnitude (S_{11}), gain and radiation patterns of the proposed designs are presented.

Chapter 7 concludes the thesis by stating the contributions of the project and the suggested possible solutions suitable for the optimization of the proposed design in the future. The proposed hybrid antenna is compared with other related works to proof the capability of the hybrid antenna in achieving wide bandwidth while maintaining its size.

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