UNIVERSITI PUTRA MALAYSIA

HYBRID GRATING BOWTIE ANTENNA BASED ON METAMATERIAL STRUCTURES AND CAVITY-BACKED REFLECTOR FOR HIGH GAIN WIDEBAND APPLICATIONS

NOOR MOHAMMED NOORI

FK 2016 67

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By

NOOR MOHAMMED NOORI

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

September 2016

DEDICATION

This thesis is dedicated to:

The sake of Allah, my Creator and my Master,

My great teacher and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life,

My beloved Parents,

My Brother and Sister,

And all my friends,

For

Their Endless Patience and Support

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

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Chairman: Assoc. Prof. Alyani Binti Ismail, PhD
Faculty : Engineering

Microstrip antenna has attracted many researchers in the applications of wireless communications due to its high performance in terms of high gain, wideband, unidirectional radiation pattern and low cross polarization. This type of antenna can be used to process a function of multimode/multiband operations, high speed data transmission and long-distance communication. There are many techniques adopted to obtain these specifications on the printed microstrip antenna.

In this thesis, high gain wideband grating bowtie microstip antenna has been designed. To achieve a unidirectional radiation pattern antenna, an electrical grating bowtie dipole and magnetic half ring dipole have been designed by using grating bowtie dipole, half ring dipole and a cavity backed. The cavity backed has been utilized here for two functions; first to work as an image to the dipoles so that the grating bowtie dipole with its image acts as an electric dipole and the half ring dipole with its image functions as magnetic dipole, in addition to reduce the back lobes. These dipoles were proposed to obtain an equal amplitude and phase in an electric and magnetic current. According to Huygens' source theory, if the current sources are excited by the same amplitude and phase, unidirectional and low back radiation patterns can be obtained accordingly. However, the results of the bandwidth and gain were still need to be improve. So that a technology of enhancing the gain and bandwidth are required. In order to earn wider bandwidth, a multistage transformer is employed. Which enhance the bandwidth from 9 % (5.3 GHz to 5.8 GHz) to 52.9 % (5 GHz to 8.6 GHz). Whereas, the gain was from 8.4 dB to 14.3 dB. To improve the radiation pattern, a method of pattern radiation improvement is required. Based on Snell's law, when the antenna loading with structure has a higher reflective index than the substrate reflective index, the energy can be congregate. Metamaterials which have higher reflective index from the substrate have been used. This metamaterial enhances the gain at a bigger scale. The investigation results of the proposed design exhibit a bandwidth of 54.2% from 5 GHz to 8.72 GHz and a stable gain from of 9.5 dBi to 16.7 dBi over the entire frequency band with a total dimension of 76.5×140 mm^2.

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

HIBRID ANTENA BOWTIE PARUTAN BERDASARKAN STRUKTUR BAHAN META DAN REFLEKTOR RONGGA YANG DISOKONG UNTUK KEUNTUNGAN WIDEBAND APLIKASI TINGGI

Oleh

NOOR MOHAMMED NOORI

September 2016

Pengerusi: Prof. Madya Alyani Binti Ismail, PhD
Fakulti : Kejuruteraan

Antena menggunakan teknik papan litar bercetak telah menarik minat para penyelidik dalam kegunaan teknologi tanpa wayar kerana prestasi yang baik terutamanya dari segi kadar rintangan yang tinggi, julat jalur yang lebar, corak radiasi satu arah dan kadar silang polarilasi yang rendah. Antena jenis ini boleh digunakan untuk pelbagai kegunaan antaranya komunikasi berkelajuan tinggi dan kominikasi jarak jauh. Dengan itu, ada pelbagai cara boleh digunakan untuk mereka bentuk antena papan litar bercetak.

Tesis ini akan menjelaskan proses mereka bentuk antena papan litar bercetak jenis bowtie. Untuk mendapatkan bacaan radiasi satu arah, parutan letrik bowtie dipole dan medan magnet separuh cincin telah digunakan dengan menggunakan parutan bowtie dipole, separa cincin dipole dan rongga sokongan. Rongga sokongan digunakan untuk dua kegunaan penting; pertama untuk gambaran kepada dipole supaya parutan bowtie dipole dengan gambaran tadi bertindak sebagai letrik dipole dan separa cincin dipole dengan gambaran sebagai medan magnet dipole, disapming untuk mengurangkan kesan kebocoran. Teknik dipole yang digunakan demi untuk mendapatkan amplitud yang sekata. Merujuk kepada teori Huygen, jika punca aliran letrik mempunyai amplitud dan fasa yang sama, radiasi satu arah serta corak radiasi belakang boleh diterima dengan sempurna. Bagaimanapun, bacaan rintangan serta jalur lebar masih memerlukan penambah baik. Dengan itu, teknologi untuk meningkatkan prestasi rintangan serta jalur lebar diperlukan. Peningkatan bacaan jalur lebar dari 9%(5.3GHz kepada 5.8GHz) kepada 52.9%(5GHz to 8.6GHz). Kadar rintangan pula dari 8.4dB kepada 14.3dB. Untuk meningkatkan corak radiasi, teknik yang diguna pakai ialah teori Snell'. Bila antena dipadankan dengan index pantulan tinggi, jumlah tenaga boleh ditumpukan kepada satu titik. Dengan itu, keputusan bacaan rintangan yang tinggi diterima. Hasil analisis keputusan, jalur lebar bacaan mempunyai peningkatan sebanyak 54.2% dari 5GHz to 8.72GHz. Manakala bacaan rintangan yang stabil dari 9.5dBi kepada 16.7 dBi melepasi julat frekuensi dengan saiz 76.5x140mm^2.

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I certify that a Thesis Examination Committee has met on 29 September 2016 to conduct the final examination of Noor Mohammed Noori on his thesis entitled "Hybrid Grating Bowtie Antenna Based on Metamaterial Structures and Cavity-Backed Reflector for High Gain Wideband Applications" 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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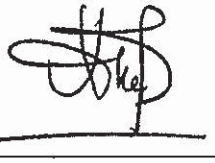

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Date: 3 November 2016

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and writing of this thesis was under our supervision;
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Supervisory	Supervisory
Committee: _____	Committee: _____

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LIST OF ABBREVIATIONS

RF	Radio Frequency
ISRP	I-Shape Resonator Pair
CBR	Cavity-backed reflector
MTM	Metamaterial
SRR	Split Ring Resonator
SR	Spiral Resonators
mm	Millimeter
CST	Computer Simulation Technology
MW	Microwave
VNA	Vector Network Analyzer
FIT	Finite Integral Technique

CHAPTER 1

INTRODUCTION

1.1 Background

Communication is defined as the way of transferring information from certain point to another one. The advantage of robust communication system is its ability to transfer a stream of information over a distance. Unique techniques have been enhanced in this area by using microwave and millimeter-wave bands in the last decade. Nowadays the antennas are considered the main components in modern communication systems, which are required for data communication links. Over the years, the microstrip antennas structure are considered as the most convenient transceiver device used for millimeter waves, integrated microwave circuits, radar and communication applications. Due to these significant advantages such as low cost, lightweight, flexible, and easy fabrication which make it better than the conventional antennas. Many researchers have focused on experimental and theoretical research on the area of microstrip patch antennas. As a result, an improvement in the antenna performance and efficiency in terms of return loss, and gain are achieved. The microstrip antennas with wideband and high gain play an important role in modern wireless communications. Wideband antenna has several advantages, which are high data rate transmitting, low power consumption, compact, low cost, and high immunity against multipath interference. The benefits of these advantages are high speed data communications, security and carrier-free nature of the signal. This offers no additional radio frequency (RF) mixing stage requirements in up/down-conversion processes. In addition, the transmission duration of a wideband antenna is shorter than a nanosecond pulse. The most important advantage of the high gain antenna is that it does not require an amplifier for long distance communication. According to the above, the wideband and high gain antenna can be used for many purposes. For instance, radar, TV, radio broadcasting, satellite communications, point to point communications, military, aircraft, missiles, tracing, Wireless local area networks and rocket applications.

1.2 Problem statement and Motivation

The nature of microstrip antenna has several limitations such as low gain, narrow band, high cross polarization and low front to back ratio. Which make it unsuitable for the applications that requires a high gain, wideband, unidirectional radiation pattern and low cross polarization in the modern development in wireless communication.

1. Scattering beam in radiation pattern: this phenomenon leads to low gain antenna which causes the limitation of the antenna applications. This weakness is due to the fact that low gain antenna cannot be used for long distance communication and also, it requires an active element such as amplifier or many repeater towers to strengthen the signal in order to reach the required destination. Additionally, the current literature review shows that

gain enhancement was still a challenge to be designed especially for wideband applications.

2. Narrow bandwidth in microstrip antenna design: this is considered the major issue that many researchers faced when designing a microstrip antenna. Narrow bandwidth has low speed data transmitting, based on Shannon's capacity equation

$$C = B\ log_2\left(1 + \frac{S}{N}\right) \quad (1.1)$$

Where
C = maximum channel capacity
B = signal bandwidth
S = signal power
N = noise power
The highest channel capacity can be obtained by increasing the bandwidth (B) as shown in equation (1.1) whereas, the narrow bandwidth antenna has a very low bandwidth value. In addition, narrow bandwidth is unsuitable for multimode/multiband functions. Furthermore, the narrow bandwidth antenna has a poor immunity against multipath interference (fading). Which results from reflected signal from various paths. This unavoidable phenomenon makes the received signal very weak. Moreover, in narrow bandwidth communication system, a carrier frequency requires sending the data signal at the desired frequency band. Therefore, an additional radio frequency (RF) mixing stage for up and down conversion processes is necessary.

3. Undesired polarization: The cross-polarization in radiation patterns have many undesirable effects on the performance of the antenna. Where the radiation energy used in an unwanted polarization implies that energy is lost from the total input energy which means that the antenna efficiency is reduced. In addition, if an antenna operates in a circular polarization mode, the presence of cross-polarization field will generate an orthogonal (opposite direction) component, which led to elliptically polarized and signal distortion. Also, high cross polarization has an interference impact on the communication system which uses the dual polarizations to achieve two communication channels for each single frequency band. Finally, the antenna that has a high cross polarization level cannot be used for application require unidirectional radiation pattern. This is because the cross polarization will swerve the position away from the main target.

1.3 Research Aim and Objectives

The main goal of this study is to design high gain and low cross polarization microstrip antenna for wideband applications.

1. To design, a high gain unidirectional radiation pattern microstrip antenna with high front to back ratio and low cross polarization.
2. To achieve a high bandwidth microstrip antenna of more than 40 % to cover the radar application range from (6 GHz to 8 GHz).
3. To fabricate the antenna using standard photolithography fabrication process and then validate the antenna by measure its performance and compare it with the simulation.
4. To compare and measure the performance of the antenna experimentally.

1.4 Scope of Research

The scope of this thesis is to design a combined electrical and magnetic poles antennas integrated with I-Shape Resonator Pair (ISRP), and cavity-backed reflector for wideband and high gain applications. This can be done by the development and improvement of the microstrip bowtie patch antenna with and without metamaterials, as well as investigation of the microstrip bowtie patch antenna parameters such as bandwidth, feeding and gain. Moreover, the study on how these parameters affect the antenna design and optimizing process shall be conducted to obtain the requirements for the wideband high gain applications. The analyses have been done by using full wave electromagnetic simulation (CST 2013). A standard photolithography process has been applied to fabricate the antenna. The frequency band which the antenna works is able to cover radar application. The measurement process was conducted in an anechoic chamber. The flow diagram of this study is presented in Figure 1.1. The blue dash-lines refer to the direction followed in this thesis to achieve the objectives, whereas the red sold-lines represent other related research areas which are outside the scope of this work.

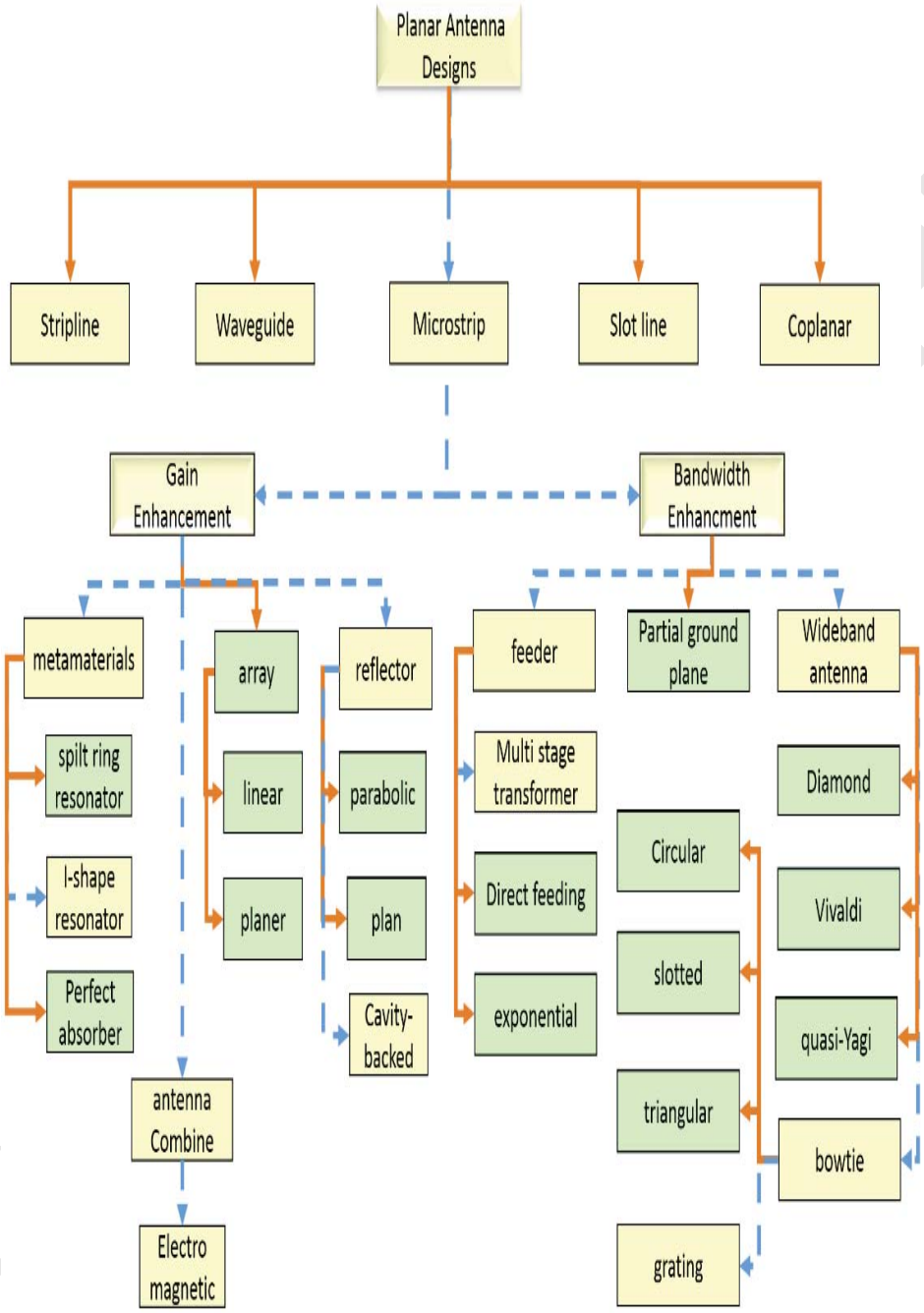

Figure 1.1 : Scope of research

1.5 Organization of the Thesis

This thesis is organized into six chapters, which are summarized as follows
Chapter one presents a general introduction to the research area and describes the current problems in designing wideband and high gain antennas that motivated this research. It also describes the goal, objectives, scope of research as well as the organization of thesis writing
A literature review on wideband high gain bowtie dipole antenna is provided in chapter two. It first presents a background on microstrip antenna and describes some types of wide band microstrip antenna. Then provided details on bowtie antenna and the ways of enhancing the bandwidth and gain of bowtie antenna as well as some recent designs and applications. Finally, it presents a background, history and classification of MTMs.

Chapter three describes the methodology of grating bowtie antenna. First of all, it presents the effect of multistage transformer. In addition, the analysis of the bowtie, half ring dipoles antenna and how to obtain a unidirectional radiation pattern are also presented. Moreover, it shows the advantages of implementing the CBR. Furthermore, the benefits of ISRP structure as unit cell and array is studied as well. Finally, the fabrication and measurement setup of the antenna with and without ISRP structure is described.

Chapter four discussed in depth the effect of both bandwidth and gain parameters. Besides that, the radiation pattern and the current distribution is considered. Finally, to validate the simulated result, both antennas with and without ISRP structure have been investigated in terms of bandwidth, gain co and cross polarization.

Chapter five is the last part of this thesis, which provides the conclusion of the achieved research, followed by the discussion of the major contributions and some recommendations for future work.

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