



**Broadly Steerable Parasitic Patch Array Antennas using
PIN Diode Switches at 5.8 GHz**

by

**Thennarasan Sabapathy
(1240810764)**

A thesis submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

**School of Computer and Communication Engineering
UNIVERSITI MALAYSIA PERLIS**

2014

ACKNOWLEDGEMENT

Hare Krishna! I do strongly believe that without the blessing of the Supreme Personality of Godhead, this research wouldn't be a success story. Therefore I would like offer the result of this work to Him.

First and foremost, I would like to express my gratitude to my PhD supervisor, Prof. Dr. R. Badlishah Ahmad for the freedom and trust he had given to me throughout the academic session. Besides, I owe him and Malaysian of Higher Education (MoHE) million thanks for the financial support for my PhD. Special thanks to my co-supervisor, Assoc. Prof. Dr. Muhammad Ramlee Bin Kamarudin for his positive way of thinking that made my simple ideas to look great. Last but not least, to my other co-supervisor or more properly should be addressed as a friend or brother, Dr. Muzammil Jusoh for his guidance and the direction of my PhD. I also would like to convey a gratitude to Ilman, Izaidy and other members of the Antenna & Microwave Research Lab (AMRELLAB) and Embedded Computing Cluster in UniMAP for the help, guidance and friendship.

A lot of thanks with love to my wife Revathi for her moral support and assistance during this PhD. Also, I would like to thank my Appa and Amma who always have a strong believe on me, always saying that “ my son is smart, he can do it”.

ஹரே கிருஷ்ணா

TABLE OF CONTENTS

	PAGE
THESIS DECLARATION	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENTS	iii
LIST OF FIGURES	ix
LIST OF TABLES	xiv
LIST OF ABBREVIATIONS	xvi
LIST OF SYMBOLS	xvii
ABSTRAK	xviii
ABSTRACT	xix
CHAPTER 1 INTRODUCTION	
1.1 Overview	1
1.2 Problem Statement	2
1.3 Research Objectives	4
1.4 Scope of Research	5
1.5 List of Contributions	6
1.6 Thesis Outline	7
CHAPTER 2 BACKGROUND STUDY AND LITERATURE REVIEW	
2.1 Introduction	9
2.2 Reconfigurable Antennas	11

2.2.1	Difference between Beamforming and Reconfigurable Radiation Pattern Antennas	14
2.2.2	Radiaton Pattern Reconfigurable (RPR) Antennas	16
2.3	Evaluation of Patch RPR Antenna	20
2.4	Parasitic Patch Array RPR Antenna	29
2.4.1	Fundamental Structure: Patch Antenna	30
2.4.1.1	Single Element Antenna – Rectangular Patch	31
2.4.1.2	Single Element Antenna – Circular Patch	33
2.4.2	Feeding Methods – Application Scenario and DC Biasing Circuitry	34
2.4.3	Theoretical Concept – Yagi-Uda and Mutual Coupling	35
2.4.3.1	Yagi-Uda	36
2.4.3.2	Mutual Coupling	38
2.5	Switching Technology	41
2.5.1	Semiconductor RF Switch – PIN diode and FET	42
2.5.2	RF MEMS Switch	46
2.5.3	Varactor	46
2.6	Review on Parasitic Patch Array RPR Antenna	46
2.7	Summary	49

CHAPTER 3 RESEARCH METHODOLOGY

3.1	Introduction	51
3.2	Research Methodolgy	52
3.2.1	Design Flow Chart	52
3.2.2	Design Specification	56
3.2.3	Electromagnetic Simulation with CST : Modeling and Analysis	55

3.2.3.1	Theoretical Basis of CST	59
3.2.3.2	Simulating Structures in CST	59
3.2.3.3	Simulating RF Switches in CST	62
3.2.3.4	Simulation Setting in CST	65
3.2.4	Prototype Antenna Development	67
3.2.4.1	Fabrication Process	67
3.2.4.2	DC Biasing Circuit Assembly	68
3.2.5	Experimental Measurement	69
3.2.5.1	Reflection Coefficient Measurement	69
3.2.5.2	Radiation Pattern Measurement	69
3.2.5.3	Gain Measurement	71
3.3	Antenna Design Methodology	72
3.3.1	Three Element Parasitic Patch Array Antenna	73
3.3.1.1	Analysis of the Parasitic Patch Array Antenna with Shorting Pins	73
3.3.1.2	Analysis on the Effect of the Physical Structure of the Parasitic Patch Array Antenna towards the Beam Steering	77
3.3.1.3	Effect of Adjacent Element Spacing towards the Beam Steering	79
3.3.1.4	Parasitic Element Size Effect towards the Beam Steering	80
3.3.1.5	Analysis on Beam Steering Angle of the Antenna with Different Shorting Pin Locations	80
3.3.1.6	Directive Radiation Pattern at $-\theta$ Direction	81
3.3.1.7	Directive Radiation Pattern at $\theta=0^{\circ}$ Direction	81
3.3.1.8	S_{11} Result for the Radiation Pattern at $-\theta$ Direction and at $\theta=0^{\circ}$ Direction	82

3.3.1.9	Optimized Antenna Design Parameters and Modes of Operation	85
3.3.2	LILPPA Antenna Design	89
3.3.2.1	Implementation of DC Biasing Circuitry on the Parasitic Patch Array Antenna	89
3.3.2.2	LILPPA Design with BAR50-02V using RF PIN Embedded Technique	90
3.3.2.3	Modified Physical Structure of the Antenna to Integrate DC Biasing Circuitry	91
3.3.2.4	Dimension Re-Optimization for the Antenna with BAR50-02V PIN Diode	96
3.3.2.5	The Effect of Number of Switches	97
3.3.2.6	Fabricated LILPPA Antenna with BAR50-02V PIN Diode	98
3.3.3	HILPPA Antenna Design	99
3.3.3.1	HILLPA Antenna with HPND-4005 Beam Lead PIN Diode	99
3.3.3.2	Dimension Re-Optimization for the Antenna with HPND-4005 PIN Diode	101
3.3.3.3	Fabricated HILPPA antenna with HPND-4005 PIN diode	102
3.3.4	BSPPA Antenna Design	103
3.3.4.1	Antenna Design with Novel Ground Plane Reduction Approach	105
3.3.4.2	Radiation Mechanism of BST Method	107
3.3.4.3	Radiation Mechanism of BSH Method	112
3.3.4.4	BSPPA Antenna Design Using HPND-4005 with DC Biasing Circuitry	114
3.3.4.5	Antenna Modification for DC Biasing	114
3.3.4.6	Dimension Re-Optimization of the BSPPA Antenna	116

3.3.4.7	Electronic Switching network for BSPPA Antenna	117
3.3.4.8	Fabricated BSPPA Antenna with Electronic Switching Network	127
3.4	Summary	128
CHAPTER 4 RESULTS AND DISCUSSION		
4.1	Introduction	130
4.2	Simulation and Measurement Results of LILLPA Antenna	130
4.3	Simulation and Measurement Results of HILLPA Antenna	135
4.4	Performance Comparison of LILLPA and HILLPA	139
4.5	Simulation and Measurement Results of BSPPA Antenna	141
4.5.1	Biasing Results by Electronic Switching Network	141
4.5.2	Results of BSPPA Antenna in BST Mode	143
4.5.3	Results of BSPPA Antenna in BSH Mode	148
4.6	Summary	153
CHAPTER 5 CONCLUSION AND FUTURE WORK		
5.1	Conclusion	155
5.2	Future Work	157
5.2.1	Exploring other RF switches Device	157
5.2.2	Multi-Objective Reconfigurable Antenna	158
5.2.3	DoA Estimation	158
REFERENCES		159

APPENDICES

APPENDIX A - List of Publications	164
APPENDIX B - Datasheet RF PIN Diode BAR50-02V	165
APPENDIX C - Datasheet RF PIN Diode HPND-4005	177
APPENDIX D - Taconic Datasheet	181

© This item is protected by original copyright

LIST OF FIGURES

NO.		PAGE
2.1	Rotatable antenna.	12
2.2	Liquid crystal antenna for reconfigurable application based on material properties.	12
2.3	Switch based frequency reconfigurable antenna.	12
2.4	Beamforming antenna system.	15
2.5	Types of RPR antennas.	16
2.6	Wire monopole RPR antennas. (a) Switched parasitic antenna on a finite ground plane with conductive sleeve. (b) Disc loaded monopole pattern reconfigurable antenna.	17
2.7	Six beam reconfigurable antenna with Inverted V-dipoles.	18
2.8	Patch RPR antenna - Yagi patch antenna with dual band and pattern reconfigurable characteristics.	18
2.9	Two symmetrically reconfigurable monopoles based pattern reconfigurable antenna on printed circuit board (PCB).	19
2.10	Patch dipole antennas for pattern reconfigurability. (a) Two printed dipole arrays for MIMO system (b) Simple dipole antenna for pattern reconfigurability.	19
2.11	Coverage illustration for the wire type RPR antenna.	21
2.12	Coverage illustration for the patch type RPR antenna.	22
2.13	Patch RPR antenna model. (a) single-polarized. (b) multi-polarized.	23
2.14	Surface current distribution pattern for both antenna models. (a) 0°, (b) 90°, (c) 180° and (d) 270°.	25
2.15	Practical scenario of SP-RPR antenna	26
2.16	Practical scenario of MP-RPR antenna	27
2.17	Illustration of polarization from various directions for MP-RPR antenna	27
2.18	Parasitic patch RPR antenna design consideration.	29

2.19	Rectangular patch antenna	31
2.20	Geometry of circular microstrip patch antenna.	33
2.21	Coaxial probe feeding technique .	34
2.22	Schematic diagram of Yagi-Uda antenna	36
2.23	Two element patch antenna with independent feed.	38
2.24	Two-port network for the two element antenna.	39
2.25	Two element patch with single driven element.	40
2.26	Different types of reconfigurable methods.	41
2.27	Regions in PIN diode	43
2.28	Series connected SPST microwave switch equivalent circuit.	44
3.1	Research work stages.	51
3.2	Design flowchart of LILLPA antenna.	53
3.3	Design flowchart of HILLPA antenna.	54
3.4	Design flowchart of BSPPA antenna.	55
3.5	Simulated antenna structure in CST.	60
3.6	Simulated reflection coefficient in CST.	61
3.7	Simulated surface current distribution in CST.	61
3.8	Antenna simulation with artificial switch.	62
3.9	Antenna simulation with TSB.	63
3.10	Antenna simulation with lumped element network.	64
3.11	Mesh definition view (a) Setting 1, and (b) Setting 2.	66
3.12	Agilent 2-D PNA Antenna measurement.	70
3.13	Gain measurement test system.	71
3.14	Antenna design. (a) A single element patch antenna, (b) associated beam pattern.	74
3.15	Mutual coupling in parasitic patch array.	75

3.16	Surface current distribution.	76
3.17	Physical structure of the parasitic patch RPR antenna.	77
3.18	Parameter sweep in simulation. (a) Effect of g and (b) effect of L'	79
3.19	Polar radiation patterns for different locations of shorting pins (a) when $S1=0$ and $S2=1$, (b) when $S1=1$ and $S2=1$, (c) Shorting locations at the antenna	82
3.20	Reflection coefficient of the antenna for various location of the shorting pin (a) $u = \pm 12$, (b) $u = \pm 14$, (c) $u = \pm 16$, (d) $u = \pm 18$, (e) $u = \pm 20$, (f) $u = \pm 22$, (g) $u = \pm 24$, (h) $u = \pm 26$, (i) $u = \pm 28$	83
3.21	Final design of the Yagi-Uda patch antenna with 4 shorting pin locations	86
3.22	The physical structure of the LILPPA using a novel DC biasing circuit geometry. (a) Front view. (b) Back view. (c) Side view - Parasitic element embedded with RF PIN diode.	91
3.23	Three types of DC biasing for BAR50-02V PIN diode. (a) Forward bias, (b) reverse bias with zero voltage, (c) Reverse bias with equal voltages	94
3.24	Switching network of BAR PIN based LILPPA.	95
3.25	Effect in beam pattern with the introduction of DC biasing switching network	96
3.26	Comparison in beam pattern with different number of switches	97
3.27	BAR PIN diode based LILPPA antenna. (a) front and (b) back	98
3.28	Implementation of the HILPPA antenna with HPND PIN Diode	100
3.29	Three types of DC biasing for HPND PIN diode	100
3.30	Effect in beam pattern with the introduction of the slots for DC biasing switching network	102
3.31	Fabricated HILPPA antenna with HPND PIN diode (a) front and (b) back	103
3.32	Geometry of the BSPPA antenna	106

3.33	The comparison of ground plane effect towards the beam-steering (a) Without ground plane reduction. (b) With ground plane reduction.	107
3.34	Simulated radiation patterns in the x-z plane for BST method. (a) Mode I ,(b) Mode II and IV, (c) Mode III and IV	110
3.35	Reflection coefficient of BST method.	111
3.36	Simulated radiation patterns in the x-z plane for BSH method.	113
3.37	Reflection coefficient of BSH method.	113
3.38	Physical structure of the BSPPA antenna with the DC biasing circuitry	115
3.39	DC power setup for a single mode of operation by BSPPA Antenna	118
3.40	Insight of the BSPPA antenna	119
3.41	Circuit A - switching circuit for common anode PIN diode (used by D2 & D3 and D4 & D5)	120
3.42	Circuit B - switching circuit for common cathode PIN diode (used by D1 & D6)	120
3.43	DC biasing circuit diagram for BSPPA antenna	121
3.44	Circuit C - modified switching circuit for common anode PIN diode (used by D2 & D3 and D4 & D5)	122
3.45	Circuit D - modified switching circuit for common cathode PIN diode (used by D1 & D6)	123
3.46	Modified switching network for BSPPA	125
3.47	Fabricated BSPPA antenna. (a) front and (b) back	127
3.48	Insight of the BSPPA antenna with the electronic switching network	128
4.1	3D radiation pattern result of simulation and measurement of BAR50-02V deployed LILPPA (a) Mode I, (b) Mode II and (c) Mode	131
4.2	Simulated surface current distribution of LILPPA with BAR50-02V (a) Mode I, (b) Mode II and (c) Mode III	132

4.3	Polar radiation pattern result of simulation and measurement of BAR50-02V deployed LILPPA (a) Mode I, (b) Mode II and (c) Mode III	133
4.4	Reflection coefficient (a) Simulation and (b) Measurement	134
4.5	3D radiation pattern result of simulation and measurement of HPND-4005 deployed HILPPA (a) Mode I, (b) Mode II and (c) Mode III	135
4.6	Simulated surface current distribution of HILPPA with HPND-4005 (a) Mode I, (b) Mode II and (c) Mode III	136
4.7	Polar radiation pattern: simulation and measurement using HPND-4005 for HILPPA. (a) Mode I, (b) Mode II and (c) Mode III	137
4.8	Reflection coefficient for the HILPPA antenna designed with HPND-4005 PIN diode. (a) Simulation, and (b) Measurement	138
4.9	3D radiation pattern of BSPPA antenna working in BST mode (a) Mode I, (b) Mode II, (c) Mode III, (d) Mode IV and (e) Mode V	143
4.10	Surface current distribution of BSPPA antenna working in BST mode (a) Mode I, (b) Mode II, (c) Mode III, (d) Mode IV and (e) Mode V	144
4.11	Polar radiation pattern of BSPPA antenna working in BST mode a) Mode I, (b) Mode II, (c) Mode III, (d) Mode IV and (e) Mode V	146
4.12	Reflection coefficient of the BSPPA antenna working in BST mode.(a) Simulation and (b) Measurement	147
4.13	3D radiation pattern of the BSPPA antenna working in BSH mode. (a) Mode IX, (b) Mode XIII, (c) Mode X, and (d) Mode VI	149
4.14	Surface current distribution of the BSPPA antenna working in BSH mode. (a) Mode IX, (b) Mode XIII, (c) Mode X, and (d) Mode VI	150
4.15	Polar radiation pattern of the BSPPA antenna working in BSH mode (a) Mode IX, (b) Mode XIII, (c) Mode X, and (d) Mode VI	151
4.16	Reflection coefficient of the BSPPA antenna working in BSH mode.(a) Simulation and (b) Measurement	152

LIST OF TABLES

NO.		PAGE
2.1	The PIN diode characteristics comparison	45
2.2	Comparison of the parasitic antennas' characteristics	47
3.1	Desired antenna specifications and performances	57
3.2	Substrate specifications	57
3.3	Mesh properties setting in CST	67
3.4	Physical parameters related to the patch RPR antenna	78
3.5	Description of beam patterns in terms of gain, tilt angle and HPBW for different value of u	84
3.6	Switching modes to obtain three directive beam patterns	87
3.7	Related terminal voltage at each switching configuration for BAR PIN based antenna	95
3.8	Related terminal voltage at each switching configuration for HPND PIN based antenna	101
3.9	Parameter sweeping of W_r and the related effects on antenna beam characteristics	108
3.10	Details of switch configuration and simulated steering angle	109
3.11	Details of switch configuration and simulated gain	112
3.12	Optimized parameters	117
3.13	Input voltage details of the transistor switches' to control the PIN diodes	126
4.1	Measured antenna characteristics	139
4.2	Radiation pattern characteristics	140
4.3	Simulated and experimental measurement result of the electronic switching network for circuit C	142
4.4	Simulated and experimental measurement result of the electronic switching network for circuit D	142

4.5	Radiation pattern characteristics of BSPPA antenna	148
4.6	Summarized performances of the designed antennas	153

© This item is protected by original copyright

LIST OF ABBREVIATIONS

4G	Fourth Generation
BSPPA	Broadly Steerable Parasitic Patch Array
CST	Computer Simulation Technology
DoA	Direction of Arrival
dB	Decibel
EM	Electromagnetic
GaAs FET	Gallium Arsenide Field Effect Transistor
GPS	Global Positioning System
HILPPA	High Isolation Loss Parasitic Patch Array Antenna
IL	Insertion Loss
ISO	Isolation Loss
LILPPA	Low Isolation Loss Parasitic Patch Array Antenna
LOS	Line-of-Sight
LTE	Long Term Evaluation
PIN Diode	Positive Intrinsic Negative Diode
PNA	Programmable Network Analyzer
RF	Radio Frequency
RPR	Radiation Pattern Reconfigurable
SMC	Surface Mount Component
TSB	Touch Stone Block
V2X	Vehicle-to-vehicle and vehicle-to-infrastructure communication
WiFi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Access

LIST OF SYMBOLS

λ	wavelength
δ	wave attenuation level
μ	magnetic current rate in the material
\mathcal{E}	electric current rate in the material
d	distance
h	substrate height
t	substrate thickness
J_b	charge distribution on the upper surface
J_s	charge distribution on the lower surface
ϵ_r	dielectric constant
f	frequency
Z_{in}	input impedance
R	resistor
S_{11}	reflection coefficient
S_{21}	transmission coefficient
L	inductor
C	capacitor
V	voltage
I	current

Antenna Tatasusunan Tampil Berkebolehan Ubah Alur secara Lebar menggunakan Suis Pin Diode pada 5.8 GHz

ABSTRAK

Kajian yang dijalankan dalam tesis ini fokus terhadap penghasilan antenna kebolehpayaan kawalan radiasi yang berupaya mengatasi masalah perhubungan komunikasi seperti pemudaran isyarat, isyarat gangguan dan halangan bebayang dengan kebolehannya untuk mengubah arah radiasi terhadap arah yang dituju. Antena kebolehpayaan kawalan radiasi jenis tampil (*patch*) mengalami kesukaran dengan kelemahan utama untuk mencapai sudut pemasangan alur ke arah tepi disebabkan satah bumi terhingga yang terletak di belakang elemen radiasi. Sudut pemasangan maksima yang dapat dicapai oleh antenna kebolehpayaan kawalan radiasi jenis tampil sebelum ini ialah 30° tetapi tanpa penggunaan suis frekuensi radio (RF) yang sebenar. Dalam tesis ini, kajian mendalam terhadap antenna tatasusunan tampil parasitik yang menggunakan suis RF yang sebenar telah dijalankan dengan dua jenis diod RF PIN, iaitu BAR50-02V and HPND-4005. Substrat Taconic telah dipilih untuk menghasilkan antenna sebab ia menawarkan kehilangan tangen yang rendah. Gandingan saling dan prinsip Yagi-Uda telah digunakan untuk mereka bentuk antenna tatasusunan tampil tiga-elemen dengan dua jenis diod RF PIN. Antenna dengan diod BAR50-02V dinamakan (*Low Isolation Loss Parasitic Patch Array*) LILPPA. Satu pemasangan terbaru diod PIN in antenna tampil telah diperkenalkan, di mana diod BAR50-02V telah dibenamkan dalam substrat antenna. Disebabkan kehilangan pengasingan yang rendah, LILPPA dengan diod BAR50-02V hanya mencapai sudut pemasangan maksima 23° . Diod HPND-4005 digunakan untuk mereka bentuk (*High Isolation Loss Parasitic Patch Array*) HILPPA. Diod HPND-4005 PIN menawarkan ISO yang tinggi pada frekuensi 5.8 GHz, maka ia membantu HILPPA mencapai sudut pemasangan maksima 30° . Dalam kedua-dua antenna, hanya empat diod RF PIN telah digunakan. Kemudian, antenna *Broadly Steerable Parasitic Patch Array* (BSPPA) telah diperkenalkan dan ia menggunakan diod PIN HPND-4005, disebabkan diode ini memberi prestasi yang mengagumkan terhadap antenna HILPPA dalam sudut pemasangan alur. Antenna BSPPA berupaya untuk meningkatkan sudut pemasangan alur kepada 50° dengan teknik-teknik seperti penambahan elemen parasitik, peningkatan nombor suis dan pengurangan satah bumi di tepi. Antenna BSPPA berupaya untuk fungsi dalam dua mod, di mana dalam mod pertama ia berupaya untuk mengubah arah alur radiasi tertuju ke lima arah, -50° , -30° , 0° , $+30^\circ$, $+50^\circ$ di satah-H. Dalam mod berikutnya, BSPPA berupaya untuk mengubah saiz alur radiasi to dari alur sempit kepada alur ke alur luas. Diod HPND-4005 PIN diodes memerlukan voltage bias terbalik yang tinggi pada keadaan OFF. Masalah timbul jika antenna ini disambung kepada liang I/O alat kawalan seperti mikrocontroler atau mikroprosesor disebabkan alat-alat ini beroperasi pada 5V dan 0V untuk operasi *High* and *Low*. Untuk mengatasi ini, an exclusive rangkaian elektronik penyuisan yang eksklusif telah dibina untuk menjalankan penyuisan diod HPND-4005 PIN. Ketiga-tiga antenna yang direka cipta dalam kajian ini mempunyai gandaan yang tinggi, lebih daripada 6 dBi dan lebar jalur operasi sesame lebih daripada than 100 MHz. Dengan ciri-ciri ini, antenna BSPPA ditemui boleh menjadi peneraju yang dapat dipercayai dalam sistem perhubungan tanpa-wayar terbaru seperti WIFI, WiMAX dan V2X.

Broadly Steerable Parasitic Patch Array Antenna using PIN Diode Switches at 5.8GHz

ABSTRACT

The work described in this thesis aimed to design radiation pattern reconfigurable (RPR) antenna that is capable to combat propagation scenarios such as fading, interference and shadowing with its ability to steer the beam towards a desired direction. Patch type RPR antennas suffer from major drawback of achieving beam tilt angle with respect to broadside due the finite ground plane behind the radiating element. The maximum tilt angle achieved is 30° by the existing patch RPR antennas without the implementation of actual RF switches. In this thesis, thorough investigation on parasitic patch array antenna with actual RF switches is conducted with two types of RF PIN diodes, namely BAR50-02V and HPND-4005. Taconic substrate is chosen to design the antennas since it offers low tangent loss. The mutual coupling and Yagi-Uda principles are adopted to design the three-element parasitic patch array antenna with the two types of RF PIN diodes. BAR50-02V is adopted to design Low Isolation Loss Parasitic Patch Array Antenna (LILPPA). A novel installation of RF PIN diodes in patch antenna is introduced, where the BAR50-02V diodes are embedded inside the substrate of the antenna. Due to low isolation loss (ISO), LILPPA with BAR50-02V PIN diode only achieves maximum tilt angle of 23° . HPND-4005 PIN diode is adopted for the design of High Isolation Loss Parasitic Patch Array Antenna (HILPPA). HPND-4005 PIN diode offers high ISO at 5.8 GHz frequency, thus it helps HILPPA to achieve maximum tilt angle of 30° . In both designs, only four RF PIN diodes are used. Next, Broadly Steerable Parasitic Patch Array (BSPPA) antenna is proposed and it uses HPND-4005 PIN diode, since the diode yields superior performance with HILPPA antenna in terms of beam tilt angle. BSPPA antenna able to improve the beam tilt angle to 50° by adopting techniques of adding parasitic element, increasing the number of switches and reducing the ground plane with respect to the broadside. BSPPA antenna is able to work in two modes where in the first mode it is capable of steering the directive beam patterns towards five directions, -50° , -30° , 0° , $+30^\circ$, $+50^\circ$ in H-plane. In the latter mode, BSPPA is able to shape the beam pattern from narrow beam to broadside beam. HPND-4005 PIN diodes require high reverse bias voltage at OFF state. The problem arises if the antenna is connected to the I/O ports of control devices such as microcontroller or microprocessor since they operate at 5V and 0V for High and Low operation. To solve this, an exclusive electronic switching network is developed to perform the switching of HPND-4005 PIN diodes. All three antennas developed in this work have high gain of greater than 6 dBi and common operational bandwidth of greater than 100 MHz. With this characteristics, the proposed antenna could be a promising candidate in latest wireless communication system such as WIFI and WiMAX.

CHAPTER 1

INTRODUCTION

1.1 Overview

Last few decades have witnessed significant changes and evolution in the area of antenna designs, with progressively growing intelligent wireless networks, smarter devices that supports multiple operations and advancing technical innovation being the catalyst for the launch and adoption of new technologies and services. In recent days, antenna designs have to satisfy the need of different types of ever-evolving technologies such as WiFi (Datar, 2008), WiMAX (Pareit et al., 2012), 4G LTE (Abeta, 2010) in various applications and occasions. It is a well-known fact that initially an antenna is used to act as an EM radiation transmitting/receiving device to a particular direction and operating at a particular frequency bandwidth (Balanis, 2005). In such a scenario, the transmitter antenna will transmit the EM energy to the receiver(s) direction while the receiver antenna is adjusted or aligned to get the optimum EM energy with clear line-of-sight (LOS).

However, the current need and expectation due to the recent development in the area of wireless communication demanded more effective functionality from the antenna. The new revolution in modern wireless technologies tends to offer the end-user more freedom and less hassle to be connected with the desired network while overcoming many propagation and network issues. Such wireless systems actually rely on a certain reconfigurability level to meet the system requirement (Haupt & Lanagan,

2013). For example, a system may need to shift the frequency of operation depending on service or availability of some unused frequency spectrum. In that case, the system requires frequency reconfigurability (Songnan et al., 2009). Apart from that situation, the reconfigurability may require at radiation pattern (Christodoulou et al., 2012) where, the system may need to change the main beam towards a certain direction in order to enable the alternative connectivity or signal reception enhancement. On the other hand, a system may also require to reconfigure its antenna polarization to match the polarization of the received signal thus increase the power receive (Jun et al, 2012).

Among these reconfigurable antennas, this thesis focuses on designing a reconfigurable antenna that can alter the radiation pattern while preserving the polarization and frequency. The antenna is able to change its radiation pattern for two different purposes. First, based on the radiation pattern change, the antenna is able to perform beam steering where the direction of the main beam is steered towards an intended direction. Such type of steerable antenna is used for direction finding application (Bailey et al, 2012; Svantesson & Wennstrom, 2001). Secondly, the antenna is capable to modify the radiation pattern to enable adjustable gain at a fixed direction. Two types of RF PIN diodes, namely BAR50-02V and HPND-4005 have been chosen and the advantages and disadvantages of these diodes when deployed at the antenna design have been presented.

1.2 Problem Statement

In various types of reconfigurable antenna, the patch type radiation pattern reconfigurable (RPR) antenna has gained significant interest due to its compact, simple and low cost design. Patch type RPR antennas are unable to obtain the maximum tilt

angle with respect to the broadside since the presence of the finite ground plane. Moreover, the implementation of RF switches on the patch RPR antenna also considered crucial due the fact that the patch RPR antenna is compact in size and the installation of various passive and active devices is expected to disrupt the performance of the antenna.

In this regard, thorough investigations have been carried out in this dissertation in reviewing the existing patch type RPR antennas. (Zhang et al., 2004) proposed a compact patch type RPR antenna that able to steer the beam towards three directions in H-plane with the maximum beam tilt angle of 35° . However, this design is not implemented with the actual RF switches in fabrication. Similarly, work by (Xue-Song et al., 2007) obtained a beam tilt angle of 40° but without the installation with the actual RF switches. Apart from that, work by (Ouedraogo et al., 2011) gave an impression that the beam tilt can be extended to 60° with respect to broadside also without the implementation of actual RF switch. However, it has high design complexity because it uses 35 switches. Basically it can be noticed that, if the designed antenna have beam tilt angle of more than 30° , then it is not fabricated with the actual RF switches. Else if the antenna able to produce beam tilt more than 30° , the antenna has high design complexity and it is not implemented with the actual RF switches. Recently, work by (Jusoh, 2013) attempted to implement the actual RF switches on the fabricated patch type antenna and the maximum tilt angle obtained is only approximately 25° . Only work in (Nair & Ammann, 2010) able to perform beam steering with beam tilt angle of more than 30° with the installation of RF switches on the antenna. However, this design unable to maintain a constant S_{11} bandwidth below than -10 dB for all switches configuration. Similar instability in S_{11} occurred for the antennas proposed in (Jusoh, 2013) where the antennas are implemented with the actual RF switches.

To the best of our knowledge, none of the previous patch type radiation pattern reconfigurable antenna with the actual RF switch implementation able to extend the beam tilt angle more than 30° . In many works, if the design able to achieve beam tilt angle more than 30° , it does not use actual RF switch or/and design wise very complex, or/and it suffers from unstable S_{11} . Overall, beam steering with patch antenna hampered by the following problems.

- a) DC biasing circuitry implementation for the reconfigurable antenna is a challenging factor.
- b) The problem of achieving adequate steering angle from the broadside where the typically achieved scanning is in the range of -30° to $+30^\circ$ from the broadside. This is due to the fact that the patch type antenna consists of a full ground plane that restricts the steering of the antenna with extended tilt angle respect to the broadside.
- c) With the installation of RF switches on the antenna, the antenna is unable to maintain constant S_{11} bandwidth for the all switches' configuration.

1.3 Research Objectives

The main goal of this research is to develop a broadly steerable reconfigurable beam steering patch type antenna for modern wireless communication to enhance the reliability of communications. It could be expected that reconfigurable antenna design community, broadband service providers and end-users to be beneficial from this research outcome. Overall, this project involves investigation on developing and analyzing the parasitic element based patch type reconfigurable antenna. This design and analysis are

inclusive of investigation, fabrication, measurement and verification. In summary, following points are considered as the objectives of this research:

- a) To design reconfigurable parasitic patch type antenna that has the capability of beam steering, inclusive of DC biasing circuitry on a single platform that has a stable S_{11} bandwidth.
- b) To evaluate the effect of DC biasing component such as isolation loss towards the beam steering characteristics of parasitic element based patch type reconfigurable antenna.
- c) To improve the beam tilt angle of the parasitic patch array antenna in order to improve coverage.

1.4 Scope of Research

This dissertation focuses on designing the reconfigurable beam steering antenna with parasitic patch arrays. Although in simulation different antennas are designed for different operating frequency to validate some performance characteristics, the fabricated antennas are specified for 5.8 GHz frequency resonant. The RF PIN diodes adopted in this project are BAR50-02V and HPND-4005. The proposed antenna performance is only comparable with patch type reconfigurable antenna and not with the other reconfigurable antenna such as a dipole or monopole array. Although performance of patch array antenna is not superior compared with the wire array antennas in terms of steering angle, it has its own advantage in some application where the full ground plane is needed. For instance, WBAN application needs patch array antenna with ground plane, hence the antenna performances will not be affected by human body effects.