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

by

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## 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

| | |
|---|---|
| $\lambda$ | wavelength |
| $\delta$ | wave attenuation level |
| $\mu$ | magnetic current rate in the material |
| $\varepsilon$ | 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 |
| $\varepsilon_r$ | 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 Tampal Berkebolehan Ubah Alur secara Lebar menggunakan Suis Pin Diode pada 5.8 GHz**

## ABSTRAK

Kajian yang dijalankan dalam tesis ini fokus terhadap penghasilan antena kebolehupayaan 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 kebolehupayaan kawalan radiasi jenis tampal (*patch*) mengalami kesukaran dengan kelemahan utama untuk mencapai sudut pemesongan alur ke arah tepi disebabkan satah bumi terhingga yang terletak di belakang elemen radiasi. Sudut pemesongan maksima yang dapat dicapai oleh antena kebolehupayaan kawalan radiasi jenis tampal sebelum ini ialah 30° tetapi tanpa pengunaan suis frekuensi radio (RF) yang sebenar. Dalam tesis ini, kajian mendalam terhadap antena tatasusunan tampal 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 antena sebab ia menawarkan kehilangn tangen yang rendah. Gandingan saling dan prinsip Yagi-Uda telah digunakan untuk mereka bentuk antena antenna tatasunan tampal tiga-elemen dengan dua jenis diod RF PIN. Antena dengan diod BAR50-02V dinamakan (*Low Isolation Loss Parasitic Patch Array*) LILPPA. Satu pemasangan terbaru diod PIN in antena tampal telah diperkenalkan, di mana diod BAR50-02V telah dibenamkan dalam substrat antena. Disebabkan kehilangan pengasingan yang rendah, LILPPA dengan diod BAR50-02V hanya mencapai sudut pemesongan maksima 23°. Diod HPND-4005 digunakan untuk merekabentuk (*High Isolation Loss Parasitic Patch Array*) HILPPA. Diod HPND-4005 PIN menawarkan ISO yang tinggi pada frekuensi 5.8 GHz, maka ia membantu HILPPA untuk mencapai sudut pemesongan maksima 30°. Dalam kedua-dua antena, hanya empat diod RF PIN telah digunakan. Kemudian, antena *Broadly Steerable Parasitic Patch Array* (BSPPA) telah diperkenalkan dan ia menggunakan diod PIN HPND-4005, disebabkan diode ini memberi prestasi yang mengagumkan terhadap antena HILPPA dalam sudut pemesongan alur. Antena BSPPA berupaya untuk meningkatkan sudut pemesongan alur kepada 50° dengan teknik teknik-teknik seperti penambahan elemen parasitik, peningkatan nombor suis dan pengurangan satah bumi di tepi. Antena 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°, +50° 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 tertimbul jika antena 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 peyuisan 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 cirri-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°, +50° 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° 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 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.