Reconfigurable Beam Steering Parasitic Patch Antenna With Embedded PIN Diode

by

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LIST OF ABBREVIATIONS

AoA	Angle of Arrivals
BER	Bit Error Rate
C-HDB	Compact High Directional Beam
CST	Computer Simulation Technology
dB	Decibel
EBG	Electronic Band Gap
EM	Electromagnetic
FPPA	Four Parasitic Patch Antenna
FEC	Forward Error Correction
GaAs FET	Gallium Arsenide Field Effect Transistor
GPS	Global Positioning System
GSM	Global System for Mobile
MCMC	Malaysian Communication and Multimedia Commission
PIN Diode	Positive Intrinsic Negative Diode
PNA	Programmable Network Analyzer
RF	Radio Frequency
SMC	Surface Mount Component
TSB	Touch Stone Block
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
ε	electric current rate in the material
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
S_{11}	reflection coefficient
S_{21}	transmission coefficient
L	inductor
C	capacitor

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ABSTRAK

Kajian di dalam tesis ini menjurus kepada kebolehupayaan kawalan radiasi antena bagi membolehkan aplikasi tanpa wayar dari satu tempat ke tempat yang lain. Konsep ini membantu penghasilan antena yang kompak, jimat kos dan fleksibel kepada alat pengguna di premis untuk beroperasi di dalam beberapa mod. Pembelajaran ini melibatkan antena di atas substrat berjalur micro yang murah, mudah dihasilkan dan senang untuk bekerjasama dengan komponen electronic yang lain. Antena dengan kebolehupayaan kawalan radiasi berguna untuk aplikasi tanpa wayar yang sedang pesat berkembang seperti *WiMAX* dan *LTE*. Tesis ini memperkenalkan kajian awal terhadap antena dengan konsep rangkaian elemen yang menggunakan PIN diod sebagai mekanisma kawalan. Dengan mekanisma itu, kajian dengan mendalam terhadap antenna dengan kebolehupayaan kawalan bentuk radiasi dapat dilakukan. Teknik *aperture coupled spiral feed* diperkenalkan didalam rekabentuk antena tersebut dimana dua papan substrate telah digunakan dengan nilai tetap dielektrik ialah 2.2. Dapat dikenalpasti dengan menggunakan teknik parasitik dan "mutual coupling", keupayaan kawalan radiasi pada empat arah yang berbeza iaitu +176°, +10°, -1° and -12° dapat dicapai. Lanjutan dari itu, kajian diteruskan dengan penghasilan antena menggunakan kaedah rangkaian parasitik elemen dan "mutual coupling". (Parasitik elemen ialah elemen yang tidak menerima arus RF secara terus. Manakala, "mutual coupling" wujud disebabkan radiasi elektromagnet diantara elemen pengalir yang bersebelahan. "Mutual coupling" digunakan oleh Yagi-Uda antena bagi menghasilkan dedikasi radiasi. Dengan itu, tesis ini mengaplikasi prinsip Yagi-Uda dan teknik penghasilan antena yang baru dengan menggabungkan empat parasitik untuk mencapai kawalan radiasi pada lima arah yang berbeza iaitu 0°, 45°, 135°, 225° and 315. Prototaip dengan kombinasi PIN Diod berbeza, BAR50-02V and HPND-4005 telah dihasilkan. Prototaip pertama menggunakan PIN Diode BAR50-02V yang telah diletakkan pada lapisan kedua Taconic dikenali sebagai *stacked FPPA*. Manakala, prototaip kedua menggunakan HPND-4005 pada lapisan yang sama dengan antenna dikenali sebagai single layer FPPA. Element antena FPPA terdiri daripada element tunggal yang dikelilingi oleh empat parasitik. Elemen tunggal tersebut diaktifkan dengan menggunakan teknik "coaxial feed". Setiap parasitik diletakkan dengan kesan pautan elektromagnetik yang optimum daripada elemen tunggal dan semua parasitik bersambung dengan kutub negatif antena melalui pin pengalir pada lokasi yang optimum. Kedua-dua prototaip berjaya mencapai "gain" melebihi 8dB pada semua arah yang ditentukan dengan kestabilan pada frequency sasaran P1 WiMAX (2.36 to 2.39 GHz). Simulasi dan pengukuran menunjukkan keputusan yang baik dan ini sekaligus mengesahkan konsep yang dibentangkan adalah benar.

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ABSTRACT

The work described in this dissertation focuses on the reconfigurable beam steering antenna functionality for point-to-multipoint wireless communication application. This concept helps to reduce the antenna size, cost, and gives more flexibility for a customer premises equipment (CPE) to be operated in several modes. The studies involve the microstrip patch antenna of low profile, low cost, ease of fabrication and easy to be integrated with other RF components. Beam steering/forming antenna is useful in the rapid growth of the wireless communication system such as Wireless Interoperability Microwave Access (WiMAX) and Long Term Evolution (LTE). This dissertation introduces the preliminary investigation on a single element reconfigurable patch antenna which uses PIN diodes as the switching mechanism. With that, reconfigurable pattern of an antenna is studied in depth. Then, the dissertation more focused on *spiral reconfigurabe* beam antenna with aperture coupled feed technique designed on two Taconic substrate with similar dielectric constant of 2.2. It is discovered that such parasitic and mutual coupling technique is able to steer the radiating beam to four different angles of +176°, +10°, -1° and -12°. Therefore, this dissertation continues on designing another steerable beam antenna that uses similar technique of *parasitic array* and *mutual coupling* method. (Parasitic element is the element that undirectly excited by the RF induced current. While mutual coupling exists due to the interaction between the adjacent element). The mutual coupling effect has been introduced by the Yagi-Uda antenna in realizing the beam directional ability. Adopting the Yagi-Uda principle, this dissertation has proposeda novel five-element patch antenna (single-fed driven element and four parasitic elements) in achieving the beam steering at ϕ of 0°, 45°, 135°, 225° and 315°. Two reconfigurable antenna prototypes are implemented with embedded RF switching technique with two different types of RF PIN diodes, namely; BAR-5002V and HPND-4005. The first prototype integrates the BAR-5002V on the second substrate layer known as *stacked FPPA*. While, the second design integrates the HPND-4005 on the similar radiating layer denotes as *single layer FPPA*. The FPPA is developed by a driven element encircled by four parasitic elements. The driven element is induced by the coaxial feed technique. Each of the parasitic element is positioned in such a way that optimum coupling effect is produced from the arrangement of the driven element and the specified shorting pin locations. Both prototype have achieved an approximate high gain of 8 dBi at all desired phi directions. Measured and simulated results with a very good agreement are obtained, thus the proposed concepts considered valid.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Recently, the reconfigurable antenna has gain huge attention among the researchers and the industry players. This is due to the fact that reconfigurable antenna has the capability of combining multiple applications in a single terminal compared to a conventional antenna which is only capable to perform a single ability in a single antenna. Reconfigurable antenna can be categorized into three types, namely; 1) switchable frequency (performed for wideband and narrowband), 2) switchable polarization (change in linear and circular polarization) and 3) switchable radiation pattern (ability to shape and steer the antenna beam). With these reconfigurable abilities, such antenna could be useful in many applications such as GPS, GSM, WIFI, WIMAX and Bluetooth. Besides that, the reconfigurable antenna offers compactness, flexibility and cost reduction without reducing the performance as well.

Initially, this dissertation carries out investigations on the use of PIN diode switch in designing the reconfigurable antenna. The study involves the antenna performance in terms of reflection coefficient, circuit biasing, radiation pattern and mutual coupling effects. Then, this dissertation focused on a beam forming antenna functionality. A reconfigurable beam forming with the aptitude of positioning the main beam towards the wanted signal while suppressing the antenna beam in the direction of the unwanted signal is capable to

mitigate fading. Moreover, the interference level at the receiver also can be reduced to ensure a spectrum efficient with a minimum BER (Rappaport, 2002). The proposed antenna is targeted to function at 2.3 GHz for WIMAX application in Malaysia. WiFi/WiMAX system usually uses an adaptive bandwidth modulation and varying levels of FEC in order to increase the data rates and indirectly extend the coverage area (J. Blas Prieto, 2008; Sung Woong Choi, 2009; Vivek K. Dwivedi, 2009). A smart antenna system could be deployed as another alternative instead of FEC.

A reconfigurable beam antennas can be divided into beam shaping and beam steering technique. The beam shape antennas are capable of directing the antenna radiation pattern at a particular direction with a certain number of gain level. While the beam steer antennas have an ability to position a single beam pattern in one direction at a time. A significant reconfigurable antennas for beam steering application have been reported in (Ali, 2010; Kang, 2012; Liu, 2010; Peng, 2011; Shynu Nair, 2010). A lot of research work concluded that the beam steer can be achieved with the monopole antenna design.

However, this dissertation has focused on the microstrip antenna that bounded to the requirement of challenging the conventional microstrip antenna performance. This dissertation enhance the ability of microstrip parasitic antenna to perform beam steering at all desired ϕ of 0°, 45°, 135°, 225° and 315° angle. Each of the beam steering angle accomplish a high gain parasitic antenna of more than 8 dBi. Besides, the design of a compact antenna that suitable for Packet One Sdn Bhd (P1 WiMAX) with the modem size of 122 mm x 137 mm.

1.2 Problem Statement

Currently the commercialized P1 WiMAX modem of Greenpacket's DX Tower WIMAX Indoor Modem and D Series WiMAX Indoor Modem have been released for Indoor application as shown in Figure 1.1 and 1.2 respectively (Berhad, n.d.). The DX WiMAX has a gain of 5dBi. Such modem operates up to 25dBm transmission power. While the D Series has a peak gain of 6dBi with directional antennas and functions up to 27dBm transmission power.

Figure 1.1: The prototype of DX Tower WiMAX Indoor Modem

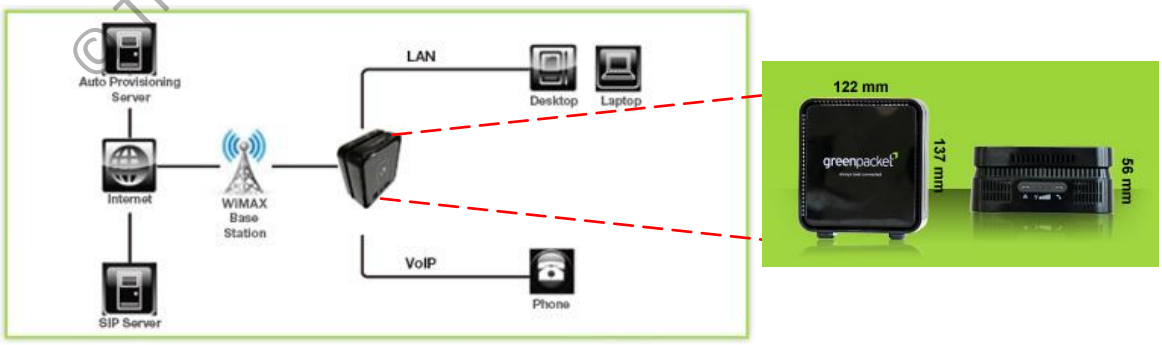

Figure 1.2: The D Series WiMAX Indoor Modem fits into the Network Architecture.

However, both modems have the following drawbacks. The Tower operates with omnidirectional antenna where such a design leads to energy waste by the unintended transmission power and it contributes heat to the modem. Besides that, the low gain omnidirectional antenna is easily exposed to the unwanted interference signals. On the other hand, the D Series modem has a directional antenna where such a design can overcome the issue mentioned above. However, since the radiation pattern is directed to a single direction only, the users need to manually align the modem for the LOS to obtain the best reception with maximum received power. The recent advancemnent in wireless communication must satisfy the need of the users where the evergrowing IT minded users expecting improvement in the data communication and preferring easy-to-use devices for wireless communication purposes. In such a scenario, the deployment of a reconfigurable antenna at the current WiMAX communication modem could be a best solution. Therefore, this dissertation proposed a reconfigurable WiMAX antenna which capable to perform beam steering electronically in order to get the optimum received power with enhanced signal-to-interference ratio. Furthemore, the proposed antenna is expected to have a dimension of less than the medium size. By sustaining the modem size, such antenna could be used inside it. Therefore, with reflect to modem size restriction, the proposed antenna design has focused on the microstrip antenna rather than a dipole or monopole antenna even though they have a better beam steering achievement (Kawakami, 2005; Schlub, 2004).

1.3 Research Objectives

This project involves studies on the reconfigurable antenna inclusive of design, fabrication, measurement and test in order to establish optimum antenna types. The objectives can be summarized as follows:

a) To design a reconfigurable beam steering antenna with desired gain (>5 dB) operability at targeted phi angles of 0°, 45°, 135°, 225° and 315°.

b) To investigate the possibility of using 'mutual coupling' effect for exciting RF current to the parasitic element. Mutual coupling is the EM interaction of the adjacent conductor element.

c) To characterize the RF current control capability and DC biasing circuit schematic between two different types of PIN diodes; BAR5002V and HPND4005.

1.4 Research Scope

This dissertation involves several simulations, fabrications and measurements of reconfigurable antenna design with the integration of RF PIN Diode switch control.

Stage 1: Literature Review

First and foremost is to review other related works of microstrip antenna which focus on the reconfigurable radiation pattern. A comprehensive study is conducted on the PIN diode switch technology as a tool to achieve reconfigurable ability of antenna. Based on previous research, the enhancement and improvement of the conventional antenna performance are proposed.

Stage 2: Reconfigurable Antenna Design and Simulation Process

The initial design is based on the basic structure of the rectangular and circular patch that developed from the calculation analysis. All designs and simulations are performed by CST software. The CST is generating the reflection coefficient, bandwidth, gain and radiation pattern. There are three types of antennas have been designed and discussed in detail in Chapter 4, 5 and 6. This dissertation implemented two techniques to represent the PIN diode switch in simulation; copper strip line and TSB.

Stage 3: Antenna Fabrication and Integration with RF PIN Diode

All antennas are fabricated after obtaining the optimal result from the simulation process. The prototype antennas are embedded neither BAR50-02v nor the HPND4005. Antenna in chapter 3, 4 and 5 are integrated with the BAR50-02v model. While the proposed antenna in chapter 6 is embedded using PIN Diode HPND4005.

Stage 4: Measurement of Fabricated Antenna

Each of the prototypes are tested and measured using the PNA and ATENLAB anechoic chamber. Radiation patterns, gain and reflection coefficient are obtained from the measurements. A comparative study of both simulated and measured results are carried out.

Stage 5: Characterization of PIN Diode Performance

The characterizations of the different PIN Diode are studied intensively in this dissertation. The parameters included isolation loss, insertion loss, biasing circuit design, reflection coefficient and minimum forward resistance will be different when using different PIN Diode. The studies are based on the provided data sheet from the