Switchable Parasitic Patch Antenna with Beam Steering for WiMAX Application

M.Jusoh[1], M.F.Jamlos[1], M.R.Kamarudin[2], N.M.Nawawi[1], T.Sabapathy[1], M.I.Jais[1]

Advanced Communication Engineering Centre (ACE)[1]
School of Computer and Communication Engineering
Universiti Malaysia Perlis (UniMAP)
Pauh Putra Campus, Malaysia
ame_tango1@yahoo.com, faizaljamlos@unimap.edu.my,
norizan@unimap.edu.my, thenna84@gmail.com,
ilman_kun@yahoo.com

Wireless Communication Centre (WCC)[2]
Faculty of Electrical Engineering
Universiti Teknologi Malaysia (UTM)
Skudai, Johor, Malaysia
ramlee@fke.utm.my

***Abstract*— A switchable parasitic patch antenna that has a capability to operate in four beams of operation is proposed. The presented antenna is developed with a single main radiator at the center of the antenna structure surrounded by four parasitic elements. It has a full ground plane functioned as a reflector that helps to boost the gain up to 8dBi. Antenna reconfiguration is achieved with the implementation of the PIN diode switches. Each of the switches is linked to the parasitic via a shorting pin. The ON/OFF PIN diode state condition means the parasitic is activated/deactivated. It is discovered in CST simulation software that the specified location of the pins is really significant to ensure the parasitic perform either as a reflector or director. The presented antenna could be a solution for application requiring the dynamic beam switching such as a smart WiMAX antenna.**

Keywords—switchable; parasitic antenna; beam steering

I. INTRODUCTION

Switchable antenna is referred to as a single antenna that is capable to function in multiple-frequency bands, multi-directional radiation patterns, whether divisive or omnidirectional, or multiple-polarization, either circular or linear or elliptical. Relative to conventional antennas, this will significantly reduce the antenna's size and cost.

Electronic reconfiguration for an antenna can be achieved using various RF switches, such as PIN diodes, micro-electromechanical (MEMs) and gallium arsenide field-effect-transistor (GaAs FETs). These devices can either be used for beam-, polarization- or frequency-alteration by switching between ‘ON’ and ‘OFF’ states [1-4], or as an impedance-matching elements [5-7].

The proposed antenna has been developed with a single main radiator surrounded by four parasitic elements with a full ground plane. After an intensive parametric routine, the optimum antenna dimension indicates main radiator (R) and all parasitic have 23.5 mm radius. This is to ensure the driven element and the parasitic have resonated at 2.38 GHz with same electromagnetic wave length. Optimization of the antenna was carried out using CST Microwave Studio software. To realize a switchable beam antenna, all parasitic are connected to the PIN diode switch via a shorting pin.

II. ANTENNA DESIGN

Fig. 1 shows the structure of the proposed antenna. The antenna's structure is constructed using Taconic substrate with relative permittivity of 2.2, substrate thickness of 1.5748 mm, copper thickness of 35 μm and electric loss tangent of 0.0009. The minimum of tangent loss value gives the maximum of electrical wave travels through the substrate that good for the conduction purpose as explained by the equation (1). The greater the loss tangent, the superior the attenuation of the electric field that make the material suitable for electromagnetic absorption or shielding principle [8]. Therefore, this research applied Taconic material with low dielectric constant and thick substrate ($0.003\lambda_o \leq h \leq 0.05\lambda_o$) due to the better efficiency and larger bandwidth [9-10].

$$tan\_\delta = \frac{\mu}{\varepsilon} \tag{1}$$

Where

δ is loss tangent; wave attenuation level in the substrate
μ is magnetic current rate in the substrate
ε is electric current rate in the substrate

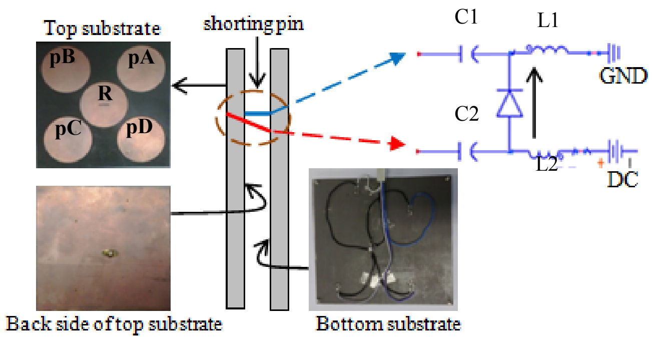


Fig. 1. The structure of the proposed antenna

The studied antenna consists of a total of 5 elements (N=5): one active element and 4 parasitic elements (P=4). The active element is depicted as R and the parasitic elements are depicted as pA,pB, pC and pD respectively in Figure 1. Each of the parasitic elements (pa-PD) is connected to the switches via a copper pin. The parasitic are activated/deactivated when the PIN diode is ON/OFF state configuration. The beam is able to steer at 13° angle (from the *z* -axis) when the pA is OFF while the other PIN's are ON. To provide a 15° angle, the PpB is OFF and other PIN's are ON. When the PC is OFF while other PIN's are ON, the beam directed to 10° angle. As pD is OFF and pA-pC are ON, the beam steered to 12°. It is discovered that when the PIN diode is ON/OFF state, the parasitic functioned as a reflector/director.

A. RF PIN diode switch

As shown in Figure 1, all the switches are implemented in the different surface of the antenna. This is to ensure less RF signal absorption or attenuation from the switches. The blue lines are the electrical paths that connected all the lump elements. The V_DC and the GND are the DC switch control voltage and the ground signal respectively. The 1.5V/0V of V_DC source is supplied to the circuit to short circuit the inductor (L1-L2) and ON/OFF the PIN diode accordingly. In order to avoid the DC signal flowing in the RF system, the DC block capacitor (C1-C2) is located at the PIN diode circuit junction.

The copper bridge is used in simulation as an approximation of the switching device. The presence of the copper bridge symbolizes the ON state while the absence of the copper bridge represents the OFF state condition. We believe this circuit maker/breaker approximation has provided tolerable of the biasing circuit concept. Finally, the optimum antenna design will be fabricated with the real surface mount component switching device.

B. Parasitic Control Formulation

A simple circular array of M-elements, one active element and (P=M-1) parasitic elements encircling the radiator is used in this paper. Such technique is similar in designing the switched parasitic dipole arrays. The elements are drawn in an x-y-axes which the center is located at (0,0) coordinate and the parasitic *w* is *x* mm away from the center. Fig.2 depicts the array used for the proposed beam steering scheme using parasitic elements.

All elements with a radius of *a* has physically same electrical length. By switching the parasitic between short-and open-circuit results in an electrical length deviation. Such variation would enable the parasitic to function as a reflector or director as the resonant length is changed [11-12]. According to Yagi-Uda antenna theory, the radiator is achieved when it is physically slightly shorter than the excited element and the radiator has slightly longer physical than the feed element [13, 10].

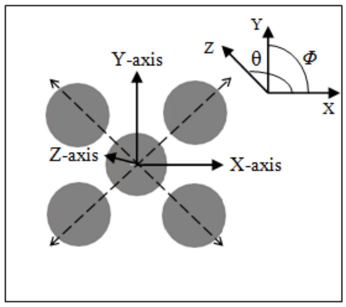


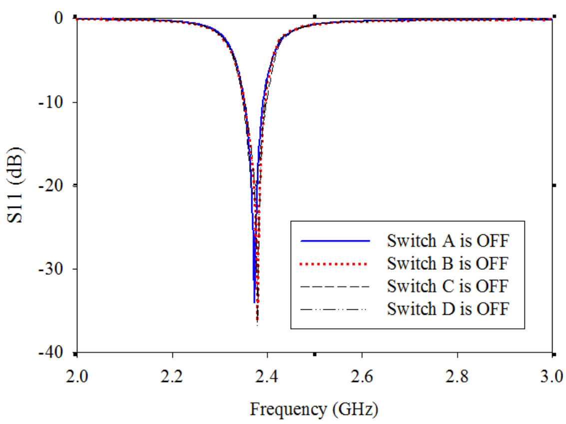
Fig. 2. Antenna geometry of one active element surrounds by 4 parasitic elements

III. RESULT AND DISCUSSION

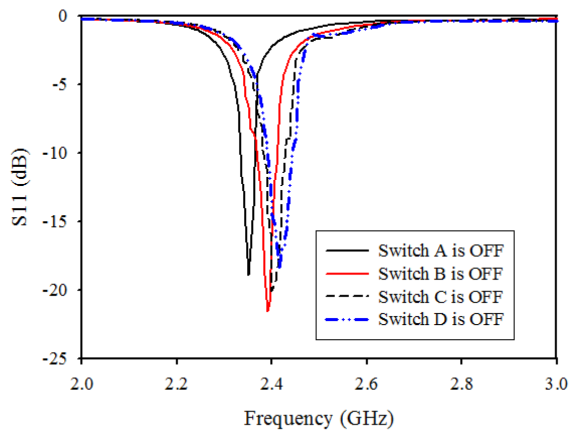
This section discusses the proposed antenna performances in either simulation or measurement, in terms of return loss result, surface current distribution and radiation pattern).

A. Reflection Coefficient

Fig. 4 (a) and 4 (b) show the simulated and measured reflection coefficient for the switchable parasitic patch antenna. The simulated S11 has almost similar frequency resonant regardless of the PIN configurations. The S11 is less than -10dB over 2.36 - 2.40 GHz with high impedance matching (IM) of -35dB. The measured return loss has a slight shifted of 20MHz to left and right of the resonant frequency. Even, the antenna has less IM of -22 dB compared to simulation. However, the switchable antenna still operates for a WiMAX operating band under frequency response (S11) of -10 dB.



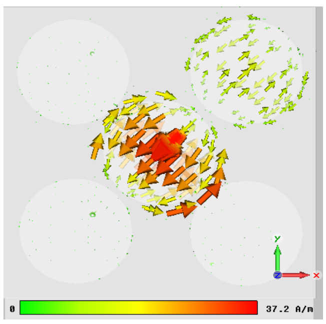
(a) Simulated



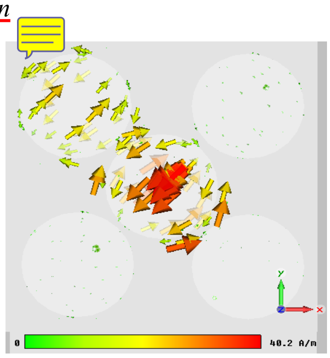
(b) Measured

Fig. 4. Simulated and measured frequency response (S11) of the switchable parasitic patch antenna. Each PIN diode that not mentioned is in ON state.

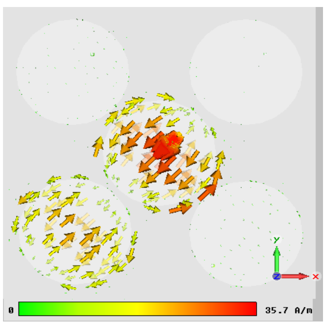
B. Surface Current Distribution



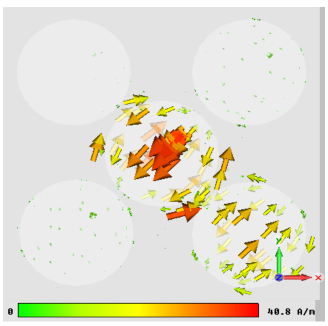
(a) PIN A is OFF



(b) PIN B is OFF



(c) PIN C is OFF

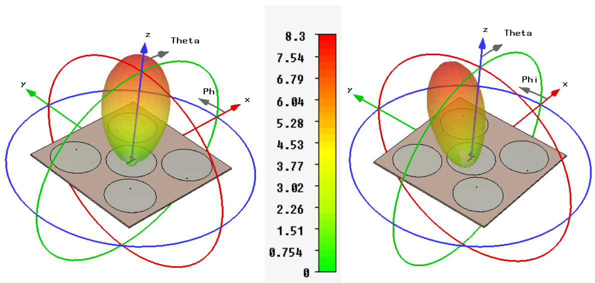


(d) PIN D is OFF

Fig. 5. H-field surface current of PIN diode configurations. Each PIN diode that not mentioned is in ON state.

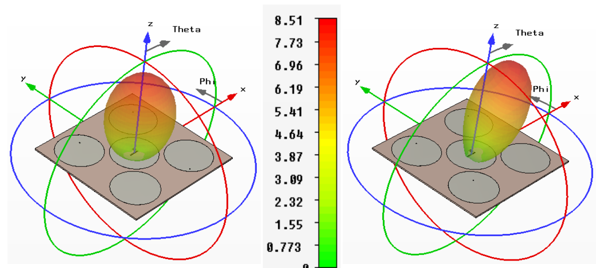
The H-field surface current distribution is observed at 2.38 GHz over the certain PIN diode configurations as shown in Fig. 5. Fig. 5 (a) indicates more current flows at pA as PIN A is OFF while pB-pD has no interaction. The surface current only exists at pB as PIN B is OFF in Fig. 5 (b). Fig. 5 (c) and 5 (d) depict the surface current at pC-pD with PIN C and D are OFF respectively. At each specific PIN 'OFF' state, all other unmentioned PIN is in the 'ON' state. It is discovered that the activation of particular PIN's contributing to the smooth flow of induced current to the specified parasitic element. Thus, the beam steering mode of operation can be realized.

C. Radiation Pattern



PIN A is OFF
(a)

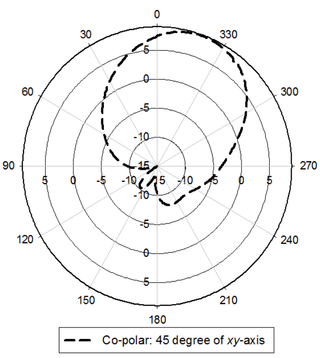
PIN B is OFF
(b)



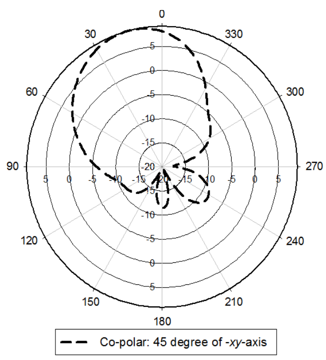
PIN C is OFF
(c)

PIN D is OFF
(d)

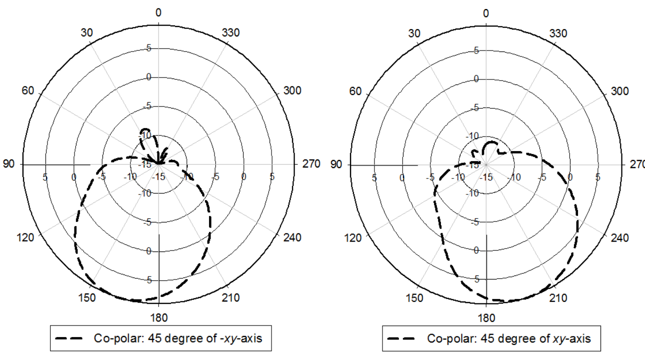
Fig. 6. Simulated 3D radiation pattern showing the beam direction in four mode operation. (a) & (c) Azimuth plane (45° of *xy* plane). (b) & (d) Elevation plane (45° of -*xy* plane).



(a)



(b)



(c) (d)

Fig. 7. Measured pattern for the four modes. (a) & (c) Azimuth plane (45° of *xy* plane). (b) & (d) Elevation plane (45° of -*xy* plane).

The antenna's beam direction depends on the activation or deactivation of the p-i-n diode biasing at switches A, B, C and D as shown in Fig. 6 and Fig. 7. When switches B, C, and D are positive with respect to A, the beam directed to 13° from the zero angle. When switch A, C and D is forward bias while B is reverse bias, the antenna's beam position to 15° angle. As shown in Fig. 7(c), the beam has steer the beam to 10° when switch C is OFF. When the switch D is OFF and other switches are ON, the antenna has it's beam at 12° angle. The antenna's half power beamwidth (HPBW) is approximately 60° of all mode operations as shown in Fig. 7. The 3D simulated patterns are shown in Fig. 6 for reference.

The antenna indicates a peak gain of 6.5 dBi when switch A is OFF, 6.2 dBi as switch B is OFF, 7 dBi when switch C in OFF and 6.8 dBi as switch D are OFF respectively. At each specific switch 'OFF' state, all other unmentioned switch is in the ‘ON’ state. The lower gain for each mode is mainly due to the signal deterioration of the surface mount component itself. Thus, the resonant frequency and bandwidth are relatively constant, this design can provide beam switching in the azimuth and elevation planes with a single feed point.

IV. CONCLUSION

A switchable parasitic patch antenna for WiMAX application is proposed. Such beam configuration is achieved using four p-i-n diodes at the specified location of the parasitic. It is discovered in CST simulation software, the specified location of the pins is really significant to ensure the parasitic perform either as a reflector or director. Besides that, the antenna design with four parasitic elements encircling the induced element contributed to the beam steering application. The presented antenna has achieved 13°, 15°, 10° and 12° when the PIN's A, B, C and D are OFF respectively. Moreover, the antenna is etched on the Taconic substrate that help the antenna to achieve better efficiency with a compact dimension of 130 mm by 130 mm.

ACKNOWLEDGEMENT

The authors acknowledge the contributions of Universiti Malaysia Perlis (UniMAP) and the Ministry of Malaysian Higher Education (MOHE) for the Ph.D. scholarship of Muzammil Jusoh which enabled the production of this article. Our gratitude also goes to members of UniMAP's AMRel Lab, School of Computer and Communication Engineering and Wireless Communication Centre (WCC), Universiti Teknologi Malaysia.

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