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Abstract: Antenna design with frequency and polarization reconfiguration for application in WiMAX and WLAN band with minimum number of p-i-n diodes is provided in this communication. The antenna geometry comprised of two annular rings with removable arc on one ring and a slot on the partial ground plane. The inclusion/ removal of arc on the left ring through two PIN diodes give the frequency reconfiguration between single WLAN (5.38 GHz) and dual WiMAX (3.17 GHz), WLAN (5.24 GHz) band. Also, the polarization switching between linear and circular state with axial ratio bandwidth of 0.03 GHz in WLAN band is obtained on switching both diodes OFF simultaneously. The measured results correspond well with the predictions, indicating that the suggested structure is relevant for WiMAX and WLAN communication in modern wireless application.

Keywords: Annular rings; WLAN; WiMAX; frequency; polarization; PIN diode

1. Introduction

Next generation wireless communication systems offer various services like Wi-Fi, WiMAX, GPS, WLAN, Bluetooth etc. for different applications in a device. As each application has independent frequency bands, polarization and radiation characteristics and requires a dedicated antenna for its services[1-6]. The integration of these services in a single device makes it complex and bulky. The reduction of physical size and complexity has caused the evolution of multi-functional antennas to improve the performance of communication system in fast changing environment. In recent years, for multi-functional, reconfigurable patch[7-10] antennas with alteration ability draws the attention of antenna researchers, as it can provide more functionalities for various applications at different frequency bands over the conventional antenna. In literature, multiple antenna designs with a single tunable parameters like frequency, polarization and pattern have been developed with good performance metric for different wireless applications and termed as frequency agile, polarization agile and pattern agile antennas. Compound or hybrid or multi-parameter agile antennas have recently received a lot of recognition because they offer more flexibility in design and operation than single tunable reconfigurable antennas[11-16]. Here two or more characteristics like frequency – polarization, frequency – pattern, polarization – pattern of a single antenna can be altered independently without affecting their individual operation. The frequency and polarization[17-21] diversity antenna have many advantages like frequency reuse for efficient spectrum utilization, increased system capacity, minimizing the fading loss due to multipath, provide immunity against interfering signals, reduce the co-channel interference and improved communication security. The hybrid antenna's constant gain for all operating modes aids in lowering the system costs, increasing system efficiency and achieving good SNR.

Sedhghara et al.[17] suggested a concentric slot rings with tuning stubs for frequency switching in 2.4 and 3.5 GHz band with polarization reconfiguration between linear, right and left hand circular polarization (RHCP, LHCP) for WLAN band and between RHCP, LHCP for WiMAX band. Bharthi et al. suggested a corner clipped square patch having a rectangular ring slot at the mid of patch with p-i-n diodes[18] for frequency and polarization reconfigurability. The resonant frequency switched between 5.2 and 5.8 GHz band on switching p-i-n diode ON or OFF with polarization reconfiguration in linear and circular state. A coaxial fed square patch design with shorting post is proposed by Qin et al.[20]. Connection of shorting post at the center of square patch arms either via PIN diode or two varactor diodes has led to the frequency or polarization switching in between horizontal, vertical and 45° linear polarization. In[22], frequency switching in eight discrete bands (1.83 – 2.65 GHz) by switchable shorting pins and polarization reconfigurability in LP, RHCP and LHCP with perturbation segments are exhibit successfully. The antenna designs for frequency and polarization agility with complex feed network is suggested in[23-25]. Here, reconfigurability operation is achieved through the feed network. Here in[25], antenna design exhibits the frequency and polarization reconfiguration with the help of metasurface. The spacing between slot antenna and metasurface determines the operating frequency, while the rotation of metasurface give rise to the swapping of polarization between linear and circular state. Dishant[26] et al. also presented a comparison of key components like material, shape, feed type, size and gain of various dielectric resonator antennas for WiMAX and WLAN applications.

The above discussed antenna structures have drawbacks like complex antenna and feed network design, high number of switches, large size and multi-layered structure. In this communication, a single feed annular rings with slot on partial ground plane having minimum number of p-i-n diodes for diversity in frequency and polarization is proposed. The antenna is switched between WiMAX and WLAN bands with linear and circular polarization diversity for WLAN band via switching p-i-n diodes ON/ OFF simultaneously. Antenna is prototyped and tested for reflection coefficient and normalized far-field radiation patterns. Paper is grouped as follows: antenna design, reconfiguration mechanism and simulated design is presented in section 2, section 3 contains the fabricated design with measured results and conclusion in section 4.

2. Reconfigurable Antenna Design and Reconfiguration Mechanism

2.1 Antenna Geometry and Empirical Equations

Here, we select annular ring as radiating element over the other shapes, as the edges at inner and outer radius results in more fringing field's results in larger bandwidth, higher radiation performances[28-30]. The dominant mode (TM11) resonant frequency for annular ring patch is approximated by mean circumferential length[17),31]. The empirical equations are as follows:

$$\lambda = \pi(R_i + R_o) \tag{1}$$

$$f = \frac{c}{\pi\,(R_i+R_o)\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$\varepsilon_{eff} = 1 + q(\varepsilon dr - 1) \tag{3}$$

Where, c = Speed of light,

f = Frequency of dominant mode

λ = Wavelength of dominant mode

$\pi\,(R_i + R_o)$ = Mean circumference length,

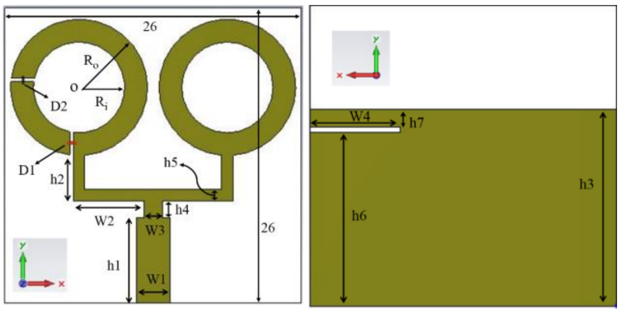
ε_{eff} = Effective dielectric constant

εdr = Relative permittivity

q = Correction factor of different dielectric materials on both sides of antenna patch.

The layout of proposed reconfigurable antenna is shown in Fig. 1. The antenna is fabricated on 1.6 mm thick inexpensive FR-4 substrate with relative permittivity (ε_r = 4.4) and loss tangent (tan δ = .02). The FR-4 material can not be used for designing antenna above 10 GHz frequency, because dielectric constant is not well controlled above 10 GHz can led to the change in operating frequency and high loss tangent for higher frequencies results in significant losses in the material, which accounts for low gain and poor radiation efficiency.

The radiating element of the suggested reconfigurable antenna comprises of two annular rings with an arc on the left ring. The optimized slot of width 0.5 mm and W4 mm length is sculpted on partial ground plane at height h6 mm from the lower edge of ground plane transforms the narrowband patch antenna into wideband antenna and gives the circular polarization for resonating frequency. The radiating structure is fed by a single microstrip line with two subsections, which is further divided into 1 mm wide two segments to energize the individual rings of the antenna. The loading or unloading of the arc on the ring is achieved by switching PIN diodes D1, D2 simultaneously either ON or OFF, has led to the frequency agility between WiMAX and WLAN bands and diversity in circular and linear polarization state for the WLAN band. The suggested design was simulated in the CST Microwave studio and optimized dimensions are as follows: h1 = 7.5 mm, h2 = 4 mm, h3 = 17 mm, h4 =1.5 mm, h5 = 1 mm, h6 =15 mm, h7 = 1.5 mm, W1 = 3 mm, W2 = 6.2 mm, W3 = 1.6 mm, W1 = 3 mm, W2 = 6.2 mm, W3 = 1.6 mm, W4 = 7.65 mm, Ro = 6 mm and Ri= 4 mm. The calculated value of resonant frequency from equations (1) - (3) is ≈5.82GHz.The total size of structure is 26×26×1.6 mm^3.



(a) (b)

Fig. 1: Layout of suggested antenna (a) front side (b) rear side.

2.2 Reconfiguration Operation

2.2.1 Frequency Diversity

As we know, the effective electrical length of any antenna design determines its resonant frequency. The alteration in effective electrical length of antenna structure by any means either electronically or optically or mechanically translates into a new operating frequency. The inclusion or removal of arc on the left ring through

PIN diodes, redirects the current in certain portion of the structure[32]. Thus, there is a change in effective electrical length resulting in switching of frequency in between WiMAX and WLAN bands.

On forward basing, diodes D1 and D2 behave as short circuit and arc is added to the left ring thus completes the left ring. The resultant structure has simulated, it offers resonating frequency range (5.24 – 5.52 GHz) with 5.37 GHz resonant frequency, thus covers the band for WLAN application. On reverse biasing, the arc is disconnected from the left ring and modified antenna structure has two resonating frequency bands. The first WiMAX (3.20 – 3.51 GHz) band with 3.36 GHz resonant frequency is more prominent than second WLAN (5.16 – 5.38 GHz) band as shown in Fig. 2.

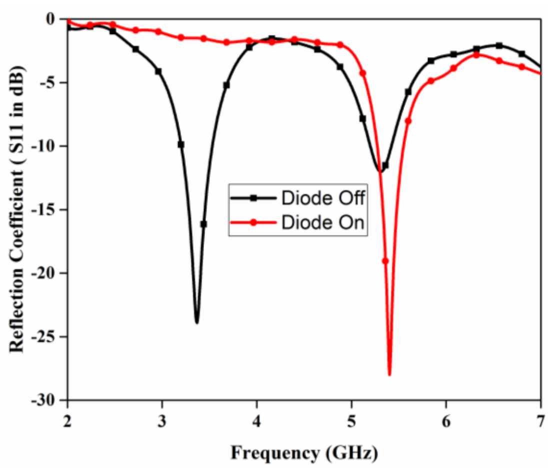
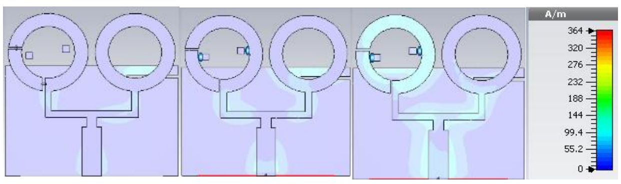


Fig. 2: Simulated Reflection coefficient Vs Frequency.

To understand the frequency reconfiguration operation the distribution of surface current on patch at 3.36 and 5.37 GHz are presented in Fig. 3(a)-(c), for both the diodes are switched ON or OFF simultaneously. It is noticed from Fig. 3(a), the current is more concentrated around the slot and sparingly distributed[33] beneath the feed lines give rise to the resonating frequency of 5.37 GHz. On reverse biasing, the current is concentrated on the same locations but with more density as displayed in Fig. 3(b) is responsible for 5.37 GHz resonant frequency with wider bandwidth, while current distribution on the left ring as well on or below the feed lines as shown in Fig. 3(c) is responsible for resonant frequency of 3.36 GHz.



(a) (b) (c)

Fig. 3: Surface current distribution (a) f = 5.37 GHz both diodes ON (b) f = 5.37 GHz both diodes OFF (c) f = 3.36 GHz both diodes OFF.

2.2.2 Polarization Diversity

As we know that, the two orthogonal modes of same amplitude[34-35] with quadrature phase difference can produce circular polarization. Here, when both the diodes are ON, the slot of quarter wavelength (λ/ 4) on the ground plane breaks the dominant mode into two near degenerate resonant modes of same amplitude and phase difference of 90°,thus producing the circular polarization. The distribution of surface current at 5.3 GHz for different phases is depicted in Fig. 4.

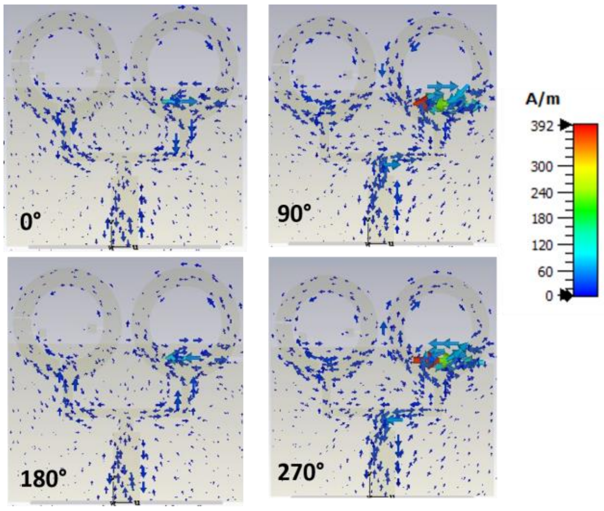
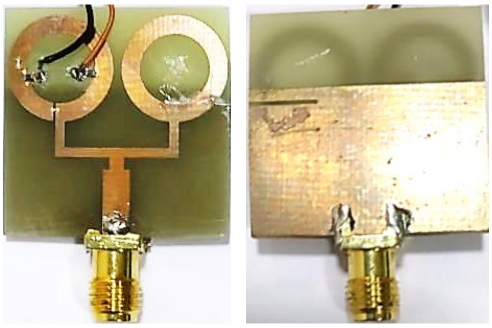


Fig. 4: Surface current distributions at 5.3 GHz.

It supports the above mentioned and determine the sense of polarization from the rotation direction of current vectors. The surface current vectors at 0° and 180° or at 90° and 270° are same[36-37] in magnitude but 180° in phase and also current vector rotates in anti-clockwise direction, so the radiation has LHCP (Left Hand Circular Polarization). Similarly, when both the diodes switched OFF, linear polarization is obtained in the resonating frequency band. Thus, reconfiguration between linear and circular polarization in WLAN band is achieved by turning diodes OFF or ON simultaneously.

3. Results

Based on above analysis, an antenna structure is designed, prototyped and measured for reflection coefficient and far-field radiation characteristics. The fabricated antenna is presented in Fig. 5. The S11of antenna for two states of p-i-n diodes are measured with Agilent N5234A Vector Network Analyzer and normalized radiation pattern in an anechoic chamber.



(a) (b)

Fig. 5: Printed Antenna (a) Radiating side (b) Ground Plane side.

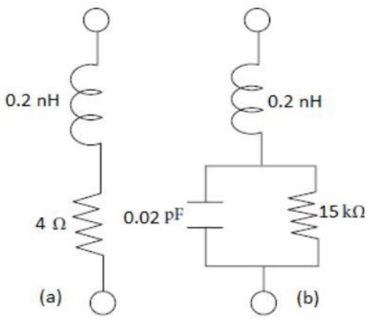
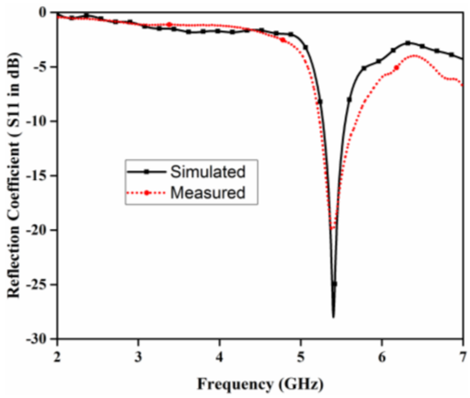


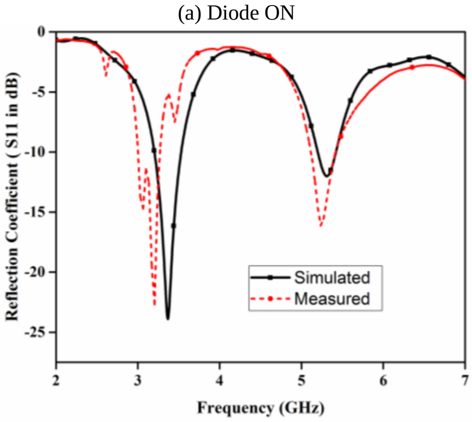
Fig. 6: RF equivalent circuit of p-i-n diode (DSG6474) (a) Forward biased (b) Reverse biased.

To reconfigure the antenna characteristics, the Alpha's silicon planar DGS 6474 PIN diode is used[38]. To choke the RF signal, the biasing voltage to the PIN diode is supplied via surface mount inductor (47 nH) connected in series with each dc feed line at each terminal. When diode is turned ON, the equivalent circuit has a 0.2 nH inductor in series with 4Ω resistor as shown in Fig. 6(a). The OFF state of PIN diode has a 0.2 nH inductor in series with a shunt combination of 15 kΩ resistor and 0.02 pF capacitor as shown in Fig. 6(b). Also p-i-n diode has switching speed of 25 ns, maximum power dissipation of 2 Watt for the frequency range from 1 – 18 GHz.

The plot of reflection coefficient against frequency for simulated and measured for ON / OFF state of p-i-n diode is presented in Fig. 7 (a) and (b). The antenna has a single resonating frequency band of 5.24 – 5.68 GHz with resonant frequency at 5.38 GHz when both diodes are ON. While antenna has dual band behaviour with 3.0 – 3.28 GHz, 5.13 – 5.42 GHz frequency bands and resonant



(a) Diode ON



(b) Diode OFF

Fig. 7: Reflection coefficient Vs Frequency.

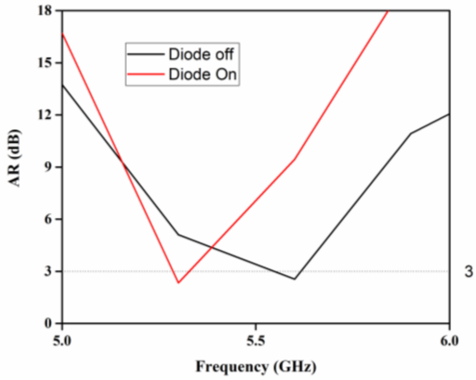


Fig. 8: Axial ratio Vs Frequency.

frequency at 3.21 and 5.24 GHz as respectively on switching OFF both diodes simultaneously The measured results agree well with the simulated ones, with only a minor deviation at the lower frequency.

From the simulated 3 dB axial ratio plot for ON/ OFF state of PIN diode is presented in Fig. 8, it is realized that the antenna has circular polarization with 0.03 GHz (5.29 – 5.32 GHz) axial ratio bandwidth (ARBW) when all diodes are switched ON. The antenna also exhibits the circular polarization behaviour in frequency band from 5.31 – 5.39 GHz with 0.08 GHz ARBW on switching OFF both diodes simultaneously. As the 3dB axial ratio frequency range does not contained with the resonant frequency range. Hence linear polarization behaviour is observed for the resonating frequency range on switching both diodes OFF simultaneously. From the plot of gain against frequency as shown in Fig. 9, it is observed that gain varies from 0.9 dBi to 2.34 dBi in the resonant frequency bands for simultaneously ON/OFF states of diodes.

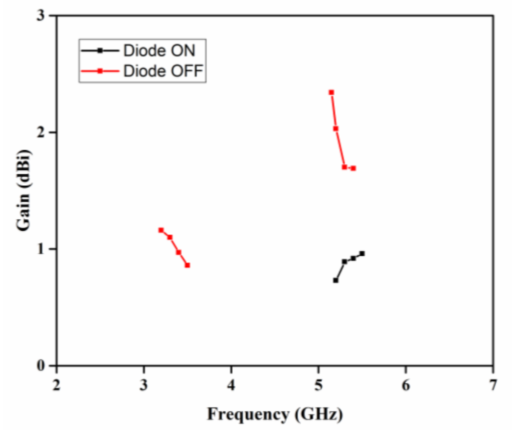
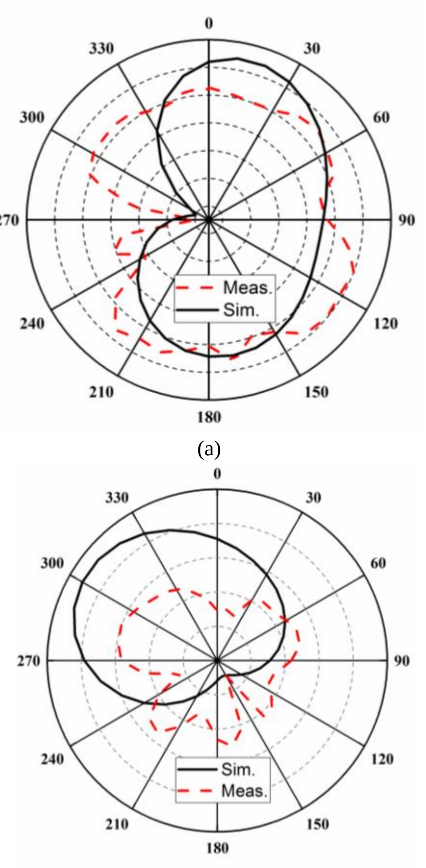


Fig. 9: Gain Vs frequency.

The measured normalized E-field radiation pattern at 3.17 and 5.3 GHz for OFF / ON state of diode is depicted in Fig. (10) and (11). The result shows that pattern is multidirectional at 3.17 GHz, omnidirectional at 5.3 GHz in Fig. 10(b) and bidirectional pattern in Fig. 11 at 5.3 GHz. A comparison table between the performances of suggested layout with previously reported frequency-polarization reconfigurable antennas is presented in Table 1. It is observed from table that the suggested antenna design is space efficient with simple structure and achieve frequency and polarization reconfiguration with the help of only two PIN diodes in comparison to all the antenna designs discussed.

4 Conclusion

A frequency agile and polarization diversity patch antenna has been simulated and prototyped in this paper. The loading or unloading of the arc on the annular ring by properly switching of PIN diodes has led to frequency switching between WLAN and WiMAX bands and polarization reconfiguration between circular and linear state for WLAN band. The good matching among the proposed and tested results confirming the validity of antenna design. A bandwidth of 280 MHz and 290 MHz is obtained when diodes are in off state and in on state a single band of 440 MHz is obtained. Also, the polarization switching is obtained between circular (ARBW = 0.03 GHz) and linear state on switching OFF diodes simultaneously. In comparison to other recorded antennas, the proposed design has small size and simple reconfigurable network makes it well suited for communication operations in modern wireless systems.



(b)

Fig. 10: Normalized E-field pattern when both diodes are OFF
(a) 3.17 GHz (b) 5.3GHz

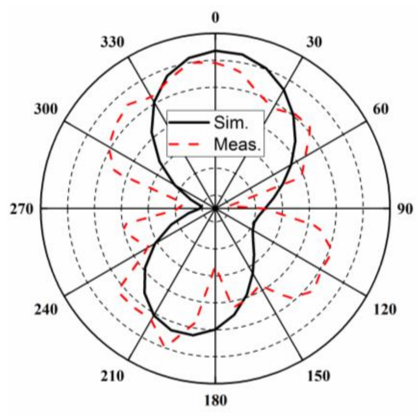


Fig. 11: Normalized E-field pattern at 5.3 GHz when both Diodes are ON

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Table 1. Performance analysis of proposed antenna with formerly reported designs

Ref.	Antenna Dim. (mm^3)	Substrate Material	Resonant Freq. (GHz)	Polarization Reconfiguration	No. of diodes
16	----	FR-4	2.4 3.5	LP, LHCP and RHCP LHCP, RHCP	5 PIN
17	----	RTduroid 5880	5.2 5.8	LP, LHCP, RHCP LP, LHCP, RHCP	8 PIN
19	70×70×3.175	RT duroid 5880	Discrete operating frequencies in 1.35 – 2.25 GHz band	Horizontal, vertical and 45° Linear Polarization	4 PIN 8 Varactor
21	60×65×1.6	FR-4	2.41 3.4 4.18	LP LHCP, RHCP LP	2 PIN diodes
23	150×150×3.05	Arlon AD 450	Discrete operating frequencies in1.17 – 1.58 GHz band	LP, LHCP and RHCP	4 Varactor Diodes
24	120×120×3.175	Rogers 5880	Eight discrete frequencies in 1.83-2.65 GHz band	LP, LHCP and RHCP	16 PIN
25	80×80×32	Rogers RO4003C	Continuous (8-11.2 GHz)	LP, LHCP and RHCP	----
Proposed Design.	26× 26× 1.6	FR-4	3.21 5.38	LP LP, LHCP	2 PIN

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