



# Design of a Compact Double-Square-Ring-Shaped Dual-Band Antenna for WiMAX/WLAN Applications

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## Abstract

In this article, a dual band frequency reconfigurable antenna is proposed for WiMAX and WLAN applications. Double-Square-Ring (DSR) shaped radiator is designed to exhibit dual mode operations and PIN diodes are implemented to switch the operating modes. Coaxial feed is selected to feed the antenna as the spurious radiation from it is minimal as compared with the microstrip feed. The current path along the radiating patch is affected with the ON and OFF conditions of the PIN diode which results in dual mode operation of the proposed antenna. The antenna is having a small footprint of  $40 \times 40 \text{ mm}^2$  fabricated on a 1.6 mm thick FR-4 substrate. Presented antenna covers an impedance bandwidth of 52 MHz in WiMAX band (2.28–2.33 GHz) and 157 MHz in the WLAN band (5.1–5.28 GHz). This antenna's working principle is explained through current distribution diagrams along with design evolution. The experimental and simulated results are presented to validate the proposed antenna design.

**Keywords** Dual band antenna · PIN Diode · WiMAX · WLAN

## 1 Introduction

The tremendous growth in communication system demands the need of multi-functional and multi band antennas to serve maximum number of users. Over several years there has been intense research on the reconfigurable and multifunctional antennas. The Internet of Things (IoT) relies heavily on reconfigurable antennas for its multifunctional capabilities. Reconfigurable antennas may switch its frequency of operation, polarization or the radiation pattern based on the application of the antenna implementations. The reconfiguration may be established with PIN, Varactor diodes as active methods or by adopting any passive

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methods. As part of the multiband antenna design, providing slots in the ground or for the radiator are major challenges to meet current requirements. The performance of the communication equipment is primarily determined by its selection of frequency, size and radiation pattern, ease of fabrication, low-profile structure, and low cost. Reconfigurable antennas are becoming increasingly important among researchers because of their benefits, such as polarization diversities, multiband operations, directional radiation patterns, and lower fabrication cost. Thorough literature survey has been made to obtain the requirement for designing an antenna and is detailed in the following sections.

## 2 Previous Work

A coaxial fed square shaped DRA antenna is presented in [1] and circular polarization is achieved by inducing two degenerate modes. A novel radiating structure is proposed with strip and wired structure for dual band and its matching is provided with bazooka balun [2]. PIN diode based pattern reconfigurable antenna with I shaped radiator is proposed in [3] with pattern tilt from  $-170^\circ$  to  $+160^\circ$ . Stacked T shaped strips in a monopole antenna with defected ground plane enabled tri band operation in [4]. PIN diodes implemented on a super wideband antenna acts as the stop band filters on the interfering band in [5]. Two C shaped elements with partial ground plane exhibits dual mode operation in [6]. PIN diodes on the partial ground switch the operation between WMAX/WLAN. Compact multiband reconfigurable antenna is presented with 2 PIN diodes on slotted ground structure [7, 8]. Hybrid re-configurability based on frequency, directivity and polarization is obtained in [9] with three varactor diodes. Multiband metamaterial based re-configurable antenna implemented in [10] with controlled metamaterial properties on the working band. In order to gain frequency diversity, PIN diodes on the slot must be biased in a certain way [11]. Enabling slots on the ground plane and radiating patch exhibits 4 radiating frequencies in [12, 13], neural network based model with pattern re-configurability presented in [14].

It is proposed to design a planar monopole UWB antenna with a slot-type split-ring resonator. In order to increase the antenna's impedance matching and operating range, a partially defected ground structure is used. A multifunctional antenna for different wireless applications is presented with five PIN diodes, which makes the system more complicated due to the presence of biasing circuits [15, 16]. An antenna with frequency reconfigurable is proposed for different frequency options. To shift the antenna's resonant bands, it works with three PIN diodes in specific locations. The antenna can operate in four modes, depending on the condition of the PIN diodes. The proposed UWB antenna has been reconfigured for WiMAX applications by using band notching techniques, as a result the antenna performance is frequently degraded [17–19]. The performance of a CPW fed bow-tie slot antenna system is discussed for different frequency bands. The proposed method involves combining two pairs of slots on the antenna's two sides to create optimized bands to operate in the 2.4–3.5 GHz range, which reduces antenna bandwidth significantly [20, 21]. The proposed antenna has a defective ground structure for multiband frequency reconfiguration with I-shaped slots in short ends and U-shaped slots with open ends, which affect the antennas' bandwidth requirement [22–24]. A reconfigurable rectangular patch is proposed for frequency and pattern reconfiguration by switching with a single PIN diode, so the required biasing network is simplified; for antenna feed optimization and impedance matching, the pattern search algorithm is used [25].

### 3 Proposed Work

In this article, a design of dual band antenna with frequency reconfiguration is described. Several implementations are available in the literature on this frequency re-configurability but there exist scope for miniaturization of the radiator with reduced distortions. Achieving frequency re-configurability on a single radiator becomes a challenge for its implementation because of the involvement of diodes and its biasing. The content of the article is presented as follows. Detailed antenna design from the evolution is presented in Sect. 3 and the results are discussed in Sect. 4. Conclusion and further scope of improvement is explained in Sect. 5. CST microwave studio is used for all simulations.

In this work, a Double Square Ring (DSR) element as a radiator along with the PIN diodes (BAR64-02 V) for frequency re-configurability is proposed. The layout of the proposed frequency reconfigurable dual-band antenna is shown in Fig. 1. This antenna has a small footprint of 40 mm × 40 mm × 1.6 mm. It is printed on a substrate (FR-4) with dielectric constant of 4.4 and a loss tangent of approximately 0.025. The DSR element consists of two radiating square patches with a full ground plane. An etched rectangular slot is created in the inner radiating patch to provide a better impedance matching and for tuning the polarization. The antenna is fed using coaxial feed from the bottom and location of the feed is found after several iterations. A chart depicting the steps necessary to achieve the desired frequency can be seen in Fig. 2.

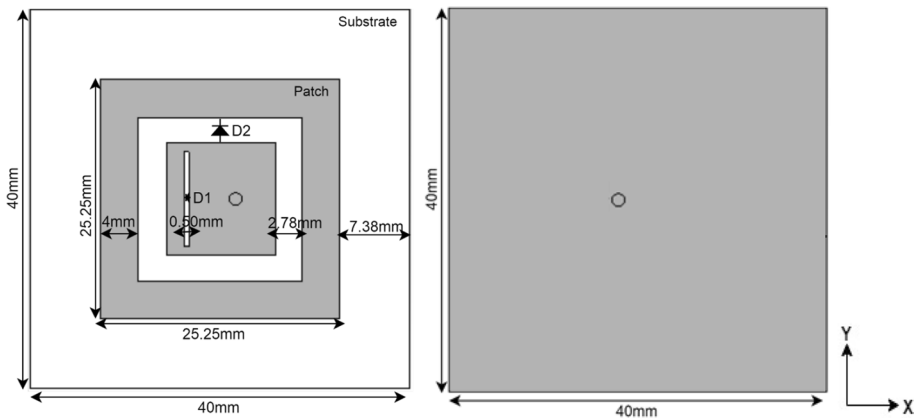
The design equations that follow (1–4) are used for the selection of antenna geometry, The square patch width is determined by

$$W = \frac{c}{2f_0} \sqrt{\frac{2}{\epsilon_r + 1}} \tag{1}$$

The square patch length is determined by

$$L = L_{eff} - 2\Delta L \tag{2}$$

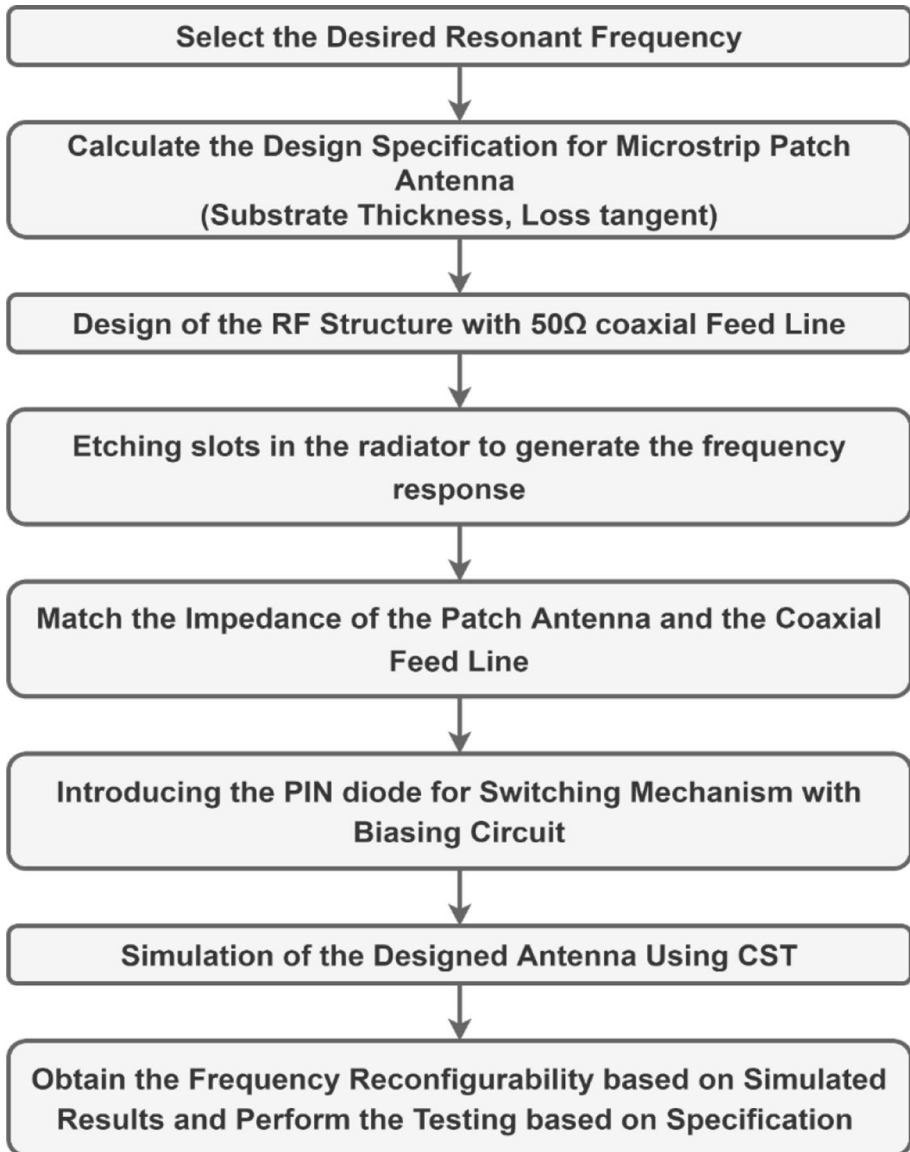
where



(a) Proposed Structure

(b) Ground plane structure

Fig. 1 Schematic of the proposed double square ring antenna



**Fig. 2** Antenna Design Process Chart

$$L_{eff} = \frac{c}{2 * f_r * \sqrt{\epsilon_{reff}}} \quad (3)$$

$C$  – velocity of light in air.

$f_r$  – resonant frequency.

$\epsilon_r$  – relative dielectric constant (4.4)

$$\Delta L = 0.412h \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{w}{h} + 0.264\right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{w}{h} + 0.8\right)} \quad (4)$$

A resonant frequency at 5.2 GHz is obtained by loading the rectangular slots in the radiating patch. WLAN applications will benefit from this new feature. The second resonant frequency is obtained by making square shape slots in the radiator. A new frequency of resonance 2.3 GHz is obtained for WiMAX applications. Antenna characteristics and performance are significantly influenced by substrate material properties such as loss tangent and dielectric constant. By choosing the right substrate material for antenna fabrication, the antenna performance degradation factors can be reduced. The dielectric constant of the substrate material should be between  $2.2 \leq \epsilon_r \leq 12$ .

The square ring slot on radiating patch makes the antenna compact and viable for the PIN diode placement. The outer square patch can be activated or deactivated using the PIN diode to adjust the proposed microstrip patch antenna's electrical length. Equivalent circuit model of a diode is illustrated in Fig. 3. When the diode is in forward bias, the resistance is  $1.5 \Omega$  with the series inductance of 0.45 nH. In reverse bias, the impedance is 0.25 pF.

The PIN diode is placed along the slot and excited for single to dual band operations. The slot length is operated by a switch using a PIN diode positioned in the antenna slot to obtain different frequencies. During simulation, a circuit based on the manufacturer data sheets were used to replace the PIN diode BAR64-02 V. The antenna operation is greatly influenced by the resistance provided by the PIN diode in both ON and OFF states. When the diode is turned ON, its equivalent resistance is very low, so it is referred as closed switch. The outside patch and inner patch are linked to one another during the ON state of switch D2, as current flow is permitted through it. Diode has a high resistance when it is switched OFF. As a result, the outer and inner patches are separated. The condition of the switch has an impact on the current flow and antenna's electrical length. Two diodes are used for achieving frequency re-configurability in the DSR antenna, which reduces distortion by simplifying the biasing circuits.

Figure 4 shows the fabricated antenna as well as the measurement equipment. An anechoic chamber is used to test the fabricated antenna. To validate the simulated results of the

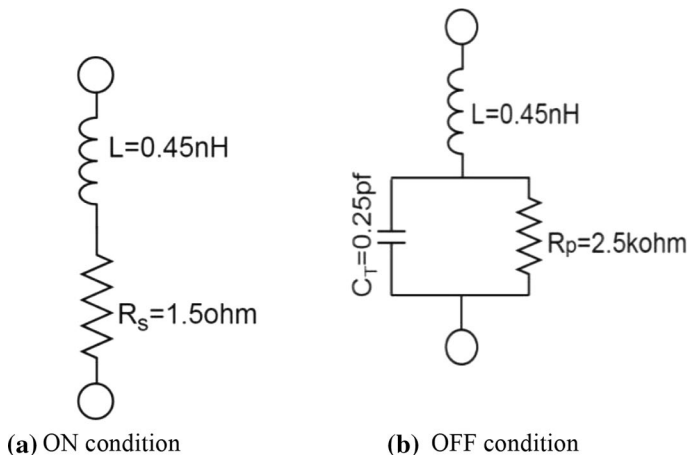
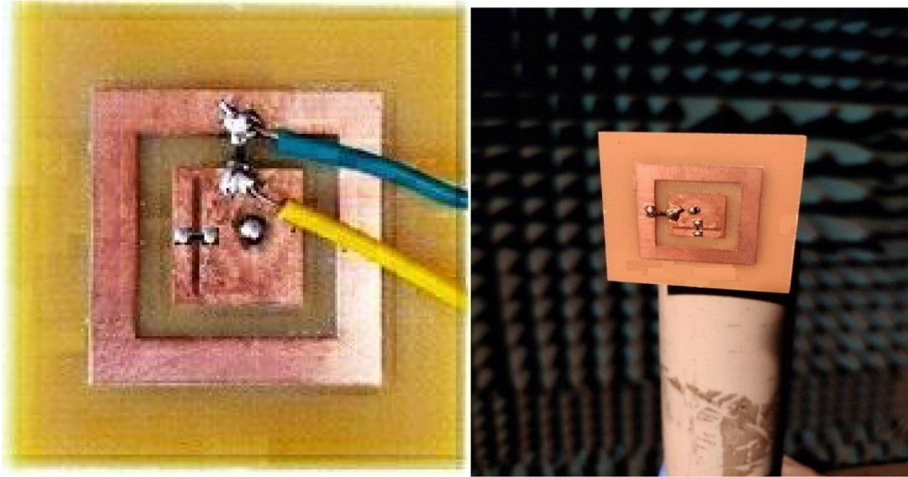


Fig. 3 Equivalent circuit model of RF PIN diode

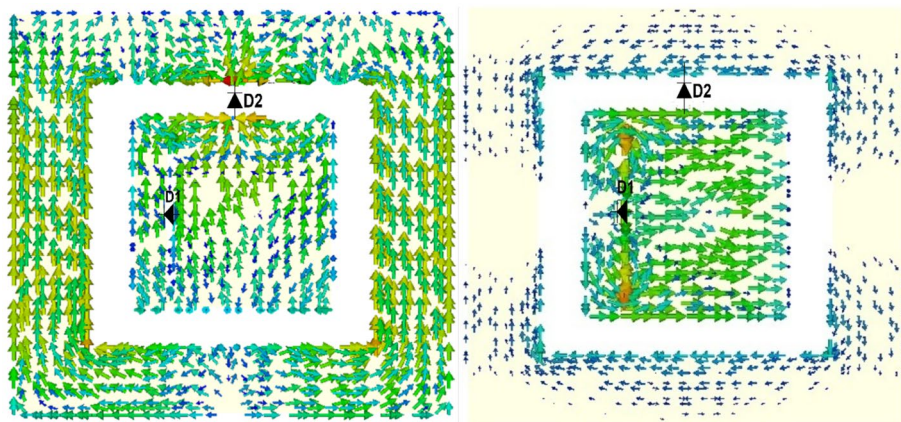


**Fig. 4** Fabricated prototypes along with the measurement setup

presented antenna, the Amkom horn antenna 1–18 GHz frequency is employed as a reference antenna with  $50 \Omega$  impedance.

#### 4 Performance Analysis

The current distribution on the radiating patch helped to understand the antenna's working principle. Figure 5 depicts the surface current distribution for two cases. Diode D1 is placed on the inner rectangular slot and D2 is placed between the square loops to



**(a)** D1-ON and D2-ON condition

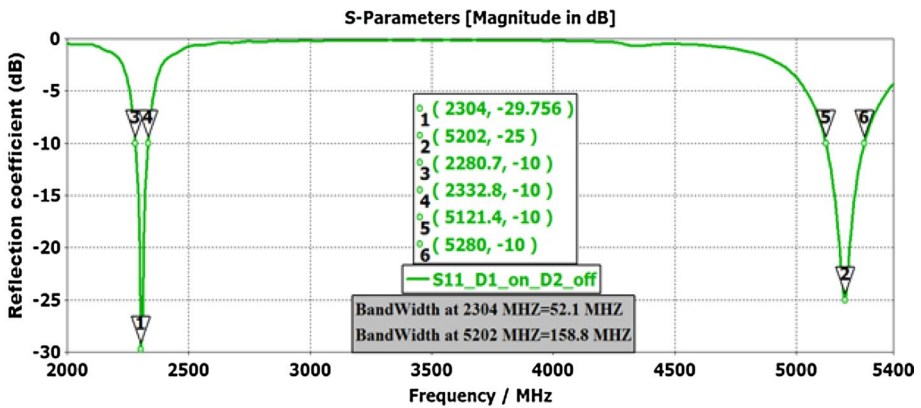
**(b)** D1-OFF and D2-OFF condition

**Fig. 5** Antenna's surface current distributions with different diode states

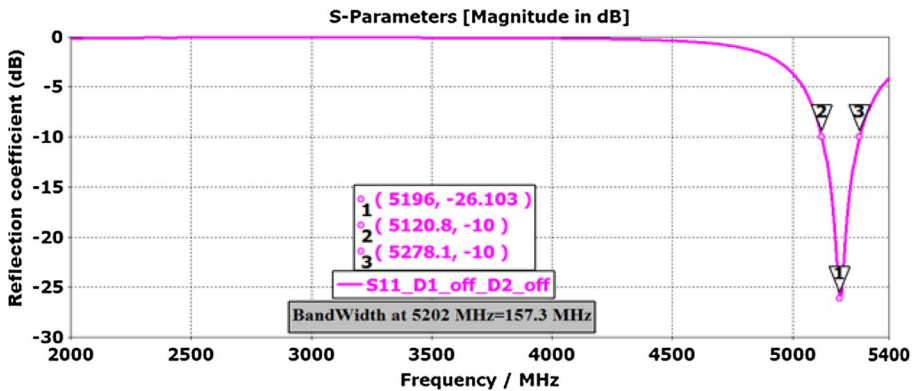
bridge the DSR elements. When D1 is turned ON and D2 is turned OFF, the current distribution is on both the inner ring and outer ring, resulting in dual frequency operation at 2.3 and 5.2 GHz.

When both the diodes are turned ON, DSR acts as a single radiator with 2.3 GHz resonant frequency. Similarly, resonance at 5.2 GHz is observed when both diodes are in OFF condition. The operating frequency is effectively controlled using both diodes, and the antenna is operated at either single or dual band frequencies. Figure 6 depicts the antenna's simulated reflection coefficient characteristics.

From Fig. 6, it is observed that the antenna has two operating modes, which are based on the states of the diode. During the D1-ON and D2-OFF states, the antenna supports dual band operation of 2.3 GHz, 5.2 GHz with the gain of 5.3 dBi and 6.8 dBi. During D1-OFF and D2-OFF states, it resonates at 5.2 GHz with 6.8 dBi gain. During D1-ON and D2-ON states, it resonates at 2.3 GHz with 5.3 dBi gain.



(a) Simulated return loss analysis of switch D1-ON and D2-OFF conditions



(b) Simulated return loss analysis of switch D1-OFF and D2-OFF conditions

Fig. 6 Antenna simulation model with return loss

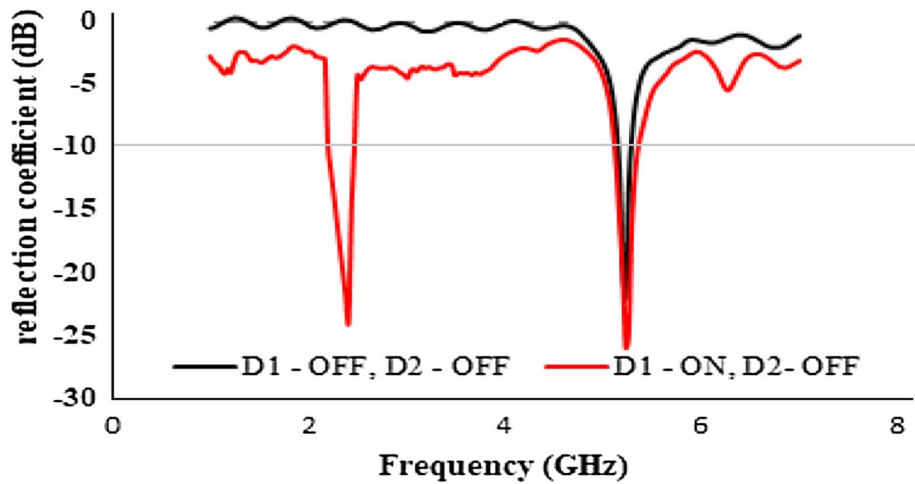


Fig. 7 Antenna measurement model with return loss

**Table 1** Measured performance metrics of the antenna

Switch condition	Simulated response			Measured response		
	Operating modes (GHz)	$S_{11}$ (dB)	VSWR	Operating modes (GHz)	$S_{11}$ (dB)	VSWR
D1-ON	2.3	-30	1.08	2.3	-25	1.16
D2-OFF	5.2	-29	1.14	5.2	-27	1.27
D1-ON	2.3	-31	1.06	2.3	-26	1.15
D2-ON						
D1-OFF	5.2	-26	1.10	5.2	-22	1.23
D2-OFF						

The measured  $S_{11}$  characteristics of the antenna are illustrated in Fig. 7. Measurements of reflection coefficient are performed using Fieldfox handheld network analyzer (N9917A). When both the diodes are turned ON or OFF, a single mode of operation is observed. The length of the patch varies depending on the switch state. As a result of this the distribution of the electric field on patch gets varied. During the OFF state, the maximum electric field of the inner square patch is centered on upper corners. During the ON state, the surface current distribution passes across the entire system.

Table 1 depicts the antenna's performance during simulation and testing. The measured results are clearly consistent with the simulated results. Differences in the measured and simulated results are caused by losses in the biasing circuit and low quality factor values for the diodes. Simulated radiation patterns for dual frequencies are shown in Fig. 8. The cross-polarization results are well below co-polarization throughout the angles. As a result, the simulated radiation pattern meets the required initial criterion, which is directional.

A comparison of several multiband reconfigurable antennas with the proposed antenna is shown in Table 2. The developed antenna design has very low spurious radiation with a peak gain of 6.8 dBi, as shown in the comparison Table 2.



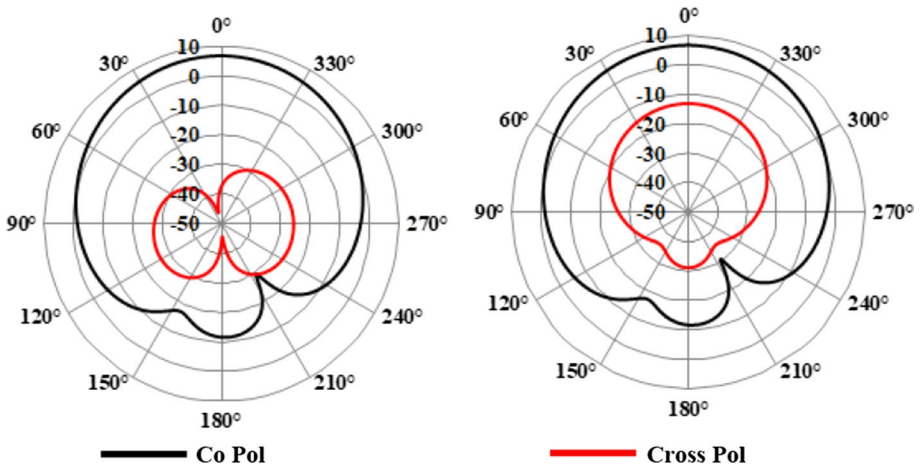


Fig. 8 Radiation pattern simulation model when the diodes D1-ON and D2-OFF

**Table 2** Analysis of existing antennas from literature with the proposed antenna

References	Antenna dimensions (mm <sup>2</sup> )	Feed type	No. of diodes	Resonant frequencies (GHz)	Peak Gain (dBi)
[7]	50×45	Microstrip feed	2	2.4/5.8, 3.5	5.8
[11]	55×45	Coaxial feed	1	4.6, 5.3	1.8
[16]	40×40	Microstrip feed	5	3.6, 5.2	6
[17]	49.4×35	Microstrip feed	3	3.3, 5.2	5
[19]	83×88	Microstrip feed	4	2.4/3.5, 5.2	3.07
[20]	80×30	Microstrip feed	Slot	2.4/3.5, 5.8	5
[23]	50×60	Microstrip feed	3	5.2, 5.8	3
[25]	66×58	Microstrip feed	1	3.8/2.47, 5.3	5.34
Proposed	40×40	Coaxial feed	2	2.3, 5.2	6.8

The proposed antenna has two PIN diodes that control two different resonant frequencies and has a small footprint of 40 mm×40 mm only.

## 5 Conclusions

A compact DSR antenna is proposed with frequency reconfiguration for WiMAX/WLAN applications. PIN diodes with proper biasing enabled the frequency re-configuration between two frequencies. DSR has two diodes, which allow the antenna to work in two different modes. This design attempts to reduce the distortions that are typically found on reconfigurable antenna's radiation levels by using its several switches and are associated with complex biasing circuits. This antenna's radiation characteristics are unaffected by the biasing circuits. The antenna performance was verified through the radiation pattern, return loss, and VSWR. The proposed antenna frequency bands can be used for satellite services,

cognitive radio services, and biomedical applications. In future, the work will implement a Varactor diode for continuous frequency tenability.

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**Availability of Data and Material** Not applicable.

**Code Availability** Not applicable.

## Declarations

**Conflict of interests** The authors declare that they have no conflicts of interest to report.

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