Progress In Electromagnetics Research C, Vol. 106, 151–161, 2020

A Compact Frequency Reconfigurable Printed Antenna for WLAN, WiMax Multiple Applications

Prem P. Singh[1, *], Sudhir K. Sharma[1], and Pankaj K. Goswami[2]

Abstract—In this research work a compact patch antenna which is reconfigurable for frequency is presented. Frequency reconfigurability is achieved by the use of two PIN diodes. Antenna operates over four frequencies, i.e., for WiMax (4.94 GHz), WLAN (5.35), and C-Band (6.25 and 6.83 GHz) applications. The overall dimension of antenna is $25 \times 25\,\text{mm}^2$, and an FR-4 substrate having dielectric constant of 4.4 and thickness 1.6 mm is used to fabricate the prototype of the proposed antenna. Different resonant frequencies are obtained by cutting a $\prod$-slot and a U-slot in radiating patch and by modifying ground slot with a modified slotted structure. One diode is used in ground, and another PIN diode is used on the patch at an appropriate position. Maximum gain of 3.91 dBi and stable radiation characteristics and VSWR < 2 are obtained at the operating bands in simulation and measurement. The antenna elicits its novelty through compactness, portability for communication devices through combination of only two PIN diode switching in cellphones, tablets PCs, and other satellite communication devices operating in C-band as per FCC standard. A prototype of antenna is fabricated, and the measured and simulated parameters are in good agreement.

1. INTRODUCTION

Today's wireless communication system demands for multiband operation, high data rate, and high channel capacity [1]. Also the system complexity must be decreased. So a reconfigurable antenna is a perfect choice for this. Integration of a frequency reconfigurable antenna with control circuits is easy. This is the reason that the research on compact frequency reconfigurable patch antennas has attracted attention of researchers these days. By loading one or more electronic control elements, reconfiguration can be achieved. Some of them are RF-MEMS switches, varactor diode, and PIN diodes. Antennas that combine two or more independent antennas operating in different frequency bands excited with single feed with efficient switching between two more bands have been presented in [2–4]. There are various technical challenges in antenna designing systems due to the increase in the number of frequency bands, congestion in spectrum,,interference, etc. In the literature from 2017 to 2020, various antennas with frequency diversity between two or more bands have also been discussed. Bharadwaj et al. [2] proposed a tri-band wine glass shaped reconfigurable patch antenna for LTE and WiFi applications with an overall dimension of 30 mm × 30 mm. The multiple bands have been obtained by inserting slots in the radiating patch and ground, and PIN diodes have been used to switch the bands from one to another. In [3], an antenna is able to switch the frequency in S- and C-bands proposed by Guo et al. Switching device used is varactor diode on the patch. The antenna's operating frequencies vary from 3.29 to 4.01 GHz and 5.35 to 7.00 GHz. The antenna comprising a central patch surrounded by four parasitic patches and varactor diodes are connected between the main (central) patch and parasitic

Received 27 August 2020, Accepted 14 October 2020, Scheduled 23 October 2020
* Corresponding author: Prem P. Singh (ppsherpur.12392@gmail.com).
[1] Department of Electronics and Communication Engineering Jaipur National University, Jaipur, India. [2] Department of Electronics and Communication, Teerthanker Mahaveer University, Moradabad, India.

patches around the central patch. The substrate size is 33.9 mm × 38 mm. These types of antennas are helpful in utilizing frequency resources and provide multiple services without interruption.

A printed W-shaped antenna for 4G LTE applications with the dimensions of $50 \times 60\,\text{mm}^2$ loaded with PIN diode was presented by Chattha et al. in [4]. This antenna operates from 0.9 GHz to 3.5 GHz for different operating frequencies. Total three diodes are used to get reconfiguration. However, the dimension of this antenna is not compatible to integrate in handheld wireless devices which require small size antennas. Jenath Sathikbasha et al. also proposed an antenna based on a defected ground structure (DGS) with frequency reconfiguration [5]. The proposed antenna finds applications in WLAN, Wi-Max, mobile and satellite communication. PIN diodes are used as a switching device, and DC blocking capacitors are inserted to control the flow of DC current across the different slots in the ground plane. The antenna has a total area of $37 \times 47\,\text{mm}^2$. Generally, DGS is used to improve the performance of the antenna such as frequency range and gain. In [6], an antenna was proposed which is useful for wireless applications with multiband operation. However, there is a disadvantage of this antenna that the antenna operates for various bands at a time, so if a single band is needed, then it is impossible. The antenna has a triangle-shaped patch, and a trapezoid-shaped slot is etched. The slots are etched in the ground plane, and a PIN diode is used. In ON state of diode, the antenna operates over dual bands, and in OFF state the antenna shows quad band characteristics. The area of the antenna is $28 \times 30\,\text{mm}^2$. A composite frequency and radiation pattern reconfigurable antenna for four different bands was proposed by Chandra et al. in [7]. The antenna has a hexagon patch with four oblique slits. Out of the four slits, two slits are longitudinal and two latitudinal. PIN diodes are used to reconfigure the antenna. The antenna is also capable to produce radiation pattern reconfigurability. The antenna has a wide frequency range from 4.25 GHz to 8.25 GHz. The resonating frequencies are 4.25, 5.65, 6.8, and 8.25 GHz. These types of antennas are useful in cognitive radio applications. Thus there are lots of structures present in the literature which are able to reconfigure different parameters according to applications. In some of the papers, it is found that switches (PIN, varactor diode) are assumed as "ON" and "OFF" in simulated designs only represented with their equivalent circuit model and only simulated results shown without any DC bias circuit for switches to alter the states of the PIN diodes. Another patch antenna with frequency diversity operating over three bands was presented by Han et al. in [8]. Antenna has a rectangular patch and slotted ground loaded with PIN diode and capacitors for DC blocking with overall area of $27 \times 25\,\text{mm}^2$. U-slot and an L-shaped slot with open ends are introduced, and two PIN diodes are inserted to realize the reconfiguration property. The effect of length and width of the feed is also studied and shows that length of the feed affects the frequency band f_2 because of variation in the parallel capacitance of antenna due to slots, and width W_p is responsible for impedance matching at frequency f_1 and f_3. A number of capacitors (10 Capacitors) is inserted in the ground which affects the working of antenna and also increases the cost of the antenna. Awan et al. designed a multiband CPW-fed antenna with an area of $315\,\text{mm}^2$ for on-demand reconfiguration for multiple applications in portable devices [9]. This antenna is basically useful for WLAN, Wi-Fi, and C-band applications operating at 2.5–3.3 GHz and 4–6.2 GHz. However, the gain provided by this antenna is low, and also bands overlap each other which creates the interference between bands.

This paper explains the design of a low profile printed antenna with frequency reconfiguration for four bands. Two PIN diodes are used as switches to reconfigure the antenna. PIN diodes are an important part of the antenna. DC biasing circuit is used to control the PIN diodes. However, DC lines create a problem of shorting with the patch of the RF current. To overcome this shortcoming, inductors are added in DC biasing circuit [10]. Rest of the paper is organized as follows. In Section 2, the layout of the proposed structure and biasing circuit used for switches is described. Section 3 explains the results and compares the simulated and measured results along with current distribution on operating frequencies. Finally, the conclusion of the paper is presented.

2. ANTENNA DESIGN

The front and bottom views of the proposed antenna are shown in Figure 1. Antenna has a compact size of $25 \times 25\,\text{mm}^2$. FR-4 material having dielectric constant of 4.4 and loss tangent of 0.002 with thickness of 1.6 mm is used as substrate. To make the antenna reconfigurable, model BAR50-02V is used in the design from Infineon technologies. The front side of the antenna consists of a circular patch

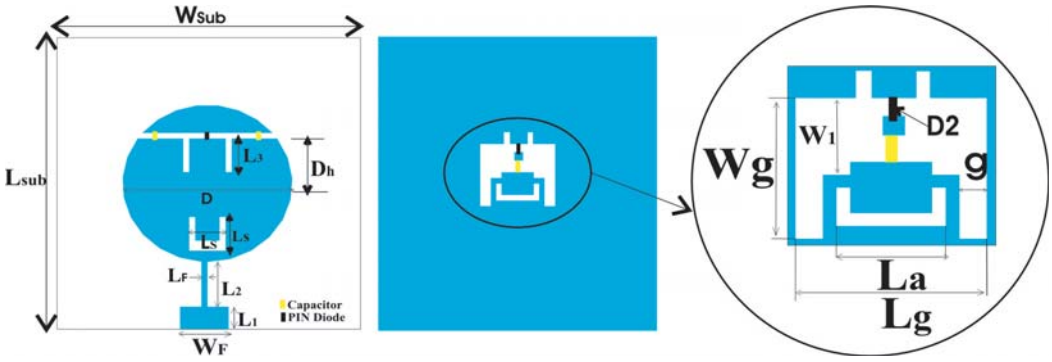


Figure 1. Antenna Geometry. (a) Top view. (b) Bottom view.

of diameter $D = 14\,\text{cm}$. The antenna is fed by a rectangular microstrip line ($L_2 \times L_F$) with lumped port excitation to provide an impedance of $50\,\Omega$. A π-shaped slot is inserted in the upper side of circular patch and in addition to this a U-slot also introduced. Etching a π-slot divides the antenna into two parts, and some of the parts of the patch are separated from the patch. To connect them, two capacitors are added in the π slot and a PIN diode in the middle of the slot. The ground plane is also defected to get the reconfiguration. Two U-shaped slots which are opposite to each other are etched in the ground responsible for changing the current distribution of the antenna when the state of PIN diode changes, and PIN diode is used in the ground. A capacitor is also used in the ground to isolate the terminals of DC supply. Optimized dimensional parameters of the antenna are tabulated in Table 1.

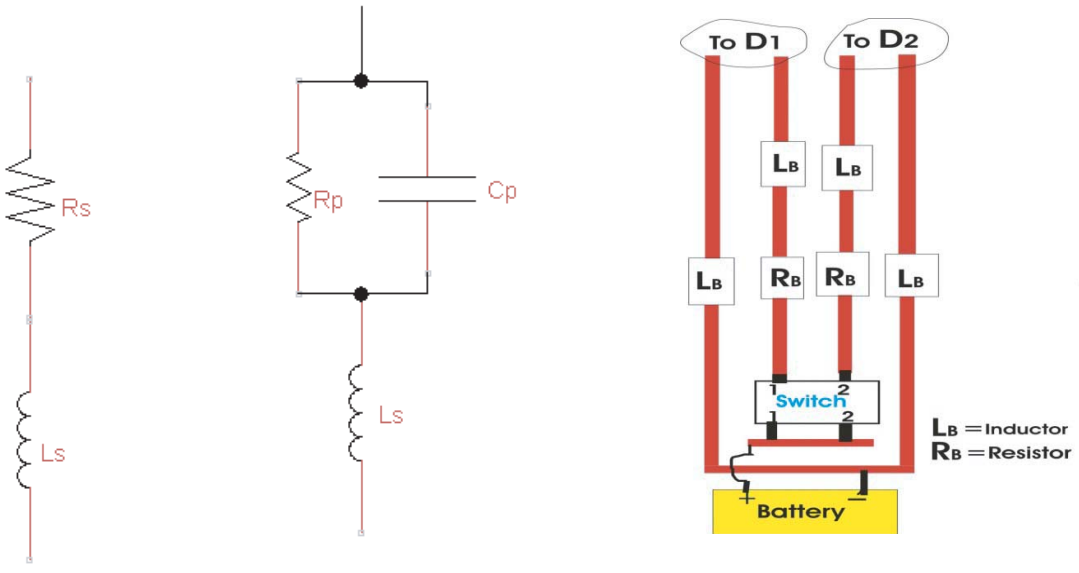
Table 1. Optimized dimensions of antenna.

Parameter	Value (mm)	Parameter	Value (mm)
L_{Sub}	25	D	14
W_{Sub}	25	L_g	7
L_1	2	W_g	5.5
L_2	4	L_a	4
L_3	3	W_1	3
L_S	3	g	0.5
L_F	0.5	D_h	4

To know more about the PIN diode, we need to see its equivalent circuit in forward and reverse bias and to know about equivalent circuit for the simulation purpose. The equivalent circuit model of PIN diode in "ON" and "OFF" states is depicted in Figure 2. In "ON" state, the PIN diode acts as a resistor (Rs) in series with inductor (Ls), and in "OFF" state it acts as a parallel combination of resistor (Rp) and capacitor (Cp). The diode has the value of $Rs = 3\,\Omega$ and $Ls = 0.6\,\text{nH}$ and $Rp = 3\,\text{k}\Omega$ and $Cp = 0.15\,\text{pF}$. Inductance in the model is because of packaging [12]. To insert the PIN diode in HFSS, two small strips are placed, and the boundary is assigned to them as lumped RLC according to the equivalent circuit shown in Figure 2.

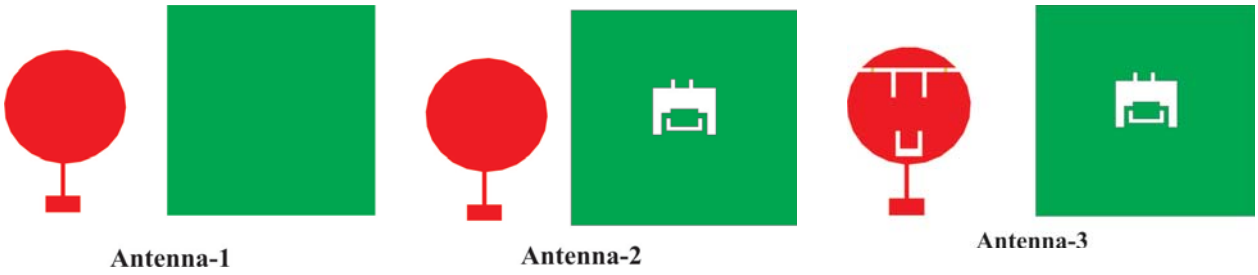
Diodes are biased with a biasing circuit, and biasing circuit consists of an RF choke inductor (L_B) having the value of 100 nH, a capacitor (C_B), and battery as shown in Figure 2(c).

An evolution process is adopted to achieve the proposed antenna as shown in Figure 3. Initially, a circle-shaped antenna with full ground is simulated illustrated as 'Antenna-1' in Figure 3. This antenna operates at 5.90 GHz. To enhance the performance and achieve the reconfiguration, slotted method approach is followed. Slotting and DGS (defected ground structure) also enhance the performance



(a) (b) (c)

Figure 2. Equivalent circuit model of PIN diode. (a) ON, (b) OFF, (c) Biasing circuit.



(a) (b) (c)

Figure 3. Step wise development process of antenna.

of the antenna [13]. Keeping this in mind, the ground is defected with two U-slots opposite to each other. The introduction of these slots in the ground changes the surface current distribution [14, 15]; the current path also changes; and thus the operating frequency shifts to a new operating frequency which is 4.92 GHz. In the next iteration, a $\prod$-shaped slot etched in the circular patch and two capacitors are added in the gap. In addition to this, a U-slot is also introduced just above the feed line. This enables the antenna to operate for the frequency of 6.73 GHz. Return loss parameters for three antenna development processes are shown in Figure 4.

Finally two PIN diodes are introduced at the optimized position to enable the antenna as a reconfigurable structure, and the antenna operates for four different frequencies, i.e., 4.94, 5.35, 6.25, and 6.83 GHz.

3. RESULTS AND DISCUSSIONS

For measurement purpose a hardware prototype of the presented antenna is fabricated in the lab. Reflection coefficients S_{11} for all the possible cases are measured and compared with the simulated results described and found generally in good agreement where small variations are caused by fabrication imperfection, effect of biasing circuitry, size of SMA connector. To understand the working principle of the proposed structure, the surface current distribution needs to be examined. "ON state of the diode is

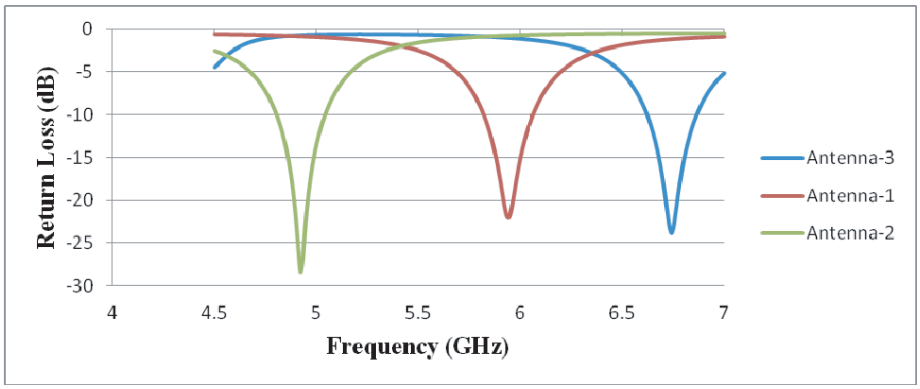


Figure 4. Evolution stage results.

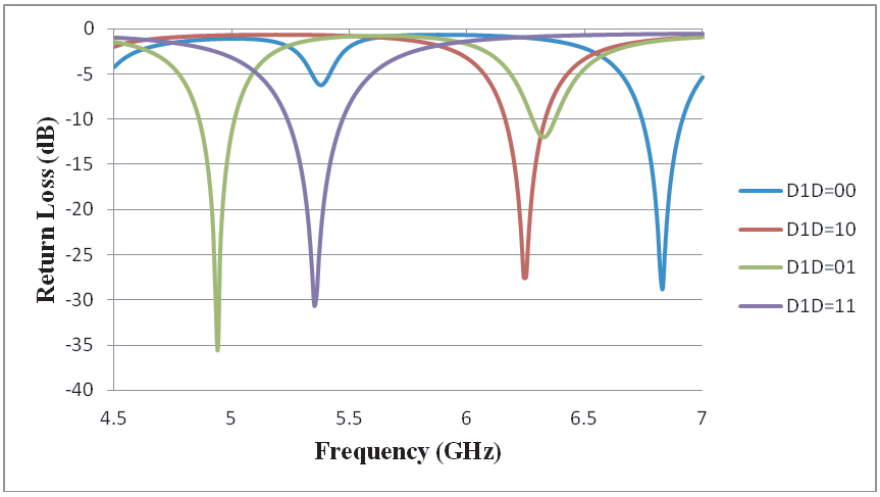


Figure 5. Simulated S-parameters (return loss).

represented as "1" and "OFF" state as "0". Total four states are possible with two diodes. These states are denoted as '00', '01', '10', and '11'. It is seen that the PIN diodes have some loading effects that shift the operating frequency in fabricated prototype. This shift is mainly due to the capacitance of the switch. Generally, C_P affects operating frequency more at higher frequencies than at lower frequencies. Inductance of the switch (L_S) has almost the same effect on both lower and higher frequency bands. Parallel resistance of OFF state diode R_P also affects the gain of the antenna. The effect of R_P on gain is more than R_S [11].

In state-1, both diodes $D1$ and $D2$ are OFF. In this case, the current path is same as antenna-3, and the current does not flow through the diode $D1$ but passes through the two capacitors between radiator and upper part of the radiator which are separated from the patch by etching a π-slot. Operating frequency with this configuration of diodes is 6.83 GHz with the S_{11} value of -28.77 dB. It is clear from surface current distribution that the current mostly concentrates in the lower U-slot in the ground and π-slot in the patch as encircled in Figure 5(a).

For state-2, when diode $D2$ turns ON, and $D1$ remains OFF, the coupling between the patch and ground increases as shown in Figure 5(b). The current flow path changes, and thus the operating frequency shifts to 4.94 GHz with S_{11} value of -35.48 dB. This frequency is controlled by the diode in the ground. From Figure 5(b) it can be observed that the surface current in the ground changes, and most of the current is concentrated at the edges of U-slot. The area of surface current flow increases, and thus operating frequency shifts to lower band. Table 2 displays all the possible cases of two diodes

Table 2. Operating states of PIN diode.

Operating Mode or State	Diode state
Mode-1	00
Mode-2	01
Mode-3	10
Mode-4	11

Table 3. Different switching cases and frequency.

State	Diode Biasing		Operating Frequency (GHz)		S_{11} (dB)	Gain (dBi)
	$D1$	$D2$	Simulated	Measured		
State-1	0	0	6.83	6.76	−28.77	3.83
State-2	0	1	4.94	4.97	−35.48	2.35
State-3	1	0	6.25	6.20	−27.60	3.23
State-4	1	1	5.35	5.38	−30.60	3.91

with all four operating frequencies corresponding to all switching configurations.

For another case, i.e., state-3, which means 10, diode $D1$ turns ON, and $D2$ turns OFF. Now due to turning ON of $D1$ the RF current path alters on the patch as well as in ground. It can also be observed in Figure 5(c) that surface current in the diode concentrates around the lower U-slot in the ground. Current path changes direction on the patch also as diode $D1$ is turned ON. This combination is responsible for the antenna to operate over 6.25 GHz which is useful for C-band applications and radar applications. The S_{11} provided in this state is about −27.60 dB. In the fourth operating mode, both diodes $D1$ and $D2$ are configured as forward biased, and then the total radiating and electrical length of the radiating patch increases. It also changes the current path and impedance. Due to this, the operating frequency shifts to 5.35 GHz from 6.25 GHz. Simulated return loss S_{11} for this state is −30.60 dB. Simulated and measured operating frequencies along with the corresponding gains for all four operating states are illustrated in Table 3. Simulated return loss parameters are illustrated in Figure 5, and Figures 6(a)–6(d) show the gain provided by the antenna.

The slotted antenna is used here to enable the antenna to become compact and eligible to integrate into handheld wireless devices. Insertion of slots in the ground and patch changes the surface current distribution with respect to changes in the current path length as the biasing of PIN diodes changes. The antenna involves unique combinational effects of two stage modifications in radiating structure. Initially, the antenna operates at 5.9 GHz. Modification in ground plane is responsible for lower band frequency, and to shift the operating frequency and enable the antenna to be reconfigured, the patch also is modified with $\prod$-slot and U-slot. This change in the structure shifts the frequency to upper band, and the antenna resonates at 6.73 GHz. Inserting PIN diode causes the path of RF current to change with ON/OFF state of PIN diode. The same is applicable to patch. As the length of the slot varies using PIN, the RF current varies proportionally. The resonant frequency is inversely proportional to the distance traveled by the induced RF current. Actually, the defects in the ground plane disturb the current distribution of ground plane, and due to this effective capacitance and inductance of microstrip line also change. To produce resonance at the desired frequency, its length should be equal to $\lambda/4$, so the lower the resonant frequency is, the higher the electrical length should be which is equal to $\lambda/4$. The lower operating frequency is 4.94. The effective electrical length required to operate at lower frequency 4.94 GHz will be higher, and the distributed current covers larger area as shown in Figure 6(b). In this case, the current is distributed on a large area and concentrated near the $\prod$-slot on patch and at the edges of the U-slot in the ground plane. The current path length $(2L_3 + L_a)$ approximates $\lambda/4$. The same is for other frequencies, and the current path lengths are given as below.

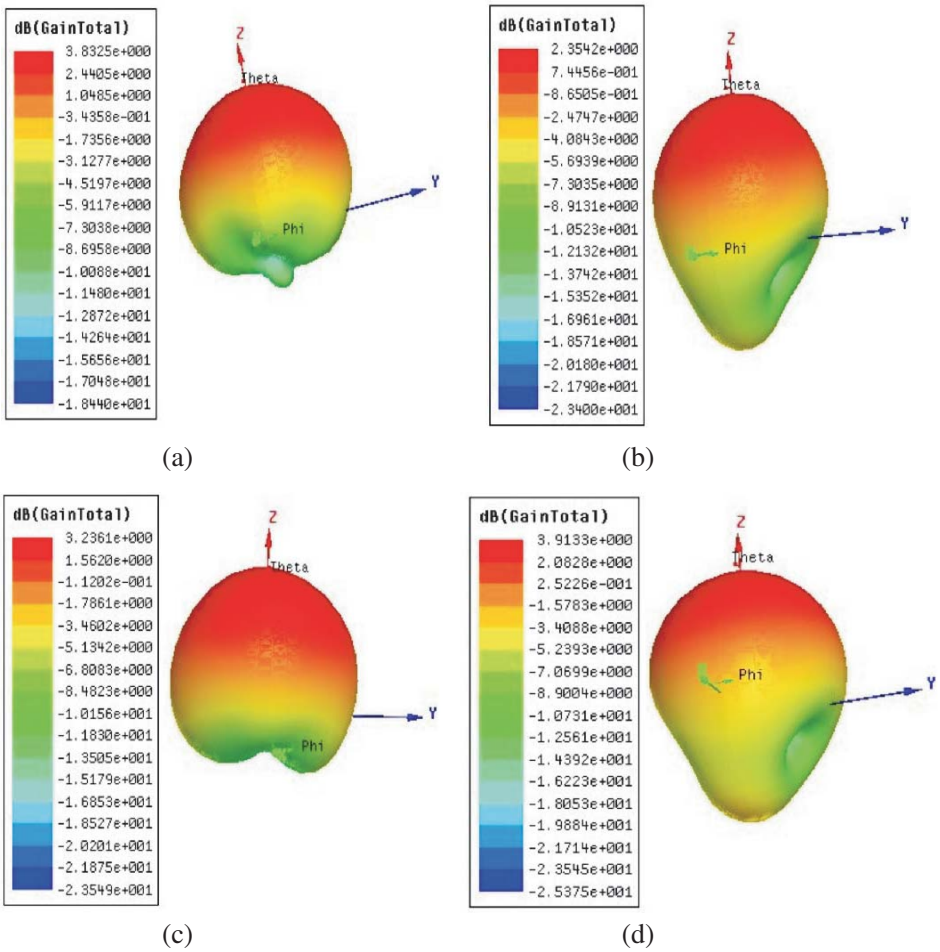


Figure 6. Gain of the proposed antenna for (a) 6.83 GHz (b) 4.94 GHz (c) 6.25 GHz (d) 5.35 GHz.

$$L_{6.83} = 2L_3 + L_2 + L_s = \lambda_{6.83}/4 \qquad L_{4.94} = 2W_g + L_2 = \lambda_{4.94}/4$$
$$L_{6.25} = 2L_a + L_2 = \lambda_{6.25}/4 \qquad L_{5.35} = 2W_g + L_3 = \lambda_{5.35}/4$$

For higher frequencies such as 6.83, 6.25, and 5.35 GHz, the effective electrical length is smaller and reduced as the operating frequency increases as shown in Figures 6(a), (c), and (d), respectively. Surface current distribution on the metallic path of the radiating structure at 4.94, 5.35, 6.25, and 6.83 GHz

Table 4. Performance comparison of the proposed antenna with designs in literature.

Ref.	Size (λ)	OF* (GHz)	N*	Switch Type	Substrate (ε_r)
[1]	$0.19\lambda \times 0.59\lambda \times 0.006\lambda$	1.8, 2.4, 3.5, 5.5	3	RF-MEMS	FR-4 (4.4)
[2]	$0.37\lambda \times 0.37\lambda \times 0.008\lambda$	3.8, 4.5, 5, 5.9	2	PIN Diode	Neltec (3.2)
[3]	$0.39\lambda \times 0.44\lambda \times 0.008\lambda$	3.52, 3.94, 5.48, 6.33, 6.86	4	Varactor Diode	FR-4 (4.4)
[4]	$0.15\lambda \times 0.18\lambda \times 0.004\lambda$	1.4, 1.8, 2.6, 3.5	3	PIN Diode	FR-4 (4.4)
[6]	$0.15\lambda \times 0.16\lambda \times 0.008\lambda$	1.6, 2.5, 5.8, 9.5 (Dual Band)	1	Copper Strip	FR-4 (4.4)
[8]	$0.20\lambda \times 0.192\lambda \times 0.007\lambda$	2.3, 5.8, 4.5	3	PIN Diode	RO4350B (2.2)
This work	$0.41\lambda \times 0.41\lambda \times 0.002\lambda$	4.94, 5.35, 6.25, 6.83	2	PIN Diode	FR-4 (4.4)

N^* — No. of Switches, OF* — Operating Frequencies

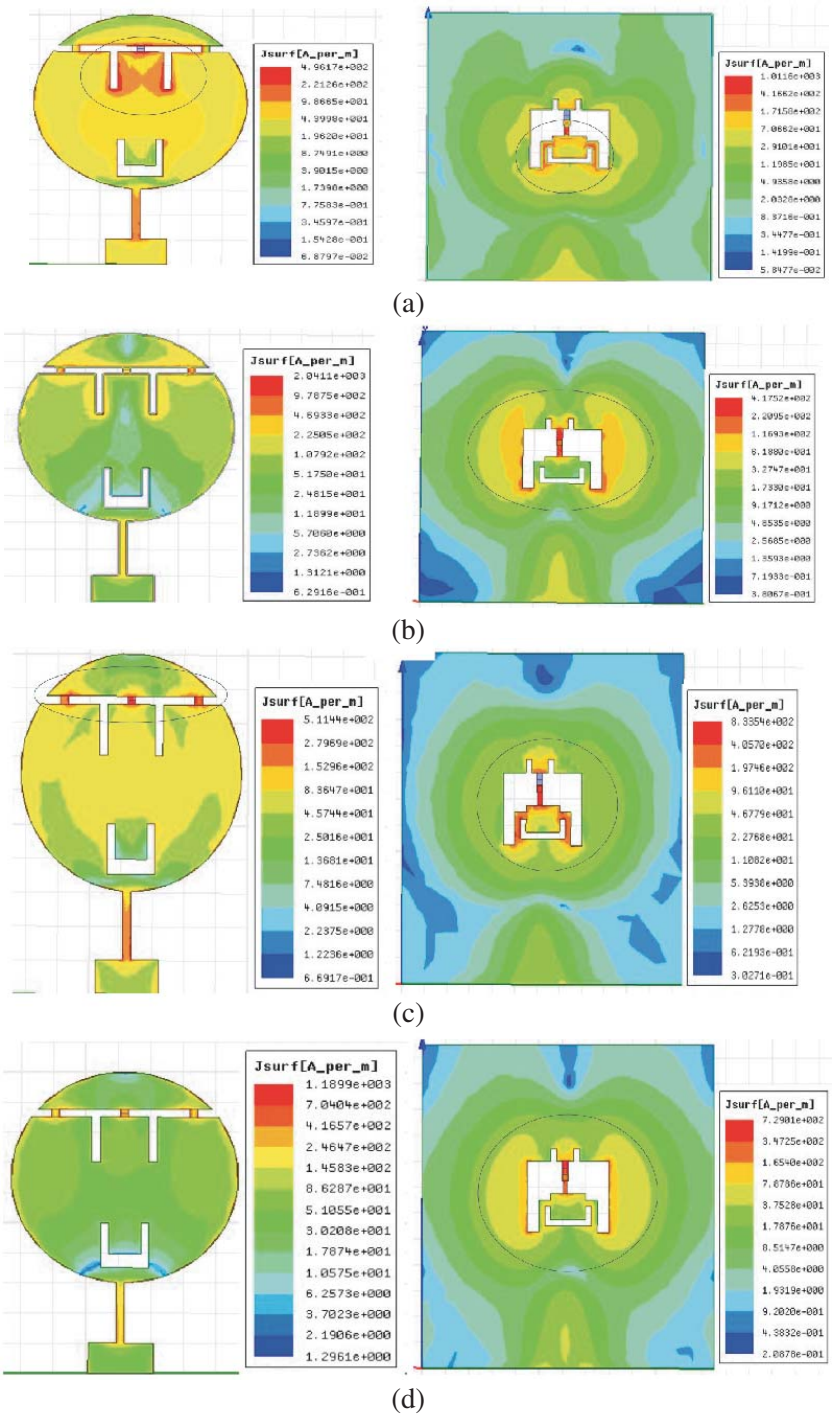


Figure 7. Surface current distribution at four frequencies (a) 6.83 GHz (b) 4.94 GHz (c) 6.25 GHz (d) 5.35 GHz.

clearly proves that the effective electric length at the respective operating frequency in the whole radiating structure establishes inverse relation with the frequency. The changes in current distribution can be seen which are encircled, shown in Figure 7.

It can be observed from Figure 8 that the simulated and measured results are in good agreement, and Figure 10 shows simulated and measured radiation patterns with good agreement for all biasing states of two diodes and operating frequencies. The simulated radiation patterns are stable for all the

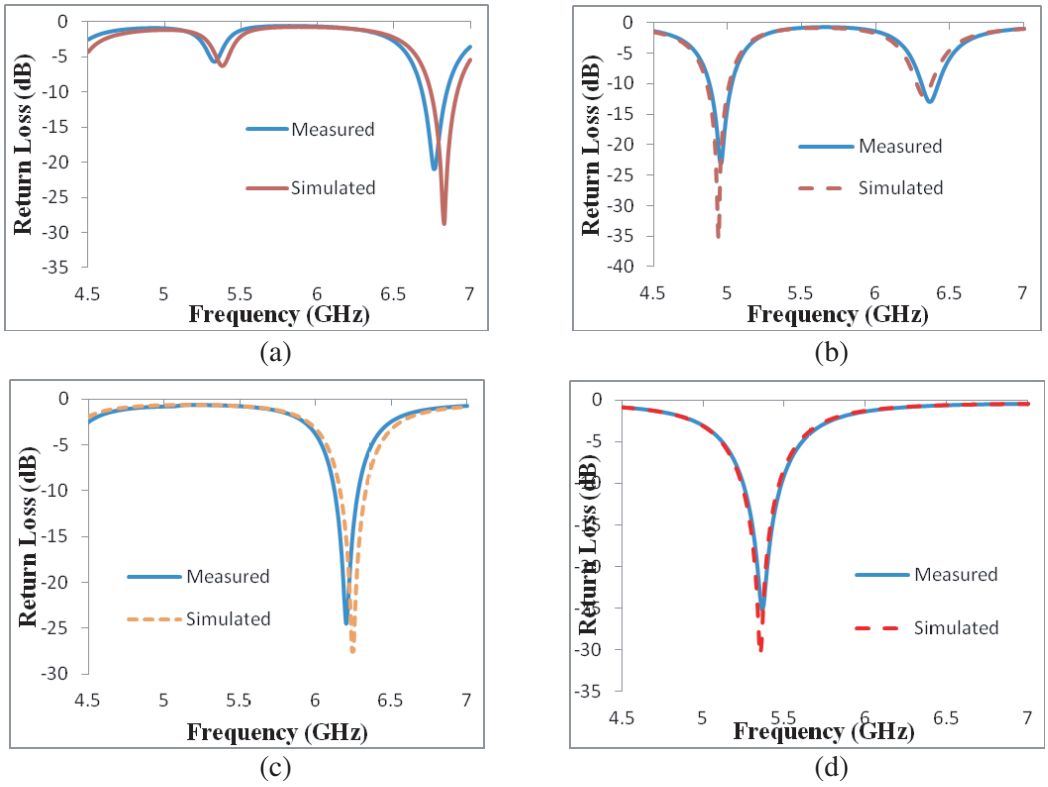


Figure 8. Comparative simulated and measured return loss (S_{11}) parameters.

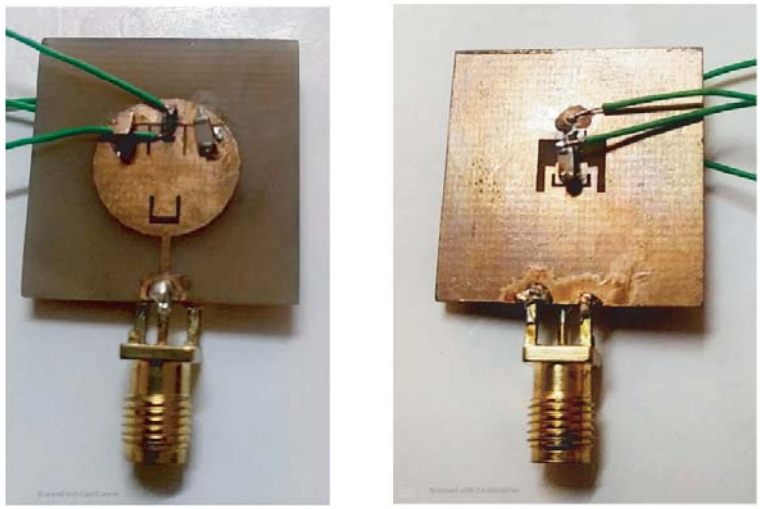


Figure 9. Prototype of proposed antenna. (a) Top view. (b) Bottom view.

diode states and frequencies.

Also the prototype of the proposed antenna is fabricated on FR-4 material as shown in Figure 9. The proposed antenna is also compared with the related literature mentioned in the paper in terms of size, number of PIN diodes, number of operating bands, and dielectric material used. Table 4 shows that the proposed antenna uses fewer switches which reduces the complexity of the system, and it is a novel structure. In addition to this, it has good gain and stable radiation pattern.

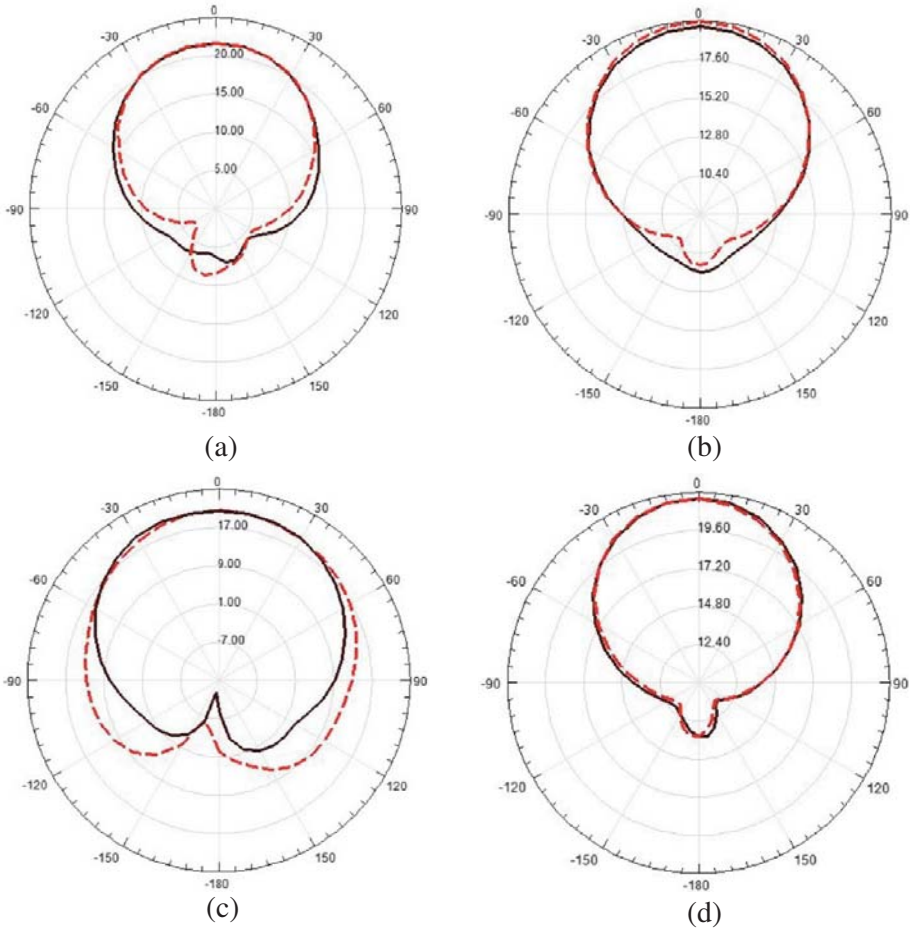


Figure 10. *E*-plane radiation pattern (solid line for simulated and dashed line for measured) for diode configuration. (a) 00 (b) 01 (c) 10 (d) 11.

4. CONCLUSION

A compact and frequency reconfigurable antenna which operates over four different frequencies is presented in this paper. The proposed antenna frequencies are 4.94, 5.35, 6.25, and 6.83 GHz. PIN diodes are used as switching devices to reconfigure the antenna, and a biasing circuit is designed to bias the PIN diodes. The proposed antenna is studied in terms of different parameters such as reflection coefficient, gain, and radiation pattern. The different switching states are responsible for achieving the desired operating frequency characteristics. By altering the biasing of PIN diodes, the designed antenna operates for different bands in different states. Satisfied efficiencies, radiation pattern, appropriate gain, and impedance match are also achieved for all four bands. The antenna has the advantage of light weight, compactness, low cost, and simple integration in portable devices. In comparison to other antennas, this antenna uses less PIN diodes and other components such as capacitors. The antenna is useful for WLAN, WiMax, and C-band (4–8 GHz) applications for satellite applications. A hardware prototype of the simulated structure is fabricated. In the future, polarization reconfigurability can be added with frequency reconfigurability.

ACKNOWLEDGMENT

We would like to thank Banasthali Vidyapith for providing testing facility and Jaipur National University for conducting research in the lab and to provide all the facilities.

REFERENCES

1. Hassan, M., Z. Zahid, A. Khan, I. Rashid, A. Rauf, M. Maqsood, and F. Bhatti, "Two element MIMO antenna with frequency reconfigurable characteristics utilizing RF-MEMS for 5G applications," *Journal of Electromagnetic Waves and Applications*, Vol. 34, No. 9, 1210–1224, 2020.
2. Bharadwaj, S., Sipal D., Yadav D., Koul S., "A compact tri-band frequency reconfigurable antenna for LTE/Wi-Fi/ITS applications," *Progress In Electromagnetics Research M*, Vol. 91, 59–67, 2020.
3. Guo, G., Deng L., Dong J., Yi T., Liao C., Huang S., Luo H., "Variode enabled frequency-reconfigurable microstrip patch antenna with operation band covering S and C bands," *Progress In Electromagnetics Research M*, Vol. 88, 159–167, 2020.
4. Chattha, H., M. Hanif, X. Yang, I. Rana, and Q. Abbasi, "Frequency reconfigurable patch antenna for 4G LTE applications," *Progress In Electromagnetics Research M*, Vol. 69, 1–13, 2018.
5. Jenath Sathikbasha, M. and V. Nagarajan, "Design of multiband frequency reconfigurable antenna with defected ground structure for wireless applications," *Wireless Pers. Commun.*, 867-892, https://doi.org/10.1007/s11277-020-07256-8, 2020.
6. Ali, T., M. M. Khaleeq, and R. C. Biradar, "A multiband reconfigurable slot antenna for wireless applications," *AEU — International Journal of Electronics and Communications*, Vol. 84, 273–280, Feb. 2018.
7. Chandra, K., M. Satyanarayana, and K. Battula, "A novel miniature hexagonal shape switched pattern and frequency reconfigurable antenna," *International Journal of Communication System*, Vol. 33, No. 5, 1–8, Sept. 2019.
8. Han, L., C. Wang, X. Chen, and W. Zhang, "Compact frequency reconfigurable antenna for wireless applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 15, No. 1, 1795–1798, Jun. 2018.
9. Awan, W., N. Hussain, S. Naqvi, A. Iqbal, R. Striker, D. Mitra, and B. Braaten, "A miniaturized wideband and multi-band on-demand reconfigurable antenna for compact and portable devices," *International Journal of Electronics and Communications*, Vol. 122, Jul. 2020.
10. Bitchikh, M., W. Rili, and M. Mokhtari, "An UWB to narrow band and bi-bands reconfigurable octogonal antenna," *Progress in Electromagnetics Research Letters*, Vol. 74, 69–75, 2018.
11. Pandhare, R. and M. Abegaonkar, "Inset-feed frequency reconfigurable compact E-shape patch with DGS," *Progress In Electromagnetics Research C*, Vol. 101, 119–132, 2020.
12. Prem, P. S., P. K. Goswami, S. K. Sharma, and G. Goswami, "Frequency reconfigurable multiband antenna for IoT applications in WLAN, Wi-Max, and C-band," *Progress In Electromagnetics Research C*, Vol. 102, 149–162, 2020
13. Shah, I., S. Hayat, A. Basir, M. Zada, S. Shah, and S. Ullah, "Design and analysis of a hexa-band frequency reconfigurable antenna for wireless communication," *International Journal of Electronics and Communications*, Vol. 98, No. 1, 80–88, Jan. 2019.
14. Choukiker, Y. K. and S. K. Behera, "Wideband frequency reconfigurable Koch snowflake fractal antenna," *IET Microwaves, Antennas & Propagation*, Vol. 11, No. 2, 203–208, 2017.
15. Behdad, N. and K. Sarabandi, "Dual-band reconfigurable antenna with a very wide tunability range," *IEEE Transactions on Antennas and Propagation*, Vol. 54, No. 2, 409–416, Feb. 2006.