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Design and analysis of multiband reconfigurable slot antenna for S, C, and X-band applications

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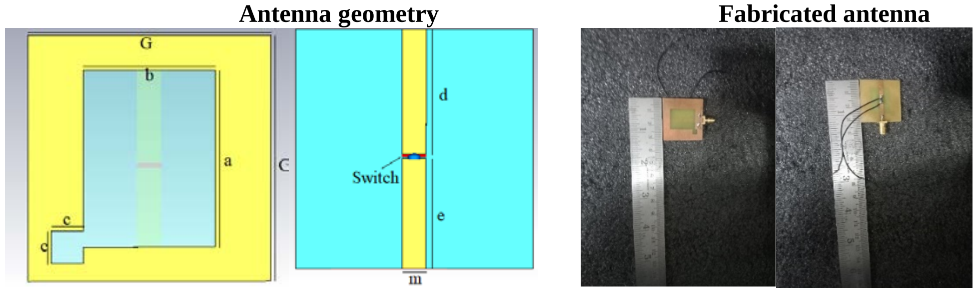
ABSTRACT

Antenna geometry **Fabricated antenna**



In this paper, a reconfigurable microstrip patch antenna with two linked slots and a microstrip feed line is reported, which is useful for Bluetooth/WLAN/ISM (2400–2484 MHz), high frequency LTE band (2496–2690 MHz), WiMAX (2.50-2.69 GHz), S-DMB (2605–2655 MHz) and X band (8.0-12.0 GHZ) applications. The antenna is reconfigured by adding a PIN diode as a switch in the feed line. The simulation of proposed antenna has been performed with CST Studio Suite 2022. The antenna resonates at 4.70 GHz and 9.765 GHz under ON condition and resonates at 2.64 GHz, 4.71 GHz, and 10.07 GHz under OFF condition. The antenna is fabricated and measured results are found in close agreement with simulated results.

Keywords: PIN diode, Reconfigurable Patch Antenna, Slots, WiMAX, X-band

INTRODUCTION

Reconfigurable microstrip patch antennas (MSA), which have a variety of uses, are necessary given the fast expansion of wireless communication. In broad demand for several applications such as PCS, satellite, radar, WLAN, and WiMAX applications, reconfigurable MSA have shown their usefulness. A reconfigurable rectangular patch antenna by a single PIN diode switch is offered and the resonating frequencies of this antenna are 2.47 GHz, 3.8 GHz, and 5.36 GHz.[1] A multiband slot antenna for Wireless Applications using PIN diode to achieve frequency reconfiguration is proposed.[2] It is a quad band antenna useful for lower WiMAX, GNSS, X-band, and WLAN applications. A reconfigurable tri-band antenna[3] with PIN diode for WLAN and WiMAX applications was investigated with operating frequencies 2.4 GHz, 3.5 GHz, 5.25 GHz, and 5.8 GHz using FR-4 substrate. Further, several designs of reconfigurable microstrip patch antennas are reported in this field such as a reconfigurable antenna for 5G and Wi-Fi applications,[4] and a reconfigurable microstrip antenna which has six frequency bands that uses PIN diode.[5] A reconfigurable microstrip patch antenna is presented for frequency and polarization-diversity functions.[6] It is a square patch consisting of a U-slot and PIN diode useful for WLAN/DMB application. A tri-band, H-shaped reconfigurable antenna is proposed for wireless communication systems which uses a varactor diode for frequency reconfigurability.[7] For fixed and reconfigurable frequency bands, a small multiband antenna is reported.[8] For use with wireless devices, a reconfigurable C-Slot patch antenna that can operate in dual and wideband mode is presented.[9] The various techniques employed by researchers for the advancement in triple,[10,11,12] and multiple band reconfigurable patch antennas.[13,14] A reconfigurable antenna with

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four resonance frequencies in the X, Ku, and K bands that uses PIN diodes has been presented.[15] It can be applied to satellite communication and radar applications. A frequency-reconfigurable antenna with inverted L-shaped slots is introduced, demonstrating utility across diverse wireless applications, including 5G.[16] Several antennas employing diverse reconfigurability methods have been documented in literature.[17-27]

The objective of this paper is to design a frequency reconfigurable microstrip patch antenna having two linked slots in radiating element and a microstrip feed line printed on the back side. The antenna is reconfigured using a lumped element switch, placed on a microstrip feed line on the back side in the simulation. Because they are simple to model and are easily integrated into the structure, lumped element switches are favoured.[28] The proposed antenna operates at 4.70 GHz and 9.765 GHz under ON condition and 2.64 GHz, 4.71 GHz, and 10.07 GHz under OFF condition. Antenna design, results and discussion, and conclusion are given in the next section.

ANTENNA DESIGN

The proposed geometry of microstrip line fed linked slots reconfigurable antenna is presented in Figure 1. which is designed on a 30 x 30 mm^2 FR4 substrate (4.4) and thickness of 1.6 mm. The radiating element of the antenna contains two connected slots of size a × b and c × c. The antenna is fed by a microstrip line feed of width m placed on the back of the substrate. A gap of size 0.5 x 3 mm^2 has been created in the feed line to insert a switch. A lumped element switch is used in the simulation. Figure 2 depicts the PIN diode's equivalent circuit. RLC lumped element model of PIN diode consists of a series connection of inductance L with resistance R for ON state and a series connection of inductance L with a parallel connection of resistance R and capacitance C for OFF state. To simplify our model, the RLC lumped element model of the switch is realized as resistor value only. Resistance is taken as 1Ω and 1MΩ for ON and OFF states respectively.[29] The switch's state determines the antenna structure's effective electrical length segments, which are responsible for emitting a specific frequency range. The final dimensions of the antenna are shown in Table 1.

Table 1. Optimized dimensions of the designed antenna

S. No	Parameter	Value(mm)
1	G	30
2	a	16.3
3	b	21.6
4	c	4
5	d	15.65
6	e	13.85
7	m	3

Current distribution for ON condition of the proposed antenna is demonstrated in Figure 3(a) at the frequencies 4.7 GHz and 9.70 GHz respectively. Both figures signify that the amount of current is found adequate inside the edges of slots. Afterward, Figure 3(b) displays the current distribution for OFF condition at 2.64 GHz, 4.71 GHz, and 10.07 GHz. From this figure, it is observed that a sufficient amount of current density is achieved. The maximum surface current distribution in the patch is 71.1 A/m. The resonance frequency f_r of the microstrip antenna can be given as,[30]

$$f_r = \frac{c}{2L_e\sqrt{\varepsilon_{re}}} \tag{1}$$

Where

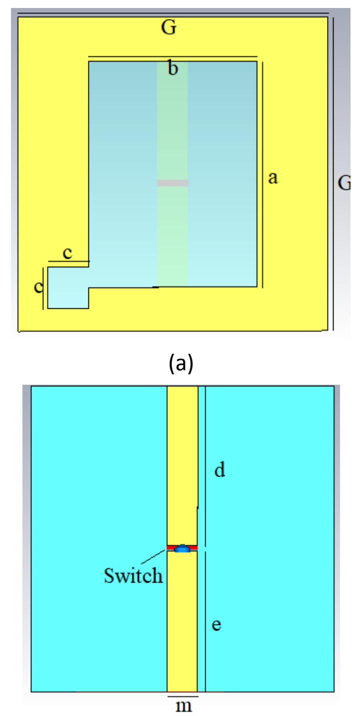
$$\varepsilon_{re} = \frac{1}{2}\left[(\varepsilon_r + 1) + (\varepsilon_r - 1)\left(1 - \frac{12h}{w}\right)^{-\frac{1}{2}}\right] \tag{2}$$

$$L_e = L + \Delta L \tag{3}$$

$$\Delta L = h0.412\frac{(\varepsilon_{re} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{re} - 0.258)\left(\frac{w}{h} + 0.8\right)} \tag{4}$$

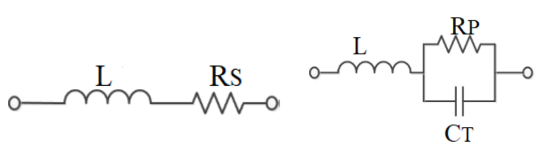
ε_{re} is the effective dielectric constant, L_e is the effective length, C is the velocity of light, and L=w=G.

The fabricated prototype of the proposed antenna is shown in Figure 4. PIN diode (BAR64-03W E6327) is employed as a switch to achieve reconfigurability.



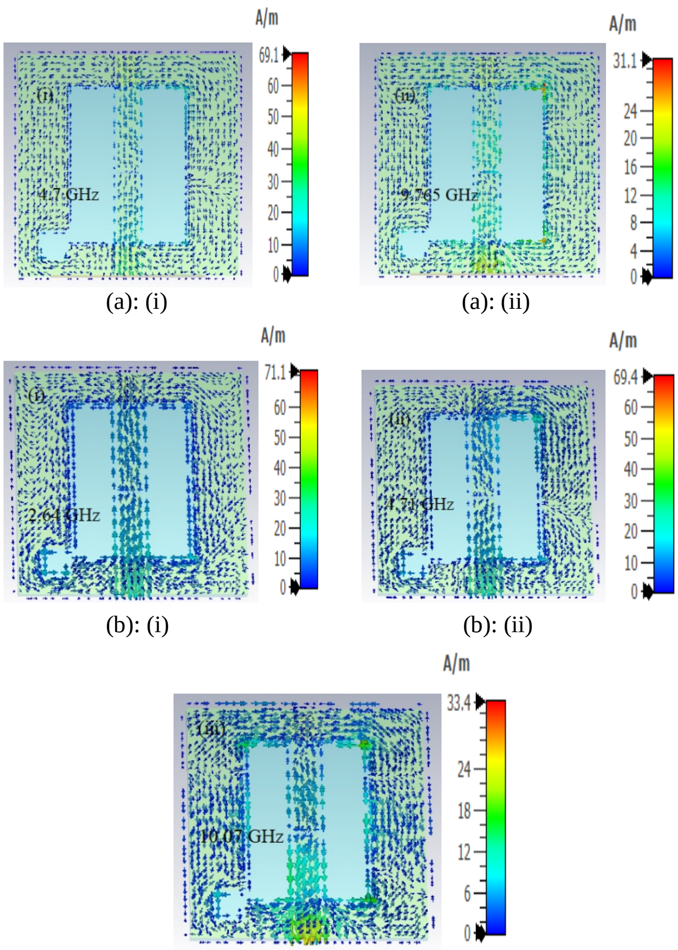
(b)

Figure 1. Geometry of antenna: (a) top view, (b) bottom view



(a) (b)

Figure 2. Equivalent circuit for PIN diode (a) On state (b) Off state

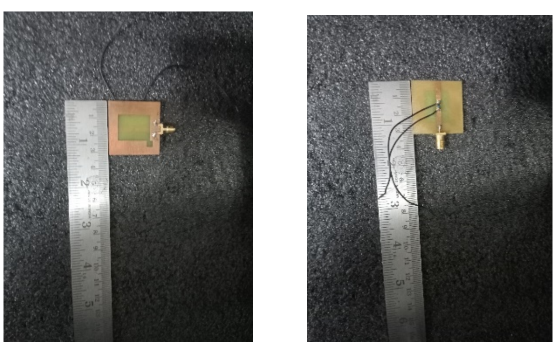


(a): (i) (a): (ii)

(b): (i) (b): (ii)

(b): (iii)

Figure 3. Current distribution at (a) (i) 4.7 GHz (ii) 9.765 GHz under ON condition (b) (i) 2.64 GHz (ii) 4.71 GHz (iii) 10.07 GHz under OFF condition



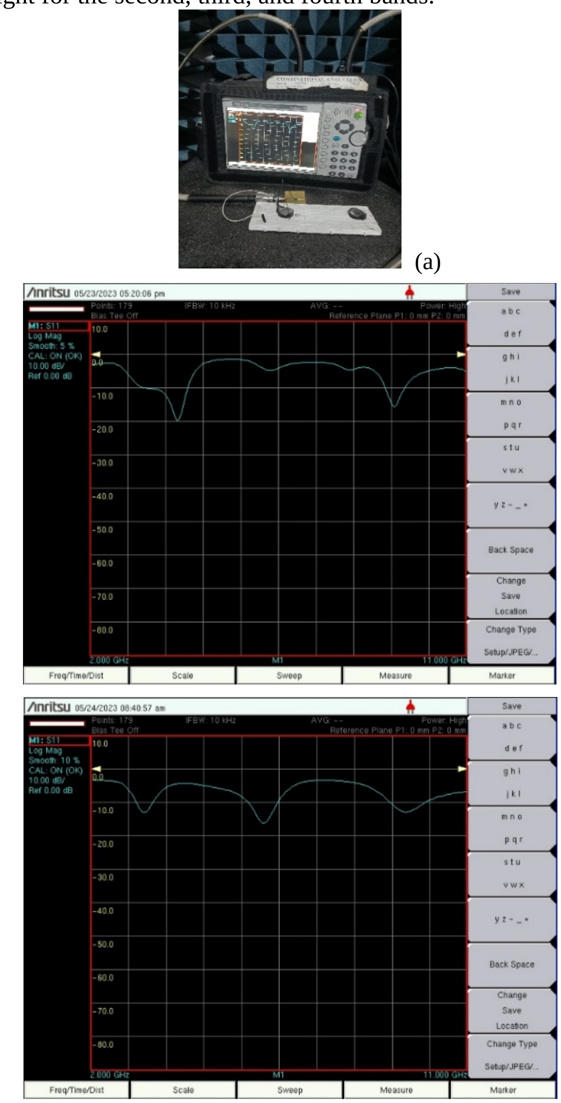
(a) (b)

Figure 4. Fabricated antenna design (a) top view (b) bottom view

Results and Discussion

The snapshot of the measurement setup and measured reflection coefficients of the antenna is displayed in Figure 5. The reflection coefficients and VSWR of the reconfigurable antenna are measured with Anritsu Vector Network Analyzer (Model: MS2037C/2). Figure 6(a)-(b) displays the measured and simulated results of the reflection coefficients of the proposed antenna. The antenna under ON condition exhibits simulated S11≤-10 dB bandwidth of 0.29 GHz (4.55-4.84 GHz) and 0.93 GHz (9.3-10.23 GHz). The antenna under OFF condition offers simulated S11≤-10 dB bandwidth of 0.45 GHz (2.41-2.86 GHz), 0.31 GHz (4.55-4.86 GHz), and 0.43 GHz (9.85-10.28 GHz).

In Figure 7(a)-(b), the suggested antenna's fluctuation in reflection coefficients with frequency for various dielectric constants is depicted. It has been shown that decreasing the dielectric constant causes resonance frequency to rise. Since FR4 is inexpensive and widely accessible, it was chosen for the proposed antenna. Figure 8(a)-(b) shows the return loss fluctuation with frequency for various substrate heights for the proposed antenna. It has been shown that lowering the height for the ON state causes resonance frequency to rise. Additionally, it shows that, in the OFF state, resonance frequency increases by raising the height for the first band, but resonance frequency decreases by reducing the height for the second, third, and fourth bands.[31-34]



(a)

(b)

(c)

Figure 5. (a) Measurement setup (b) S11 at ON condition (c) S11 at OFF condition

Figure 9(a)-(b) demonstrates variations of simulated and measured VSWR v/s frequency (GHz) for the designed antenna for both ON and OFF conditions respectively. Figure 10 depicts the gain vs frequency. It is observed that the maximum gain is 4.43 dBi when the switch is ON and for OFF state it is 4.40 dBi.

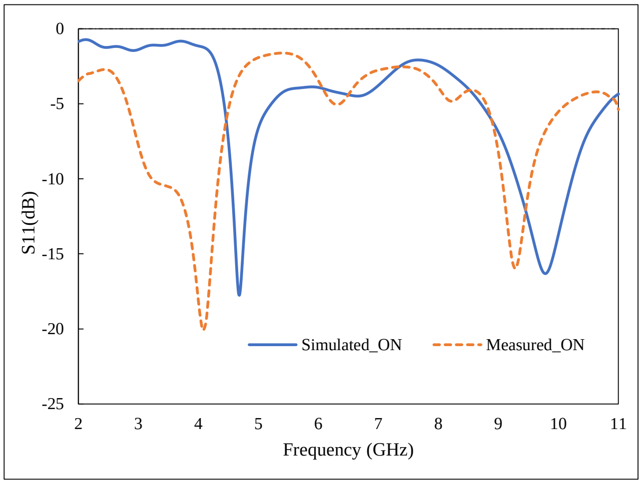


Figure 6. (a) Return loss (dB) versus frequency (GHz) under ON condition

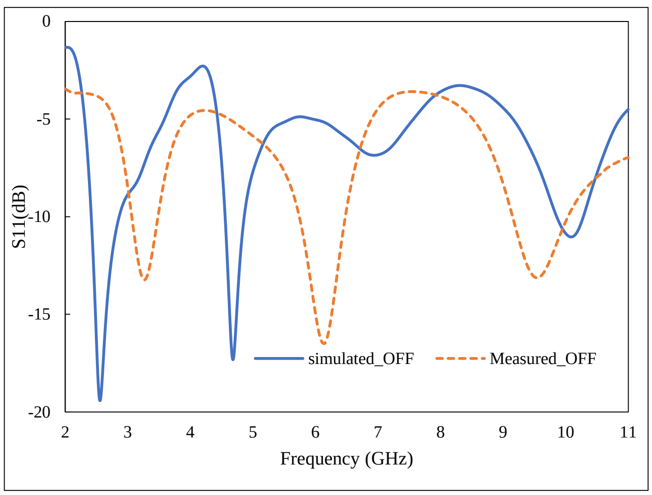


Figure 6. (b) Return loss (dB) versus frequency (GHz) under OFF condition

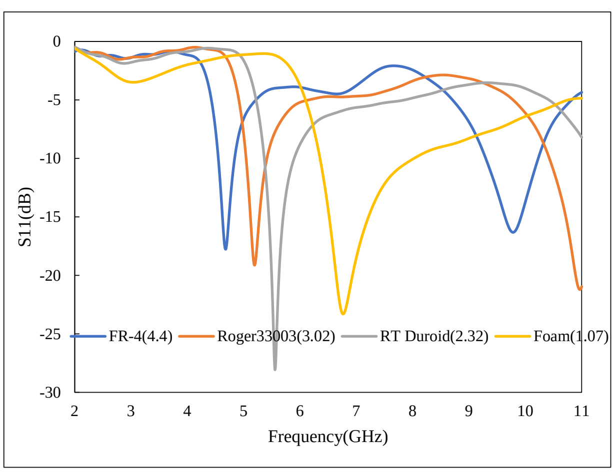


Figure 7. (a) Return loss (dB) versus frequency (GHz) under ON condition

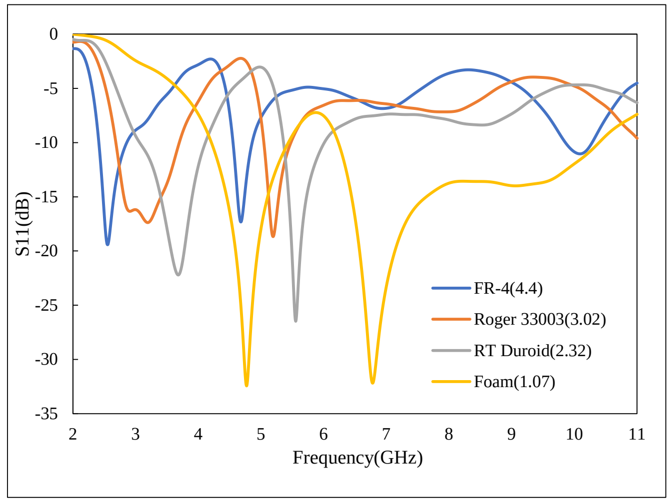


Figure 7. (b) Return loss (dB) versus frequency (GHz) under OFF condition

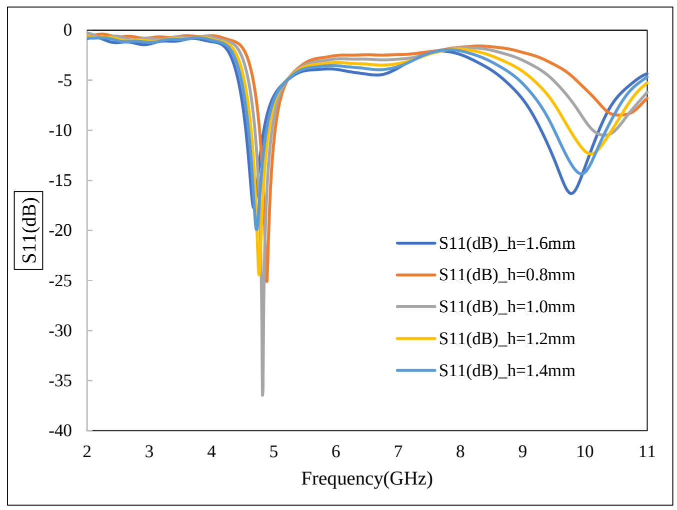


Figure 8. (a) Return loss (dB) versus frequency (GHz) under ON condition

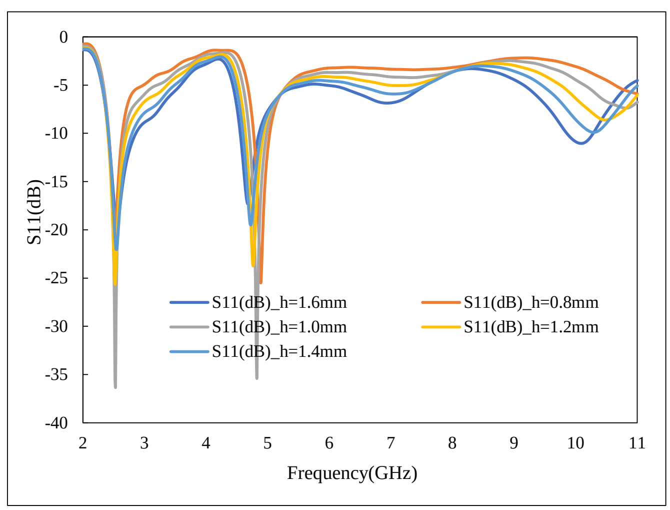


Figure 8. (b) Return loss (dB) versus frequency (GHz) under OFF condition

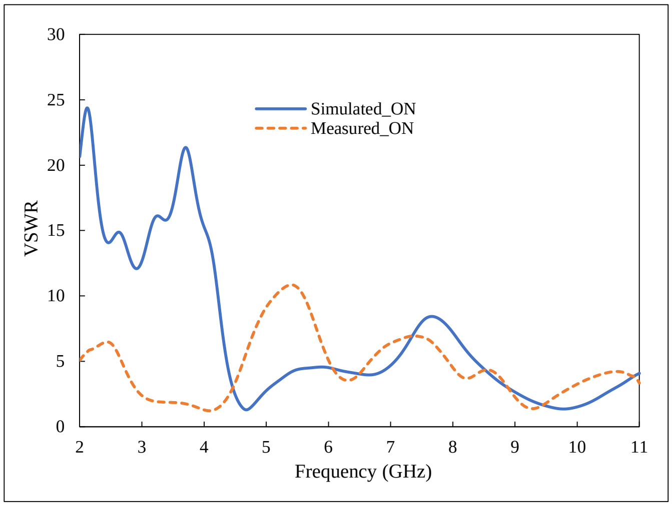


Figure 9. (a) VSWR versus frequency (GHz) under ON condition

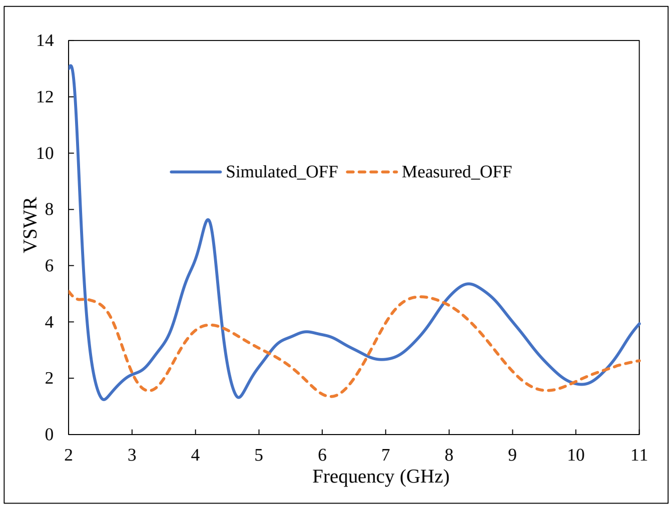


Figure 9. (b) VSWR versus frequency (GHz) under OFF condition

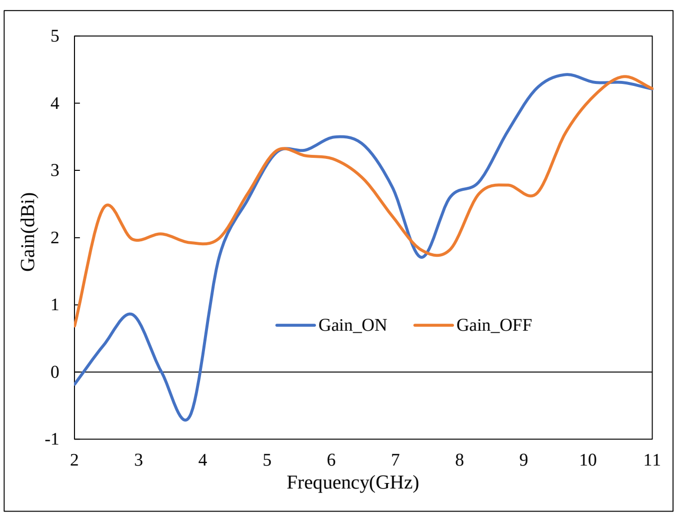


Figure 10. Gain (dBi) versus frequency (GHz)

The efficiency of proposed antenna is shown in Figure 11 for ON and OFF states of the switch. Maximum obtained efficiency is 78.78% at 8.75 GHz for ON state and 82.08% at 2.45 GHz for OFF

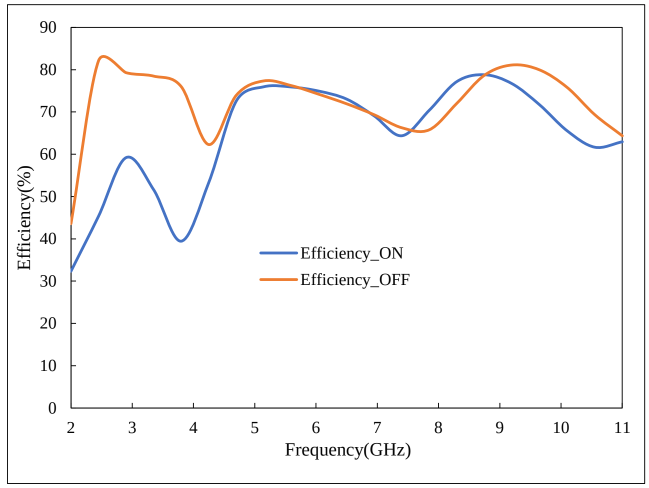
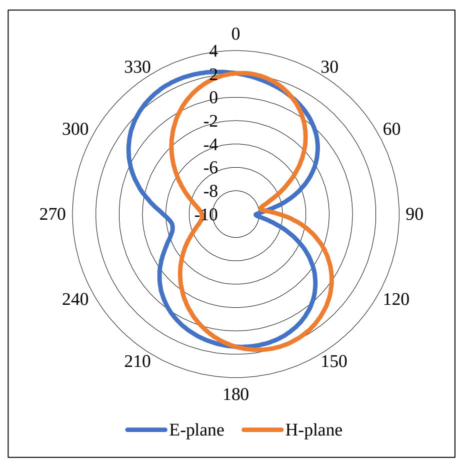
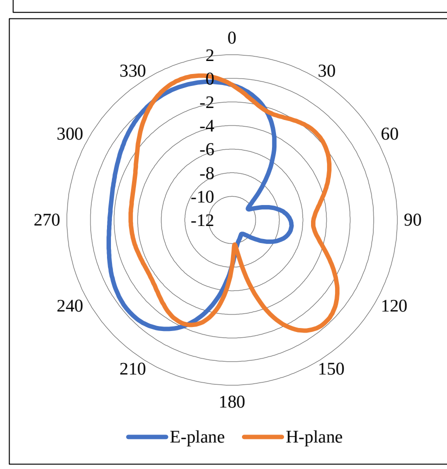


Figure 11. Efficiency (%) versus frequency (GHz)

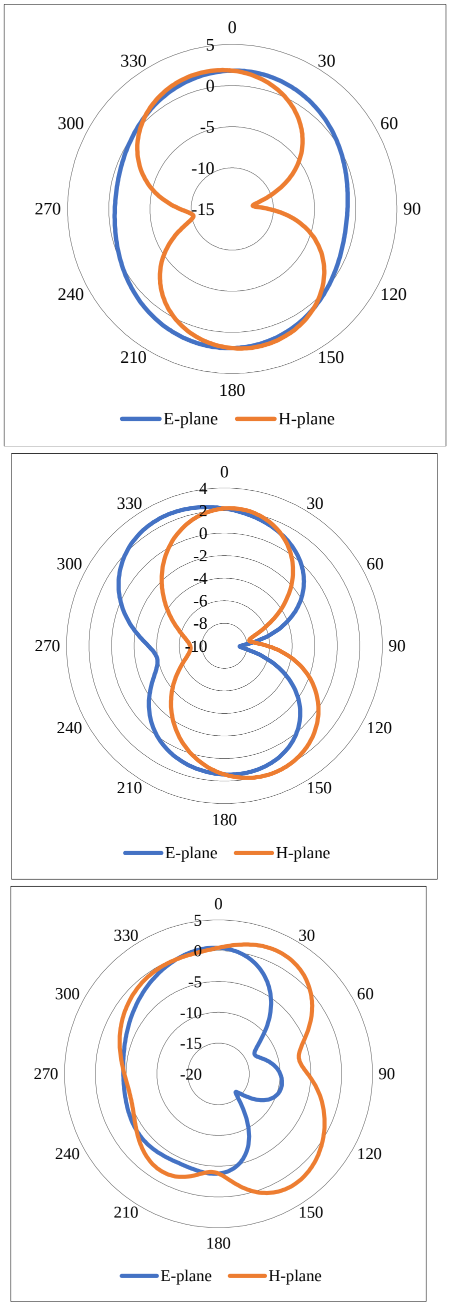
state. Figure 12 demonstrates the simulated E- and H-plane gain pattern for the resonating frequencies 4.70 GHz, 9.765 GHz, 2.64 GHz, 4.71 GHz, and 10.07 GHz. The far-field region is obtained for proposed antenna with a maximum gain of 2.54 dBi and 4.45 dBi at 4.70 GHz and 9.765 GHz respectively for ON state. Further, for OFF state of switch, the maximum gain is obtained 2.04 dBi, 2.67 dBi, and 4.09 dBi at 2.64 GHz, 4.71GHz, and 10.07 GHz respectively. The 3D radiation pattern for this antenna at 9.765 GHz and 4.70 GHz under ON condition and at 2.64 GHz, 4.71 GHz, and 10.07 GHz under OFF condition is shown in Figure 13.



(a)



(b)

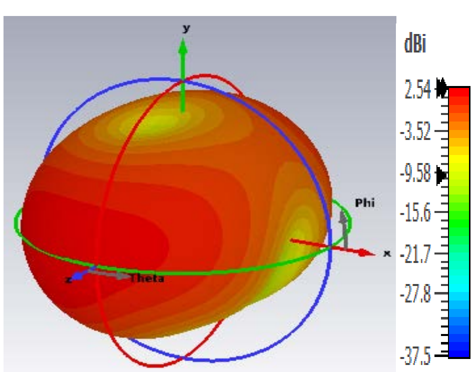


(c)

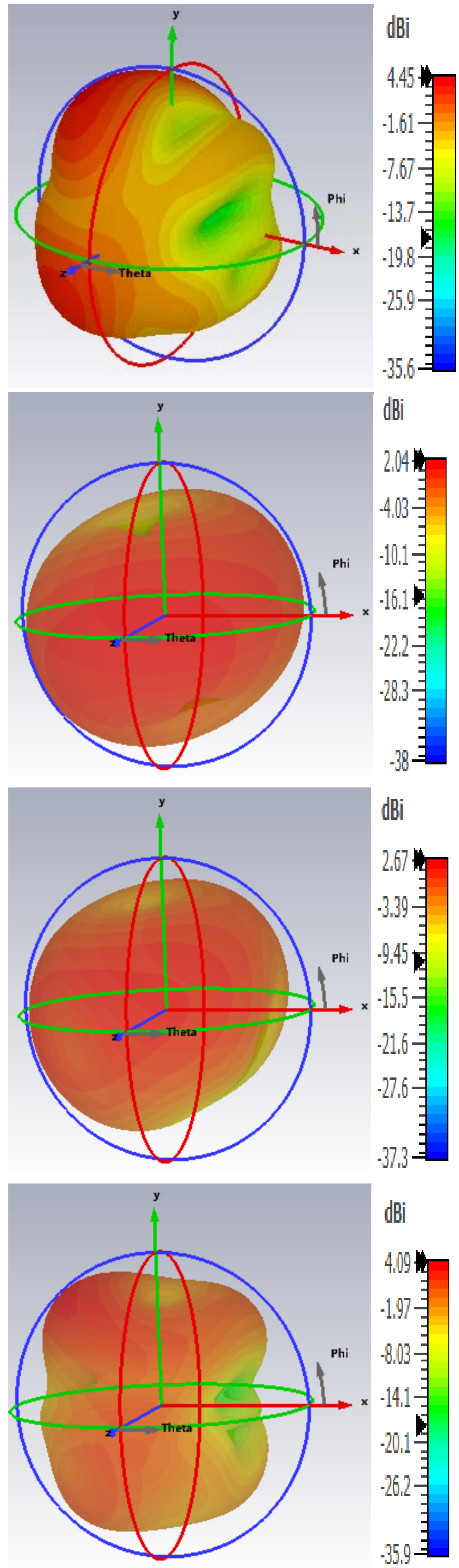
(d)

(e)

Figure 12. Simulated radiation pattern of antenna in E–H plane at: (a) 4.70 GHz (ON) (b) 9.765 GHz (ON) (c) 2.64 GHz (OFF) (d) 4.71 GHz (OFF) (e) 10.07 GHz (OFF)



(a)



(b)

(c)

(d)

(e)

Figure 13. 3D far-field gain pattern of antenna at: (a) 4.70 GHz (ON) (b) 9.765 GHz (ON) (c) 2.64 GHz (OFF) (d) 4.71 GHz (OFF) (e) 10.07 GHz (OFF)

The designed reconfigurable microstrip patch antenna is simulated in CST studio suit 2022, whereas fabricated and measured results are achieved using Anritsu Vector Network Analyzer. The performance-effecting parameters are simulated and measured such as return loss, VSWR, gain, efficiency, and radiation pattern for ON and OFF states of the switch. A comparison analysis for the proposed antenna with reference is given in Table 2.[10-14] The size of the designed antenna is less compared to the various antenna presented in the literature. The gain obtained for proposed antenna is higher compared to various antenna presented in the literature.[10-14]

Table 2 Comparison of the proposed antenna with the existing antenna

Ref.	Dimensions (mm^2)	No of operating bands	Frequency (GHz)	Gain (dBi)
[10]	35x40	triple	2.45, 3.50, 5.20	1.48–3.26
[11]	40x40	triple	2.45, 3.50, 5.20	1.7–3.4
[12]	39x37	triple	2.45, 3.0, 5.20	1.32–2.32
[13]	35 x 40	six	2.1, 2.4, 3.3, 3.5, 5.28, 5.9	1.92–3.88
[14]	35x40	triple	2.45,3.45, 5.4	1.92–3.02
This work	30x30	five	2.64, 4.70, 4.71, 9.77, 10.07	2.04-4.45

Conclusion

The offered design of a reconfigurable linked slot antenna has been carried out and reconfigurability is introduced by varying the length of the strip line feed designed on the back of the antenna. The proposed antenna works in different frequency modes, depending on the switch's state. The designed antenna offers dual bands in ON condition and triple bands in OFF condition. This antenna is useful for WLAN, Bluetooth, ISM (2400–2484 MHz), LTE band (2496–2690 MHz), WiMAX (2.50-2.69 GHz), S-DMB (2605–2655 MHz), and X band (8.0-12.0 GHZ) applications. The measured and simulated results are obtained adequate. In the future, researchers may focus on size reduction and bandwidth enhancement.

Conflict of Interest

Authors declared no conflict of interest.

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