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Design and Analysis of Microstrip Line Feed C-Shape Frequency Reconfigurable Antenna for Wireless Application

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Abstract: In this work, a frequency-reconfigurable C- shape multiband antenna using a 1.6 mm FR-4 substrate and a partial ground plane is presented. Frequency reconfiguration is accomplished in simulation using the lumped element switch. The proposed antenna has been simulated using CST Studio Suite 2022. The provided antenna is capable of operating in four modes, depending on the state of the switch. The suggested antenna functions in dual band in mode 1-3 and triple band in mode 4. The resonant frequencies of antenna are 2.19 GHz, 2.44 GHz, 2.98 GHz, 3.01 GHz, 5.67 GHz, 7.53 GHz, 7.59 GHz, 7.71 GHz and 8.17 GHz, and corresponding bandwidths are 0.36 GHz, 0.46 GHz, 0.71 GHz, 0.74 GHz, 1.56 GHz, 2.92 GHz, 4.17 GHz, 2.62 GHz and 1.56 GHz. It can be used for numerous applications such as UMTS, Bluetooth, WLAN, high-frequency LTE, S-DMB, WiMAX, C and X band applications.

Keywords: *Multiband, PIN diode, Reconfigurable Antenna, Slots.*

1. Introduction

Reconfigurable antennas are generally widely used to meet the needs of the modern communication system. A controlled dynamic modification of features like frequency and radiation pattern is possible with reconfigurable antennas. There are several kinds of reconfiguration techniques, including the capacity to change frequency, polarization, and radiation pattern. A double band patch with a 40x40 mm^2 dimension is described in **[1]**. To use this antenna in the WLAN and WiMAX frequency bands, a PIN diode and capacitor may be added. It is recommended that a PIN diode be used in a multi-band patch for wireless application to attain frequency adjustment **[2]**. It is a multi-band antenna that works well for smaller GNSS, WLAN and WiMAX usages. A reconfigurable patch **[3]** having a PIN diode was investigated using a FR-4 substrate for WLAN and WiMAX applications at the operating frequencies of 3.5, 2.4, 5.8 and 5.25 GHz. Other reconfigurable microstrip patch antenna

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designs, a reconfigurable patch antenna **[4]** with six frequency bands, and a reconfigurable antenna for Wi-Fi and 5G applications **[5]** have also been reported in this field. The author in **[6]** reports about a brand-new truncated metallic ground surface and 9-shaped multiband reconfigurable antenna. This antenna works in both WiMAX's single band and dual band, which includes WLAN and Wi-Fi. Two monopole antennas **[7]** have been created for use with mobile wireless technologies including WLAN WiMAX, and Wi-Fi usages. The emitting elements of these antenna are constructed from two distinct geometrical shapes on a cheap FR-4 material. Metallic copper truncated ground is utilised to provide the maximum radiation efficiency and radiation pattern achievable. The specifications of antenna include VSWR (1.5), bandwidth (6-35%), gain (1.7-3.4 dB) and radiation efficiency (85-90%), and they span the frequency ranges of 2.45, 3.50 and 5.20 GHz. Low-profile, small reconfigurable multi-band monopole planar antennas that operate in single- and dual-band modes have been demonstrated **[8]**. Antenna1 makes use of WLAN and Wi-Fi in dual-band mode. Antenna2 has two distinct dual-band modes, notably (Wi-Fi and WLAN) and (WiMAX and WLAN), depending on whether the switch is ON or OFF. A compact reconfigurable monopole antenna with the lumped element switch has been used **[9]** to function in three different frequency bands under ON and OFF situations. Several antennas employing diverse reconfigurability methods have been documented in literature **[10-17]**.

This paper proposes a compact frequency reconfigurable C-shape multiband antenna, featuring two PIN diodes inserted into slots within the radiating structure and on the

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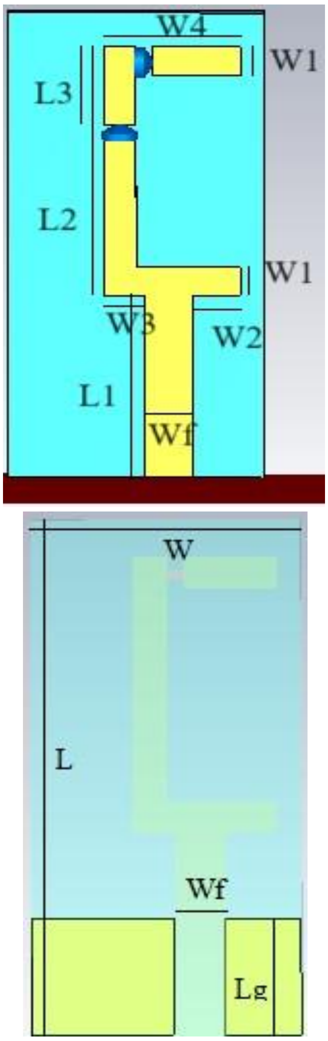
opposite side of the partial ground. The antenna's reconfiguration is achieved through lumped element switches placed in these slots during simulation. The subsequent sections include antenna design, results and discussion, and conclusion.

Antenna Design The structure of the suggested C- shape reconfigurable antenna is displayed in **Figure 1**. Radiating component of the antenna is printed on a FR-4 substrate 1.6 mm thick with dimensions of 33x16 mm^2 and dielectric constant of 4.4. A partial ground plane supports it. Since the FR-4 material is easily accessible, the patch design is extra usable and less costly. The antenna is excited by a 50-ohm, 3 mm wide microstrip line. The feed-line port is utilised to activate the patch. The radiating structure, as shown in **Figure 1**, has been designed with two 1 mm wide slots for the installation of lumped element switches. The status of the switch affects the effective electrical length segments of the antenna, which play a crucial role in emitting signals within designated frequency ranges. To optimize bandwidth, a ground plane (partial) is positioned on the backside.



(a) **(b)**

Figure 1: Geometry of antenna **(a)** top side **(b)** back side

A PIN diode (BAR64-02v) is utilized as the switching component to achieve frequency reconfigurability. The equivalent circuits employed in CST simulation software are shown in **Figure 2**. For forward bias, a 4-ohm resistance is used, while for reverse bias, a parallel combination of a 4-kilo-ohm resistance and a 0.025 pF capacitance is applied, following the specifications in the datasheet.

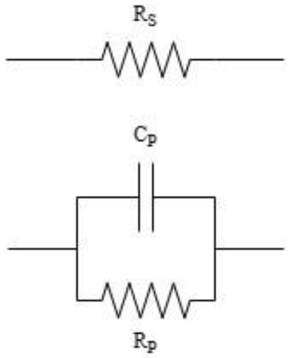


Figure 2. Equivalent circuit for PIN diode

The patch dimensions have been computed using the following mathematical equations. The microstrip antenna's resonance frequency (f_r) **[18]** can be expressed as

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

where

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

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

and

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

where, ε_{re} represents the dielectric constant (effective), L_e stands for the length (effective) and c denotes the light velocity. **Table 1** provides the dimensions of the designed antenna.

Table 1. Optimal dimensions of the designed patch

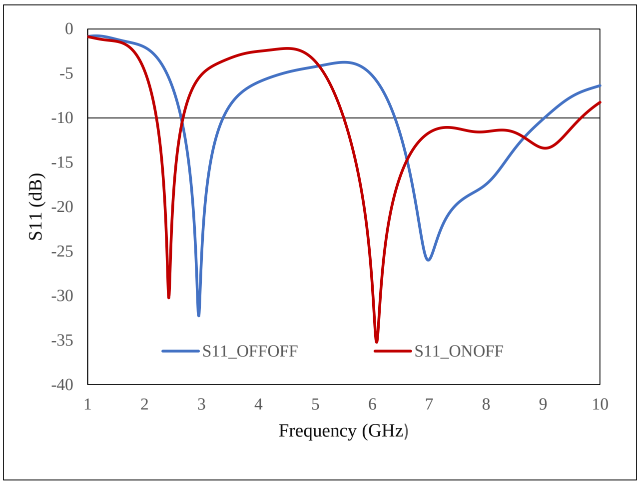
S. No	Parameter	Value(mm)
1	L	33
2	W	16
3	L1	13
4	L2	17.6
5	L3	5.5
6	Lg	7.5
7	Wf	3
8	W1	2
9	W2	3
10	W3	2.5
11	W4	8.5

Results and Discussion

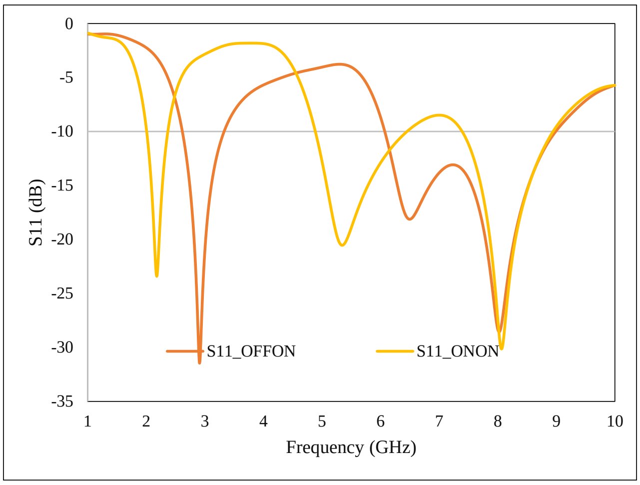
There are four operating modes for the proposed antenna. **Table 2** lists the switching modes for the planned antenna. The antenna displays simulated bandwidths ($S_{11} \leq -10$dB) of 0.74 GHz (2.64-3.38 GHz), 2.62 GHz (6.40-9.02 GHz) at resonating frequencies of 3.01 and 7.71 GHz, respectively, in mode 1 (Sw1=OFF, Sw2=OFF). With resonating frequencies of 2.44 and 7.59 GHz, the antenna delivers simulated bandwidth ($S_{11} \leq -10$dB) of 0.46 GHz (2.21-2.67 GHz) and 4.17 GHz (5.50-9.67 GHz) in mode 2 (Sw1=ON, Sw2=OFF). The antenna has simulated bandwidths ($S_{11} \leq -10$dB) of 0.71 GHz (2.62-3.33 GHz) and 2.92 GHz (6.07-8.99 GHz) in mode 3 (Sw1=OFF, Sw2=ON), with operating frequencies of 2.98 and 7.53 GHz. The patch has a bandwidth ($S_{11} \leq -10$dB) of 0.36 GHz (2.01-2.37 GHz), 1.56 GHz (4.89-6.45 GHz), and 1.56 GHz (7.39-8.95 GHz) in mode 4 (Sw1=ON, Sw2=ON), and the resonance frequencies are 2.19, 5.67 and 8.17 GHz, respectively. The results (simulated) of the return loss of the intended antenna in various modes are shown in **Figure 3(a)–(b)**. **Figure 4(a)–(b)** shows simulated VSWR Vs frequency (GHz) for the designed antenna. It is found that VSWR is less than 2 for every resonating band indicating optimum matching.

Table 2: Switching modes in the designed antenna

Modes	Sw1	Sw2	Operating Bands (GHz)	Resonant Frequencies (GHz)
Mode1	OFF	OFF	2.64-3.38 / 6.40-9.02	3.01, 7.71
Mode2	ON	OFF	2.21-2.67 / 5.50-9.67	2.44, 7.59
Mode3	OFF	ON	2.62-3.33 / 6.07-8.99	2.98, 7.53
Mode4	ON	ON	2.01-2.37 / 4.89-6.45 / 7.39-8.95	2.19, 5.67, 8.17

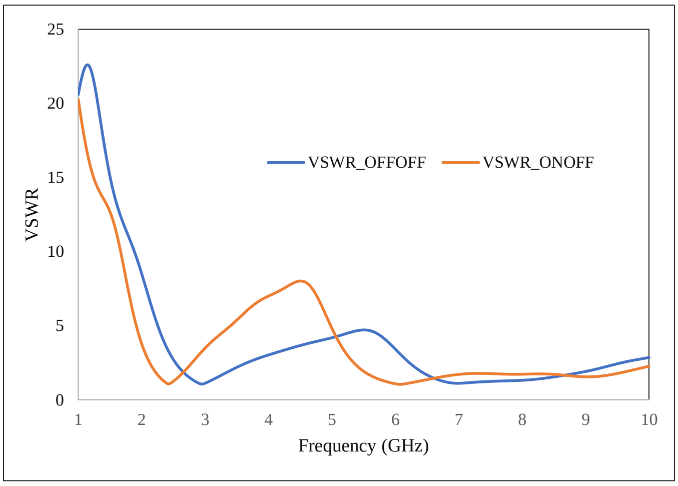


(a)

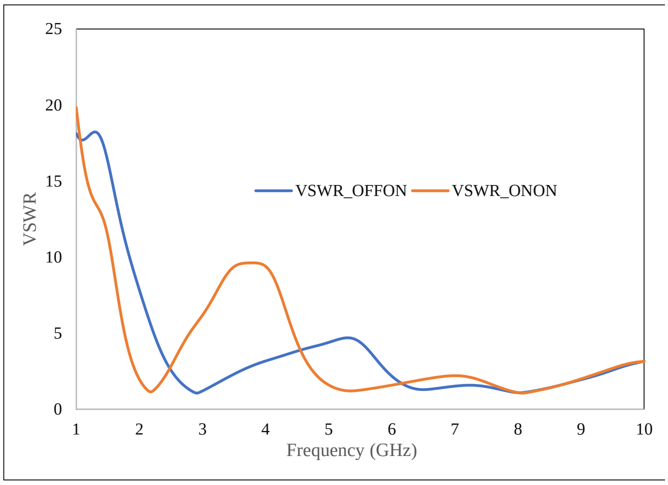


(b)

Figure 3: Return-loss (dB) Vs frequency for **(a)** mode 1-2 **(b)** mode 3-4



(a)



(b)

Figure 4: VSWR Vs frequency (GHz) for **(a)** mode 1-2 **(b)** mode 3-4

Figure 5 illustrates the simulated gain of an antenna varying with frequency. Peak gains of 3.68 dBi, 2.40 dBi, 3.51 dBi, and 2.52 dBi were attained in Modes 1-4, respectively.

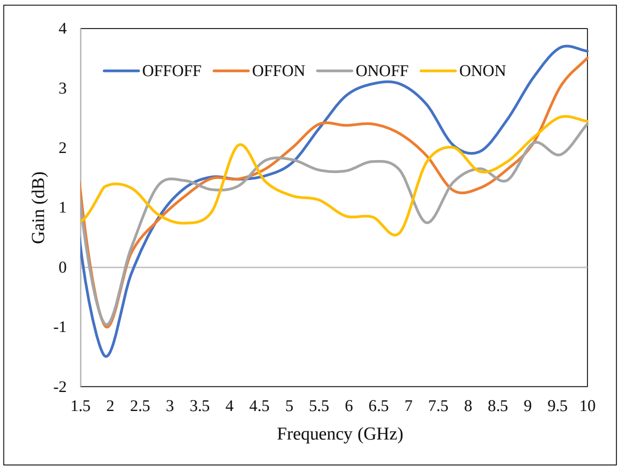


Figure 5: Gain (dBi) Vs frequency (GHz)

Figure 6 displays efficiency of the antenna (simulated) for various modes. The greatest antenna efficiency for Modes 1-4 is observed to be 78.20%, 78.97%, 76.19% and 81.53%.

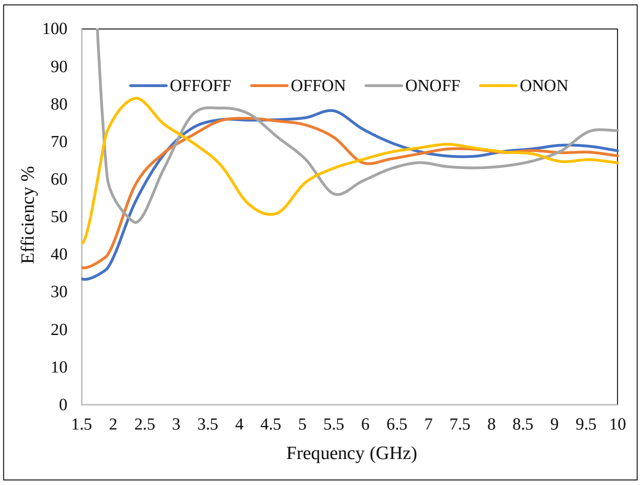
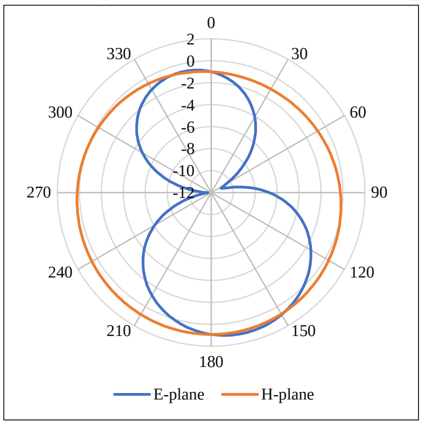
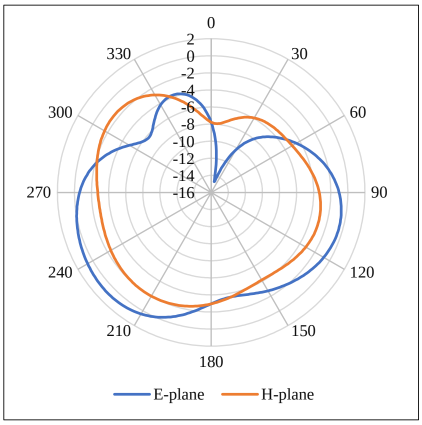


Figure 6: Efficiency (%) Vs frequency (GHz)

For frequencies of 3.01 GHz, 7.71 GHz, 2.44 GHz, 7.59 GHz, 2.98 GHz, 7.53 GHz, 2.19 GHz, 5.67 GHz, and 8.17 GHz, **Figure 7** depicts the simulated radiation patterns of the recommended antennas in the H-plane and E-plane. For frequencies of 3.01 GHz, 2.44 GHz, 2.98 GHz and 2.19 GHz, the gain pattern of the provided antenna is a figure-of-eight and omnidirectional in the E- and H-plane. During reconfiguration, this antenna maintained the required radiation pattern with all the variables present.



(i)



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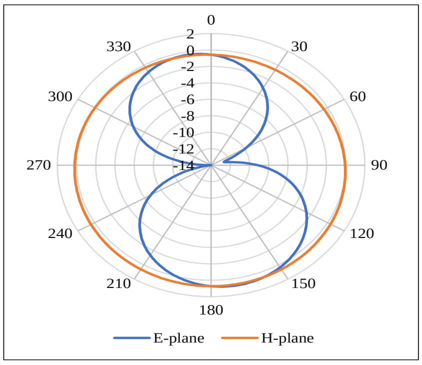

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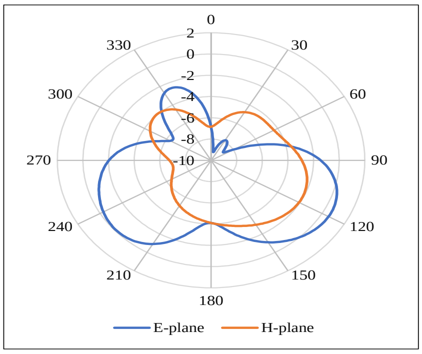

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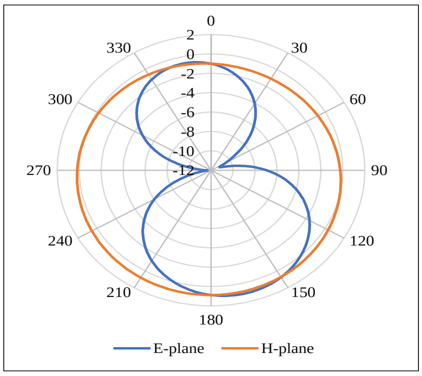

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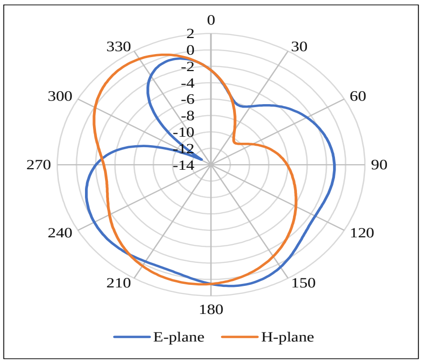

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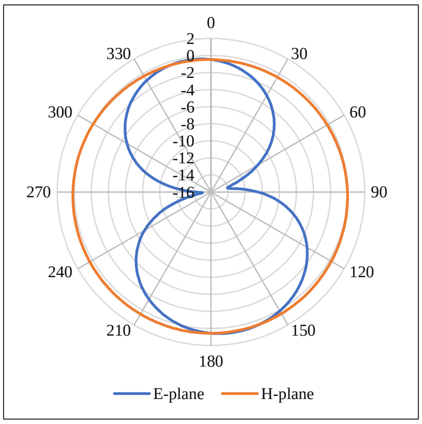

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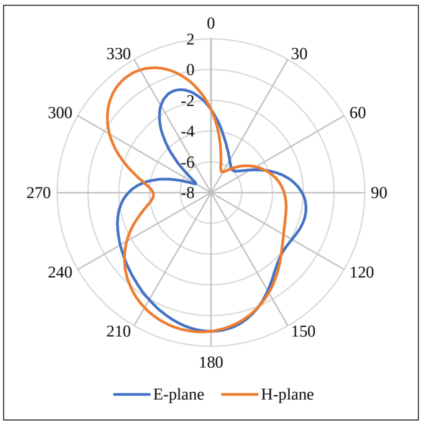
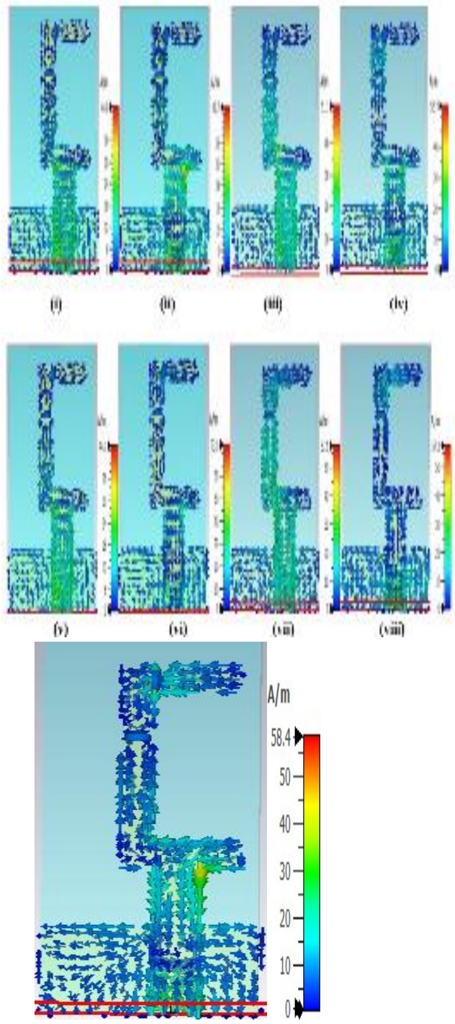


(ix)

Figure 7: The simulated gain pattern of the antenna in H–and E–plane at **(i)** 3.01 GHz **(ii)** 7.71 GHz for mode 1, **(iii)** 2.44 GHz **(iv)** 7.59 GHz for mode 2, **(v)** 2.98 GHz **(vi)** 7.53 GHz for mode 3, **(vii)** 2.19 GHz **(viii)** 5.67 GHz **(ix)** 8.17 GHz for mode 4

Figure 8(i-ii) illustrates the surface current distribution of the designed antenna at 3.01 GHz and 7.71 GHz for mode 1. Subsequently, **Figure 8(iii-iv)** presents the current distribution for mode 2 at 2.44 GHz and 7.59 GHz. Moving on, **Figure 8(v-ix)** showcases the current distribution for modes 3–4 of the reconfigurable antenna at the frequencies 2.98 GHz, 7.53 GHz, 2.19 GHz, 5.67 GHz and 8.17 GHz. These figures reveal that a adequate level of surface current density is attained, with the highest current distribution in the microstrip antenna reaching 73.6 A/m.



(ix)

Figure 8: Current distribution at **(i)** 3.01 GHz **(ii)** 7.71 GHz for mode 1, **(iii)** 2.44 GHz **(iv)** 7.59 GHz for mode 2, **(v)** 2.98 GHz **(vi)** 7.53 GHz for mode 3, **(vii)** 2.19 GHz **(viii)** 5.67 GHz **(ix)** 8.17 GHz for mode 4

Table 3 provides a comparison of this work with reference. The antenna is smaller than other antennas reported and achieves a larger bandwidth compared to other antennas that have been studied earlier.

Ref.	Dimensions (mm^2)	No of switches	No of operating bands	Frequency (GHz)	-10 dB BW MHz
[6]	35x40	1	3	2.45, 3.50, 5.20	330-1250
[7]	35x53	1	3	2.45, 3.50, 5.20	147–1820
[9]	39x37	1	3	2.45, 3.0, 5.20	550-1220
[14]	35x40	2	6	2.1, 2.4, 3.3, 3.5, 5.28, 5.9	335-1220
[15]	35x40	1	3	2.45,3.45, 5.4	490-1360
[16]	60x60	3	5	2.4, 4.26, 4.32, 4.58, 5.76	60-170
[8]	40x22	1	4	2.45, 5.13, 3.49, 5.81	750-1260
[17]	37x35	2	4	2, 3.4, 2.4, 3.1	200-960
This work	33x16	2	8	2.19, 2.44, 2.98, 3.01, 5.67, 7.53, 7.59, 7.71, 8.17	360-4170

Conclusion

This work introduces a frequency-reconfigurable microstrip patch antenna in a C-shape configuration, employing PIN diodes as switches. To minimize implementation costs, an affordable FR4-epoxy substrate material and a simple microstrip feedline are utilized. The proposed antenna operates in four modes, transitioning between dual-band operation in Modes 1-3 and triple-band operation in Mode 4. Bandwidths of 0.36 GHz, 0.46 GHz, 0.71 GHz, 0.74 GHz, 1.56 GHz, 2.92 GHz, 4.17 GHz, 2.62 GHz, and 1.56 GHz are achieved at resonating frequencies of 2.19 GHz, 2.44 GHz, 2.98 GHz, 3.01 GHz, 5.67 GHz, 7.53 GHz, 7.59 GHz, 7.71 GHz, and 8.17 GHz, respectively. Despite its compact size, this antenna offers easy integration with various devices, making it suitable for applications such as UMTS, Bluetooth, WLAN, high-frequency LTE, S-DMB, WiMAX, C and X band applications.

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