A 28/38 GHz tuned reconfigurable antenna for 5G mobile communications

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ABSTRACT

In this paper, a compact tuned reconfigurable microstrip antenna for fifth generation (5G) mobile communications is designed to operate at 28 GHz or 38 GHz or both frequencies. The proposed antenna can be reconfigured by using a group of PIN diodes switches across a slit in the upper traditional patch antenna or through the ground plane side. The tuning between the 28 GHz and 38GHz frequency bands can be achieved through ON/OFF states of the PIN diodes switches. The tuned reconfigurable antenna is simulated using CST software package and then fabricated and measured. The simulated and measured results show good agreement with a little deviation. The proposed tuned antenna is small in size with 18×11.25 mm^2 overall area.

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1. INTRODUCTION

Fifth generation (5G) mobile communications networks have a great effect on modern technology. This technology aims to deliver higher data speeds up to several gigabits per second, greater reliability, very low latency, substantial network capacity, higher performance, and improved efficiency. The 5G technology is not only the expected generation of mobile communications from 1G to 4G, but introduces a new approach that offers ubiquity of connectivity for application as automotive communications, large video downloads and low data rate applications, including remote sensors and both of internet of things (IoT) and industrial internet of things (IIoT).

The frequency bands for 5G mobile communications are currently believed to be 28/38 GHz and 60/73 GHz for mobile and wireless communication, respectively [1], [2]. Many researchers have studied millimeter wave (MMW) frequency bands antennas and a lot of recent multiband antenna structures have been designed for 5G cellular communication networks. Many antennas can operate at only single band at 28 GHz [3] or at 38 GHz [4] or with wide bandwidth covering 28 GHz or 38 GHz [5]–[9]. Anab *et al.* [10] used each of rectangular dielectric resonator antenna (DRA) and rectangular patch antenna for their design. The resonance frequencies for the DRA were 25.4 GHz, 34.6 GHz, and 38 GHz with wide bandwidth covering 28 GHz, while the microstrip antenna was operating at 28 GHz and 38 GHz. A tri-band antenna was presented at [11] to operate at 4.7 GHz, 28 GHz, and 39 GHz for 5G sub-6 GHz and MMW communications. Another dual band antenna [12] at 24 and 28 GHz with maximum gain of 3.99 dBi was constructed by using two rectangular radiating patches and a partial ground. Marzouk *et al.* [13] developed three multi-input multi-output (MIMO) antenna structures for operating at 28 GHz and 38 GHz. Also, a dual band microstrip antenna was constructed in [14] to operate at both 38 GHz, and 60 GHz for 5G mobile handsets. Shareef *et al.* [15] designed a multiband antenna covered the range of frequencies 33 GHz, 34.5 GHz, 41.1 GHz, and 42.4 GHz. Other microstrip antennas with partial ground in [16] were operated at 25.87 GHz, 38.75 GHz, 43G GHz, 46.25 GHz, 48.7 GHz, 51.5 GHz, 71 GHz, and 83.5 GHz. Another dual band antenna [17] at 28 GHz and 38 GHz had a circular patch as primary patch and secondary parasitic patch element. The antenna was implemented for a single element and two-port MIMO antenna [17]. Also, another dual band four-port MIMO antenna at 28 GHz and 38 GHz was discussed in [18], the single antenna element was a rectangular patch with slots and a circular stub with a small size of 13×15 mm^2. A tri-band antenna at 28 GHz, 38 GHz, and 55 GHz (V-band) was described in [19], [20].

On the other hand, one of the 5G antennas requirements is the use of frequency reconfigurable antennas where the same antenna can be used for several communications modes like cognitive radio communications or diversity. Additionally, by utilising frequency reconfiguration, an efficient use of the spectrum as well as power consumption are realized. There are many different mechanisms to achieve reconfigurability through using PIN diodes, microelectromechanical systems (MEMS), varactors, mechanical actuators, optical switches, liquid crystals, and metamaterials. These techniques can control the surface's current distribution of the antennas, achieving a modification to the antenna's properties. In general, the MMW antennas design should be low profile, low cost, planar design, high performance, and compact in size.

Many recent frequency reconfigurable antennas for 5G applications were presented in [21]–[31]. A patch antenna in [21] was designed to switch between 2.4 GHz according to the Wi-Fi application and 28 GHz band for 5G applications by using a metal pad. Another reconfigurable antenna was established in [22] to operate at either 28 GHz or 38 GHz by using two MEMS switches. A metamaterial reconfigurable antenna was constructed in [23], where the antenna structure consisted of a 3×3 array of nine unit-cells, and the unit cell was a split ring resonator surrounding a hexagonal patch. Two pin diodes were used to connect another two-unit cells to the array antenna. Another reconfigurable array antenna in [24] was presented to operate at 28 GHz or 38 GHz using two diodes above each T-slot antenna [24].

Costa *et al.* [25], presented an optically controlled frequency reconfigurable slotted-waveguide antenna using silicon photoconductive switches to switch between 28 GHz and 38 GHz frequency bands. Another reconfigurable antenna consisted of two patches, and parasitic stubs on the ground plane with n-channel metal-oxide semiconductor (NMOS) transistor switches was presented in [26]. A hybrid reconfigurable antenna was developed for pattern and frequency switching between 28 GHz and 38 GHz using PIN diodes switches [27]. Shereen *et al.* [28] discussed the same reconfiguration in [27], where the antenna resonance frequency in [28] was at 26.4 GHz covering the 24.2 to 26.5 GHz band or at 28 GHZ, covering the band of 27.4 to 29.8 GHz. Shereen *et al.* [29] presented a hybrid reconfigurable antenna at 28/38 GHz using PIN diodes. Azam *et al.* [30] described a reconfigurable antenna that operating at frequency bands 25.6 and 39.3 GHz and Jilani *et al.* [31] introduced reconfigurable antenna that was operated at the frequency band 27.3 to 40 GHz.

In this paper, the presented tuned reconfigurable antenna is achieved by etching a slit through the antenna's ground plane or the antenna patch that was previously described in article [10] where the antenna was semi-elliptical slot rectangular patch antenna. The presented tuned antenna is developed for frequency switching between 28 GHz or 38 GHz or both bands. A number of PIN diodes switches are employed over each slit to control the current distribution over the antenna. The proposed tuned reconfigurable antenna is constructed using Rogers RT/Duroid5880 with overall size 18×11.25×0.787 mm^3. The presented antenna can operate either at 28 or 38 GHz or both frequencies which is different from [22], [24], [27], [31] that operated only at 28 GHz or 38 GHz. Although the antenna in [29] could operate at 28 or 38 GHz or both frequencies, it had a large size (54×114×0.508 mm^3 and ε_r=2.2) compared to our proposed antenna size. The antenna is suitable for 5G mobile communications; and achieving realizable power consumption in addition to an efficient use of the frequency spectrum. All details of the design, simulation, fabrication and measurements will be described in the following sections.

2. PROCEDUERS FOR THE PROPOSED TUNED RECONFIGURABLE ANTENNA

The basic dual band microstrip antenna is constructed on Rogers RT/5880 (ε_r=2.2, h=0.787 mm, tanδ=0.0009). The dimensions of the conventional rectangular patch antenna with semi-elliptical slots and the antenna surface current distribution are shown in Figures 1 and 2, respectively. As seen in Figure 2(a) and Figure 2(b), the radiation is concentrated around the antenna patch and the feeder's edges.

It is well known that antenna operating frequency can be altered by adjusting the antenna's effective length. Consequently, the antenna surface current distribution is changed and the resonance frequency is modified. The proposed 28/38 GHz tuned reconfigurable antenna is modified by making a slit in the antenna patch or in the ground plane (Figure 3). The slit in the ground plane is responsible for rejecting the 28 GHz band, while the rejection of the 38 GHz resonance frequency is due to the slit in the antenna patch as seen in Figure 3(a) and Figure 3(b). Based on those modifications of the antenna structure, the antenna can operate either at 28 or at 38 GHz or at both frequencies (Figure 4). For achieving the resonance frequency selection, a group of PIN diodes switches are used as shown in Figure 4(a) and Figure 4 (b). An additional two conducting strips are connected to the antenna feeder for improving the frequency response at 28 GHz resonance (will be discussed in section 3), Figure 4(a). In Figure 5, the tuned reconfigurable antenna's simulated current distribution is depicted. Where for case-1, Figure 5(a) shown the distribution of the surface current is mainly concentrated on the patch antenna and around the edges of the antenna when it resonates at 28 GHz, while no current is distributed on the patch at 38 GHz. For case-2, Figure 5(b) shown the current is distributed on the antenna surface at 38 GHz, while at 28 GHz, there is no distribution of current. For case-3, Figure 5(c) displays the current distribution for the operation of the dual bands that is compatible with Figure 2 for the complete patch antenna without any slits.

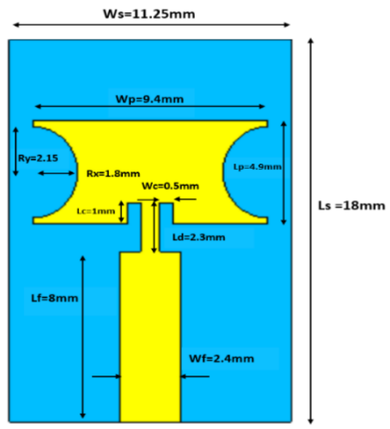
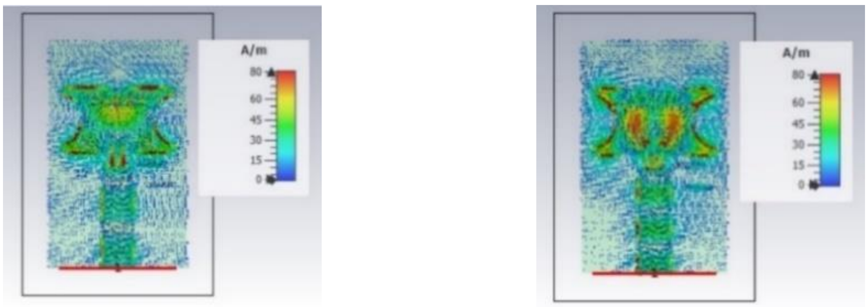
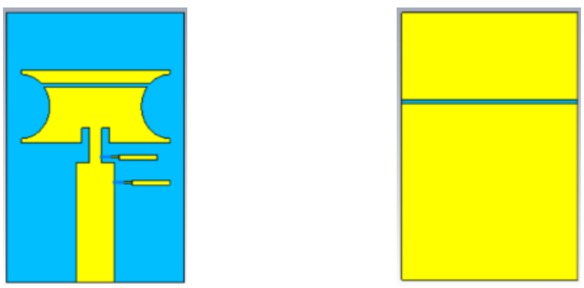


Figure 1. The structure of basic dual band microstrip antenna



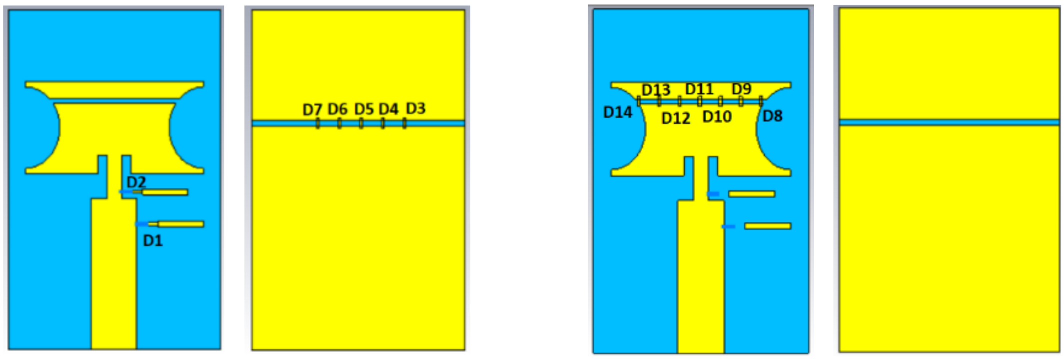
(a) (b)

Figure 2. The surface current distribution for the basic dual band antenna at (a) 28 and (b) 38 GHz



(a) (b)

Figure 3. The antenna slit in (a) the antenna patch to reject 38 GHz and
(b) the ground plane to reject 28G Hz



Top view Bottom view
(a)

Top view Bottom view
(b)

Figure 4. The proposed antenna structure with different diodes states to resonate only at (a) 28 and (b) 38 GHz

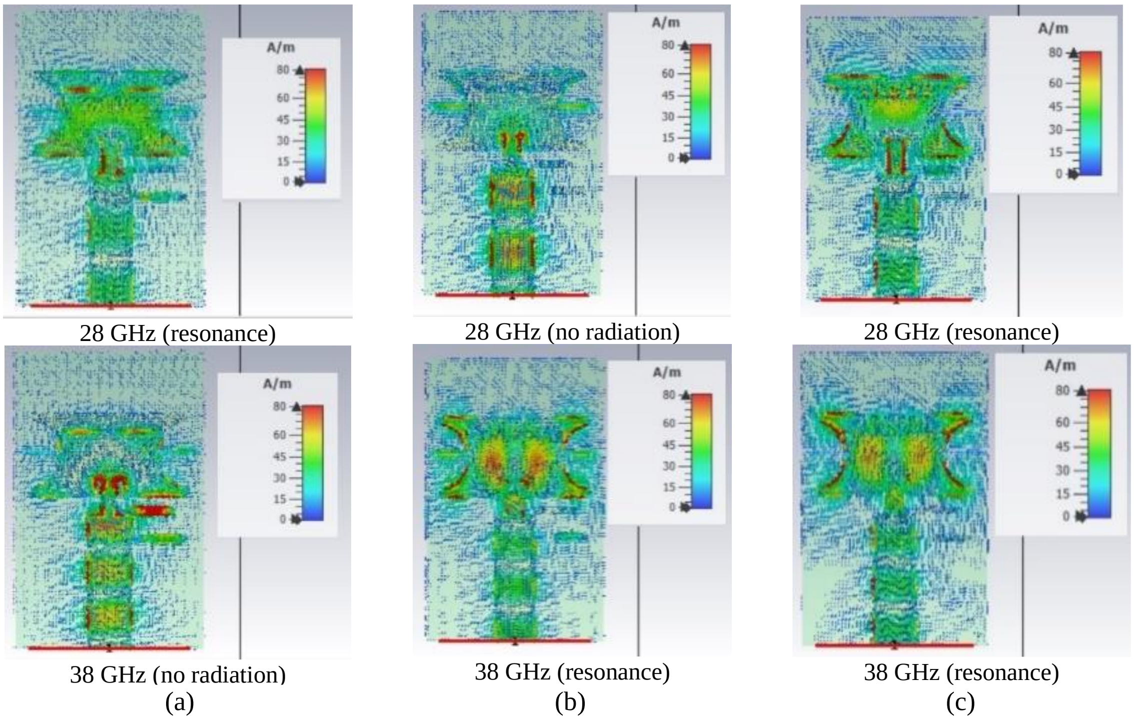


Figure 5. The surface current distribution for the proposed tuned reconfigurable antenna at (a) 28 GHz resonance (case-1), (b) 38 GHz resonance (case-2), and (c) dual bands (case-3)

3. DISCUSSION OF SIMULATED AND MEASURED RESULTS

The simulated S_{11} result for the basic dual band antenna using the CST readymade software package is shown in Figure 6. The simulation results indicate an acceptable return loss of −18.7 and −30.6 dB at 28 and 38 GHz resonance frequencies, respectively. Also, the antenna's simulated gain is displayed in Figure 7 achieving 6.27 and 5.35 dBi; at the frequencies 28 GHz and 38 GHz; respectively. Figure 8 gives the simulated dual band antenna's radiation patterns, provide nearly omnidirectional radiation patterns in both E and H-planes at both frequencies, Figure 8(a) and Figure 8 (b). Furthermore, the 3D gain graphs for both frequencies are shown in Figure 9, Figure 9(a) for 28 GHz while Figure 9(b) for 38 GHz. With using CST software package for the proposed tuned reconfigurable antenna design, Table 1 illustrates the ON/OFF states for the diodes and the corresponding resonance frequency value and its return loss value $|S_{11}|$. The sketch for the return loss $|S_{11}|$ for each case is seen in Figure 10.

Table 1. Diodes group states and its corresponding resonance frequency

	Resonance frequency (GHz)	PIN diodes (D1 and D2)	PIN diodes (D3 to D7)	PIN diodes (D8 to D14)	S_{11}(dB)
Case-1	28.0	ON	ON	OFF	-26.4
Case-2	38.0	OFF	OFF	ON	-28.6
Case-3	28.0 and 38.0	OFF	ON	ON	-12.03 and -25.9

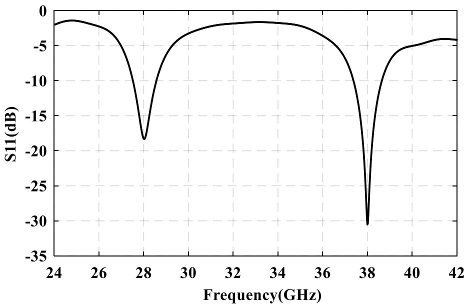


Figure 6. The Simulated S_{11} results of the basic dual band microstrip antenna

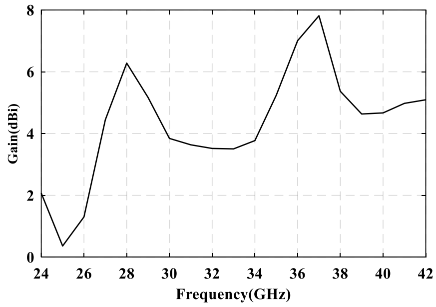
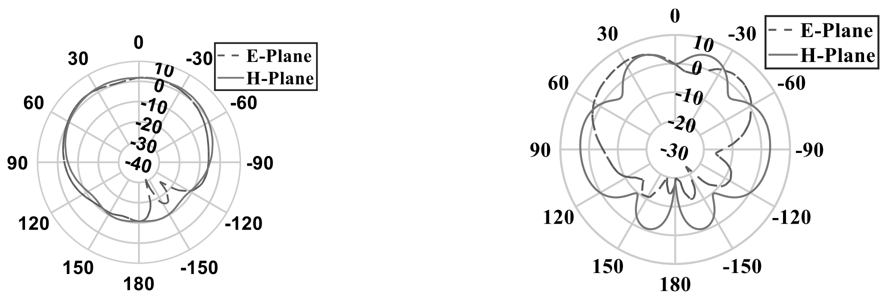


Figure 7. The simulated gain for the basic dual band microstrip antenna

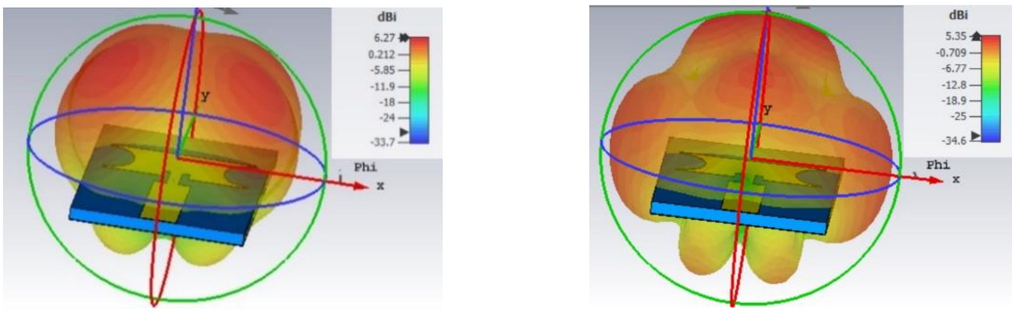


(a) (b)

Figure 8. The basic dual band antenna's simulated radiation patterns at (a) 28 GHz and (b) 38 GHz

Furthermore, the 3D gain pattern plots for case-1 (28 GHz resonance), case-2 (38 GHz resonance), and case-3 (28 and 38 GHz) are given in Figure 11, achieving 7.4, 5.11 dBi at 28, 38 GHz and 6.72, 5.71 dBi at 28 GHz, 38 GHz, respectively as seen in Figures 11(a)-(c). By adding two additional strips near the antenna feeder, the return loss (S_{11}) for the harmonics at 42 GHz is smaller than this without the use of the conducting strips, Figure 12.

A parametric study is done for the effect of number of PIN diode on the resonance frequencies. Seven PIN diodes and five PIN diodes are used for the patch slit and the ground slit, respectively. If the number of used PIN diodes decreases, the resonance frequency at 28 GHz in the dual band mode (case- 3) is slightly shifted. Figures 13 and 14 illustrate a parametric study for the effect of using different numbers of PIN Diodes in both slits to achieve a suitable return loss (S_{11}) especially at 28 GHz resonance frequency in the dual mode operation (case-3).



(a) (b)

Figure 9. The 3D view simulated gain plots for the basic dual band antenna at (a) 28 GHz and (b) 38 GHz

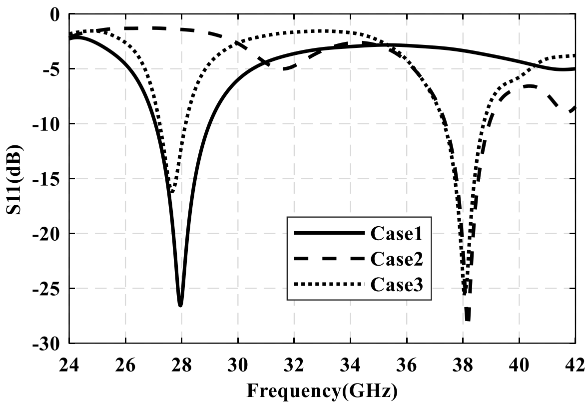


Figure 10. The simulated return loss S_{11} for different resonance frequencies for the proposed tuned reconfigurable antenna (28 GHz, 38 GHz, and both bands)

The proposed tuned reconfigurable antenna is fabricated using thin film technology and photolithographic techniques followed by measurements made with a vector network analyzer (VNA) Rohde and Schwarv model ZVA67 (10-67 GHz). Due to the unavailability of PIN diodes switch matrix box, two circuits are fabricated for short circuit (S.C) and open circuit (O.C) instead of (ON/OFF state) of the PIN diodes to realize case-1 and case-2. Figure 15 shows the results of $|S_{11}|$ simulation and measurements for the first two cases presented in Table-1, Figure 15(a) for case-1 and (b) for case-2. The little deviation between the results from simulation and measurement is caused by fabrication tolerance and connector mismatch. An acceptable bandwidth of 1.53 GHz and 2.21 GHz (where S_{11}<-10 dB) can be noticed at resonance frequencies 28 GHz and 38 GHz, respectively. Figure 16 shows the experimental setup used to measure the radiation patterns of the proposed tuned antenna. Figure 16(a) shows the schematic diagram for the radiation pattern measurements. The VNA which operates in two-port measurement mode is used to measure each transmission coefficient S_{21} for the antenna under test and the standard gain horn antenna (model LB-28-10 (26.5-40 GHz)) as shown in Figure 16(b). The measured E-and H-planes radiation patterns for the proposed tuned reconfigurable antenna at the frequencies 28 GHz and 38 GHz are given in Figure 17. It is clear that the radiation patterns that were simulated and those that were measured are compatible with little deviation, Figure 17(a) and Figure 17(b). The proposed antenna gives a nearly omnidirectional radiation pattern for both E and H-planes at 28 GHz and 38 GHz. Also, the simulated and measured proposed antenna gain are shown in Figure 18. The measured gain is 6.95 dBi at 28 GHz, and 5.2 dBi at 38 GHz as seen in Figures 18(a) and 18(b). Table 2 illustrates a comparison between the presented tuned reconfigurable antenna and the basic dual band antenna in [10], where the data rate is calculated using Nyquist bit rate equation, [10]. It is obvious that the proposed tuned reconfigurable antenna has better return loss, bandwidth and bit rate than basic dual band antenna in [10]. Table-3 gives a comparison between the presented tuned reconfigurable antenna and different other 5G antennas in the literature.

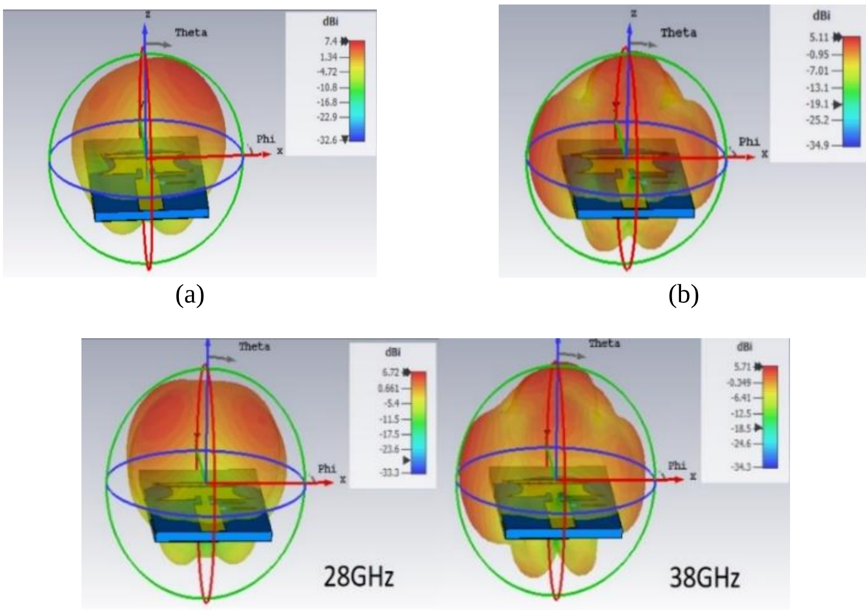


Figure 11. 3D view of simulated gain pattern plots for the tuned reconfigurable antenna at (a) case-1 (28 GHz), (b) case-2 (38 GHz), and (c) case-3 (28 GHz and 38 GHz)

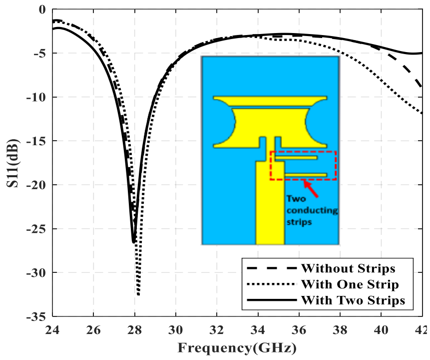


Figure 12. The simulated S_{11} for the tuned reconfigurable antenna at 28 GHz (case-1) with and without using conducting strips

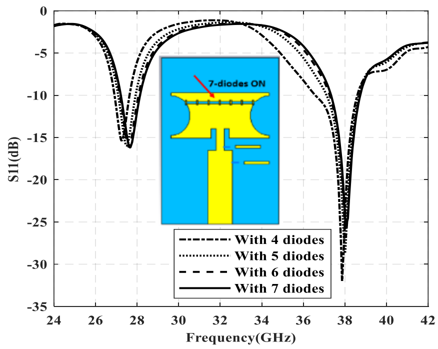


Figure 13. Variation of $|S_{11}|$ against a number of PIN diodes used in the antenna patch slit in the dual mode (case-3) of the proposed tuned reconfigurable antenna

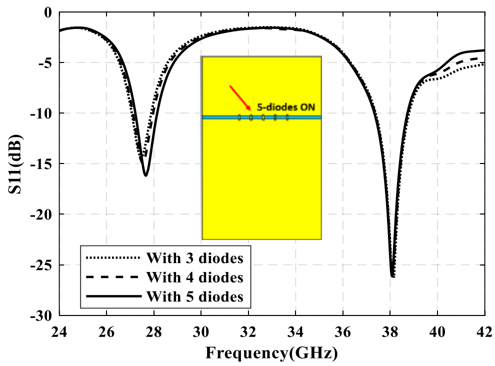
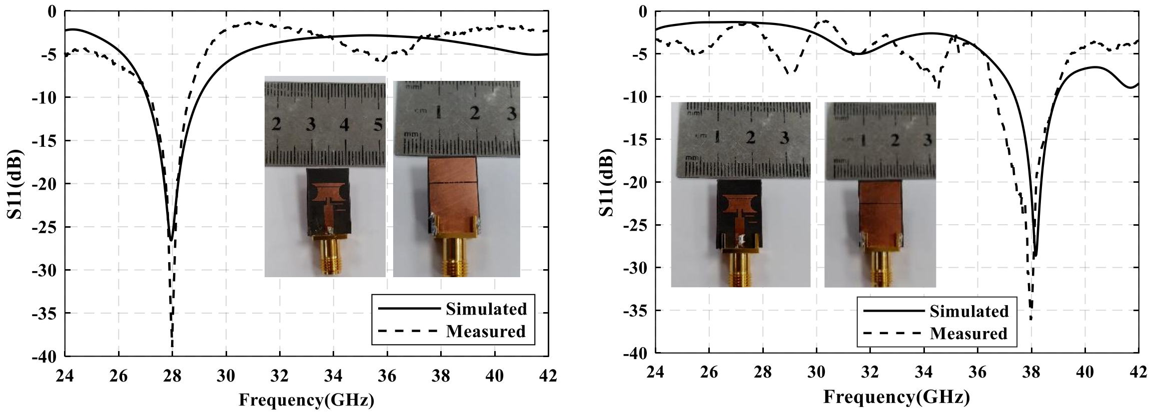
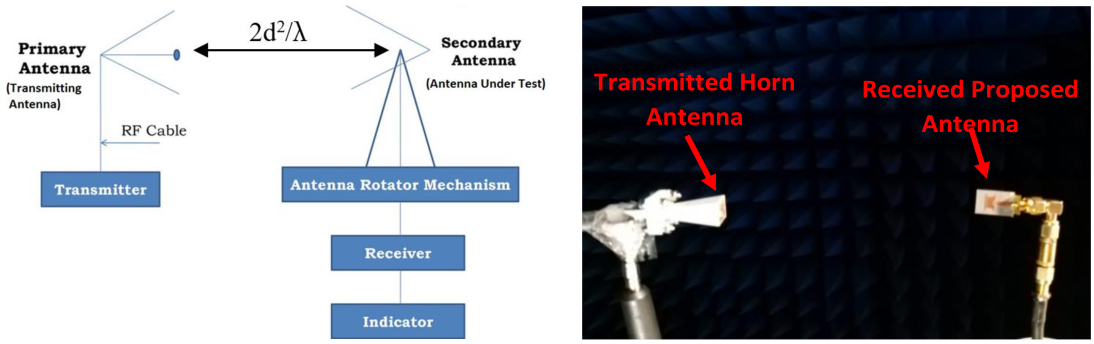


Figure 14. Variation of $|S_{11}|$ against a number of PIN diodes used in the antenna ground slit in the dual mode (case-3) of the proposed tuned reconfigurable antenna



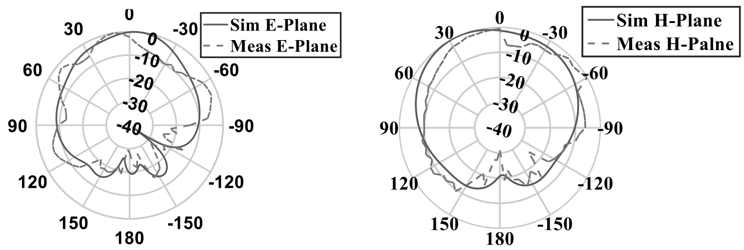
(a) (b)

Figure 15. The simulated and measured S_{11} results of proposed tuned reconfigurable antenna at (a) case-1 (28 GHz) and (b) case-2 (38 GHz)

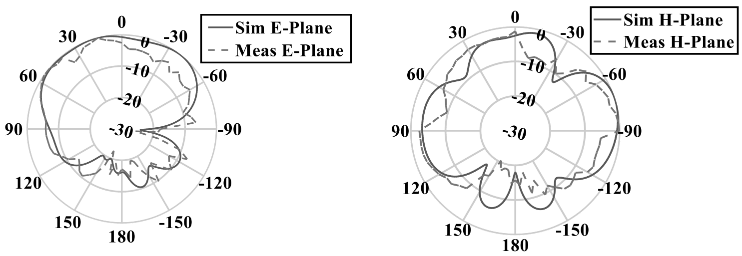


(a) (b)

Figure 16. The setup for radiation pattern measurements (a) schematic diagram and (b) experimentally setup



(a)



(b)

Figure 17. The simulated and measured normalized radiation patterns for the proposed tuned reconfigurable antenna at (a) 28 GHz (case-1) and (b) 38 GHz (case-2)

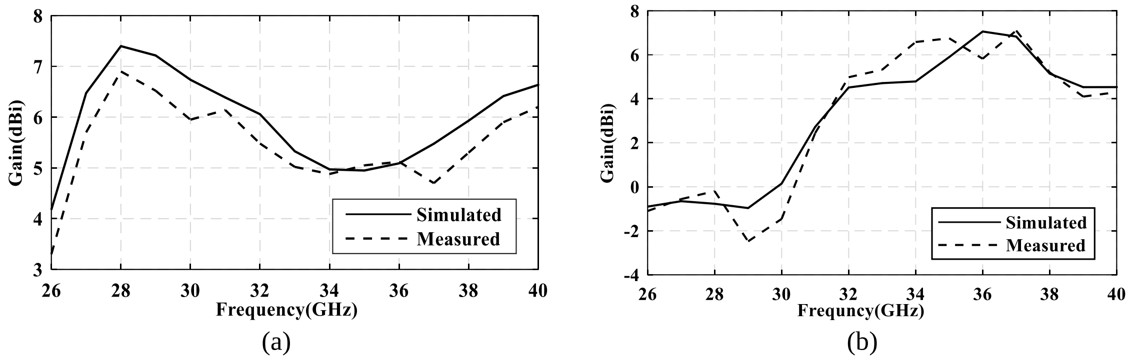


Figure 18. The simulated and measured gain vs the frequency for the proposed reconfigurable antenna at (a) 28 GHz (case-1) and (b) 38 GHz (case-2)

Table 2. Comparison of proposed tuned reconfigurable antenna over basic dual band antenna in [10]

Antenna characteristics	Resonance frequency (GHz)	Measured S_{11} (dB)	Measured bandwidth (GHz)	Measured gain (dBi)	Bit rate (Gbps)
Dual band antenna [10]	28.0	-23.6	1.49	5.41	2.98
	38.0	-27.1	1.01	4.89	2.02
The proposed reconfigurable antenna	28.0	-38.8	1.53	6.95	3.06
	38.0	-37.2	2.21	5.2	4.42

Table 3. Comparison of proposed tuned reconfigurable antenna with other 5G antennas

Ref	Antenna size (mm^2)	Substrate (ε_r, h in mm)	Resonance frequency (GHz)	Frequency reconfigurable?	S_{11} (dB)	Max gain (dBi)
[10]	13×11.25	Rogers RT 5880 (ε_r =2.2, h=0.787)	28.0 38.0	No	-23.6 -27.1	5.41
[11]	30×22	Rogers RT 5880 ($\varepsilon_{r=}$ 2.2, h=0.508)	4.7 28.0 39.0	No	-17.5 -15 -14	7.06
[12]	25×20	FR-4 (ε_r =4.4, h=1.6)	24.0 28.0	No	-14.86 -32.72	3.99
[13]	55×110	Rogers RT 5880 ($\varepsilon_{r=}$ 2.2, h=0.508)	28.0 38.0	No	−21.57 −24.59	8.27
[14]	15×25	Rogers Ro3003 ($\varepsilon_{r=}$ 3, h=0.25)	38.0 60.0	No	-32.5 -19.8	6.2
[17]	19.3×8.8	Rogers Ro3003 ($\varepsilon_{r=}$ 3, h=0.25)	28.0 38.0	No	-17 -29	6.2
[19]	8×8	Rogers RT/duroid 5870 ($\varepsilon_{r=}$ 2.33, h=0.79)	28.0 38.0 55.0	No	-27 -28 -21	7.35
[21]	26.5×30	FR4 ($\varepsilon_{r=}$ 4.4, h=1.6)	2.4 28.0	Yes	-22.39 -22.15	-
[24]	39.8×3.25	Rogers RT 5880 ($\varepsilon_{r=}$ 2.2, h=0.508)	28.0 38.0	Yes	-20 -20	-
[25]	3.56×49.9	-	28.0 34.0 38.0	Yes	-15 -25 -17	-
[26]	112×52	Rogers RT 5880 ($\varepsilon_{r=}$ 2.2, h=0.508)	28.0 38.0	Yes	-35 -33	7.1
[27]	23.5×25.5	RT Duroid 5870 (ε_r=2.33, h=0.506)	28.0 38.0	Yes	-32.3 -42.1	10.2
[28]	23×25	RT Duroid 5870 (ε_r=2.33, h=0.506)	26.4 28.0	Yes	-40 -39	4.8
[29]	54×114	Rogers RT 5880 ($\varepsilon_{r=}$ 2.2, h=0.508)	28.0 38.0	Yes	-34.5 -37.3	9.01
[30]	10.72×7.24	Rogers RT 5880 ($\varepsilon_{r=}$ 2.2, h=0.381)	25.6-39.3 (covering 28, 38)	Yes	< -10	8.4
[31]	11×25.4	PET Film ($\varepsilon_{r=}$ 3.2, h=0.135)	27.3-40 (covering 28, 38)	Yes	< -10	6.2
Proposed work	18×11.25	Rogers RT 5880 (ε_r =2.2, h=0.787)	28.0 38.0	Yes	-38.8 -37.2	6.95

4. CONCLUSION

In this paper, a compact tuned reconfigurable microstrip antenna at 28/38 GHz is designed, simulated and measured. The proposed antenna can be reconfigured by using a group of PIN-diodes switches across a slit in the antenna patch or through a ground slit. The results from simulation and measurement are in good agreement, with very little deviation shown as a result of fabrication tolerance and connectors mismatch. The proposed tuned reconfugurable antenna operates at 28 GHz with measured return loss ≤ -38.8 dB and 6.95 dBi gain or at 38 GHz with measured return loss ≤ -37.2 dB and 5.2 dBi gain. The proposed antenna can operate at 28 GHz or 38 GHz or at both frequencies which is different from the other antennas in the literature survey that operated only at 28 GHz or 38 GHz. The designed antenna is appropriate for 5G mobile communication applications.

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