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Compact and Switchable Printed Antenna Covering mm-wave for 5G system.

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Abstract

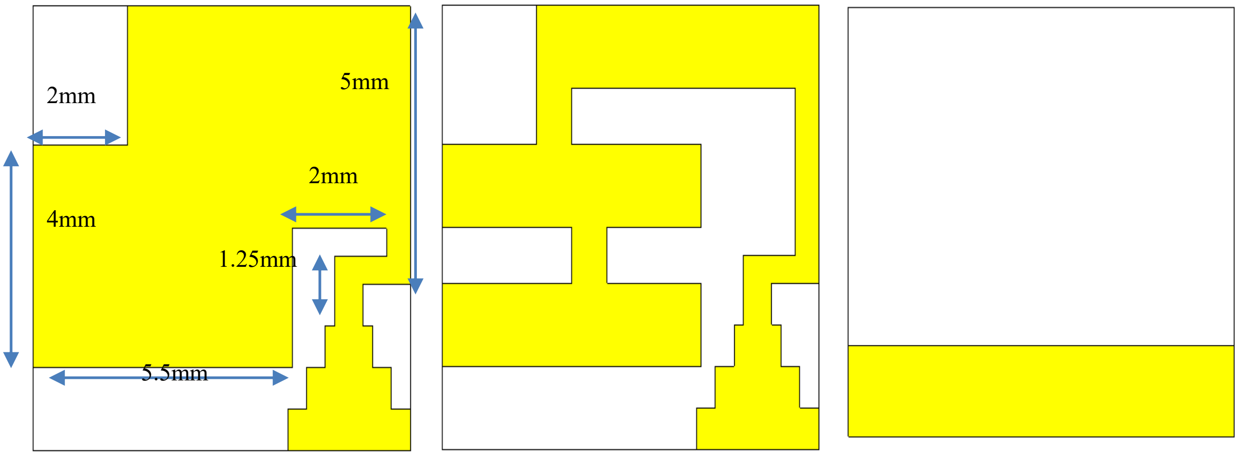
In recent years, there has been a growing demand for reconfigurable antennas in 5G (mm-wave band) applications. These antennas are designed to adapt and adjust their radiation patterns, polarization, or operating frequencies to meet the various requirements of 5G application. The main advantage of reconfigurable antennas is their ability to avoid noisy environments and direct the signal towards the intended user. Given the rapid growth of wireless communication, particularly in the context of 5G technology, researchers are handled with the task of developing an antenna that is smaller in size, but capable of providing a wider bandwidth and higher gain. This study constructs a compact-frequency reconfigurable antenna with three PIN diodes to operate in the millimetre-wave frequency range for use in 5G communication systems. We designed the suggested antenna using a Roger RT 5880 substrate, which has a relative dielectric constant of 2.2 and a thickness of 0.8 mm. This antenna covers a dual band of frequencies (25.3, 26.1, 28.2, 29, 45.6, 56.5) GHz by simply switching the diodes ON/OFF. The total dimension of the antenna is $8 \times 8 \times 0.8$ mm^3. This antenna is not only compact, but it also offers a great gain that varies from 3.61 to 6.34 dB, as well as 97% efficiency, bandwidth 14.9 GHz in the 5G bands. It was simulated using CST 2018 software package.

1. Introduction

The development and implementation of fifth-generation (5G) communication systems requires a thorough understanding of propagation channels and extensive channel estimation due to the need for faster and more responsive wireless networks that offer broader coverage and higher data rates [1]. With the progress in wireless communication systems and technologies, an increasing attention is being given to frequency reconfigurable antennas. These antennas possess the ability to alter and manipulate their characteristics, rendering them highly adaptable to various wireless systems. Through modifying the frequency range [2], radiation pattern [3], or polarization [4], these antennas can fulfill the requisites of diverse wireless systems. The act of altering the current distribution of the radiator is known as reconfigurability. One way to do this is by using various switches, such as Varactor diodes [5], PIN diode [6], RF-MEMS switches [7], lumped elements, and photo conducting switches [8]. In scenarios where multiple wireless standards require support, frequency reconfigurable antennas are notably advantageous as they can easily adjust to operate within different frequency bands [9]. Furthermore, these antennas provide the benefit of being able to conform to evolving wireless standards and technologies, making them a versatile and future-proof solution. A dual-band or multi-band antenna can be created by incorporating slots of various shapes, such as U slots, T slots, I slots, L slots, rectangular slots, V slots, fork-shaped slots, etc. These slots alter the flow and distribution of current. Slotting allows you to create a trapezoidal slot on the radiating patch and a rectangular slot on the ground plane [10]. Many researchers offered a reconfigurable antenna that works within mm-wave, 5G band [11], [12], [13], [14], [15], [16], [17]. In [11], the researchers created with an overall dimension of $18\times11.25\times0.787$ mm^3, using Rogers RT/Duroid5880. However, the design was very complex, using many PIN diodes to achieve reconfigurability. In addition, the antenna had a large size associated for the recommended antenna size. Reference [12] indicated the configuration. The reconfigurable antenna is a unidirectional-printed antenna consisting of a tuning fork structure with two prongs of different lengths. The antenna was constructed with a flexible sheet of LCP Rogers ULTRALAM 3850 substrates, specifically the Roger R5A model. The antennas dimensions were 16×14 mm^2. Already in the works, these systems will probably operate in a range of switch topologies from 20.7 to 36. However, the radiating patch and the antenna's size, which have a tuning fork-like form and are fed by a 50-matched coplanar waveguide (CPW) feeding structure, have made the design more complicated. Researchers in [13] requested to have developed a reconfigurable antenna with a size of $12\times12\times0.8$mm, operating at MMW frequencies, specifically designed for 5G networks, where the patch's structure consists of a Y shape. Both sides of the feed line symmetrically distribute the patch. However, include a restricted bandwidth, poorer gain. This feeding technique, known as the coplanar waveguide (CPW) feeding technique, achieves reconfigurability because there is no connection between the patch and the strip. A dual-band microstrip patch antenna for 5G mobile phones, operating at frequencies of 38 and 60 GHz was reported in [14]. The microstrip patch antenna under consideration is fabricated on a Rogers RO3003TM substrate with a dielectric constant (εr) of 3.0. The substrate has dimensions of $15\times25\times0.25$mm. To ensure optimal impedance matching and create balloon-shaped radiation patterns over both the lower and higher frequency bands of operation, the single antenna design combines two rectangular patches with specific geometric alterations. The microstrip line serves as the primary transmission line for the first patch, generating radiation in the lower band (38 GHz), while capacitive and inductive feeds generate radiation in the higher band (60 GHz). However, no practical solution for reconfigurability is available. The frequency operates exclusively at either 38 GHz or 60 GHz. A rectangular patch antenna array with dimensions of 4×2 was described in [15]. A parallel network using microstrip technology supplied the array. The substrate used is a fused quartz with a dielectric permittivity of 3.75 (εr). The antenna has dimension of $25.4\times25.4\times0.2$mm^3. Despite the fact that the stated 4×2 array antenna designs showed a single band of operation, the antenna was large and non-reconfigurable. A different approach in [16] has been studied to create a millimeter-wave (MMW) frequency-reconfigurable antenna for two important fifth generation (5G) bands, with an overall size of $11\times9\times0.787$ mm^3. A coplanar waveguide (CPW) feeds a slotted T-shaped patch in the suggested design. The operating frequency is changed between the 28 and 38 GHz bands using two switches in the slots. However, the size of the antenna was significant and influenced by a waveguide port specifically designed for the CPW feed, hence adding intricacy to the antenna's design. A pattern reconfigurable stacked microstrip patch antenna ($40\times20\times1.85$ mm^2) was presented for 60 GHz central frequency in [17]. However, the working frequency is only at a single band; specified the diode condition, the frequency works only at 60 GHz. All the reconfigurable antennas are larger in dimensions and, therefore, they are challenging to fit in small devices. This study specifically designs and builds a compact, frequency-reconfigurable antenna for 5G applications. With an overall dimension of 8×8×0.8 mm³. In this investigation, we used a Roger RT/5880 substrate with a dielectric constant (Ɛr) of 2.2, which is 0.8 mm thick. The antenna was powered using the Microstrip line feeding technology. Three PIN-diodes utilized to achieve frequency reconfiguration, to operate in mm-wave band with maximum bandwidth 14.9 GHz. The simulation is done through CST (Computer Simulated Technology).

2. Design steps

A dual-band reconfigurable antenna with a total size of 8 × 8 mm² constructed on Rogers RT/5880 (Ɛr = 2.2, h = 0.8 mm, tan δ = 0.0009) is designed in this work. Figure 1 illustrates the step-by-step procedure for developing an antenna. Step-a involved designing an antenna, despite the fact that it is not easily reconfigurable, as shown in Figure 1(a). Step-b establishes the modification of the patch to create the proposed antenna with reconfigurable capabilities. All steps used the partial ground method, as shown in Figure 1(c).



(a) Step-a **(b) step-b** **(c) back view.**

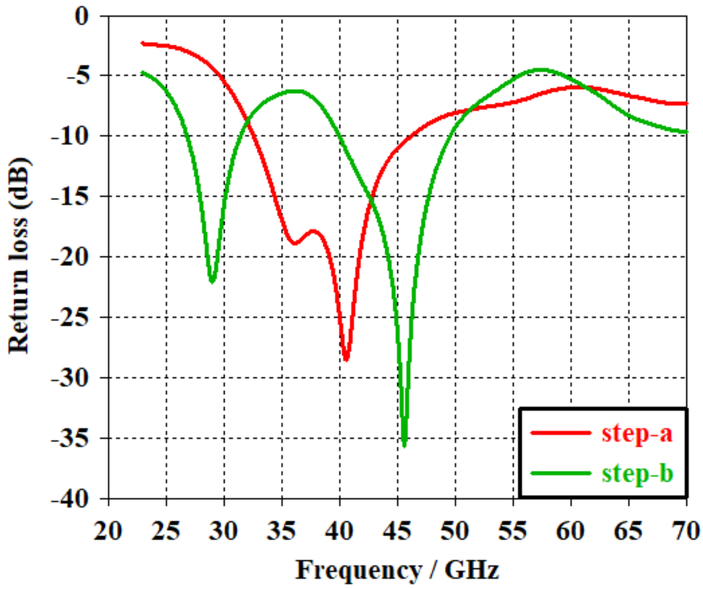


Figure 1. Proposed Antenna design steps

The results of the antenna design steps are shown in Figure 2. The antenna in step-a operates at 40 GHz within a single band and has a return loss less than -10 dB. While the suggested antenna in step

(b) operates in two frequency bands (29 and 45.6 GHz), can also adapt the antenna by using PIN diodes to achieve the desired response.

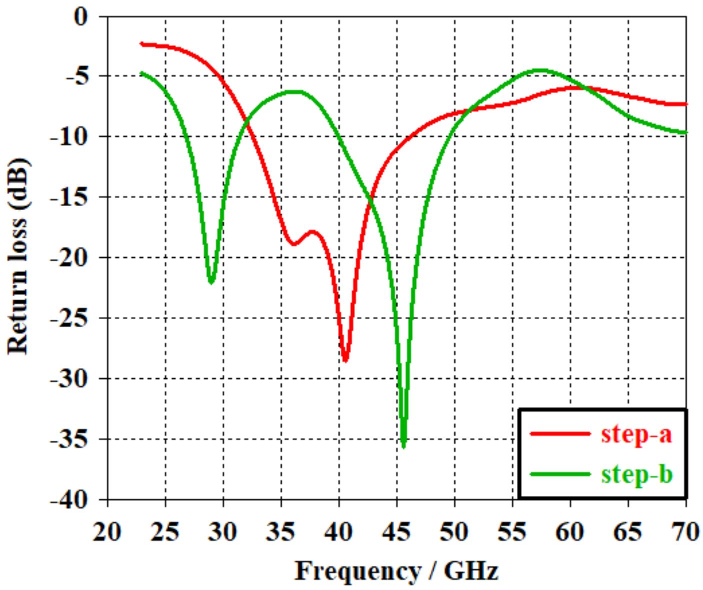
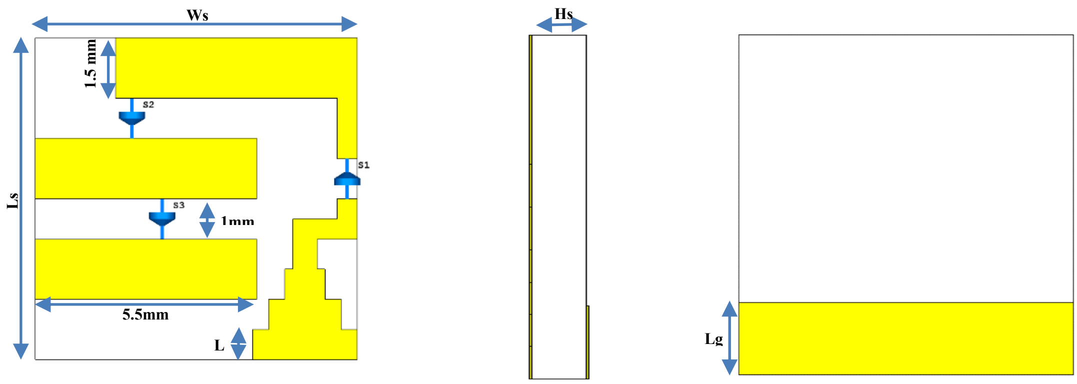


Figure 2. Simulated Return loss (s11) for both antenna design steps (a, b)

3. Propose setup

The patch shapes design, which consists of steps near the feed line and partial ground, is shown in Figure 3. Three switches separate the presented antenna to operate in five different states. A microstrip line with a width of 2.6 mm and a characteristic impedance of 50 ohms is employed to stimulate the antenna. Table 1 displays the dimensions of the suggested antenna.



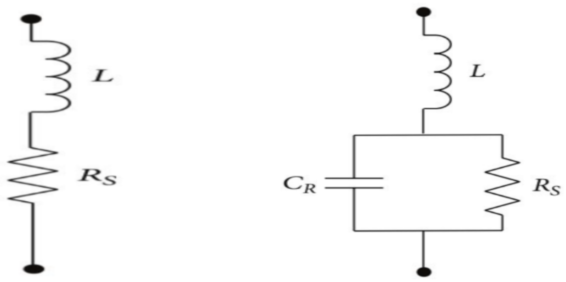
(a) Front view **(b) Side view** **(c) Back view**

Figure 3. Proposed reconfigurable antenna

Table 1. Dimensions of proposed antenna

Parameter	Symbol	Value(mm)
Width of substrate	Ws	8
Length of substrate	Ls	8
Highest of substrate	Hs	0.8
Width of ground	Wg	8
Length of ground	Lg	3
Highest of ground	Hs	0.035
Length of feed	Lf	0.75
Width of feed	Wf	2.6
Slot (S1)		1* 0.5
(S2, S3)		1*0.75

Three switches (MA4AGBL912) are employed to regulate the length of the antenna [18]. Figure 4 illustrates the use of these diodes in the simulation to alter the frequency. When in the ON state, they function as a short circuit, causing a decrease in the effective area. Conversely, when in the OFF state, they function as an open circuit, increasing the slot area and causing the antenna to operate at lower frequencies. A series combination of resistance (Rs= 4.2 Ω) and inductance (L=0.5 nH) represents the PIN-diode in its "ON" state. In the "OFF" state, the PIN-diode has a capacitance value (C= 21 fF) although shunt resistance is (R=3 KΩ). The CST Studio Suite is employed to simulate and optimize the proposed antenna.



(a) ON state. (b) OFF state.

Figure 4 : pin-diode equivalent circuit.

Table 2 shows that in state-1, when all switches are ON, the frequency of 45.6 GHz reached its lowest value for its size. This confirms the idea that employing overall antenna dimensions is necessary to achieve the minimum frequency. In contrast, in state-2, when all switches are OFF and the antenna size was extremely small, the suggested antenna will operate at the highest frequency (56.6 GHz) of its dimensions. This antenna is not only compact, but it also offers a high gain of 6.34 dB. This is due to the antenna's size, patch area, and current distribution method. Furthermore, using substrate thickness and feeding line procedures will result in the millimeter wave frequency achieving its maximum frequency. The distribution of the current and antenna size, along with the performance of the fractal reconfigurable antenna, will make more frequency bands (28.2, 45.7 GHz) available in state-3 when (S1, S2) are ON and (S3) was OFF. In state-4, both switches (S1, S3) are OFF. The reconfigurable antenna operates at frequencies of 25.3 and 56.2 GHz. In state-5, when both switches

(S1, S2) are OFF and S3 was ON, the same antenna operated at 28.4 GHz and 56.6 GHz, with a bandwidth that might exceed 11.6 GHz.

Table 2. Simulated results of the proposed antenna

		S1	S2	S3	Frequency (GHz)	Max. Gain(dB)
State 1	**ON**	✓	✓	✓	29	**3.61**
	OFF				45.6	
State 2	**ON**				26.1	5.97
	OFF	✓	✓	✓	56.6	
State 3	**ON**	✓	✓		**28.2**	**3.92**
	OFF			✓	**45.7**	
State 4	**ON**		✓		**25.3**	**6.34**
	OFF	✓		✓	**56.2**	
State 5	**ON**			✓	**28.4**	**6.09**
	OFF	✓	✓		**56.6**	

The proposed antenna's computed S-parameters are displayed in Figure 5 below. In state-1 the antenna operates at a resonant frequency of 29 and 45.6 GHz, with a return loss of less than -23, -34 dB and a bandwidth of (4.8, 9.4) GHz, respectively. This recently introduced functionality is advantageous for apps that utilize 5G technology. In state-2, the suggested antenna operates at frequencies of 26.1 and 56.6 GHz. It has a return loss of less than -16 and -14 dB, as well as a bandwidth of 7.5 and 14.9 GHz, respectively. State-3 exhibits a resonance frequency of 28.2 GHz with a bandwidth of 4 GHz, while its resonant frequency is 45.7 GHz with a bandwidth of 11.2 GHz. In contrast, state-4 has a resonance frequency of 25.3, 56.2 GHz and a bandwidth of 7.8, 14.7 GHz, with S11 less than -15.7, -14 dB, respectively. In addition, by distributing the current evenly across the radiating patch, a new resonance frequency of 28.4, 56.6 GHz was achieved, with S11 values of -18.5, -14 dB, respectively. This also resulted in a bandwidth of 7.2, 11.6 GHz. Presently in state-5. Which is suitable for wireless communication systems operating within the specified frequency range.

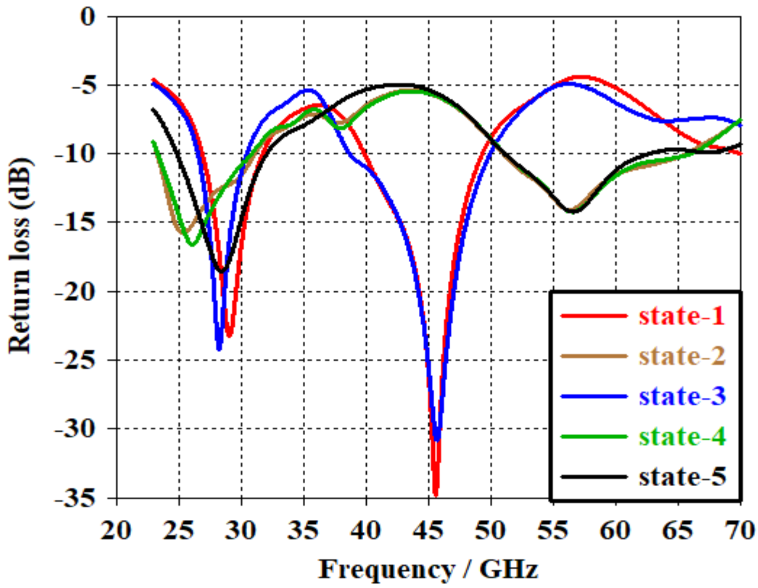
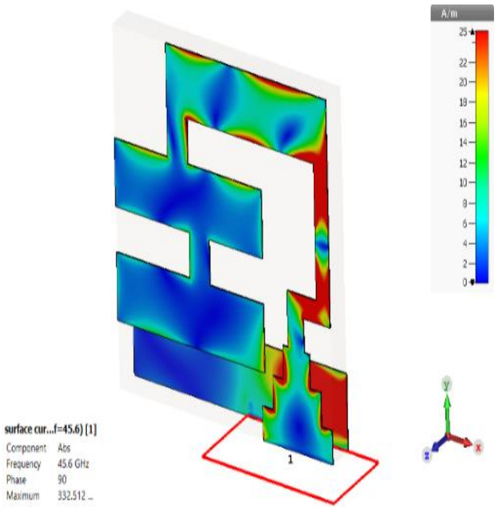


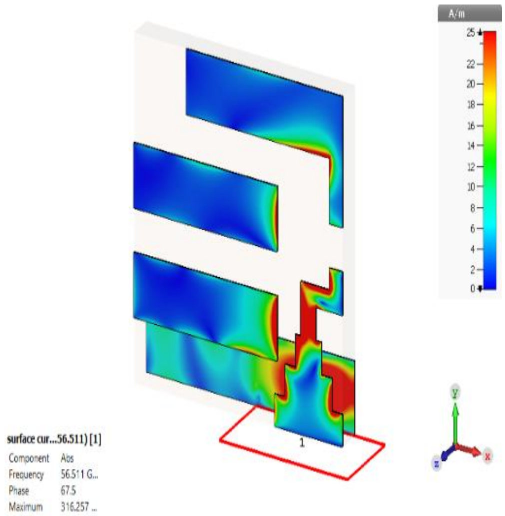
Figure 5. Simulated Return loss parameter (S11) results using three switches

The concentration of radiation around the antenna patch and the feeder's edges can be observed in Figures 6. It is also well known that changing the antenna's length and surface current distribution can change its operating frequency. During state-1, Figure 6 (a) illustrates that the current mostly flows via the feed line section and forms a vertical line on the patch at a lower frequency of 45.6

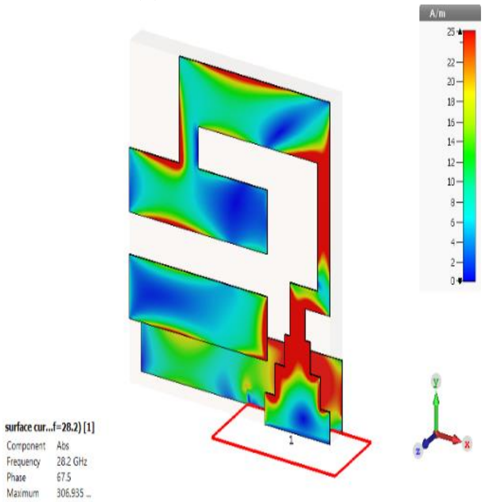
GHz. In state-2, Figure 6 (b) primarily displays the distribution on the feed line part and the edges of two rectangular parts of the patch at a relatively higher frequency (56.5 GHz). Figure 6(c), state-3, displays the current distribution, where the cut-off of the second rectangular part completely alters the current's direction. The distribution of the current extended beyond the first rectangular part's edge and the entire feeding line, tracing the longest path of the proposed antenna and resulting in a low frequency of 28.2 GHz. In Figure 6(d), state-4, the current only flow in the edge of the total patch, this result in a low-frequency band (25.3 GHz). In Figure 6 (e), state-5. When the current flowed to the top of the feeding line and the edge of the second rectangular section, the antenna produced the second minimum frequency, 28.2 GHz.



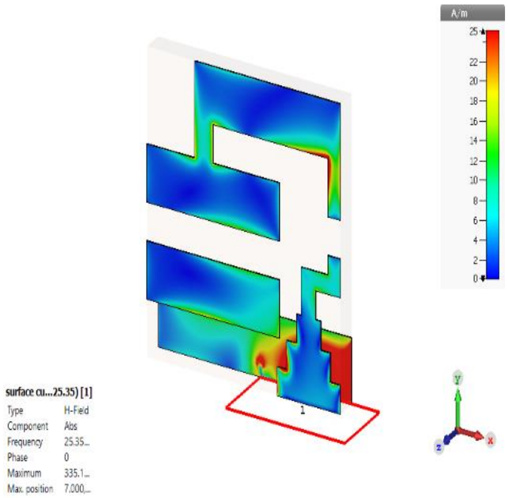
(a) State-1 at 45.6 GHz.



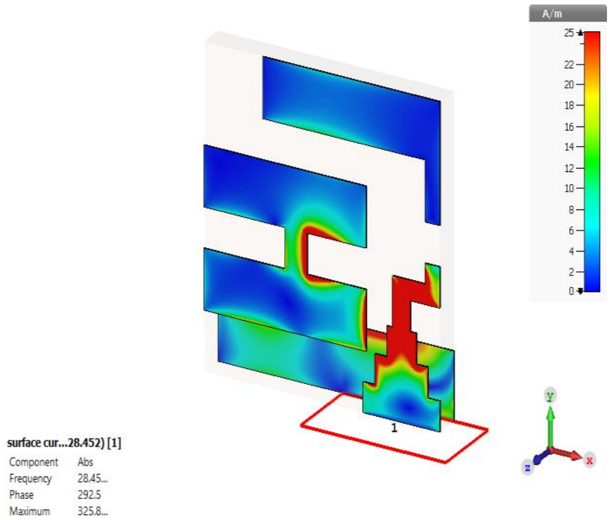
(b) State-2 at 56.5 GHz.



(c) State-3 at 28.2 GHz.



(d) State-4 at 25.3 GHz.



(e) State-5 at 28.4 GHz.

Figure 6. The surface current distribution for the presented antenna at all states.

Figure 7 presents Realized Gain plots of all switch states, the values reported for the given frequencies are respectively, 3.61, 5.97, 3.92, 6.34, 6.09 dB.

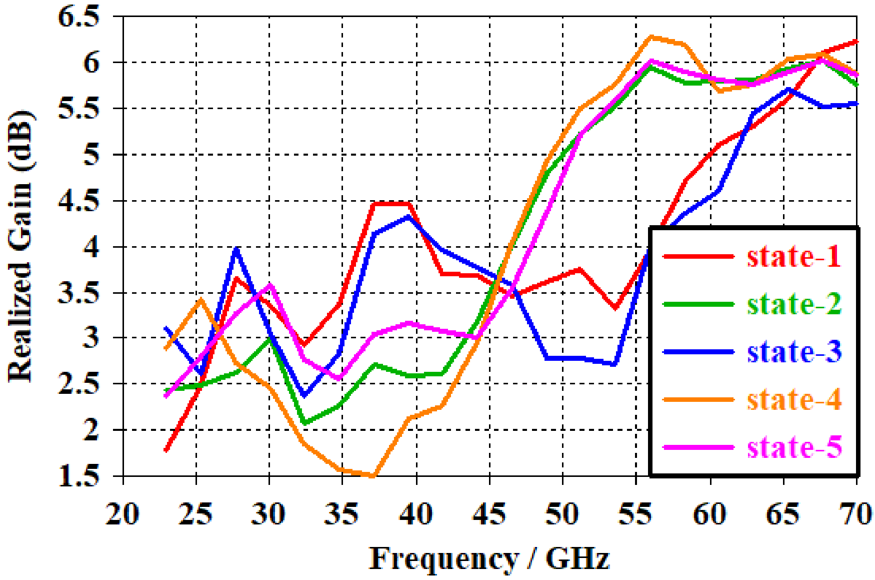
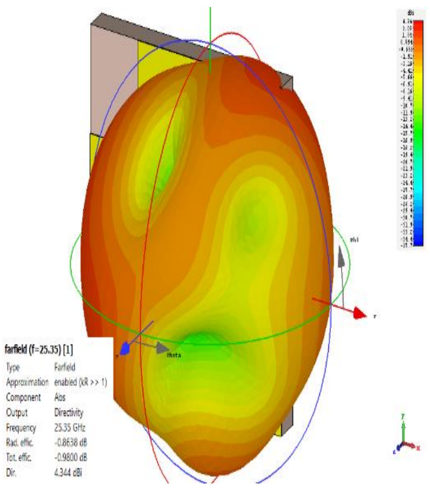
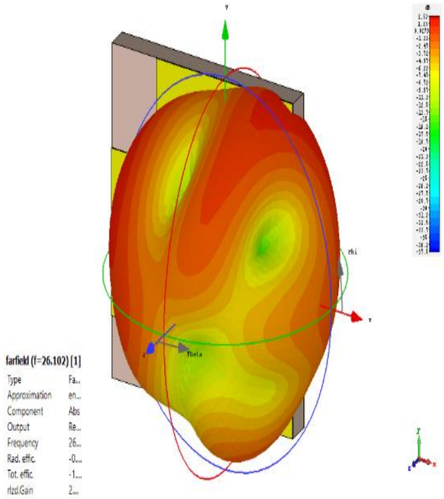


Figure 7. The simulated gain for the basic dual band antenna

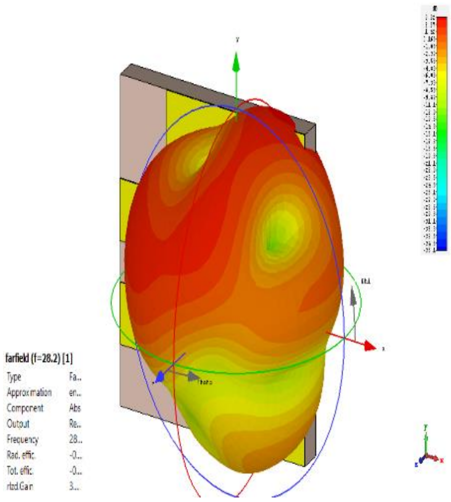
Figure 8(a, b, c, d, e) shows the 3D gain graphs for the antenna at 25.3, 26.1, 28.2, 29, 45.6, and 56.7 GHz, respectively.



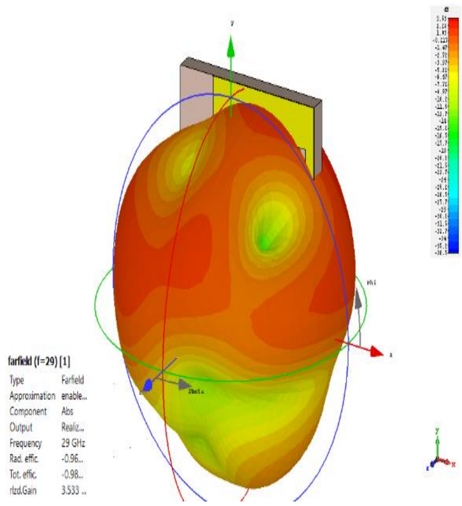
(a) 25.3 GHz.



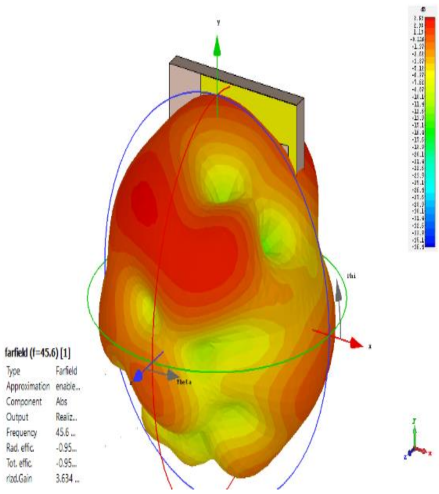
(b) 26.1 GHz.



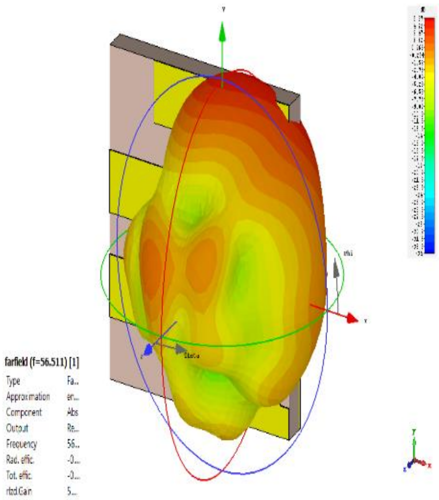
(c) 28.2 GHz.



(d) 29 GHz.



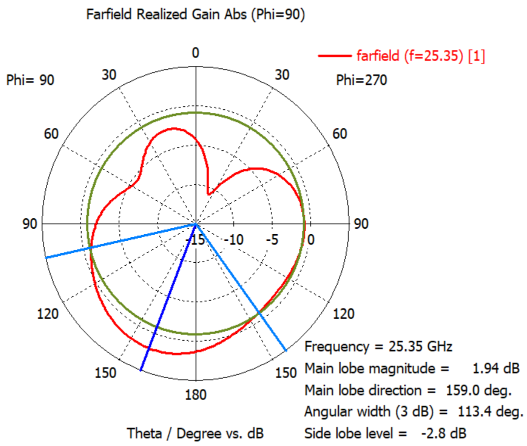
(e) 45.6 GHz.



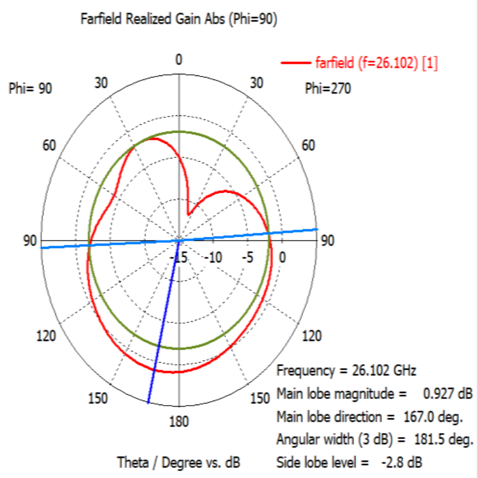
(e) 56.5 GHz.

Figure 8. 3D Plot at all states

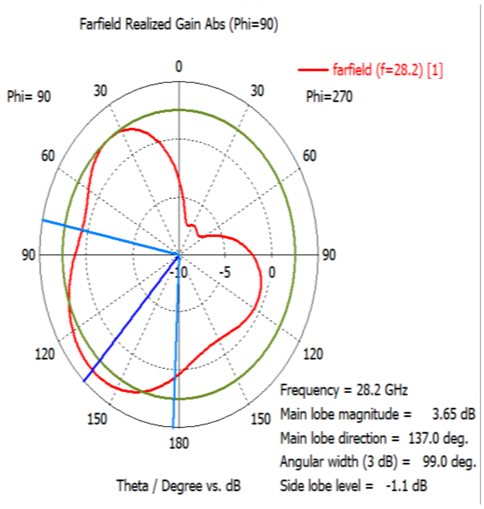
At all frequencies, the simulated dual-band antenna's radiation patterns exhibit nearly directional characteristics in both the E and H planes, as shown in Figure 9.



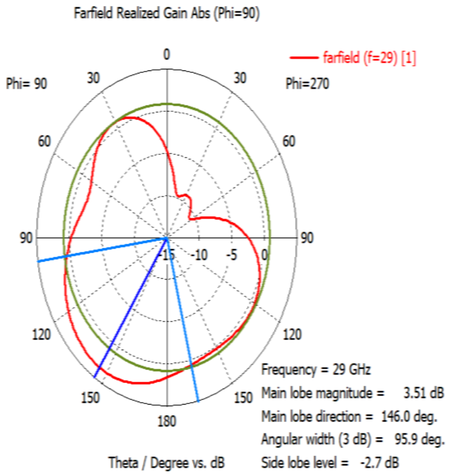
(a) 25.3 GHz.



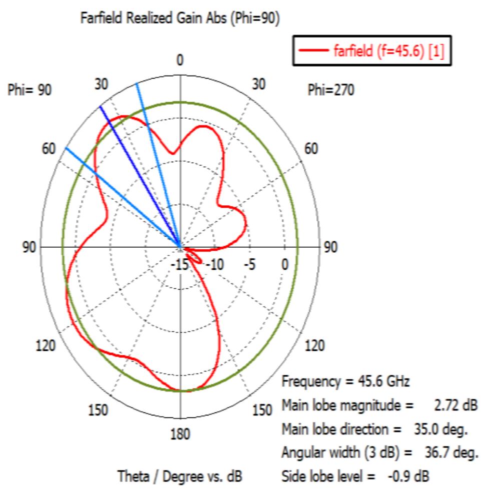
(b) 26.1 GHz.



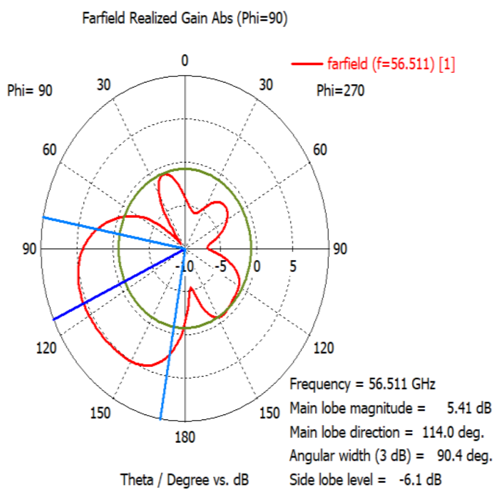
(c) 28.2 GHz.



(d) 29 GHz.



(e) 45.6 GHz.



(e) 56.5 GHz.

Figure 9. The basic dual band antennas simulated radiation patterns at 25.3, 26.1, 28.2, 29, 45.6, 56.5 GHz.

Below is a brief table that summarizes the tasks associated with reconfigurable antennas in the millimeter wave range for applications related to 5G networks. (Table 3). It is found that the suggested antenna has better performance and a smaller size than those already composed, specifically in the terms of compactness.

Table 3. The performance of the suggested reconfigurable antenna is evaluated in comparison with other 5G antennas

Ref.	Antenna size (mm³)	Substrate	Resonance frequency (GHz)	Frequency reconfigurable?	Bandwidth (GHz)	Max gain (dB)
[11]	18×11.25×0.787	Rogers RT/Duroid5880	28 GHz or 38 GHz	frequency	2.21	5.35
[12]	16 × 14	Rogers ULTRALAM 3850	20.7-36 GHz	frequency	12.5	5
[13]	12×12×0.8	Rogers RT 5880	26-29 GHz	frequency	3.9	1.893
[14]	15×15×0.25	Rogers RO 3003	38-60	Non-reconfigurable	3.2	5.5
[15]	5.4×25.4×0.2	Fused quartz	60	Non-reconfigurable	-	15.6
[16]	11 × 9	flexible PET	28-38 GHz	frequency	-	4.69
[19]	50 x 40	Roger RT5880	5.5-5.9 /55-95	Non-reconfigurable	4/40	9/9
[17]	40 × 20 ×1.85	Taconic TLY-5	60 GHz	pattern	13	1.5
Our work	8×8×0.8	Roger RT 5880	25.3, 26.1, 28.2, 29, 45.6, 56.5 GHz	frequency	14.9	6.34 (Realized gain)

Conclusion

This research presents a reconfigurable antenna with fractal frequency for 5G applications. The frequency range that the proposed antenna covers is (25.3, 26.1, 28.2, 29, 45.6, 56.5) GHz. The main features of the antenna are its small size (8×8×0.8mm³) and straightforward design, as well as its outstanding measured performance in terms of radiation efficiency, operational bandwidth, steady high gain, and return loss, an almost directional radiation pattern. Thus, a straightforward patch produced a gain of 6.34 dB, a directivity of 7.25 dBi, and an S11 <-10 dB. Using CST software, the efficiency ranged from 83–85% within the operational region.

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