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Millimeter-Wave Reconfigurable Antenna for 5G Wireless Communications

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Abstract—In the present day scenario, the need for 5G technology is increasing daily, so we design a reconfigurable antenna working in the millimeter-wave range (25 GHz–30 GHz). The antenna is designed using HFSS software, and the antenna is loaded with compact planar metamaterial. This design includes 9 unit cells arranged in a 3×3 array, and each unit cell is made up of a hexagonal patch surrounded by a split ring resonator. Apart from this two unit cells are connected using pin diodes. By operating these two pin diodes in different modes, we get four different characteristics. The designed antenna radiates at 27 GHz with a gain of 2.6 dB to 4 dB. The designed antenna is compact and easy to fabricate with dimensions of 30 mm $\times$ 23 mm.

1. INTRODUCTION

In this present-day technology, the number of applications used by people is increasing day to day. Using a single antenna element that radiates at a particular frequency is no longer a preferred option. Through research works, the concentration shifts from a particular frequency to wide range frequency bandwidth such as UWB (ultra-wideband), ranging from 3.1 GHz to 10.6 GHz. Although the work shifts from single frequency to a band of frequencies using a single antenna for a single application leads to a lot of complexities in structures which leads to an idea of reconfigurable antenna, the name itself suggests its properties such as frequency, and some times it can be radiation pattern and even direction of polarization according to the application. Nowadays, the demand for 5G technology has been increased tremendously, so the demand for the antennas working in millimeter-wave technology has been increased [1, 3]. To increase the channel capacity, we have designed a reconfigurable antenna that works in a millimeter-wave range radiating at 27 GHz.

It is an antenna capable of modifying its properties like frequency, polarization, radiation pattern, and combining any of these properties which can be termed as a hybrid. Generally for any application, we need an antenna; for example when we consider Bluetooth and WIMAX, Bluetooth works at 2.4 GHz, and WIMAX works at 5.2 GHz. Here we have to use different antennas for each of them, and sometimes may be an array of antennas to ensure sufficient gain and directivity which can be a complex thing. So the main advantage of using a reconfigurable antenna is that it can replace n number of antennas with a single antenna. This replacing reconfigurable antenna can be a single antenna or an array of antennas.

Reconfigurable antenna is broadly classified into four types. They are [2–8]:

a) Frequency reconfigurable antenna

b) Polarization reconfigurable antenna

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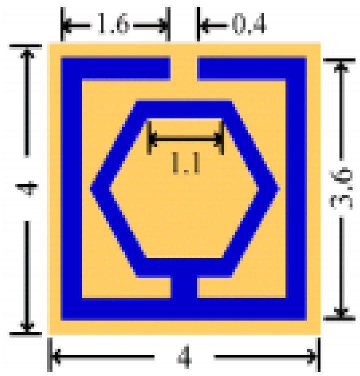
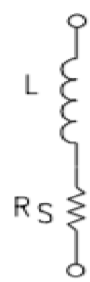


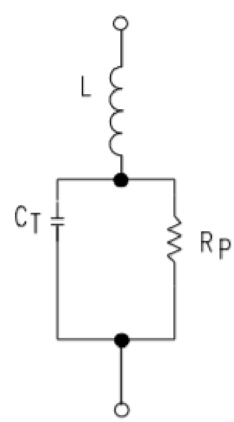
Figure 1. Dimensions of the unit cell.

c) Radiation pattern reconfigurable antenna
d) Hybrid reconfigurable antenna

The first one is the usage of pin diodes which comes under electrical technique; the second is the usage of photoconductive material which comes under optical technique; the third is using structure alteration which comes under physical technique; and the fourth is using ferrites and liquid crystals which comes under material change technique. For a frequency reconfigurable antenna, we mainly use electrical mechanisms such as RF-MEMS, pin diode, and varactor diode. In our project, we have used pin diodes. The model of the pin diode used here is BAR 64-03W, and its cut-in voltage is 0.4 V. The equivalent circuit of the pin diode is shown below Fig. 2. When the diode is excited, the circuit is shown below.



When the pin diode is OFF, the equivalent circuit is shown below.



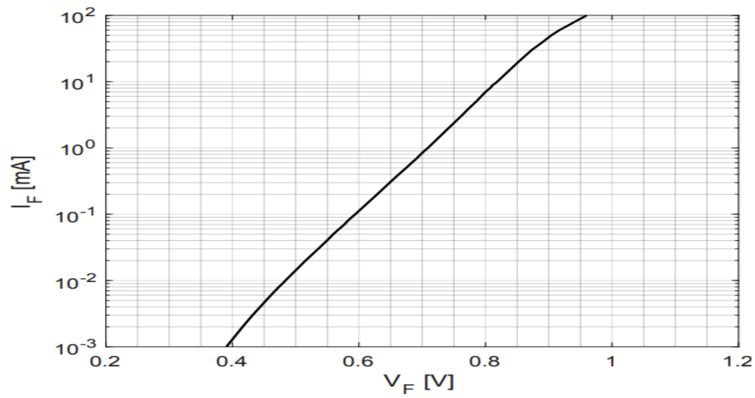


Figure 2. DC characteristics of pin diode BAR 64-03W.

2. DESIGN OF ANTENNA

At first, a unit cell is designed with dimensions shown in Fig. 1. The reason for using a split ring resonator is to have a metamaterial structure so as to reduce the mutual coupling between antenna elements. At first, a MIMO antenna is designed. A 3×3 array of unit cells is implemented [9, 10] to enhance the channel bandwidth from 25 GHz to 30 GHz which is in a millimeter-wave range. Here the substrate is loaded with compact planar metamaterial [13].

The reason for using metamaterial designed with a near-zero index is that there will be losses due to refraction through the substrate. Our main aim is to reduce that refraction by making the refractive index almost equal to zero, termed a near-zero index. While designing the substrate what we used is RT Duroid. In addition, the port of the antenna is fed by a transmission line with 50-ohm impedance, and line dimensions are 6 mm $\times$ 2.4 mm. This designed antenna operates in a millimeter-wave range, i.e., 25 GHz to 30 GHz, with a gain nearly equal to 4 dB and a return loss > -24 dB which is an accepted value. To increase the applications of this designed antenna, we opted for a frequency reconfigurable antenna [11], which means that we can modify the operating frequencies of the antenna by implementing some methods mentioned in the introduction.

The method used here for reconfiguring the antenna is the usage of pin diodes. One of the reasons for using a pin diode is that it acts as a switch and provides better controllability [12]. From the above Fig. 3. we can see two more unit cells added to the initially designed structure. While designing we directly disconnected and connected the extra unit cells in four modes, i.e., 11, 10, 01, 00. Here '1' means that the cell is connected, and '0' means that the cell is disconnected, but while fabricating we

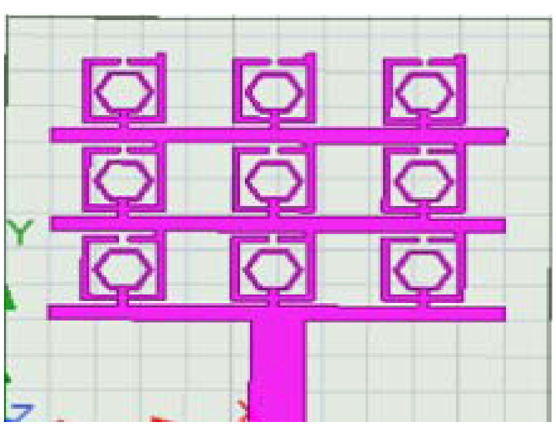


Figure 3. Design of antenna using HFSS.

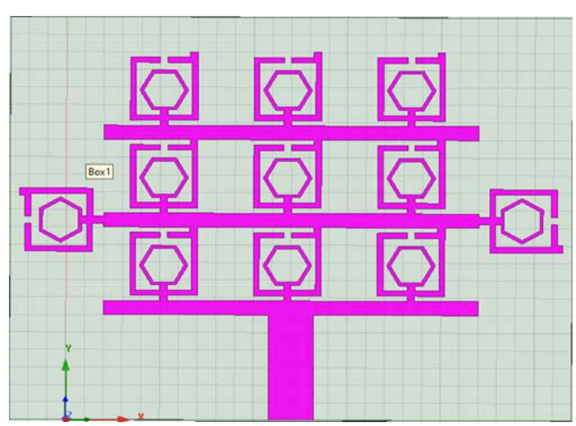
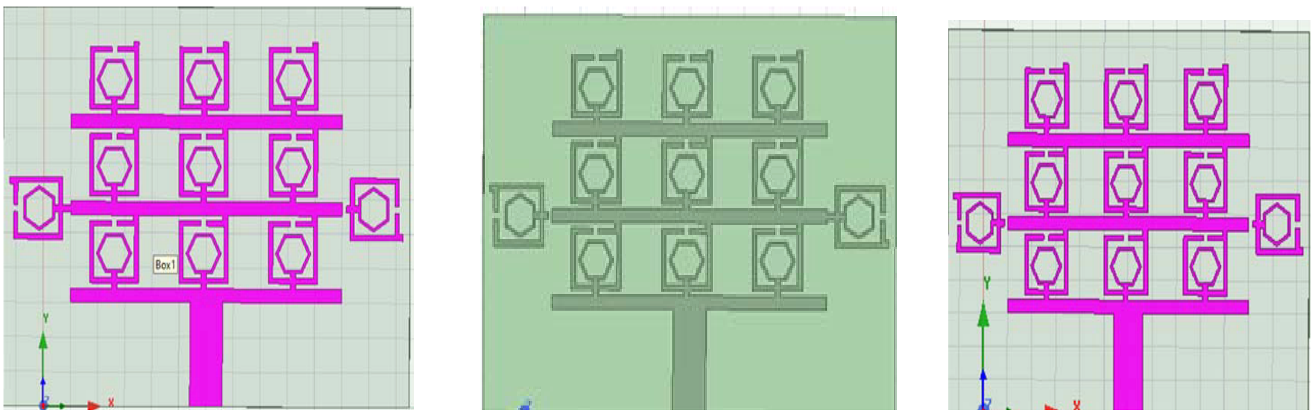


Figure 4. Design of reconfigurable antenna using HFSS.

used pin diodes to connect and disconnect them.

Fig. 4 shows the design of 11 mode using HFSS; Fig. 5(a) shows the design of 10 mode; Fig. 5(b) shows the design of 01 mode; similarly, Fig. 5(c) shows the design of 00 mode which is similar to the designed single antenna element. This designed reconfigurable antenna works in the same frequency range as the single antenna element that is 25 GHz to 30 GHz, though the results such as return loss, gain, and VSWR vary from one mode to another mode, we can select the mode of operation based on the required application. For example, one application may need a certain gain at one frequency. The dimension of the connected and disconnected parts is 0.3 mm × 0.4 mm, and the overall dimension of the designed antenna is 30 mm × 23 mm. The antenna is fabricated and shown in Fig. 6.



(a) (b) (c)

Figure 5. (a) Design of 10 mode. (b) Design of 01 mode. (c) Design of 00 mode.

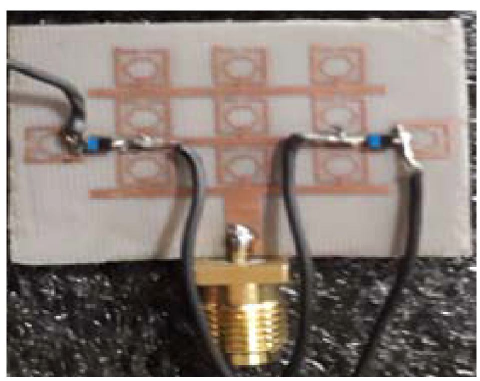


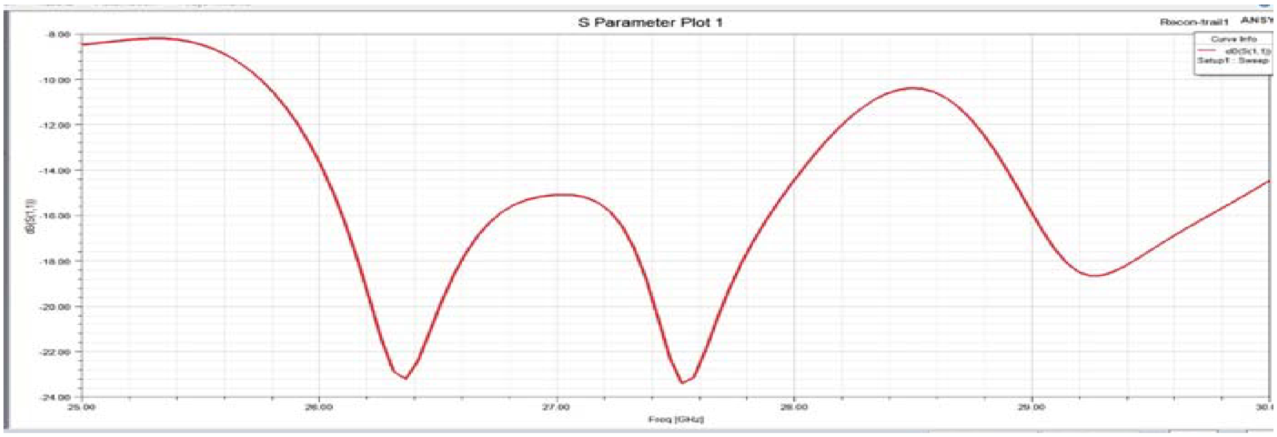
Figure 6. Fabricated reconfigurable antenna.

3. RESULTS

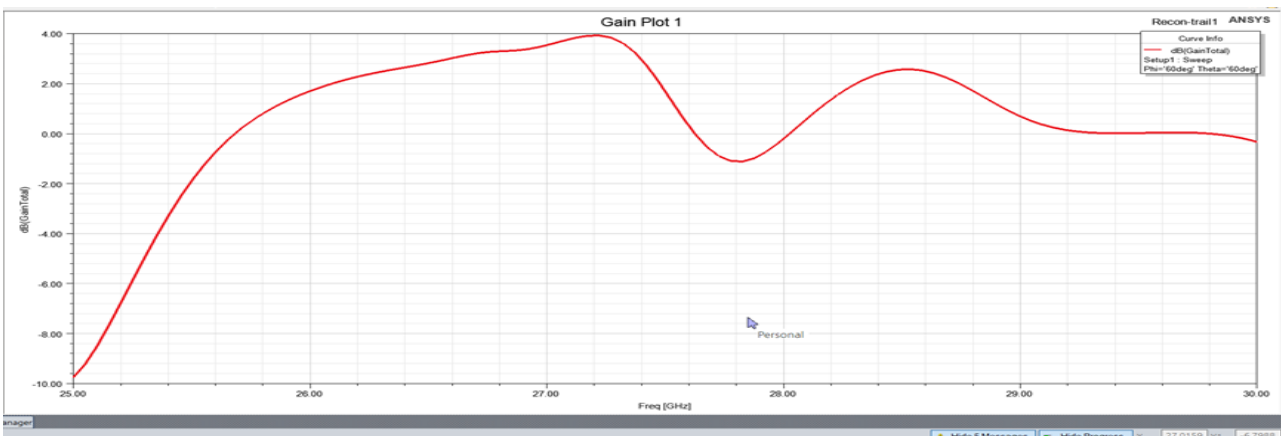
The designed antenna is simulated and analyzed properly, and the parameters that we observed mainly are the S_{11} parameter and gain for every mode. The S_{11} plot mainly depicts return loss; the accepted value of return loss of any antenna is < -10 dB; and the S_{11} plot of every mode of this designed antenna lies in this accepted range. The gain plot mainly depicts output power to input power ratio, and the gain of the designed antenna varies between 2.6 dB and 4 dB. The S_{11} and gain plots of all the four modes of this designed reconfigurable antenna are shown below.

11 MODE:

In the above Fig. 7(b), at 27.8 GHz, the gain curve has a negative slope which means that the gain has remained nearly equal to 1. So from the previous values of gain, it has decreased a bit, resulting



(a)

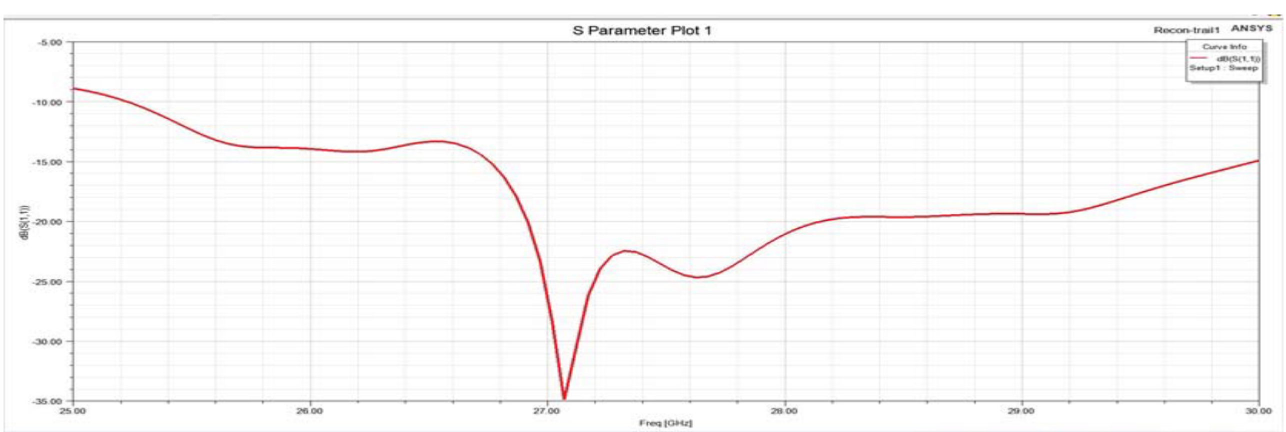


(b)

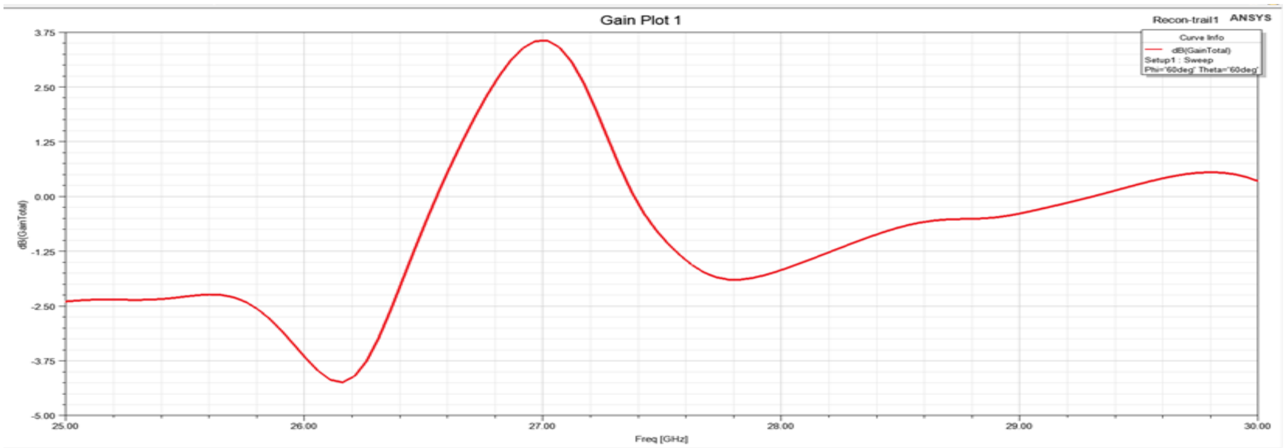
Figure 7. (a) S_{11} plot of 11 mode. (b) The gain plot of 11 mode.

in a concave shape or negative slope. This decrease in gain can be observed in every mode because we mainly designed the antenna to operate at 27 GHz with a maximum gain around this particular frequency. So it can be decreased around other frequencies which results in a concave shape.

10 MODE:



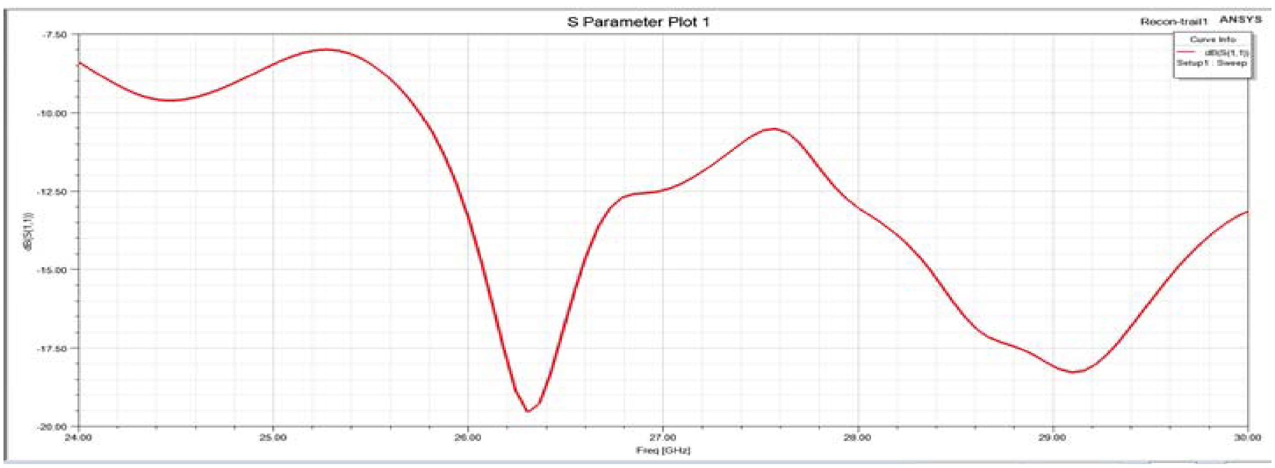
(a)



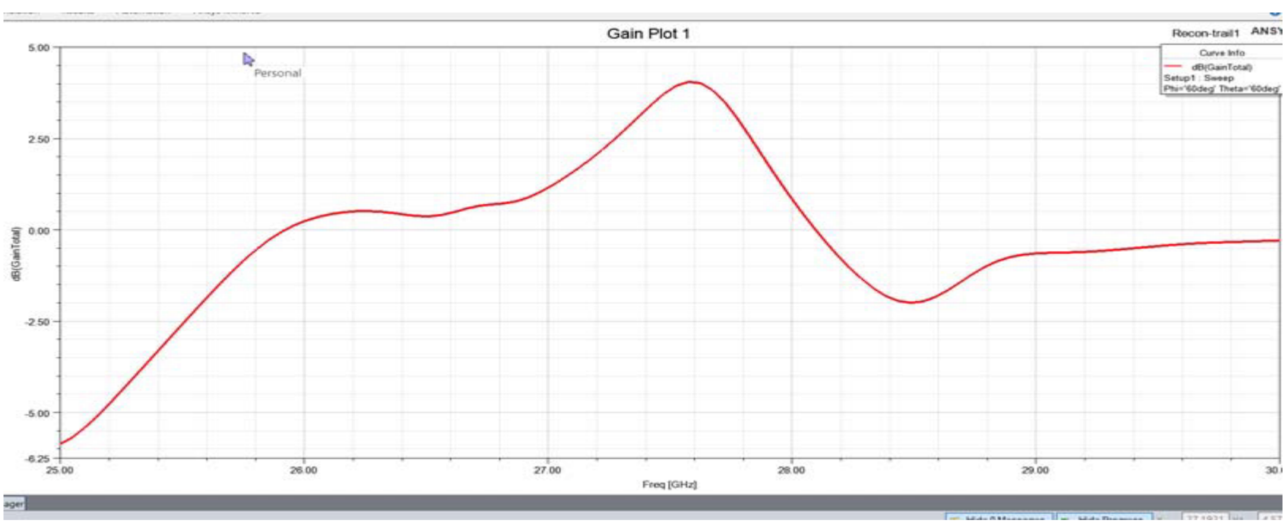
(b)

Figure 8. (a) S_{11} plot of 10 mode. (b) The gain plot of 10 mode.

01 MODE:



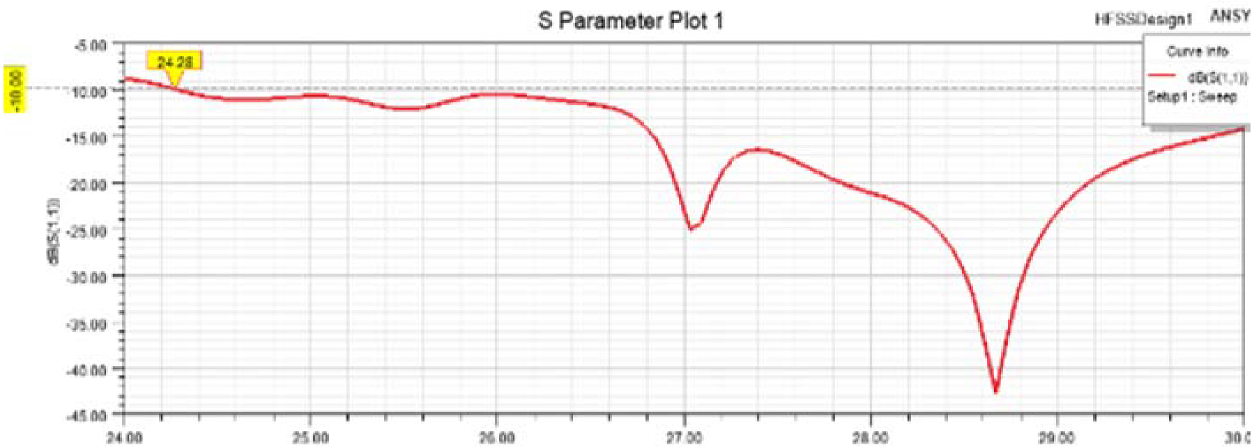
(a)



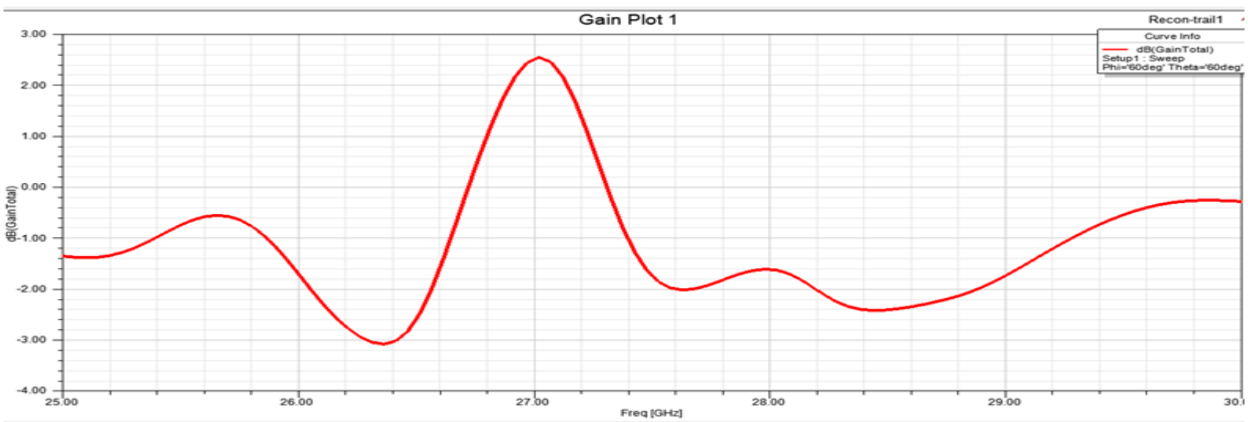
(b)

Figure 9. (a) S_{11} plot of 01 mode. (b) The gain plot of 01 mode.

00 MODE:



(a)



(b)

Figure 10. (a) S_{11} plot of 00 mode. (b) The gain plot of 00 mode.

From the above Figs. 6, 7, 8, 9, it is observed that the gain varies from 2.6 dB to 4 dB, and each antenna radiates in the millimeter-wave range which is the desired feature. Here the gain is calculated as an average gain, so it appears narrow. The efficiency plot for the designed antenna is shown below in Fig. 11.

Table 1 shows the frequency of operation and maximum gain obtained of each and every mode in which the antenna is operated.

Table 1. Frequency of operation and maximum gain of different modes.

Antenna mode	Frequency of operation	Peak Gain (dB)
00 Mode	27 GHz to 28.7 GHz	2.5 dB
01 Mode	26.3 GHz	1 dB
10 Mode	27.2 GHz	3.6 dB
11 Mode	27.8 GHz	4 dB

The performance comparison of proposed antenna model with Existing Techniques is given in Table 2.

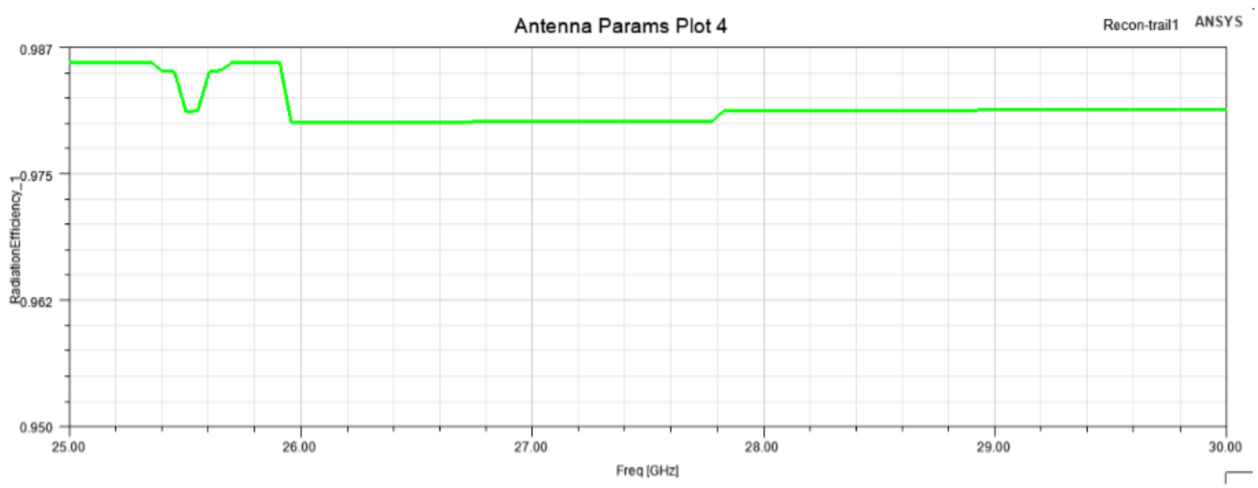


Figure 11. Efficiency plot for the designed reconfigurable antenna.

Table 2. Performance comparison of proposed model with existing techniques.

Reference	[1]	[2]	[3]	[7]	[8]	[13]	Proposed work
Technique	Dual polarised microstrip patch	Polarization switching	Metasurface single polarised	Printed microstrip antenna	Wearable flexible folded antenna	Metamaterial based MIMO antenna	Metamaterial Reconfigurable antenna
No. of Ports	2	1	1	1	1	2	2
Size ($W * L$)	0.41× 0.41 mm	18.5× 18.33 mm	12× 12 mm	23× 31 mm	83× 89 mm	52× 23 mm	30× 23 mm
BW (GHz) < -10 dB	23–39	5.1–6.3	25–29.5	3.1 GHz and 6.8 GHz	2.45–3.33	24.00–29.90	25.00–30.00
Edge to Edge Spacing	9.5 mm	nil	0.4 mm	nil	Nil	0.36	0.25 mm
Max. Gain (dBi)	5 for single antenna	6.5 to 4.0	11	3.71	3.0–6.4	13.40	2.6 to 4
Rad Efficiency %	Nil	Nil	95	80.0–83.1	Nil	98	98

4. CONCLUSION

For future 5G communication systems, a millimeter-wave reconfigurable antenna has been proposed with an overall dimension of 30 mm × 23 mm and works with 98% efficiency. The observed and simulated findings are very similar, and the suggested MTM reconfigurable antenna has good performance, making it suitable for future 5G networks. Based on this we create a frequency reconfigurable antenna which operates in four different modes, i.e., 11, 10, 01, 00 and gives gain varying from 3.75 dB to 4 dB approximately. In future, the proposed frequency reconfigurable antenna can be used for wearable WBAN applications [14, 15].

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