Frequency Reconfigurable Microstrip Patch Antenna with Dumbbell-shaped slot for 5G Wireless Applications

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Abstract

The antennas offering dynamic frequency adjustment feature are becoming more promising. In the presented antenna structure, an antenna capable of reconfiguring its frequency dynamically has been designed and analyzed. The microstrip patch antenna consists of two PIN diodes at different positions. The range of frequency is from 24.33 GHz to 27.50 GHz. The presented antenna finds its application in 5G NR mmWave applications, offering extreme data speeds and capacity. The return loss and VSWR values obtained lies in the desired range. The total antenna gains have been simulated using ANSYS HFSS software.

Keywords*:- Frequency Reconfigurable, Microstrip patch antenna, PIN Diode, FR2, Return Loss, Gain, ANSYS HFSS*

INTRODUCTION

5G is the 5th generation cellular communication technology. This network is designed to provide much faster connectivity and a much better user experience across the globe. This technology will supposedly deliver higher multi-Gbps peak data speeds, greater reliability, massive network capacity and increased availability [1].

5G has been allocated mobile bands between 24.24 GHz and 86 GHz by the World Radio communication Conference (WRC)-15[2]. The primary technologies for 5G include the millimeter wave bands (26, 28, 38 and 60 GHz). They offer a maximum data rate of 20 Gbps. Another underlying technology is Multiple MIMO (Multiple Input Multiple Output). This technology offers performance up to 10 times that in the case of 4G networks.

The demand for wireless communication is increasing day by day. For this, there is an increasing need for antennas that provide good isolation between different wireless standards, offers low front-end processing and capable of modifying and reconfiguring the frequency as per the requirement[3]. Multiple antennas can be substituted with a single antenna[4]. There exist several advantages of using reconfigurable antennas; for example, they offer Multi-band functions, beam-steering and polarization diversity, which results in an overall reduction in antenna size and complexity, reduction in antenna cost and enhancement of antenna efficiency[5]. There exist basically three switching techniques by which reconfiguration can be achieved in the antenna. PIN diodes, varactor diodes or RF-MEMS may be used to achieve reconfiguration. This provides PIN diodes with fast switching capabilities. The antenna characteristics are modified by alerting the current flow pattern through the antenna structure.

An antenna which can modify their characteristics such as their frequency, radiation pattern and state of polarization as per the need of the system[6]. These antennas are widely used in the modern wireless communication industry. Either PIN diodes, varactor diodes or RF-MEMS may be used to achieve reconfiguration. Here, frequency reconfiguration has been achieved in the presented antenna[7]. The presented antenna also finds application in Satellite Communications, military applications and also in RADAR tracking.

Table I. State Table

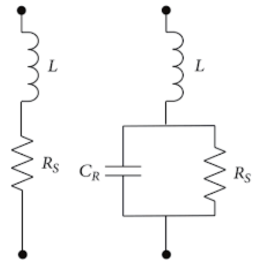
STATE	DIODE D1	DIODE D2
F1	ON	OFF
F2	ON	ON
F3	OFF	ON
F4	OFF	OFF

Frequency reconfiguration is a feature by which antennas can adjust their frequency of operation dynamically. A major advantage of using these antennas is that multiple antennas can be substituted with a single antenna structure[8].

A diode is a two-terminal electronic component that allows current to flow primarily in one direction. PIN diodes consist of an undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region[9]. These regions are heavily doped in order to provide ohmic contacts. Here, BAP 65-02 PIN diodes have been used.

DESIGN THEORY

The presented antenna has been designed on a Rogers RT Duroid5880 substrate with a thickness of 1mm, permittivity of 2.2, and tangential loss of 0.0009. The antenna consists of a dumbbell shaped slot in which two BAP 65-02 PIN Diodes have been incorporated at appropriate positions and having appropriate values for the Lumped RLC network[10]. The equivalent circuit model used for the BAP 65-02 PIN Diode has been illustrated in Figure 1(a) and figure 1(b), for the case of forward biased and reverse biased condition respectively, along with the values associated with lumped RLC network.



(a) (b)

Fig. 1(a) PIN Diode equivalent circuit model for forward biased condition

Fig. 1(b) PIN Diode equivalent circuit model for reverse biased condition

In the presented antenna design, inset-feeding technique has been used. Figure 2 shows the overall view or the 3-diemsional view of the antenna.

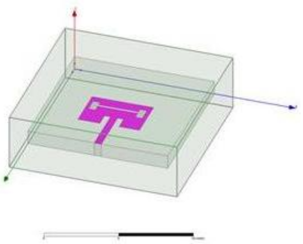


Fig. 2: Overall View of the designed antenna

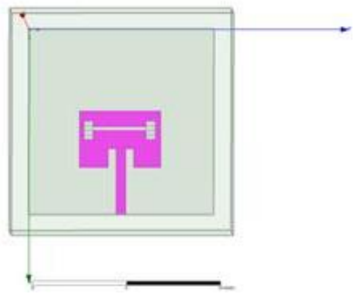


Fig. 3: Top View of the designed antenna

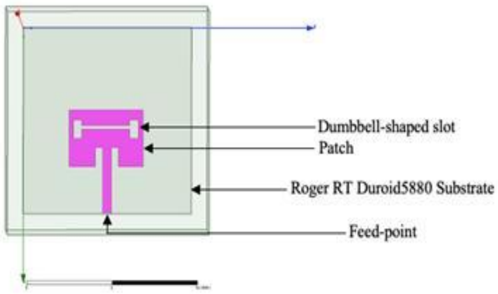


Fig. 4: Top View of the designed antenna without diodes

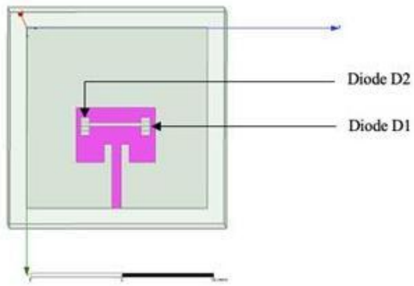


Fig. 5: Top View of the designed antenna with diodes

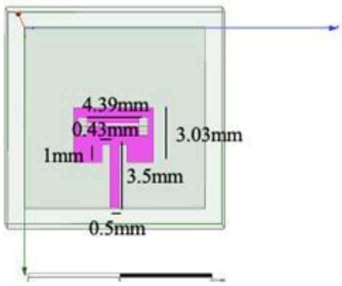


Fig. 6: Top View of the designed antenna with dimensions

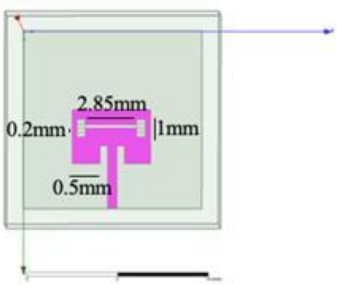


Fig. 7: Top View of the designed antenna with dimensions

Table II Comparative Result of Table 1

STATE	GAIN (dB)	DIRECTIVITY (dB)	ANTENNA EFFICIENCY (%)
F1	6.99	7.12	98.17
F2	6.59	7.13	92.42
F3	6.99	7.14	97.89
F4	6.97	7.03	99.14

Table III Comparative Result of Table 2

STATE	RESONANT FREQUENCY (GHz)	S11 (dB)	VSWR
F1	27.00	-31.61	1.05
F2	24.33	-26.35	1.10
F3	27.00	-28.30	1.07
F4	27.50	-14.57	1.45

Table 2 and Table 3 shows the reflection coefficient value, VSWR value, total antenna gain, directivity and the antenna efficiency obtained corresponding to each of the four diode states. The antenna efficiency corresponding to each state has been determined using the expression:

Antenna Efficiency = Total Gain/Directivity (Eq. 1)

SIMULATED RESULTS

A. For F1 State

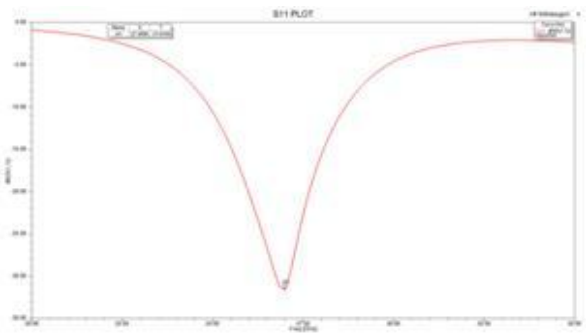


Fig. 8: S11 Plot

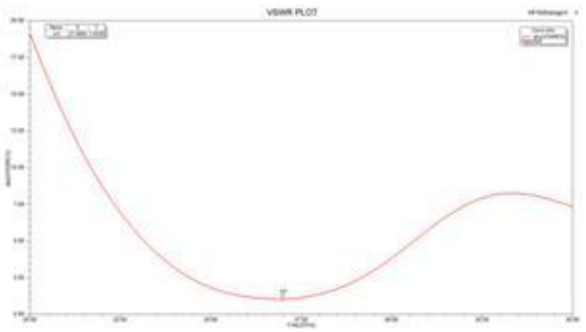


Fig. 9: VSWR Plot

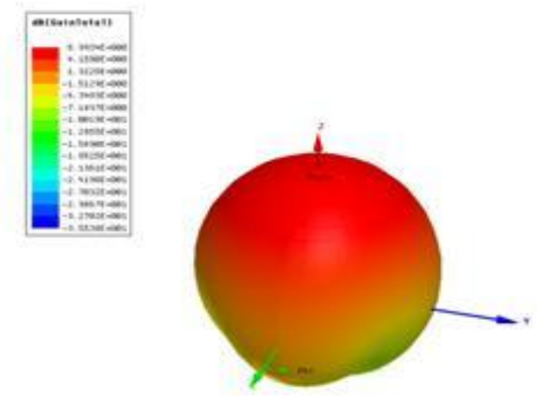


Fig. 10: 3D Radiation Pattern

As can be depicted from figure 8, figure 9 and figure 10, for the F1 state, we have obtained reflection coefficient of -31.61 dB, VSWR of 1.05 and total gain of 6.99 dBat a resonant frequency of 27 GHz. As per theory, reflection coefficient below -10dB is considered desirable for any working antenna and VSWR between 1 and 2 implies good matching between the transmitter and the transmission line, so here, the obtained reflection coefficient and VSWR values lies in the desirable range [11].

B. For F2 State

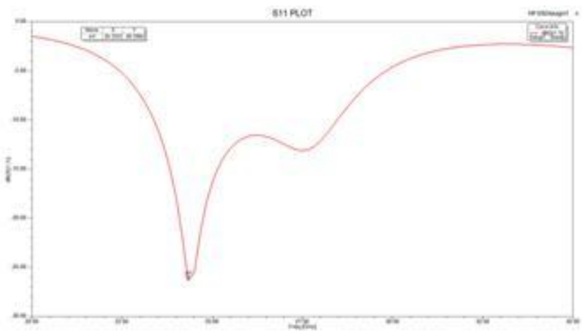


Fig. 11: S11 Plot

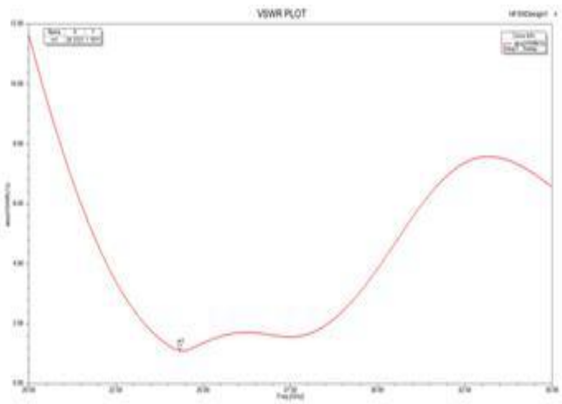


Fig. 12: VSWR Plot

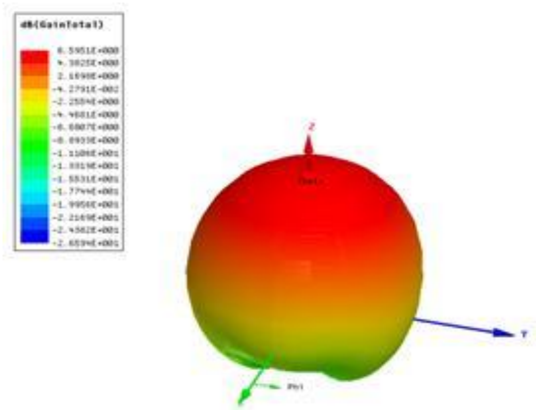


Fig. 13: 3D Radiation Pattern

C. For F3 State

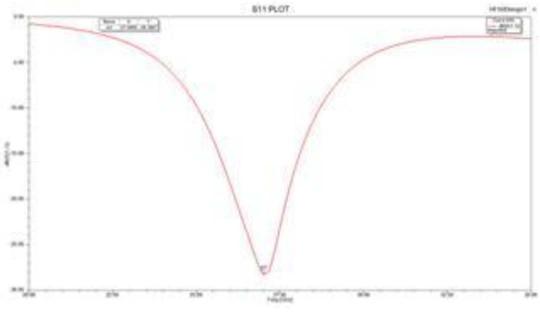


Fig. 14: S11 Plot

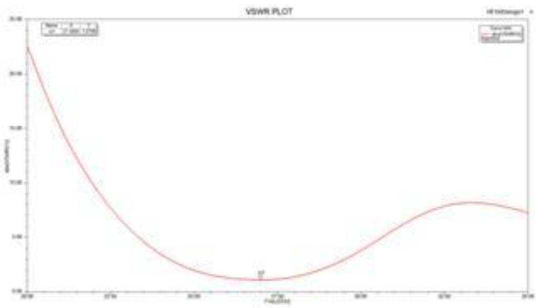


Fig. 15: VSWR Plot

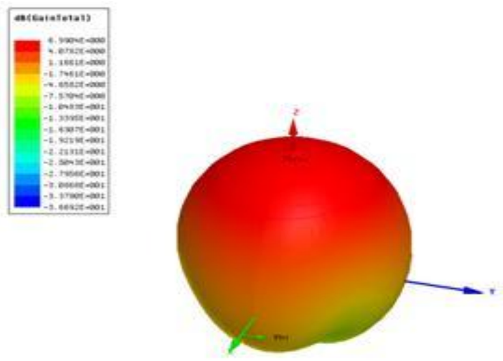


Fig. 16: 3D Radiation Pattern

As can be depicted from figure 14, figure 15 and figure 16, for the F3 state, we have obtained reflection coefficient of -28.30 dB, VSWR of 1.07 and total gain of 6.99 dB, directivity of7.14 dB and antenna efficiency of 97.89% at a resonant frequency of 27 GHz.

D. For F4 State

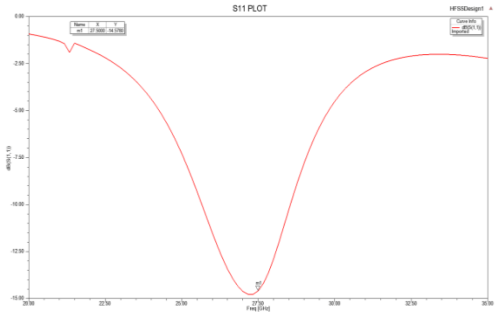


Fig. 17: S11 Plot

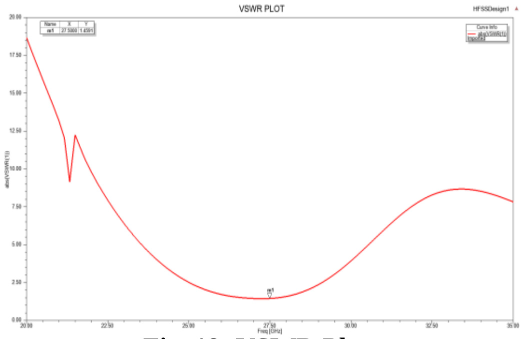


Fig. 18: VSWR Plot

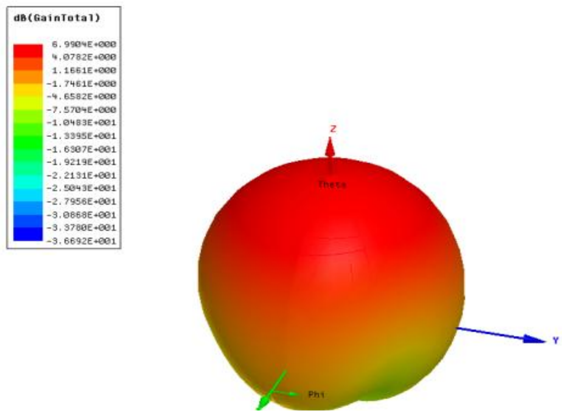


Fig. 19: 3D Radiation Pattern

As can be depicted from figure 17, figure 18 and figure 19, for the F4 state, we have obtained reflection coefficient of -14.57 dB, VSWR of 1.45 and total gain of 6.97 dB, directivity of 7.03 dB and antenna efficiency of 99.14% at a resonant frequency of 27.5 GHz.

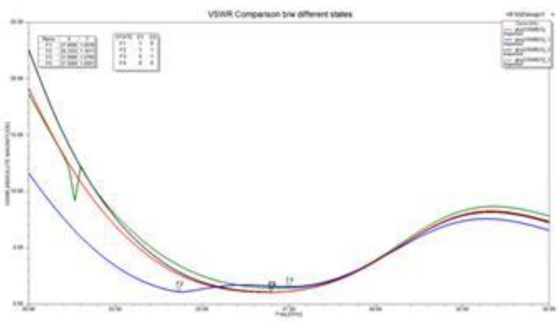


Fig. 20: Comparative VSWR Plot for different diode states

Figure 20 depicts the comparative VSWR plot obtained when the diodes operate under different states. Here, the configuration of both the diodes and the corresponding resonant frequency and S11 values has also been mentioned in tabular form. The states corresponding to plots of different colours have also been marked.

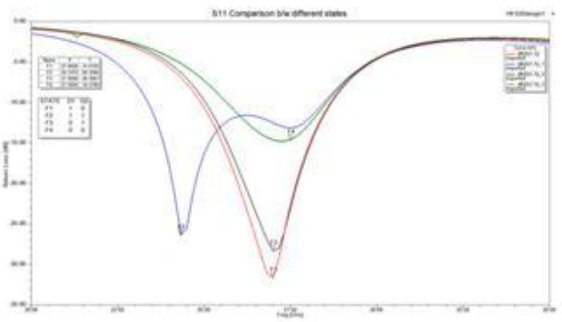


Fig. 21: Comparative S11 Plot for different diode states

Figure 21 depicts the comparative S11 plot obtained when the diodes operate under different states. Here, the configurations of both the diodes and the corresponding resonant frequency and S11 values have also been mentioned in tabular form. The states corresponding to plots of different colours have also been marked.

CONCLUSION

In this paper, Frequency Reconfigurable Microstrip Patch Antenna with Dumbbell-shaped slot has been presented. The antenna has been designed on a Rogers RT Duroid5880 substrate because it offers low dielectric loss, making it compatible with high-frequency applications. The substrate has a thickness of 1 mm, permittivity of 2.2, and tangential loss of 0.0009. Here, designing has been done using AnsysEM17.2 HFSS Software. In the presented antenna, frequency reconfiguration has been using BAP 65-02 PIN Diodes in the frequency range of 24.33 to 27.5 GHz, which showa good reflection coefficient, and VSWR between 1 and 2 has been obtained in all the states. Also, the high gain with good antenna efficiency corresponding to each state has been achieved and mentioned. The frequency range and results so obtained are suitable for 5G related applications, as the frequency range for 5G related application lies between 24.2 GHz to 86 GHzfalls in the desired frequency range allotted by World Radio Communication Conference (WRC).

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