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RESEARCH PAPER

Multi-Resonant Slotted Microstrip Patch Antenna Array with PIN Diode Configuration for 5G Application

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A B S T R A C T:

The fifth generation (5G) applications require the components of the wireless communication systems to operate at large frequency ranges. This is to increase the data rate capability and reduce the network traffic in the systems. Therefore, the main purpose in this paper is to propose and design a 4×1 microstrip patch antenna array with frequency reconfigurability feature using the Computer Simulation Technology (CST) microwave studio. To do this, slots and PIN diodes are inserted in each of the radiating patches. Comparing to the conventional 4×1 microstrip array, the proposed microstrip array has capability to resonate not only at 28 GHz, but also at 24, 26, and 31 GHz as well. Also, the bandwidth at each of these resonance frequencies is about 0.5%. The antenna array gain is more than 11.5 dBi over the operating frequency range. The radiation pattern is directive with very low side lobe level at both the E- and H- planes. The proposed microstrip antenna is low profile and compact in which it may be of interest in some 5G applications.

Keywords: Antenna Array; PIN Diodes; 5G; Reconfigurable; Slots.
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1.INTRODUCTION :

5G applications have some duties for antenna design such as low profile, small size so the antenna should be compact as it can be and conformability. According to these specifications microstrip antennas are one of ideal choice used for this kind of application and for various applications related to military and space systems. One of disadvantage regarding to this kind of antennas is the lower bandwidth but it can be increased by using an array antenna (Smith et al., 2000). Another disadvantage is the single frequency resonant, but it can be solved also using reconfigurable antennas which attracted much attention recently in different applications such as frequency, polarization and beam switching. RF switches, MEMS and tunable materials (Lim et al., 2010) – (Rodrigo et al., 2012), are typically used to implement the antenna configurations. Pattern reconfigurable antennas have been used to improve the communication link by changing the antenna main lobe angle.

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Phased array, antenna array and parasitic elements are the three main reconfiguration methods studied in the literature (Rodrigo et al., 2012) – (Jusoh et al., 2014). The most common method to reconfigure radiation pattern is by altering effective antenna geometry using PIN diode or RF-MEMS. It is noticeable that PIN diode is cheaper, more reliable, faster in switching speed, and simpler in fabrication process. Whilst RF-MEMS has wider bandwidth, high isolation, low insertion loss, low power consumption, however it requires high electrostatic voltage for actuation (Zohur et al., 2013). PIN diodes can be connected to the transmission line and used as beam steering to control the shift of the main beam lobe for left or right according to the configurations of diodes (Mingle et al., 2019).

Hexagonal microstrip patch arrays operating at 3.5 GHz was presented for wireless backhaul (Al-Gburi et al., 2022). The 1×8 array has a gain of 6.938 dBi. An inset fed technique was used in a 2×3 array in order to improve the gain and standing wave ratio of the microstrip array (Buravalli et al., 2020). Various slot shapes etched to a single microstrip patch array was investigated in (Nahas, 2022) in order to enhance the gain of the microstrip patch. It was found that significant gain achievement can be obtained when the L-shape slot is introduced. A corporate feed network configuration was introduced to the microstrip arrays presented in (Abdulmajid, 2021) mainly to enhance the bandwidth of the array. More than 148.54% of impedance bandwidth of the 8-element array is enhanced. Additionally, another new corporate fed network was integrated with a four-element microstrip patch array was proposed in (Maharjan and Choi, 2020), and the as a result of the new fed network, the bandwidth is improved.

Moreover, new set of reconfigurable antennas derived from PIN diodes have been used for Reconfigurability are given in (Ladas et al., 2008)- (Mak et al., 2007). According to different references as mentioned before, using PIN diode can be in different way as mentioned in this work which leads to control beam angle and shift the resonant frequency to the lower band.

This paper presents a 5G printed microstrip antenna array with parasitic elements. The proposed antenna array used PIN diodes to switch the parasitic element ON and OFF to change the frequency band and control the main beam.

2.FREQUENCY RECONFIGURABLE MICROSTRIP ANTENNA DESIGN

2.1Antenna Array Design

Figure 1, fed by a microstrip transmission line. The patch antenna, microstrip transmission line and ground plane are made of high conductivity metal generally copper. The patch length L_p, Width W, and sitting on top of a substrate of thickness h with permittivity ε_r. The frequency of operation of the patch antenna of figure 1 is determined by the length L, the center frequency f_0 will be approximately given by (Balanis, 2015):

$$f_0 = \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_r\,\varepsilon_0\,\mu_0}} \qquad (1)$$

where; ε_r is the permittivity of substrate, ε_0 and μ_0 are the permittivity and permeability of free space, L is the effective length of the patch, $C = 3 \times 10^8\ m/s$

The dimensions of the patch and substrate are calculated by (Agarwal, 2020):

Width of the patch W:

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \qquad (2)$$

Effective dielectric constant:

$$\varepsilon_{r\,eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}(1+12\ \frac{h}{w})^{-1/2} \qquad (3)$$

$8h$: thickness of dielectric substrate

Fringing length ΔL:

$$\Delta L = 0.412h\,\frac{(\varepsilon_{r\,eff}+0.3)}{(\varepsilon_{r\,eff}-0.258)}\,\frac{(w/h+0.264)}{(w/h-0.8)} \qquad (4)$$

Length of patch L_p:

$$L_p = L - 2\Delta L \qquad (5)$$

Length of substrate L_s:

$$L_s = 6h + L_p \qquad (6)$$

Width of substrate W_s:

$$W_s = 6h + W \qquad (7)$$

The Edge-Fed 4x1 microstrip patch array antenna designed at 28 GHz frequency with RT5880 as substrate with dielectric constant ε_r = 2.2, loss tangent tan(δ) = 0.0009, substrate thickness h = 0.508mm and copper thickness t = 0.035mm was used.

In the next step, creating parasitic elements and connecting them with ON and OFF state pin diodes leads to change the frequency depending on the states of pin diodes configurations. Figure 2 shows the S11 of the antenna which resonant at 28 GHz with gain 13.4 dB as seen in figure 3.

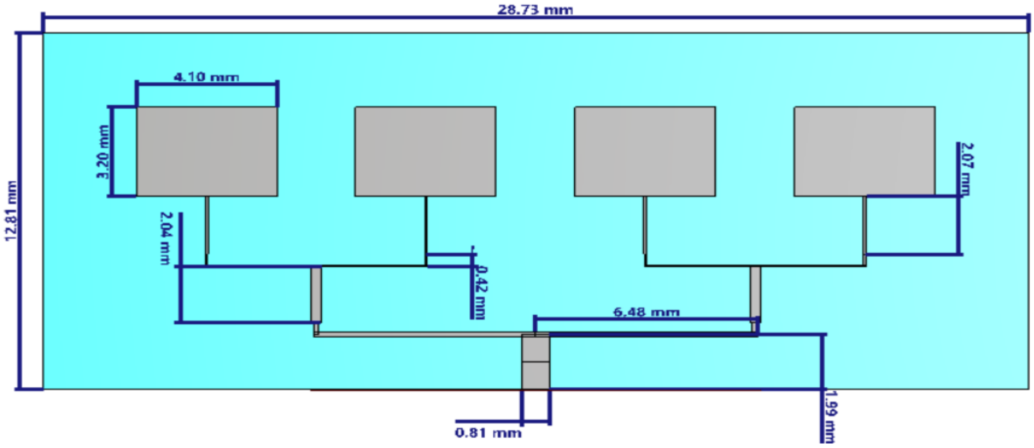

Figure 1. Microstrip antenna array as 4x1 elements.

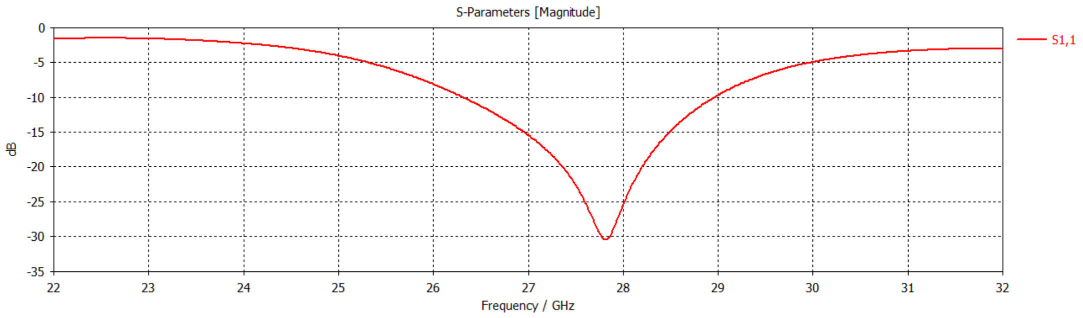

Figure 2. S11-parameters of 4x1 printed antenna array.

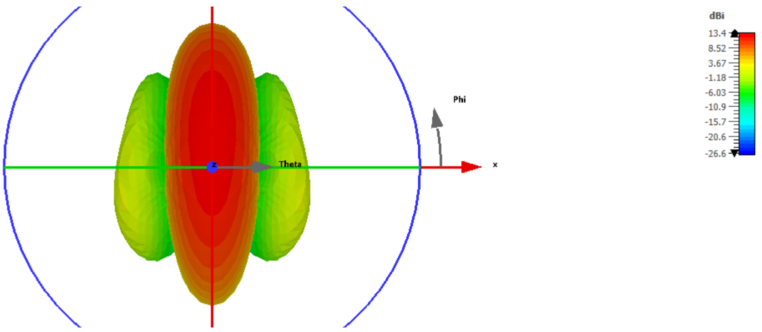

Figure 3. Gain radiation plot of 4x1 printed antenna array.

2.2PIN Diodes Configurations

In the design of the frequency reconfigurable array antenna, four PIN diodes are integrated on four patch antennas. The diode is MACOM MADP-000907-14020, In the interest frequency band, the turn-on and turn-off of the diode can be equivalent to the equivalent circuit models shown in Fig.4 (a) and (b), where the inductance *L*=30pH, capacitance *C*=0.025pF, resistance *R*=7.8Ω (Yang et al., 2016). The designed antenna array loaded with PIN diodes is shown in Figure 5. The anodes of diodes are connected to one end of the patch, and cathodes are connected to the other end. Apply a certain bias voltage to the feeder to control the states of the diode. In the simulation, the on and off states of the diode are simulated in the way of equivalent circuits, and the state of the diode is changed by reconfiguring the parameters *R*, *L*, and *C*. Figure 6 shows the S11 simulation results of the antenna when diodes are on and off. When diodes are off, the patch antenna is not connected to the parasitic elements, the resonance point of the antenna array is 28GHz, and the operating bandwidth is 26.3-29GHz. When diodes are turned on, it can be seen that the resonant frequency of the antenna has moved to 26GHz, and the working bandwidth is 25.5-27.4GHz.

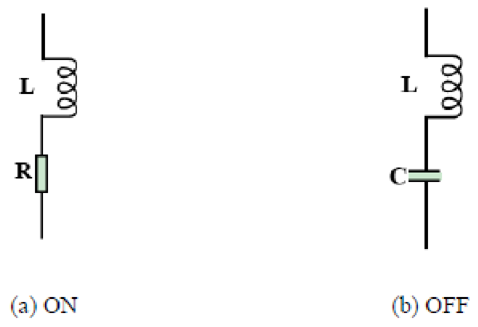

Figure 4. The equivalent circuits of the ON and OFF states.

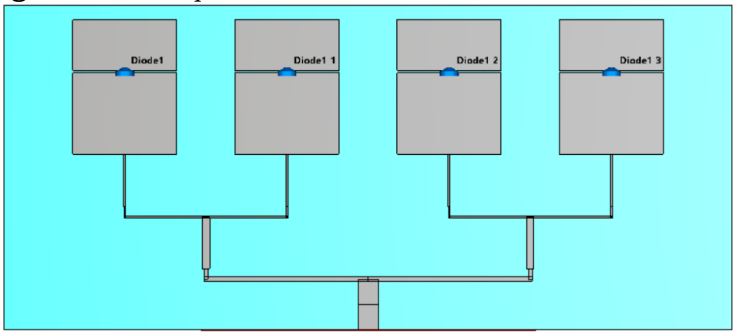

Figure 5. Printed 4x1 antenna array with PIN diodes.

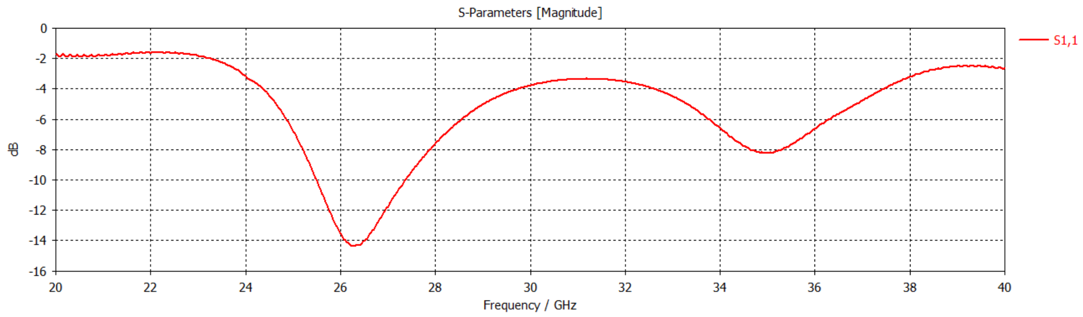

Figure 6. S11 of the printed antenna array with PIN diodes.

2.3 Proposed frequency reconfigurable antenna array design

According to the section above, adding parasitic elements and connect them with patches elements using PIN diodes can change the frequency of resonant. In this part, creating more parasitic element in the top and left of the radiating elements and connect with them using parasitic elements can shift the resonant frequency and at the same time can control the main beam of the proposed antenna according to the PIN diodes configurations because as known the main beam of printed patch antenna is the middle of the radiation elements but when connect the parasitic elements by diodes the size of patch will change which leads to change the center of the beam. Figure 7 shows the proposed antenna structure with PIN diodes. In this design, the exist of the parasitic elements lead to create new resonant if it is attached with the PIN diodes or to be as director to have higher gain if the diodes are off. After creating the design, noticing the frequency cannot be shifted to lower frequency less than 26GHz. So, creating slot in the middle of each patch element leads to shift the resonant to 24GHz. Figure 8 shows the final proposed design with slots and PIN diodes. Changing the state of diodes between elements will have a disadvantage according to the gain so for that having two states as all ON or OFF will be proposed for all designs. Which gives more than one scenario according to the state of diodes as off which means parasitic elements work as director everyway means in all

sides or as components from the middle radiating elements by the connecting of diodes as on state.
Finally, the existing of parasitic elements with diodes not only shift the resonant frequency but also can change the main beam to a specific angle. This happen according to the theory of the microstrip antenna which mention that the center of the radiation pattern of the antenna will be at angle 0 degree which is the center of the radiating element. When adding parasitic element, the distribution of the current in the top layer of the proposed antenna will change which leads to change the resonant frequency. Moreover, when adding diodes as ON state the size of the radiating element will change so the center of this layer will change which leads to change the main beam angle as exist in figures 9 and 10. Figures 11 and 12 show the proposed antenna steps and the return loss of each step. In these two images, the return loss of steps is included for comparing the steps and mention the role of including and creating parasitic elements connected with diodes and slots.

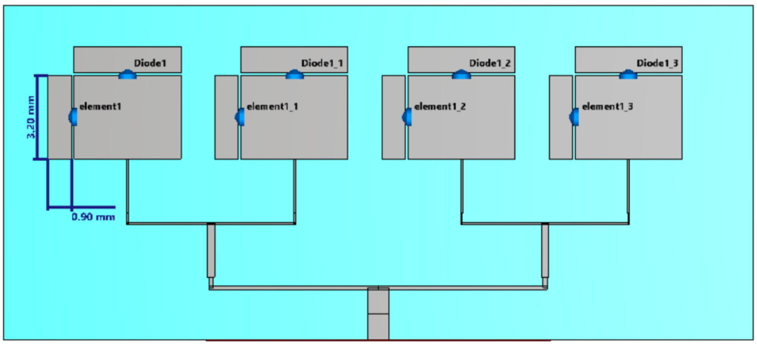

Figure 7. Proposed microstrip antenna array with PIN diodes.

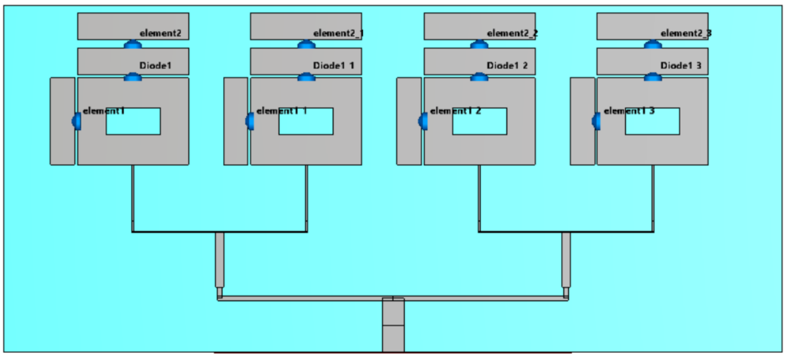

Figure 8. Proposed microstrip antenna array with slots and PIN diodes.

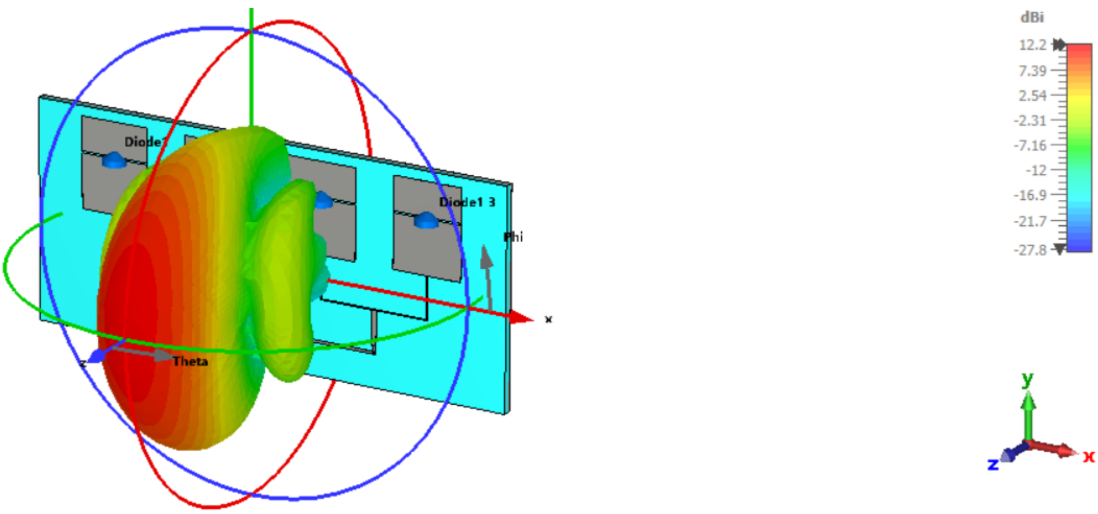

Figure 9. 3D Radiation pattern of microstrip array antenna with 4 PIN diodes.

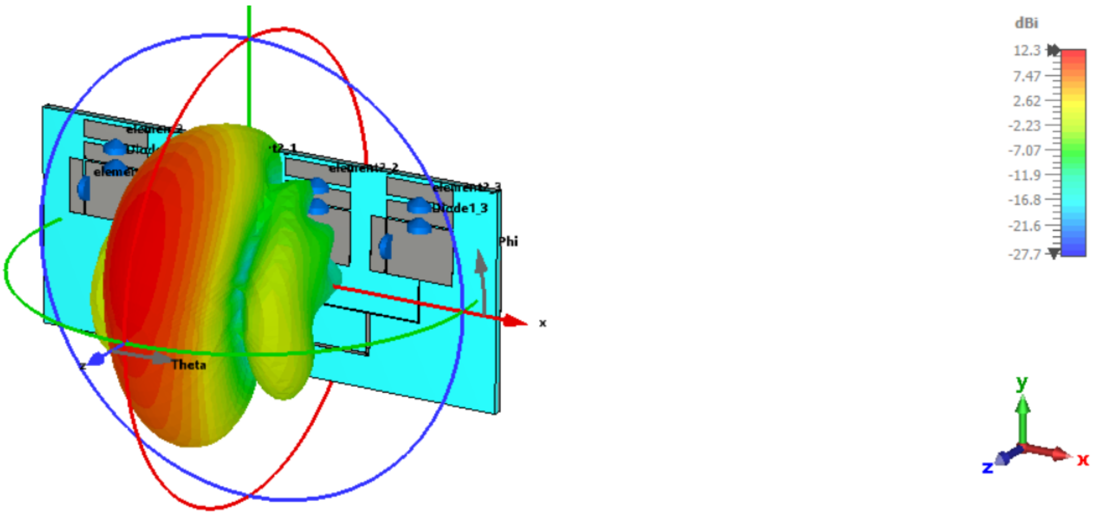

Figure 10. 3D Radiation pattern of microstrip array antenna with 12 PIN diodes.

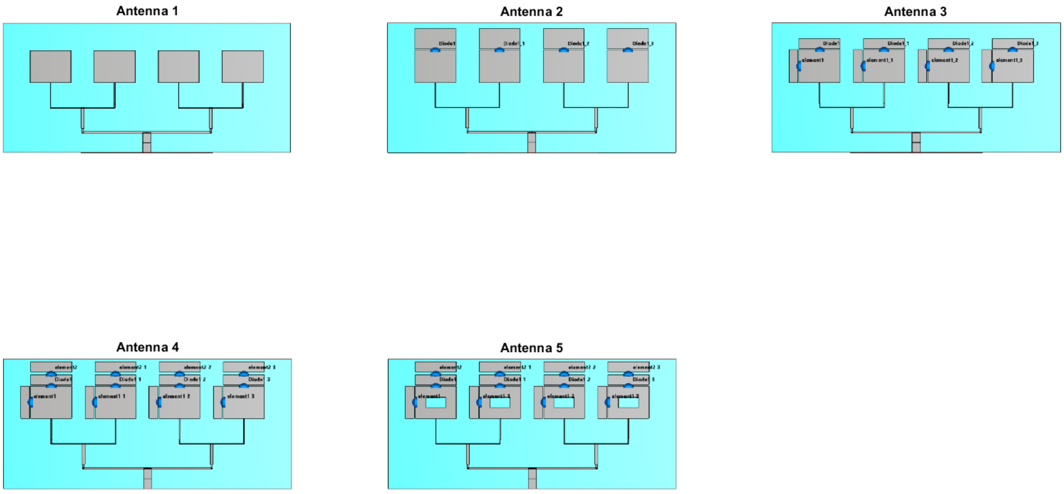

Figure 11. Proposed antenna structure steps.

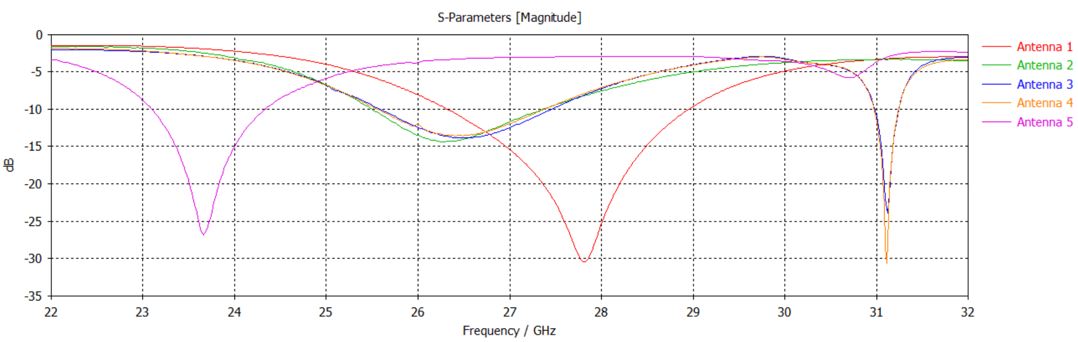

Figure 12. Return loss of the proposed antenna steps.

Table 1 summarize the results of each step according to the resonant frequency, return loss, bandwidth and gain.

Table 1: Detailed results of proposed antenna steps.

Antenna Design	Resonant Frequency	S11 (dB)	BW (%)	Gain (dB)
1	28	-30	9.6	13.4
2	26	-15	9.23	12.2
3	31	-14	3.2	12.4
4	31	-17	6.8	12.3
5	24	-26	5	11.5

3.CONCLUSIONS

In this paper, the proposed design is a frequency reconfigurable microstrip slotted antenna array loaded with 12 PIN diodes. The 4x1 microstrip antenna array is designed by combining the patch antennas. 12 PIN diodes are integrated as three diodes on each microstrip patch antenna element, and the cathodes of diodes are connected to the other end of radiating element. In the simulation, the on and off states of the diodes are controlled by setting the parameters of the equivalent circuit. The simulation results show that when diodes are switched on and off, the operating frequency band of the antenna array can be changed from 28GHz to 26GHz and after creating slots is shifting to 24GHz, realizing the reconfigurable radiation characteristics in the multiple frequency bands for 5G applications. In the different operating frequency bands, the maximum gain of the antenna is more than 13 dB, and it has good directivity as radiation shapes as main and side lobes. The designed frequency reconfigurable array antenna has a certain guiding significance for the reconfigurable design of the antenna array and has a good application prospect in the antenna array system.

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