An open double ring antenna with multiple reconfigurable feature for 5G/IoT below 6GHz applications

Duong Thi Thanh Tu[1], Son Cao[1], Hien Duong[2]
[1]Faculty of Telecommunication 1, Posts and Telecommunications Institute of Technology, Hanoi, Vietnam
[2]Faculty of Civil Engineering, Thuyloi University, Hanoi, Vietnam

Article Info

Article history:

Received Jul 13, 2021
Revised Sep 8, 2021
Accepted Dec 6, 2021

Keywords:

5G/IoT
Frequency and radiation pattern
PIN diode
Reconfigurable antenna

ABSTRACT

In this paper, we proposed a hybrid or compound reconfigurable antenna using three PIN diode switching to achieve the different types of reconfiguration: frequency and radiation pattern. Based on an open ring structure with the varied active PIN diodes, the proposed antenna radiation pattern can scan a beam along with one of five directions with the same operating frequency. Depended on the number of active PIN diodes, the antenna operating frequency also can switch to two of six bands which are 1.9 GHz, 2.4/2.6 GHz, 3.5 GHz, 5 GHz, and 5.6 GHz. All frequency bands are popular ones of wireless communication as well as 5G/IoT applications. In addition, the antenna gets a compact size of 30mm *30 mm*1.6 mm and wide bandwidth due to using the radiating shape of a double ring. All details of antenna design are optimized by CST software, and the simulation results agree well with the measurement results.

Corresponding Author:

Duong Thi Thanh Tu
Faculty of Telecommunication 1, Posts and Telecommunications Institute of Technology
Km 10 Nguyen Trai Road, Hanoi 100000, Vietnam
Email: tudtt@ptit.edu.vn

1. INTRODUCTION

Recent years, varied spectrum standards for different technologies require multi-function characteristic to support multi-service for only one terminal [1]. Reconfigurable antenna with the advantage of multifunctional capabilities has attracted many researchers all over the world for modern wireless communication [1]-[4]. There are several types of single as well as hybrid or compound reconfigurable antenna which can tune collectively various parameters of an antenna. For single function reconfiguration, there are polarization, radiation pattern, and frequency reconfigurable antenna. For multi-function reconfiguration, there are radiation pattern and frequency; bandwidth and frequency; polarization and frequency; polarization, radiation pattern, and frequency; reconfigurable antenna. Besides, depending on the way to adjust antenna operation by switches, there are some popular ways due to their small size, low cost, and fast switching. They are using PIN diode, applying varactor or proving RF micro-electromechanical systems (MEMS) [3]. Many reconfigurable antenna studies for advanced communication systems have been reported in recent years [1], [2], [4]-[23]. Some research are frequency and bandwidth ones, a few are polarization and frequency or polarization and radiation pattern ones. There are several frequency multiband ones [1], [4]-[7]. However, frequency and radiation pattern reconfigurable antennas are the most popular because the compound of beam switching and frequency changing offer remarkable efficiency in spectrum [1], [2], [8]-[13].

Ahmad *et al.* [8] present a multiband 5G antenna with multi-reconfiguration function. The antenna achieves six frequency bands for switching and seven beams for steering but the number of the PIN diode is eight. The higher quantity of high-quality active elements are the higher antenna payment are and the more complex control circuitry and biasing networks are [1]. This is why it is not easy to fabricate these designs in reality. It is also the disadvantage of the antenna with diode-loaded ELC resonators [11]. Palsokar and Lahudkar [9] use only one PIN diode, and apply two switches for their designs [10]. However, the frequency bands and beams that these antennas can change are small. It is the drawback of three PIN diode antenna [12] which the number of switching frequency is three, and the flexible one [13] which the number of shifting phases is two.

In this work, we proposed a compound dual-band reconfigurable antenna for 5G/ IoT devices. The antenna consists of three PIN diodes that can change antenna operating frequencies from different dual-band to other ones of (1.9 GHz and 4.7 GHz), (2.55 GHz and 4.7 GHz), (2.6 GHz and 5.5 GHz), and (3 GHz and 5.6 GHz). The operating bands are cover popular bands of 5G/IoT below 6 GHz applications such as 1.9 GHz, 2.4/2.6 GHz, 3.5 GHz, 5 GHz, and 5.6 GHz. Besides, the radiation pattern is steered along $\pm 161^0$ at 1.9 GHz, $\pm 110^0$ and 180^0 at 2.55 GHz, $\pm 144^0$ and $\pm 148^0$ at 4.7 GHz, 0^0 and 180^0 at 5.6 GHz. In particular, the proposed antenna can scan beam along with one of five directions of $\pm 158^0$, $\pm 163^0$, and 170^0 at 5 GHz. With the novel shape of open double ring, the antenna not only gets a compact size which can be fitted on a small form factor but also can suitable for multiple technologies.

The main paper is divided into three parts as; the antenna structure and the reconfigurable features are presented in section 2. The simulated results are studied and discussed in section 3.1 while the fabricated antenna and its measurement are analyzed in section 3.2. Finally, section 5 is the conclusion of our study.

2. ANTENNA STRUCTURE AND RECONFIGURABLE FEATURES

The antenna shape has an important role determining the antenna's characteristics [24]. Changing the the position of the radiating patch and electrical length and by switches is the popular way to get reconfiguration features of a reconfigurable antenna [3]. In our work, we need three PIN diodes to switch three different parts of the open double-ring structure to change the radiation direction and electrical length. It is why, the antenna can be switched to the desired beams as well as the frequencies.

2.1. Open double-ring structure

The proposed open double-ring antenna includes two open rings and three PIN diodes which is placed as demonstrated in Figure 1. Firstly, based on the method to calculate the parameters of the disk antenna. The draft radius of open double ring is determined because both antenna have the similar type of radiation fields [24]. Then, we optimize the radii using CST software. For the TM_{nm} mode, the operating frequency can be decided as:

$$f_{nm} = \frac{X_{nm}c}{2\pi r\sqrt{\varepsilon_r}} \tag{1}$$

where f_{nm} is the resonnant frequency at TM_{nm} mode, X_{nm} is the m^{th} zero of Bassel function of order n Jn' (ka), c is the speed of light in a vacuum, r is the effective radius, and ε_r is the dielectric constant of the substrate. It is proven that the mode corresponding to *n=m=1* has a minimum radius or operating frequency and it is called the dominant mode. That is why the TM_{11} mode is popularly chosen to calculate the radius of a disk (*r)* for a desired operating frequency as:

$$r = a\left\{1 + \frac{2h}{\pi a\varepsilon_r}\left(ln\frac{\pi a}{2h} + 1.7726\right)\right\}^{1/2} \tag{2}$$

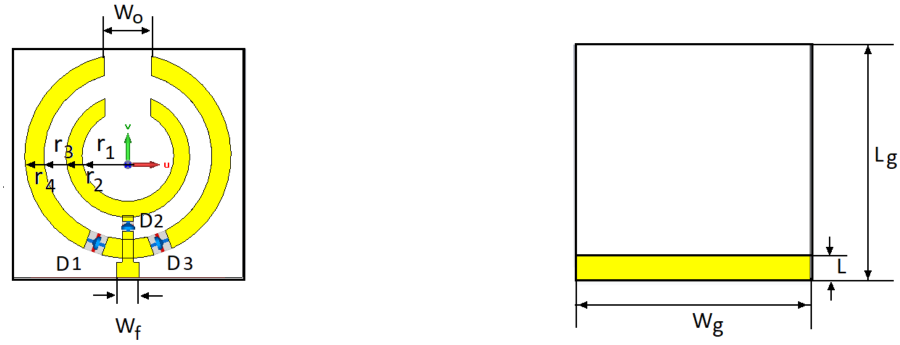
where *h* is the thickness of the dielectric, *a* is determined from the basic relation as following:

$$X_{nm} = ka \tag{3}$$

and k is obtained by (4):

$$k = \frac{2\pi\sqrt{\varepsilon_r}}{\lambda_0} \tag{4}$$

After calculating and optimizing by CST software, the detailed dimensions of our open double ring antenna are presented in Table 1.



(a) (b)

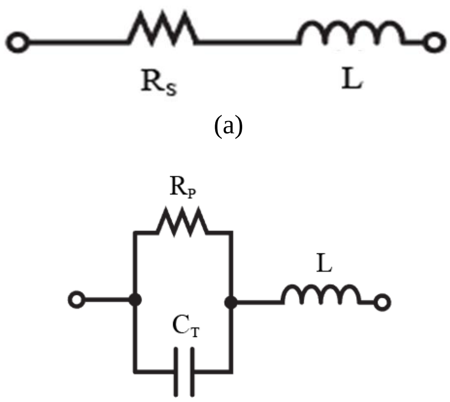
Figure 1. Geometry of the proposed open double ring antenna (a) radiation plane and (b) ground plane

Table 1. The detailed dimensions of the open double ring antenna

Parameter	W_g	L_g	W_f	W_o	L	r_1	r_2	r_3	r_4
Size (mm)	30	30	2.9	6.1	3	6	8.1	11	13.5

2.2. PIN diode switching

PIN BAP65-02 diode is popular to become the switch of the reconfigurable antenna because of their low cost, ease of usage, and small size [25]. Thus, we also using PIN BAP65-02 diode to provide the switching. Based on suitable polarity voltage, the PIN diode can be turned on the activate state or not (ON or OFF state). These states of the PIN BAP65-02 diode is obtained via inductor L, resistance RS, RP, and capacitor CT are illustrated in Figure 2.



(a)

(b)

Figure 2. The equivalent of BAP65-02 (a) ON state (b) OFF state

The ON state of PIN diode is determined by inductor L and series resistor R_S while the OFF state is get by a series inductor L connecting with a parallel circuit which includes a capacitor C_T and a resistor R_P. The parameters of the RLC circuit in the both states of PIN diode are reported in Table 2. It is clearly seen that the lower value of R_S in the series RL circuit lets the current go from the feeding line to the radiation elements while the higher value of R_P, C_T in the RLC circuit prevents the current from moving between the feeding line and the radiation element.

Table 2. The values of RLC circuit in PIN BAP65-02

Parameters	L	C_T	R_S	R_P
Value	0.6mH	0.5pF	1Ω	20kΩ

2.3. The compound reconfigurable antenna

From Figure 1, it is obvious that the open outer ring element is divided into two symmetrical radiation parts by D1 and D3 PIN diode. D2 PIN diode is used to connect the open inner ring with the total or apart of the open outer ring as well as the feeding line. Basing on the state of active or inactive (ON or OFF) of three PIN diodes, the radiation element and its position are changed. It is the reason that the proposed antenna can achieve varied resonant frequencies and the varied directions of these bands can be obtained as illustrated in Table 3**.**

Table 3. The six reconfigurable states of the open double ring antenna

Reconfigurable state	PIN diode D1	D2	D3	Radiation element	Resonant frequency (GHz)	Operating band (GHz)	Radiation direction
State 1	ON	OFF	OFF	The right part of outer open ring	1.9 4.7	1.86-1.96 4.3-5.16	-161^0 144^0
State 2	OFF	OFF	ON	The left part of outer open ring	1.9 4.7	1.86-1.96 4.3-5.16	161^0 -144^0
State 3	ON	ON	OFF	The right part of outer open ring and inner ring	2.55 4.7	2.37-2.77 4.3-5.16	110^0 148^0
State 4	OFF	ON	ON	The left part of outer open ring and inner open ring	2.55 4.7	2.37-2.77 4.3-5.16	-110^0 -148^0
State 5	ON	OFF	ON	The outer open ring	2.6 5.54	2.3-2.9 4.9-6	180^0 0^0
State 6	ON	ON	ON	Both open rings	3 5.6	2.56-3.73 5.08-6	180^0 147^0

It can obvious that depending on the number of the active PIN diode, antenna operating frequencies can change from different dual-band to other ones. They are (1.9 GHz and 4.7 GHz), (2.55 GHz and 4.7 GHz), (2.6 GHz and 5.5 GHz), and (3 GHz and 5.6 GHz). These operating bands are cover six popular bands of 5G/IoT below 6 GHz applications such as 1.9 GHz, 2.4/2.6 GHz, 3.5 GHz, 5 GHz, and 5.6 GHz. Besides, the radiation pattern is steered along $\pm161^0$ at 1.9 GHz, $\pm110^0$ and 180^0 at 2.55 GHz, $\pm144^0$ and $\pm148^0$ at 4.7 GHz, 0^0 and 180^0 at 5.6 GHz. Thus, the proposed antenna can achieve double reconfiguration features of the dual-band antenna. They are frequency and radiation pattern reconfigurable ones.

3. RESULT ANALYZING AND DISCUSSION

Here is the simulated and measured result analyzing and discussion of antenna's characteristics. In section 3.1, the simulated results are performed on the CST MICROWAVE STUDIO commercial software that includes the S11 parameters in different states of the switch using the PIN diode corresponding to the 2D radiation patterns. After that, the reflection coefficient results on the VNA are present in section 3.2.

3.1. Simulated results

3.1.1. Frequency dual-band reconfiguration

The S11 parameters of the open double ring antenna with one, two, and three active PIN diodes (ON state) are presented in Figure 3. Using only one active PIN diode, the antenna can operate at State 1 or State 2. In both cases, the electrical length is the same which equal to half of the outer ring. Thus, there are two resonant frequencies as seen in Figure 3(a). They are 1.92 GHz and 4.72 GHz. We can determine these operating frequencies of the proposed antenna though analysis of antenna structure and a rough calculation basing on (5). For example, the high band can achieve when the electrical current concentrates on the right/left outer curve of the ring shape. It is calculated as:

$$f_H = \frac{1.84118*3.10^8}{2\pi*(13.5*\frac{1}{2}+2.5).10^{-3}*\sqrt{4.3}} = 4.58 \text{ GHz} \quad (5)$$

If two PIN diodes are active, the electrical length is changed. At State 3 and State 4, the radiation element includes half of the outer ring and the inner one. Thus, from the Figure 3(b), we can see the resonant frequency at the high band is unvaried while it moves to 2.55 GHz at the low one. At State 5, we can see from the Figure 3(c) that the shape of the radiation patch is shifted to the total outer ring, so both operating bands are changed. In this case, dual bands are 2.6 and 5.5 GHz. When all three PIN diodes are active, the reconfigurable antenna is at State 6. In this way, the radiation structure consists of both open rings hence the antenna bandwidths are opened, and the resonant frequencies are drifted as shown in Figure 3(d). From

Figure 1 and Figure 3, it is concluded that the dual-band antenna can change from two operating bands to other ones when the number of the active PIN diode is changed.

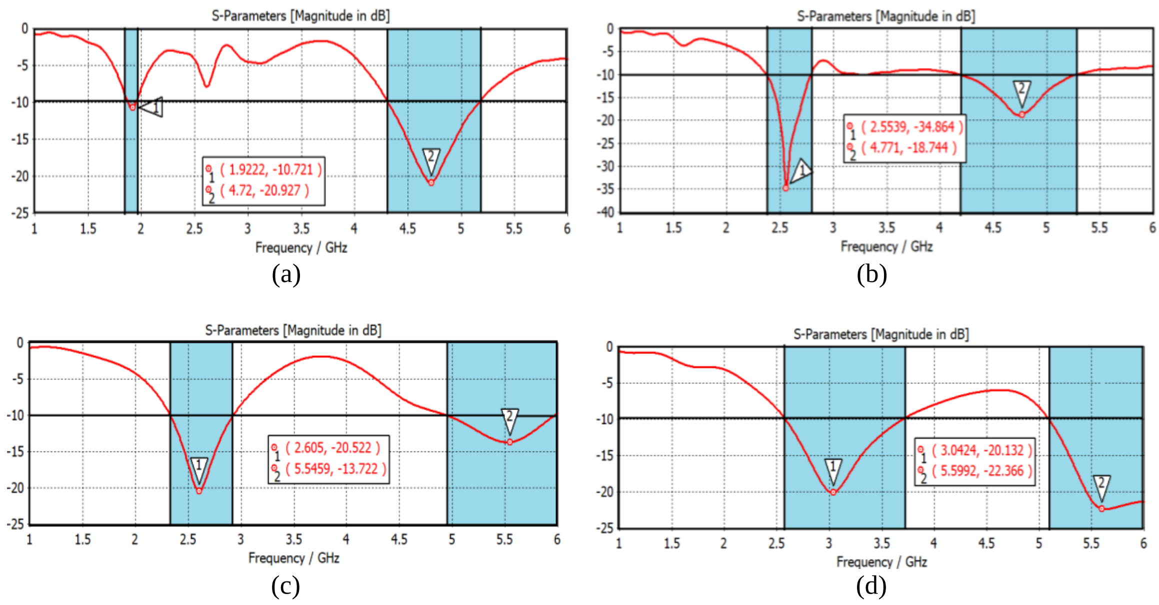


Figure 3. S11 parameters of the open double ring antenna with different active PIN diode; (a) one active PIN diode, (b) two active asymmetric PIN diodes, (c) two active symmetric PIN diodes, and (d) three active PIN diodes

3.1.2. Radiation pattern reconfiguration

Depending on the active PIN diode position and the number on the antenna structure, the antenna radiating directions are changed to make radiation pattern reconfiguration as illustrate from the Figure 4(a) to Figure 4(d).

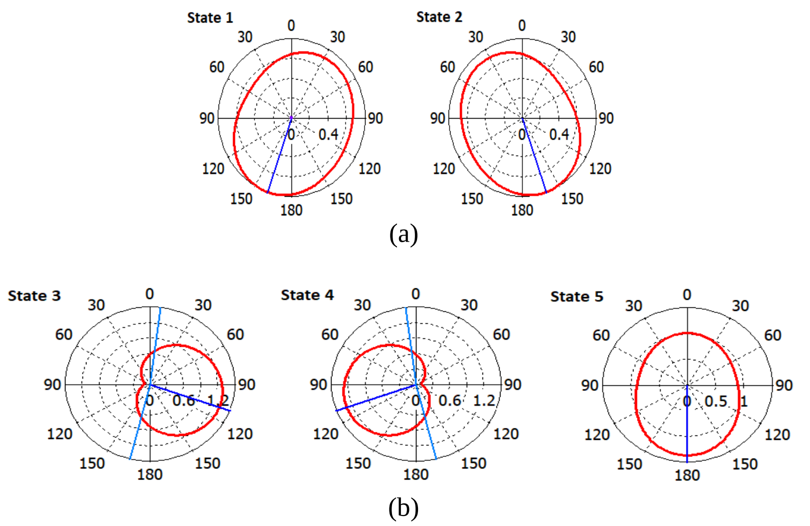
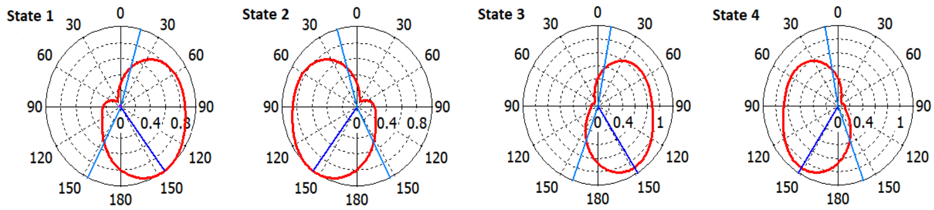
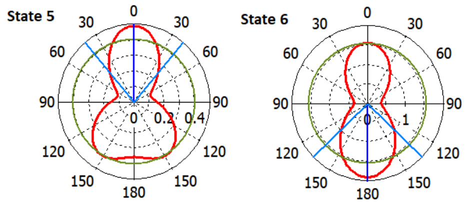


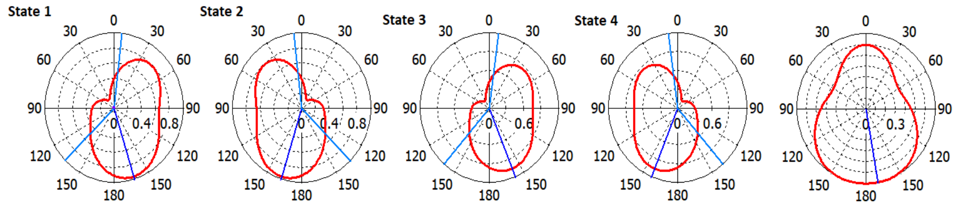
Figure 4. The simulated 2D radiation pattern at different operating frequency (a) 1.9 GHz and (b) 2.55 GHz



(c)



(d)



(e)

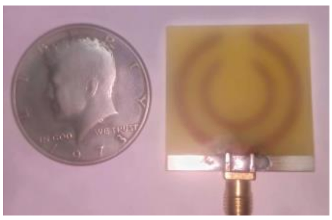
Figure 4. The simulated 2D radiation pattern at different operating frequency (c) 4.7 GHz (d) 5.6 GHz and (e) 5 GHz *(continue)*

The antenna operates at 1.9 GHz at State 1 and State 2 as shown in Table 3. It can be seen from Figure 4(a) that if PIN diode D1 is active, the 2D radiating direction is -161^0 and it is switched to +161^0 in case only PIN diode D2 is ON. At 2.55 GHz resonant frequency, the antenna steers beam along ±110^0 and 180^0 at State 3, State 4, and State 5 respectively as shown in Figure 4(b). These directions are achieved by different of turning ON two of three PIN diodes. The same beam switching is gotten when the antenna operates at the 2.4 GHz/ 2.6 GHz band. The antenna operates at 4.7 GHz at four states so that it can scan the beam in four different directions of ±144^0 and ±148^0 as shown in Figure 4(c). It is the same when we see the Figure 4(d), the antenna can steer beam along 0^0 and 180^0 at 5.6 GHz resonant frequency. As seen from Figure 3, there are five states that antenna can operate at 5 GHz band. They are form State 1 to State 5. It means that at this band, the antenna can scan the beam along with five different directions of ±158^0, ±163^0, and 170^0 as shown in Figure 4(d). Thus, it is concluded that by changing the number and the position of the active PIN diodes, the dual-band antenna can change the radiating direction at all six operating bands and the maximum beams that the antenna can steer are five at the 5 GHz band.

3.2. Measured results

The compound reconfigurable antenna is fabricated by FR4 substrate with a height of 1.6 mm. After that it is measured by VNA. The total size of fabricated antenna is 30x30x1.6 mm^3 as illustrated in Figure 5.

(a)



(b)

Figure 5. The fabricated compound reconfigurable antenna (a) radiation plane and (b) ground plane

The measured S11 parameters of the open double ring antenna with one, two, and three active PIN diodes are presented in Figure 6. The measured and simulated results are similar each other. The antenna can to switch from double operating band mode to other ones. For S11 parameters under -10dB, the antenna obtains an impedance bandwidth in 1.92 GHz (26%), 2.55 GHz (15.69%), 2.6 (53.8%), 3 GHz (39%), 4.8 GHz (40.8%), 4.9 GHz (18.2%), and 5.2 GHz (38%).

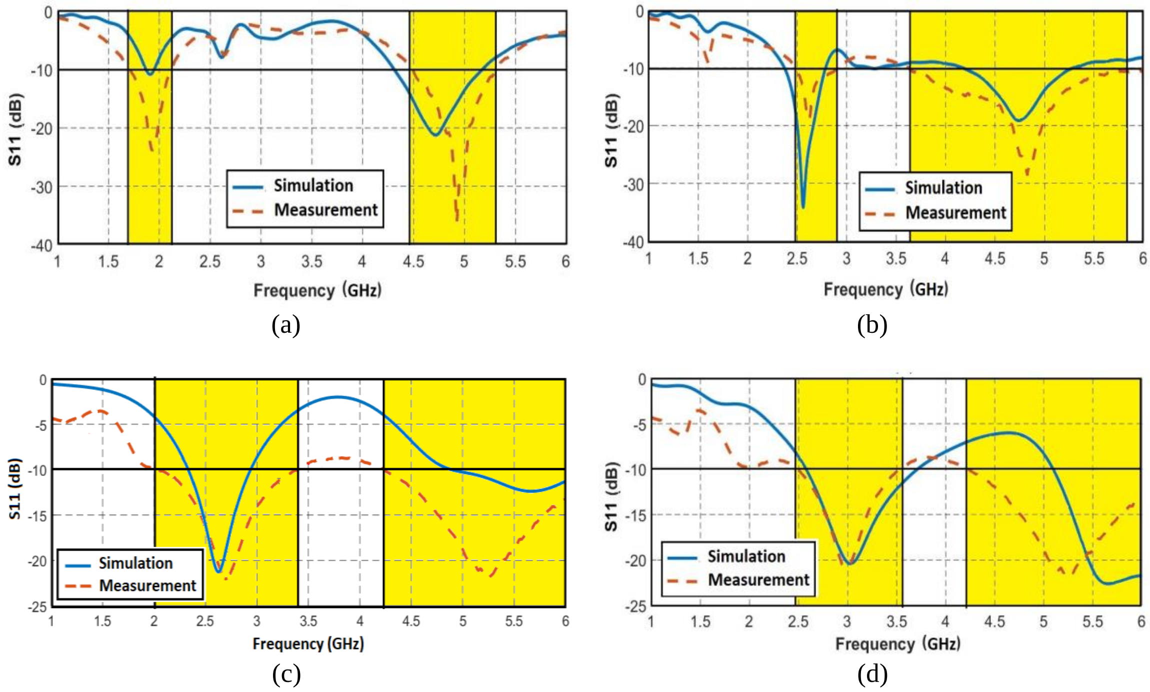


Figure 6. Simulated coefficient of the open double ring antenna with different active PIN diode; (a) one active PIN diode, (b) two active asymmetric PIN diodes, (c) two active symmetric PIN diodes, and (d) three active PIN diodes

The Table 4 is the comparison of our antenna and several recently reported frequency and radiation pattern reconfigurable antennas. We can noted that the volume of almost all antennas [9]-[11], and [13] is larger than our antenna in this work. Although the total size of antennas in [8] and [12] are small-scale, they still have a bigger dimension because their lower resonance are 2.6 GHz and 3.1 GHz when the proposed antenna is 1.9 GHz. In addition, the open double ring antenna use only three switches to get the max beam shifting of 5 and can change from dual-band to other ones of six well-known wireless bands below 6 GHz.

Table 4. The comparison of performance antenna between recently published frequency and radiation pattern reconfigurable ones and this study

Ref	Size (mm^2)	Operating frequency (GHz)	Operations	Reconfigurable state/switches	Freq. number	Max beam number per frequency
[8]	27x30	2.6; 3.5; 4.2;4.5;5;5.5	Single band; dual band	17/8	6	7
[9]	58x66	2.47; 3.8; 5.36	Single band; dual band	2/1	3	2
[10]	50x40	1.8;2.1;2.45	Single band; dual band	4/2	3	3
[11]	29x34	1.8; 2.1;2.2; 2.4; 2.6;3.5;4;5	From single band to quad band	14/5	multiple	5
[12]	23x31	3.1; 6.8	dual band	4/3	2	4
[13]	40x50	1.8; 2.1; 2.4	Single band; dual band	4/2	multiple	2
This work	30x30	1.9; 2.4; 2.6; 3.5; 4.7;5;5.6	dual band	6/3	6	5

4. CONCLUSION

A frequency and radiation pattern reconfigurable antenna is designed for IoT, 5G and for other below 6 GHz applications. Basing on three PIN BAP65-02 diodes, the open double ring antenna gets four reconfigurable frequency states for changing from dual-band operating to others of six popular bands of 1.9 GHz, 2.4 GHz, 2.6 GHz, 3.5 GHz, 5 GHz, and 5.6 GHz. Depending on the position and number of active PIN diodes, the antenna can scan the beam along from two to five directions at six different frequencies. Using the FR4 substrate, the antenna achieves a small size of 30x30x1.6mm^2 with an open-double ring structure. It is easy to fabricate by printed technique. Thus it can be suitable for future 5G/IoT devices.

REFERENCES

[1] N. O. Parchin, H. J. Basherlou, Y. I. A. Al-Yasir, R. A. Abd-Alhameed, A. M. Abdulkhaleq and J. M. Noras, "Recent Developments of Reconfigurable Antennas for Current and Future Wireless Communication Systems," *Electronics*, vol.8, no. 2, 128, pp. 1-17, February 2019, doi: 10.3390/electronics8020128.

[2] M. K. Shereen, M. I. Khattak and G. Witjaksono, "A brief review of frequency, radiation pattern, polarization, and compound reconfigurable antenna for 5G applications," *Journal of Computational Electronics*, vol. 18, pp. 1065-1102, May 2019, doi: 10.1007/s10825-019-01336-0.

[3] M. S. Shakhirul, M. Jusoh, Y. S. Lee and C. R. N. Husna, "A Review of Reconfigurable Frequency Switching Technique on Microstrip Antenna," *Journal of Physics: Conference Series, 1st International Conference on Green and Sustainable Computing (ICoGeS) 2017*, Kuching, Sarawak, Malaysia, 25–27 November 2017, vol. 1019, pp. 1-8, doi: 10.1088/1742-6596/1019/1/012042.

[4] H. Dildar *et al.*, "Design and Experimental Analysis of Multiband Frequency Reconfigurable Antenna for 5G and Sub-6 GHz Wireless Communication," *Micromachines*, vol. 12, no. 1, pp. 1-15, 2021, 10.3390/mi12010032.

[5] U. George and F. Lili, "A simple frequency and polarization reconfigurable antenna," *Electromagnetics*, 2020, vol. 40, no. 6, pp. 435-444, 2020, doi: 10.1080/02726343.2020.1811940.

[6] J. Kumar, B. Basu, F. A. Talukdar and A. Nandi, "Stable-multiband frequency reconfigurable antenna with improved radiation efficiency and increased number of multiband operations," *IET Microwave, Antennas & Propagation*, vol. 13, no. 5, pp. 642-648, 2019, doi: 10.1049/iet-map.2018.5602.

[7] A. Vamseekrishna, B. T. P. Madhav, T. Anilkumar and L. S. S. Reddy, "An IoT Controlled Octahedron Frequency Reconfigurable Multiband Antenna for Microwave Sensing Applications," in *IEEE Sensors Letters*, vol. 3, no. 10, pp. 1-4, Oct. 2019, Art no. 3502204, doi: 10.1109/LSENS.2019.2943772.

[8] I. Ahmad *et al.*, "Design and Experimental Analysis of Multiband Compound Reconfigurable 5G Antenna for Sub-6 GHz Wireless Applications," *Wireless Communications and Mobile Computing*, vol. 2021, pp. 1-14, April 2021, doi: 10.1155/2021/5588105.

[9] A. A. Palsokara and S. L. Lahudkar, "Frequency and Pattern Reconfigurable Rectangular Patch Antenna using Single PIN diode," *International Journal of Electronics and Communications*, Oct 2020, vol. 125, doi: 10.1016/j.aeue.2020.153370.

[10] A. Ghaffar, X. J. Li, N. Hussain and W. A. Awan, "Flexible Frequency and Radiation Pattern Reconfigurable Antenna for Multi-Band Applications," *2020 4th Australian Microwave Symposium (AMS)*, 2020, pp. 1-2, doi: 10.1109/AMS48904.2020.9059296.

[11] G. Singh, B. K. Kanaujia, V. K. Pandey, D. Gangwar and S. Kumar, "Pattern and frequency reconfigurable antenna with diode loaded ELC resonator," *International Journal of Microwave and Wireless Technologies*, vol. 12, no. 2, pp. 163-175. March 2020, doi: 10.1017/S1759078719001077.

[12] A. Iqbal *et al*., "Frequency and Pattern Reconfigurable Antenna for Emerging Wireless Communication Systems," *Electronic*, vol. 8, no. 4, pp. 1-12, April 2019, doi: 10.3390/electronics8040407.

[13] A. Ghaffar *et al.*, "A Flexible and Pattern Reconfigurable Antenna with Small Dimensions and Simple Layout for Wireless Communication Systems Operating over 1.65-2.51 GHz," *Electronics*, vol. 10, no. 5, pp. 1-13, March 2021, doi: 10.3390/electronics10050601.

[14] Y. Yang and X. Zhu, "A Wideband Reconfigurable Antenna With 360° Beam Steering for 802.11ac WLAN Applications," in *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 2, pp. 600-608, Feb. 2018, doi: 10.1109/TAP.2017.2784438.

[15] G. Jin, M. Li, D. Liu and G. Zeng, "A Simple Planar Pattern-Reconfigurable Antenna Based on Arc Dipoles," in *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 9, pp. 1664-1668, Sept. 2018, doi: 10.1109/LAWP.2018.2862624.

[16] Z. Gan, Z. Tu and Z. Xie, "Pattern-Reconfigurable Unidirectional Dipole Antenna Array Fed by SIW Coupler for Millimeter Wave Application," in *IEEE Access*, vol. 6, pp. 22401-22407, 2018, doi: 10.1109/ACCESS.2018.2810194.

[17] G. Yang, J. Li, D. Wei, S. Zhou and R. Xu, "Pattern Reconfigurable Microstrip Antenna With Multidirectional Beam for Wireless Communication," in *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 3, pp. 1910-1915, March 2019, doi: 10.1109/TAP.2018.2885230.

[18] H. Zhou *et al.*, "Reconfigurable Phased Array Antenna Consisting of High-Gain High-Tilt Circularly Polarized Four-Arm Curl Elements for Near Horizon Scanning Satellite Applications," in *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 12, pp. 2324-2328, Dec. 2018, doi: 10.1109/LAWP.2018.2873898.

[19] S. Ahdi Rezaeieh and A. M. Abbosh, "Pattern-Reconfigurable Magnetoelectric Antenna Utilizing Asymmetrical Dipole Arms," in *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 4, pp. 688-692, April 2019, doi: 10.1109/LAWP.2019.2901264.

[20] M. Sun, Z. Zhang, K. An, X. Wang, Y. Jiang and A. Chen, "Dual-Sense Circular Polarization Antenna Based on Reconfigurable Orthogonal Network," *International Journal of Antennas and Propagation*, vol. 2019, pp. 1-7, doi: 10.1155/2019/1670786.

[21] X. Yi, L. Huitema and H. Wong, "Polarization and Pattern Reconfigurable Cuboid Quadrifilar Helical Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 6, pp. 2707-2715, June 2018, doi: 10.1109/TAP.2018.2816785.

[22] R. Dewan, M. K. A. Rahim, M. R. Hamid, M. Himdi, H. B. A.Majid, and N. A. Samsuri, "HIS-EBG unit cells for pattern and frequency reconfigurable dual band array antenna," *Progress In Electromagnetics Research*, vol. 76, pp. 123-132, 2018, doi: 10.2528/PIERM18090202

[23] E. S. Silveira, F. Antreich, and D. C. Nasimento, "Frequency-reconfigurable SIW microstrip antenna," *AEU International Journal of Electronics and Communications*, September 2020, vol. 124, doi: 10.1016/j.aeue.2020.153333.

[24] R. Garg, P. Bhartia, I. J. Bahl and A. Ittipiboon, *Microstrip Antenna Design Handbook*, Norwood, Massachusetts: *artech house*, 2001.

[25] "*BAP65-02 Datasheet-E-Tech Electronics LTD*," Accessed on: Nov. 3, 2021 [Online]. Available: https://www.alldatasheet.com/datasheet-pdf/pdf/148884/ETL/BAP65-02.html

BIOGRAPHIES OF AUTHORS

Duong Thi Thanh Tu gets a Ph.D. degree from the School of Electronics and Telecommunications, Hanoi University of Science and Technology in April 2019. She is currently a senior lecturer at the Faculty of Telecommunications 1, Posts and Telecommunications Institute of Technology. Her research interests include network management, wide band and reconfigurable antenna designing for advanced wireless networks such as IoT, 5G commutation systems, and special structure of material studying such as metamaterial, electromagnetic bandgap structure for stop band building in MIMO and array systems. She can be contacted at email: tudtt@ptit.edu.vn.

Son Cao is a student of Electronic and Communication in Posts and Telecommunications Institute of Technology. In addition, he is also an internship at Viettel High Technology Industries Corporation-VHT. His current research centers on reconfigurable antenna design for IoT or 5G mobile communication systems. He can be contacted at email: soncx.B17VT304@stu.ptit.edu.vn.

Hien Duong Master in Hydraulic Engineering from ThuyLoi University. She is currently a lecturer at the Faculty of Civil Engineering, ThuyLoi University. Her research interests include designing IIoT solutions for smart buildings and designing antennas using special material structures. She can be contacted at email: duongthanhhien@tlu.edu.vn.