A Frequency and Radiation Pattern Reconfigurable Antenna Using Composed Structure of Pseudo-Fibonacci and DGS for 5G IoT/ WiFi 6/CR Applications

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Abstract—Compound reconfigurable antennas have been studied in recent research for modern wireless communication systems due to their advantage of multifunctional capabilities. In this paper, a novel composed structure of frequency and radiation pattern reconfigurable antenna is proposed. The antenna uses four pseudo-Fibonacci curves and the E shape of Defected Ground Structures (DGS) to make the varied directivity radiation. The steering beam along can achieve based on the position of the active PIN diode in different directions. The resonant frequency can also switch from one to other bands depending on the number of active PIN diodes. The antenna gets a compact size of 30mm x 30mm x 1.6mm that can be fit on a small form factor while still being able to scan along with 8 radiation directions of 0 °, 90 °, 180 °, 270 °, or 45 °, 135 °, 225 °, 315 °and 4 frequencies at 3.5GHz and 5GHz bands. The antenna directivity reaches 2.283dBi and 4.185dBi at 3.5GHz and 5GHz bands, respectively. The simulation, measurement, and experiment results agree well to ensure the proposed reconfigurable antenna can apply for terminals in 5G IoT, 5GHz WLAN, or cognitive radio systems.

Index Terms—Reconfigurable antenna, fibonacci, DGS

I. Introduction

Due to the significant advantage of multifunctional capability that can reduce the size and cost of an antenna while ensuring the other performance parameters, the reconfigurable antenna has been studied intensively in recent years. With the facilitating-multiple services in a compact structure, such antenna is a good candidate for use in the future generation of mobile and wireless communication systems such as 5G, 6G, IoT, CR [1]-[8]. There are many reconfigurable-antennas type with a single reconfigurable function or multiple ones. The hybrid reconfigurable antennas whose operation frequency and radiation pattern characteristics can be reconfigured are the most popular ones because the composing of frequency agility and beam scanning offer better efficiency in their respective spectra [8]-[14].

Ikhlas Ahmad et al. [9] introduces a compound reconfigurable antenna that achieves seven radiating directions for steering and six frequency bands for scanning. The number of PIN diodes that is used for changing antenna states is eight. Thus this design can get the disadvantage of complex control circuitry and radiation efficiency decreasing due to a large number of high-quality active elements [8]. It is also the drawback of the antenna that Ghanshyam Singh *et al*. [10] presented. To decrease the harmful effect of switching components, Anuradha A. Palsokar and S. L. Lahudkar [11] use only one PIN diode for their designs. However, the antenna gets fewer changing states of frequency band and radiation beam. It is the same character of three PIN diode antennas [12] which the number of switching frequency is three, and the flexible one [13] that the number of shifting phases is two.

In addition, DGS structure is one of the techniques that widely is used in modern antenna designs [15]-[22]. It recently takes apart to enhance antenna performance [15], [16], get a more compact size [17], make multiband operation [18]-[21] or improve isolation between antenna elements [22]. There are several reconfigurable antenna studies that use the DGS in their work [17]-[18], [21]-[22].

In this paper, using a novel compound design of pseudo-Fibonacci curves and the E shape of Defected Ground Structures (DGS), the proposed hybrid of frequency and radiation pattern reconfigurable antenna achieves a striking compact size that is equivalent to a coin while still being able to work with multiple frequencies and multiple radiating directions for 5G IoT, WiFi 6, or cognitive radio (CR) communication.

The rest of this paper is organized as follows. In Part II, the antenna design with the pseudo-Fibonacci curve and E shape of DGS is presented. The simulated results are analyzed in Part III when the measured and experimental ones are given in Part IV. Finally, Part V concludes the study.

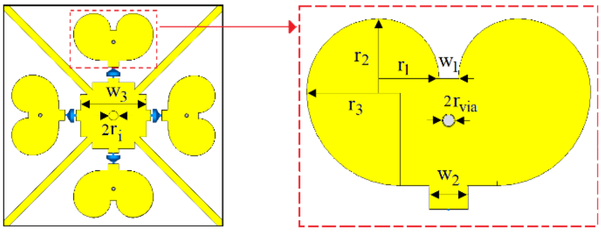
II. Antenna Design

A. Antenna Structure

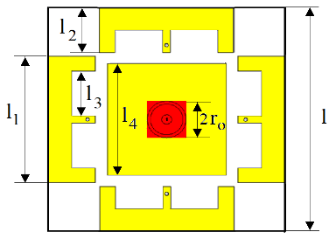
The shape of both antenna sides has a significant effect on the antenna's characteristics [23]. In this paper, four PIN diode switches are used to control four different parts on both antenna sides to change the electrical length. Thus, the antenna can operate at one of four frequencies as well as the beam can scan along in one of four directions at the same operation band.

Manuscript received July 10, 2022; revised November 17, 2022.
doi:10.12720/jcm.17.12.1003-1008

As shown in Fig. 1, the structure of the proposed pseudo-Fibonacci/DGS antenna includes three parts: Radiating patch, defected ground, and four PIN diodes.



(a) Top view



(b) Bottom view

Fig. 1. Geometry of the proposed antenna.

TABLE I. THE DIMENSION OF THE PROPOSED ANTENNA

Parameter	r_1	r_2	r_3	r_{via}	r_i	r_o	w_1
Value (mm)	2.3	2.8	3.6	0.25	0.635	2.45	0.73
Parameter	w_2	w_3	l	l_1	l_2	l_3	l_4
Value (mm)	1.5	9	30	17	6	6	15

Based on FR4 substrate with a dielectric constant of 4.3 and thickness of 1.6mm, the antenna dimension is calculated and optimized by CST software and presented in Table I. The antenna is a bit compact with a total size of $30x30x1.6mm^3$.

On the radiating side of the proposed antenna, each pseudo-Fibonacci curve is formed by three quarter circle arcs as seen from Fig. 1(a). The radii of these arcs (r_{FS}) are developed from the Fibonacci sequence that is calculated by the following:

$$(r_{FS})_n = \frac{(\phi^n - (-\phi^n)}{\sqrt{5}} + A \qquad (1)$$

where A is a constant that is optimized by simulated software, n = 1 to 3, ϕ is golden ratio [24] which is given by (2):

$$\phi = \frac{1+\sqrt{5}}{2} = 1.618 \qquad (2)$$

On the ground side, four E shape structures are etched corresponding to four double Fibonacci curves on the top plane as shown in Fig. 1(b). With this structure, the antenna can get directivity radiation to enlarge the number of switching beams. Besides, four vias connect the double Fibonacci on the top plane to the E shape structure on the ground plane to decrease the PIN diode effect on antenna radiation efficiency.

B. *Pin Diode Switching*

In this work, the PIN BAP65-05 diodes are used to make the switching due to their ease of usage, low cost, and small size [25]. The PIN diode can be turned on or off by using a suitable polarity voltage.

TABLE II. THE COMPARISON OF ELEVEN SWITCHING STATES

Switching state	**PIN diode D1**	**D2**	**D3**	**D4**	**Frequency (GHz)**	**Phase**
S1	ON	OFF	OFF	OFF	5.325	0^0
S2	OFF	ON	OFF	OFF		90^0
S3	OFF	OFF	ON	OFF		180^0
S4	OFF	OFF	OFF	ON		270^0
S5	ON	ON	OFF	OFF	5.645	45^0
S6	OFF	ON	ON	OFF		135^0
S7	OFF	OFF	ON	ON		225^0
S8	ON	OFF	OFF	ON		315^0
S9	ON	OFF	ON	OFF	5.71	0^0
S10	OFF	ON	OFF	ON		90^0
S11	OFF	OFF	OFF	OFF	5.08	0^0

Due to other states that are three states of 3 diodes ON and one state of all diodes ON are not resonated at the appropriate telecommunication band, they are not put in this work. Based on the switching of ON and OFF of four PIN diodes, the antenna can achieve eleven states with the operating frequencies and radiating directions as shown in Table II.

III. SIMULATION RESULTS

The hybrid reconfigurable feature of the proposed antenna is frequency and radiation pattern. These functions are analyzed by CST software in this section.

A. *Frequency Reconfiguration*

As can be seen from Fig. 1 and Table II, the number and position of active PIN diodes can change the electrical length of the antenna. In this way, they can make different operating frequencies. It is more clear when seeing the reflection coefficient results of the designed antenna with different quantities of active PIN diodes (ON state) which are presented in Fig. 2.

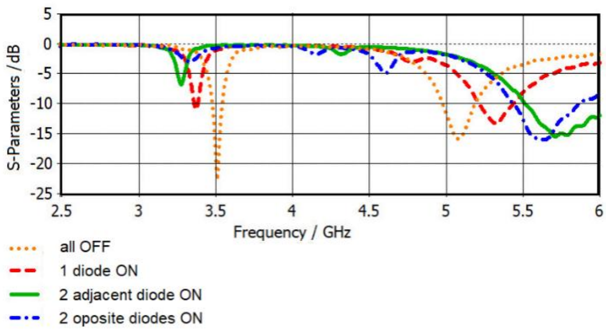


Fig. 2. The reflection coefficient result of the proposed antenna.

When all PIN diodes are OFF, the antenna can operate at two bands of 3.5GHz and 5.08GHz with a bandwidth of 77MHz and 211 MHz, respectively. The operating frequencies will change to another dual-band antenna of 3.377GHz and 5.325GHz with the 45MHz and 249MHz bandwidth when only one PIN diode is activated. If two adjacent PIN diodes are at the ON state, the antenna will work at 5.645 GHz and get a bandwidth of over 556 MHz. In the case of active two opposite PIN diodes, the operating band will switch to 5.71 GHz while the bandwidth is still unchanged.

Thus, the proposed antenna achieves two states of frequency reconfigurable. One state is four different frequencies at 5GHz band. Another is two different frequencies at 3.5GHz band. They are suitable for CR communication, 5G, and WiFi 6 applications.

B. Radiation Pattern Reconfiguration

Depending on the position and the number of the active PIN diode on the antenna structure, the antenna radiating direction can switch to one of eight ones. The antenna can achieve a maximum of four steering beams at the same operating frequency. As can be seen from Fig. 3(a) by one PIN diode is ON state, the antenna operates at 5.325 GHz, and the radiating direction can steer from 0 ° to 90 °, 180 °, and 270 ° depending on the position of activating pin diode. It is similar to the case of two active PIN diodes. It is illustrated in Fig. 3(b) that when two adjacent PIN diodes are activated, the resonant frequency is 5.645 GHz and the beam can scan from 45 ° to 135 °, 225 °, and 315 °. In case of two opposite PIN diodes are active, the antenna can operate at the State of S9 and S10 with the same 5.71 GHz frequency. The radiation pattern has a dipole form, and the beam can switch from 0 ° to 90 ° that as shown in Fig. 3(c).

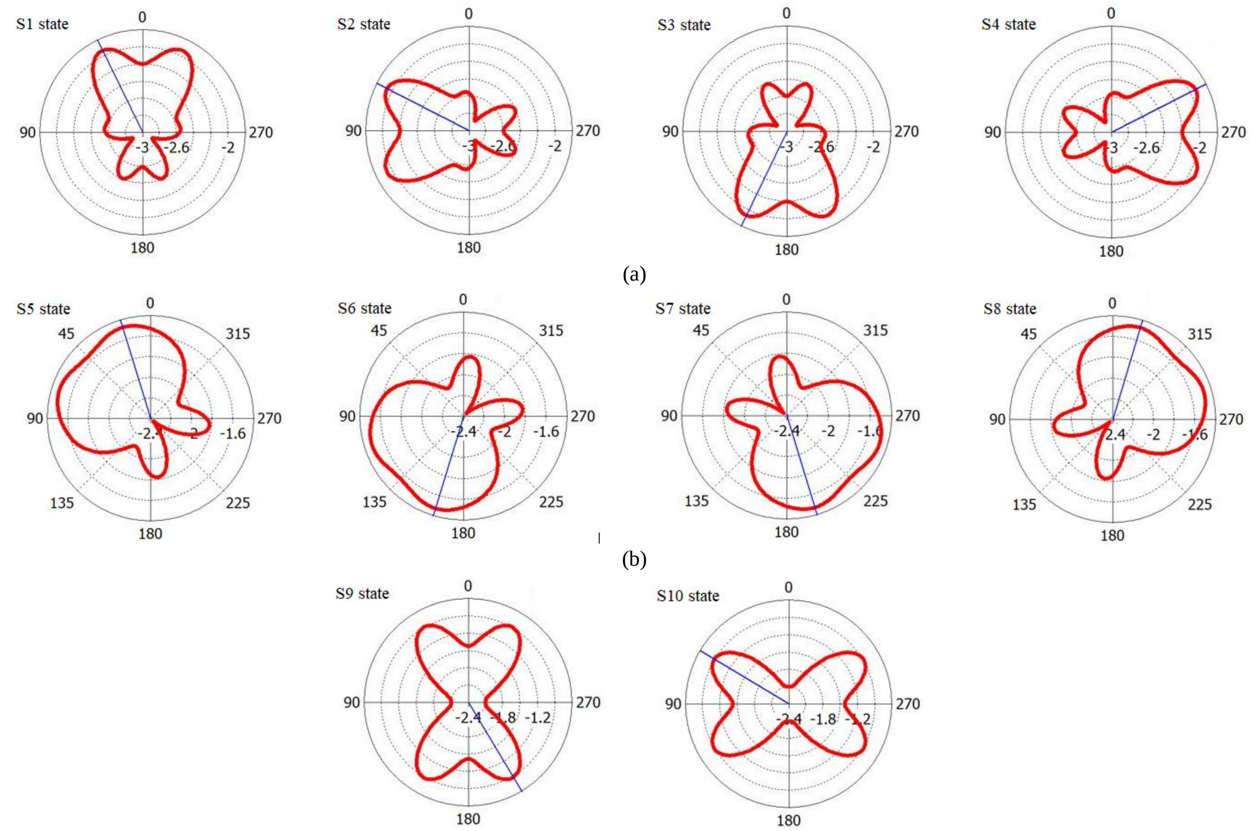


Fig. 3. The simulated radiation pattern at $\varphi=90^0$ plan of the proposed antenna at the different operating frequencies.

TABLE III. THE COMPARISON OF THE PROPOSED ANTENNA AND RECENT PUBLISHED

Ref	Operating freq (GHz)	reconfigurable states/ switches	Max frequency reconfiguration	Max steering beams/ frequency
[1]	2.4	4/4	1	4
[4]	2.6; 3.5; 4.2;4.5;5.0;5.5	17/8	4	5
[5]	1.8; 2.1;2.2; 2.4; 2.6;3.5;4;5	14/5	4	4
[6]	2.47; 3.8; 5.36	2/1	2	1
[7]	3.1; 6.8	4/3	2	4
[8]	1.8; 2.1; 2.4	4/2	2	3
[9]	26; 28	4/3	2	3
This work	5.08; 5.325; 5.645;5.71	11/4	6	4

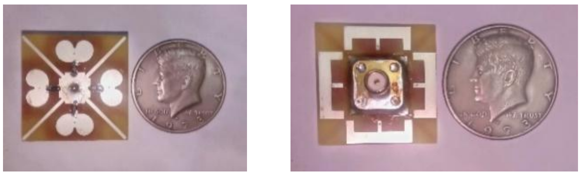
C. Comparison

The proposed antenna is compared with other recently reported frequency and radiation pattern reconfigurable antennas. This comparison is shown in Table III. It can denote that in this work, the hybrid of frequency and radiation configurable antenna uses a reasonable quantity of switches to get a high ratio of reconfigurable states per number of switching. In addition, it achieves significant scanning beams and switching frequencies, too.

IV. Experimental Results

A. Fabricated Antenna

Based on the FR4 substrate with a height of 1.6mm, the proposed antenna is fabricated and gets a compact size of 30x30x1.6mm^3. Its layout is presented in Fig. 4.



(a) Top view (b) Bottom view

Fig. 4. Fabricated hybrid antenna.

B. Measured Result Based on VNA

The reflection coefficient results (S11) of the proposed antenna are measured by Vector Network Analyzer (VNA). The measurement is performed at different states of zero, one, and two adjacent and opposite PIN.

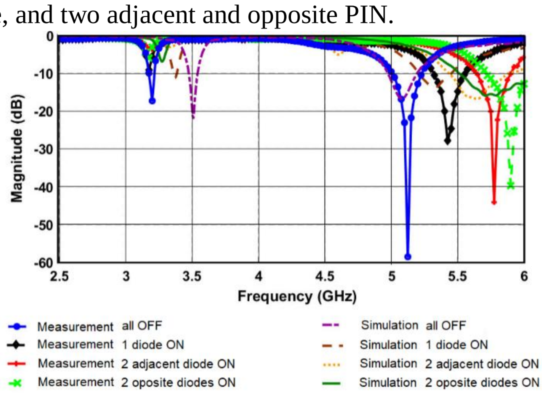


Fig. 5. Comparison of measurement and simulation results.

The comparison between measurement and simulation is shown in Fig. 5. It is seen that the measured results are similar to the simulated ones. The fabricated antenna can switch one of four 5GHz bands or two 3.5GHz bands. For S11< -10 dB, the hybrid reconfigurable antenna achieves an impedance bandwidth in all 5GHz bands over 200 MHz. Thus, it is rather suitable for CR communication as well 5G IoT at 5 GHz band.

Besides, the proposed antenna can operate at the 3.2GHz band of about 50MHz bandwidth for Wimax/ LTE applications.

C. Case Study: Using the Proposed Antenna for USB WiFi Adapter

The proposed antenna has experimented on a 5 GHz WiFi band in obstacle conditions. A vital channel from a laptop to a mobile phone is set up to evaluate the signal intensity of the proposed antenna. The demonstration paradigm is shown in Fig. 6 which includes a USB WiFi Adapter, a laptop, the proposed antenna, and a mobile phone. USB WiFi Adapter supports a 5GHz receiver/transmitter circuit to connect to the laptop through a USB port and a dipole antenna. The mobile phone has the role of a 5GHz transmitter. Provided with estimating the proposed antenna, a dipole antenna is used to compare with Fibonacci/DGS one by WiFi Analyzer software.

Fig. 6. The experimental paradigm.

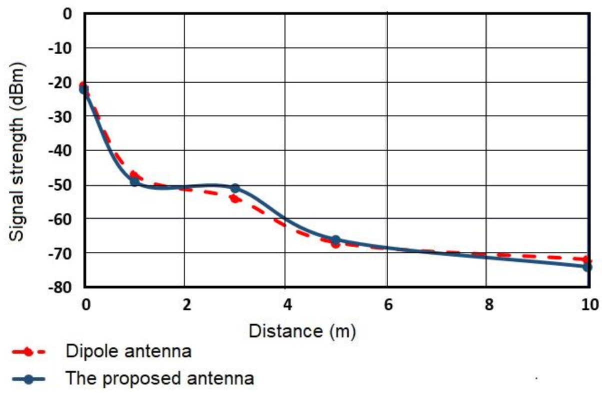


Fig. 7. Experimental results at the 5GHz band.

The signal strength comparison between the Fibonacci/DGS proposed antenna and the dipole one is shown in Fig. 7. Due to the small transmitting power of the mobile phone, the distance of the receiving signal with a receiving sensitivity of -76 dBm is still quite short, about 10m. However, the signal intensity is received from the proposed antenna is equivalent to the reference antenna which is an antenna dipole having a 2 dBi gain. This is demonstrated that the proposed antenna can work well with WiFi receiving and transmitting equipment indoor or outdoor.

V. Conclusion

In this paper, a novel pseudo-Fibonacci/DGS antenna that can reconture with frequency and radiation using PIN diode switching is presented. The hybrid reconfigurability is achieved using four PIN diodes. The antenna operates at 3.377GHz, 3.5GHz, 5.08 GHz, 5.325 GHz, 5.645GHz, and 5.71 GHz frequencies and steering at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° directions. The bandwidth of

5GHz operating bands is much more than 200 MHz. All characteristics are suitable for 5G, 5G IoT, WiFi 6, and CR communication.

The MIMO antenna with decoupling structure will be developed to achieve much more high gain and can support a double data rate for equipment in the future work.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

All authors had contributed to this work. Tu and Son conducted the research; Son designed and optimized antenna parameters; Tu analyzed both simulated and experimental data; Tu, Nga and Dung wrote the paper; Son, Tan, and Nga fabricated antenna, measured, and did an experiment; all authors had approved the final version.

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