RADIATION PATTERN AND FREQUENCY RECONFIGURABLE ANTENNA USING PADOVAN SEQUENCE

ANTEN TÁI CẤU HÌNH THEO GIẢN ĐỒ BỨC XẠ VÀ TẦN SỐ SỬ DỤNG CHUỖI PADOVAN

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Abstract:

This paper proposes a radiation pattern and frequency reconfigurable antenna using four PIN diodes. The antenna structure is based on the Padovan sequence of nine squares on the patch and four ones on the ground. In this way, the antenna's radiation pattern can be recognized at +52° and −27°. Also, the reconfigurable frequency of the proposed antenna can change from 5 GHz to 18.74 GHz. The total antenna size is rather small, which is 44.44 x 35 x 1.52 mm^3. Besides, the antenna can achieve rather high efficiency and a quite good bandwidth at almost operating bands.

Keywords:

Reconfigurable antenna, radiation pattern reconfigurable, frequency reconfigurable, Padovan, PIN diode.

Tóm tắt:

Nội dung bài báo đề xuất một cấu trúc anten đa tái cấu hình: vừa có thể tái cấu hình theo giản đồ bức xạ vừa có thể tái cấu hình theo tần số dựa trên các trạng thái bật – tắt khác nhau của bốn diode PIN. Để làm được điều này, thiết kế anten được biến đổi theo hình vuông Padovan với 9 phần tử trên mặt bức xạ và bốn phần tử trên mặt phẳng đất. Anten thu được có thể tái cấu hình theo giản đồ bức xạ tại hai phương +520 và −270, tái cấu hình theo tần số từ 5Ghz đến 18.74GHz với kích thước tổng thể khá nhỏ, đạt 44.44 x 35 x 1.52 mm^3. Bên cạnh đó, các tham số quan trọng khác của anten tái cấu hình như hiệu suất và băng thông thu được khá tốt ở phần lớn các tần số cộng hưởng của anten.

Từ khóa:

Anten tái cấu hình, tái cấu hình theo tần số, tái cấu hình theo đồ thị bức xạ, Padovan; điôt PIN.

1. INTRODUCTION

The requirements for advanced antennas' multi-functional abilities are continuously increasing for wireless communications, radar systems, and satellite telecommunications. Their properties can adjust to achieve the desired characters like frequency band, radiation direction, or polarization. Reconfigurable antennas have many advantages over wideband antennas, such as smaller size, comparable radiation patterns among all multiple frequency bands, productive utilization of electromagnetic range, and frequency discernment, decreasing the co-channel interference and jamming [1]. Only in 2018-2019, a score of researches about reconfigurable antennas have been reported with different variations such as frequency reconfigurable [2]-[7], radiation pattern reconfigurable [8-15]. In [9], a wideband antenna was reconfigured radiation pattern by G. Jin et al. The antenna uses four diodes to change to four different directions but the average performance approximately 60%. Also, the antenna size is rather big, which is 75×75×0.75 mm^3, so it hard to apply to the user equipment. Scale problem is a challenge of the antenna in [11] because of numerous layers that significantly create large elevation. In [14], a design antenna with a ring structure can change radiation patterns by matching impedance, but performance only reaches 50%.

In this paper, a frequency and radiation pattern reconfigurable antenna using four PIN diodes is presented. The proposed antenna operates with four states of frequency reconfiguration and two states of radiation pattern one. Besides, using the variable squares based on the Padovan sequence, the antenna achieves a striking compact size. Thus, it can be easily integrated into modern compact devices while still being able to work with multiple technologies.

The rest of this paper is organized as follows. In Part 2, the antenna design is presented. The simulated and analysis are studied in Part 3. Finally, Part 4 concludes the study.

2. ANTENNA DESIGN

2.1. Padovan sequence

Unlike Fibonacci – golden ratio on the 2D dimension, the Padovan sequence that is a golden ratio on the 3D dimensions is set through a cubic function. The Padovan sequence is defined by basic number value: 1, 1, 1, 2, 2, 3, 4, 5, 7, 9, … which is formed by formula (1).

$$P(n)=P(n-2)+P(n-3) \quad (1)$$

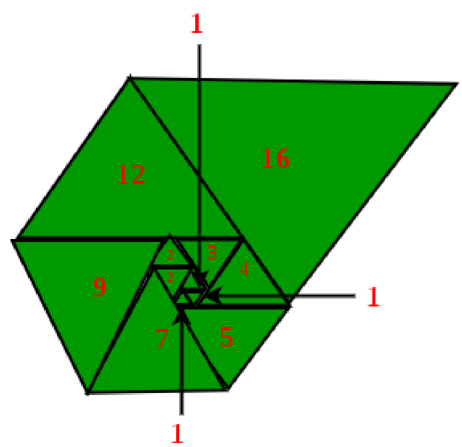


Fig. 1. Padovan sequence variation

Like Fibonacci's spiral, the Padovan sequence varies to become Padovan's spiral that is shown in (2).

$$\lim_{n\to\infty}\left(\frac{P(n)}{P(n-1)}\right)=\rho \quad (2)$$

where the real value of ρ is built through a cubic formula (3).

$$\rho=\frac{\sqrt[3]{9+\sqrt{69}}}{18}+\frac{\sqrt[3]{9-\sqrt{69}}}{18}\sim 1.324717957 \quad (3)$$

2.2. Antenna structure

2.2.1. Antenna using Padovan sequence

Figure 2 shows the proposed antenna's geometrical structure that consists of three parts: the radiation patch, the substrate, and the ground plane. The substrate layer is RO4350B with h_s= 1.52 mm and ε=3.48, loss tangent 0.0037. The patch is constructed by the Padovan geometric sequence in the form of nine squares. These squares are arranged in ascending order in a counter-clockwise direction starting from 180° direction with incremental size 1, 1, 1, 2, 2, 3, 4, 5, 7. The ratio k = 2 is built according to the following formula (4) and (5).

$$P(n) = P(n-2) + P(n-3) \quad (4)$$

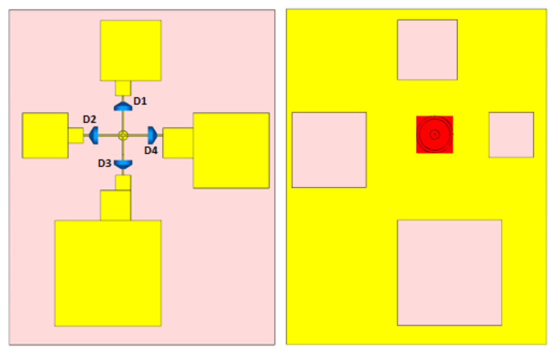
$$P(N) = P(n) \times k \quad (5)$$

where P(n) is the value from the Padovan sequence, P(N) is the real value of the radiation patch.

It is the same rule for the ground plane with the form of four DGS squares. The antenna is connected by coaxial cable through the ground plane to be exposed to the radiation patch. The position of coordinates (x,y) is (-3.5;6.5). Four diodes are connected to the feeding network by a microstrip line of 5.166 mm long and 0.2 mm width. The other antenna dimensions are detailed in Table 1.

Table 1. Parameters and their dimensions (mm)

Parameter	Value	Parameter	Value
W	35	P2	4
L	44.44	P3	6
Ld	5.16	P4	8
Wd	0.2	P5	10
k	2	P7	14
P1	2		



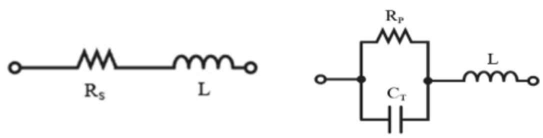
(a) (b)

Fig. 2. Antenna geometric. (a): Frontside; (b): Backside

2.2.2. PIN diode

To switch the different antenna states, four PIN MA4AGBLP912 diodes are used due to low loss and high switching speed. The PIN diode can be turned on and off by using suitable polarity voltage. The ON state is made by a resistor in series with the inductor and the OFF state is made by a resistor connected in parallel with the capacitor then in series with the inductor. The values R, L, C of the diode PIN under both ON and OFF conditions are shown in Table 2.

The different states of the antenna are shown in Table 3. Using four PIN diodes for the four radiating elements, the antenna can resonate at the respective frequencies while maintaining the same direction of the radiation plot. Besides, at a defined resonant frequency, the antenna will also have different radiation directions based on the state of the diode is activated.



(a) ON state (b) OFF state

Fig. 3. Equivalent of PIN diode

Table 2. Diode's parameters

Parameter	L	C_T	R_S	R_P
Value	0.5nH	0.025pF	4Ω	10kΩ

Table 3. States of antenna

States	Active diodes	D1	D2	D3	D4
S1	1/4 ON	OFF	OFF	OFF	ON
S2	2/4 ON	ON	ON	OFF	OFF
S3		OFF	OFF	ON	ON
S4		ON	OFF	OFF	ON
S5		OFF	ON	ON	OFF
S6		ON	OFF	ON	OFF
S7	3/4 ON	ON	ON	ON	OFF
S8	4/4 ON	ON	ON	ON	ON

3. SIMULATION RESULTS AND ANALYSIS

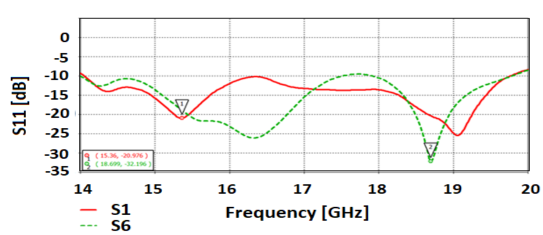
The simulated results are performed on the CST MICROWAVE STUDIO commercial software that includes the S11 parameter in different states of the switch using the PIN diode corresponding to the 2D radiation patterns. Part 3.1 presents the frequencies of the reconfigured band while keeping the radiation intact. Section 3.2 analyzes the radiation pattern reconfiguration of the proposed antenna.

3.1. Frequency reconfiguration

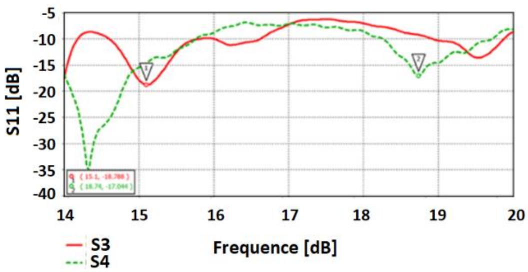
According to a state combination of four diodes from D1 to D4, the antenna can be reconfigured in four frequencies including 5 GHz, 6.81 GHz, 15.1 GHz, and 18.74 GHz as being shown in Table 4. It is more clearly as seen in Figure 4 and 5. At the first case of the frequency reconfiguration, the proposed antenna can operate at 5GHz or 6.8 GHz at the same direction angle of approximately -11°. The second frequency reconfigurable case is at the direction angle of +60°, the antenna can also operates at 15.1 GHz or 18.7 GHz band.

Table 4. The different states of the frequency reconfiguration

State	F (GHz)	S11 (dB)	B (%)	G (dBi)	η (%)
S1	5	–17.17	2.67	4.7	64.78
S3	15.3	–20.97	37.0	5.12	84.65
S4	18.7	–32.16	10.3	6.43	86.09
S6	6.8	–21.68	6.81	4.63	82

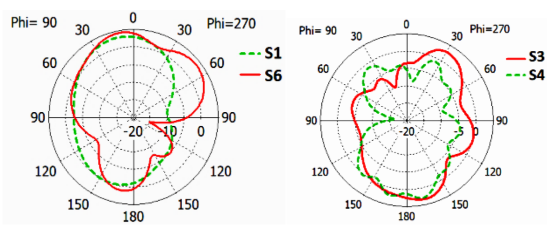


(a) at S1 and S6 states



(b) at S3 and S4 states

Fig 4. S11 parameters of frequency reconfiguration



(a) at S1 and S6 states (b) at S3 and S4 states

Fig 5. Radiation pattern of frequency reconfiguration

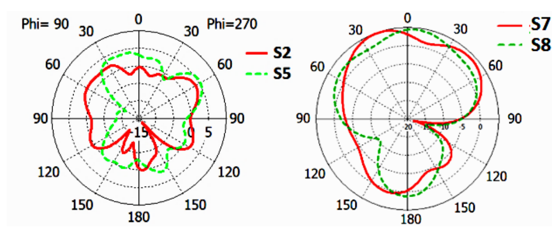
3.2. Radiation pattern reconfiguration

The proposed antennas are structured for elemental radiation at different points on the rectangular platform. Thus, the directional radiation at the two and three diodes is activated for different radiations. Table 5 and Figure 6 and 7 display the changing of the radiation antenna by turning the diodes OFF or ON at different positions while maintaining the same frequency.

Table 5. The different states of the radiation pattern reconfiguration

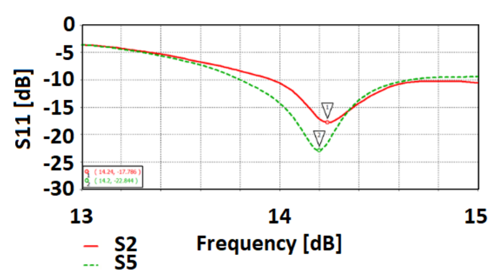
State	Freq. (GHz)	D (°)	S11 (dB)	B (%)	Gain (dBi)	η (%)
S2	14.24	+52	–26.7	20.75	4.8	77.19
S5	14.2	–27	–22.8	6.11	6.1	78.44
S7	6.7	–19	–13.6	2.56	4.89	81.06
S8	6.6	+6	–23.0	5.96	5.51	85.52

The antenna operates at 14.2 GHz when two over four diodes turn ON. Fig 6(a) shows the main beam radiation direction between these two states in plan φ= 90°. At 6.7 GHz, the antenna can change its direction from +6° to –19° as shown in Fig 6(b).

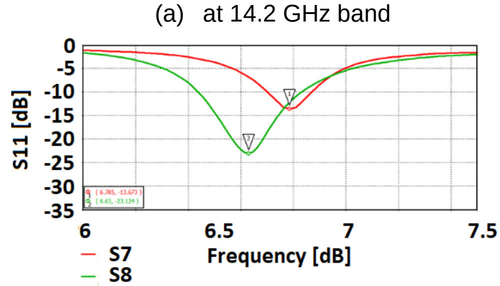


(c) at 14.2 GHz band (b) at 6.7 GHz band

Fig. 6. The direction pattern of radiation reconfiguration



(a) at 14.2 GHz band



(b) at 6.7 GHz band

Fig. 7. S11 parameters of radiation reconfiguration

In Table 6, the proposed antenna is compared with some other recently reported reconfigurable antennas. It can be noted that the total size of antennas [8], [12] is larger than the proposed antenna while their lower resonant frequencies are the same. Though the operation frequencies in [9], [13], and [14] are lower four times. However, the volume of these publics is much larger.

Table 6. Comparison of the proposed antenna and recent public antennas

References	Volume (mm^3)	Radiation patterns	Switching elements/ reconfigurations	Frequency (GHz)	Gain (dBi)	B (%)	η (%)
[8]	10,268.8	6	6/12	5.1 - 5.9;	10	14.5	80.5
[9]	4,275	4	4/4	2.25 - 3.16;	4.11	33.6	60
[11]	32,357.5	6	6/6	3.5 - 3.9;	5.2 - 6.0	10	72 - 86
[12]	79,849	$-80° \leq \theta \leq +80°$	changing feed network 1 over 4 channels	5.2;	10.5	5.8	74
[13]	1,600,000	3	3/30	1.02 - 1.8;	5.2 - 6.2	58	80 - 85
[14]	136,687.5	2	2/2	1.74;	3 - 3.9	14.1	50
This article	2,473.086	2	4/4	5; 6.6; 14.2; 15.3;18.7	4.7 - 6	2.67; 5.96; 14.97; 37.02; 7.82	64.78-86.09

4. CONCLUSION

In this paper, the proposed Padovan antenna which can reconfigure with frequency and radiation using PIN diode switching is presented. The output of the antenna provides high efficiency and overall small size compared to the reconfigurable antennas studied recently. With reconfiguration in frequency from 14.2 GHz to 18.7 GHz in the Ku band, the antenna is suitable for communication application in satellite protection. At 5 GHz, antenna operation can access in standard Wi-Fi at 5^{th} generation is 802.11ac. All antenna performance characters are analysed by CST simulation. The measurement results as well as the power effect on PIN diode will be done in the future research.

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