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Design of the One-bit Unit Cell for A Broadband Reflectarray

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***Abstract*- In this paper, the unit cell of a broadband beam-steerable reflectarray antenna is proposed. The unit cell consists of tightly coupled dipoles and two delay lines. Radio frequency (RF) switches are placed on the delay lines to adjust the reflection phase of the element. The proposed unit cell achieves one-bit phase shifting over a wide bandwidth. To verify the design, a reflectarray composed of the proposed unit cell is simulated. The reflectarray consists of 27x9 units and a feeding antenna which is a log-periodic dipole array (LPDA). The reflectarray works from 3.5 GHz to 5 GHz and the scanning range of the main beam is from -15° to +15° .**

***Index Terms*—Reflectarray, beam-steerable, broadband reflectarray.**

I. Introduction

In recent years, reconfigurable reflectarrays with high gain and beam-scanning capabilities have been widely applied in radar and satellite communication. While traditional phased array antennas can also meet these requirements, the complexity of the beamforming network and the use of a lot of transmit/receive modules result in high costs. One-bit reconfigurable reflectarray, widely adopted for beam-scanning applications, offers a favorable balance between design complexity and performance due to the utilization of a single-pin diode switch for each unit [1]-[3]. In [4]-[6], diodes are placed on the radiator, primarily achieving phase control by rotating the elements. In [7]-[10], diodes are positioned on delay lines, which modulate the reflection phase of units by changing the length of the delay lines. This approach provides an effective means of achieving one-bit reconfigurable reflection phase.

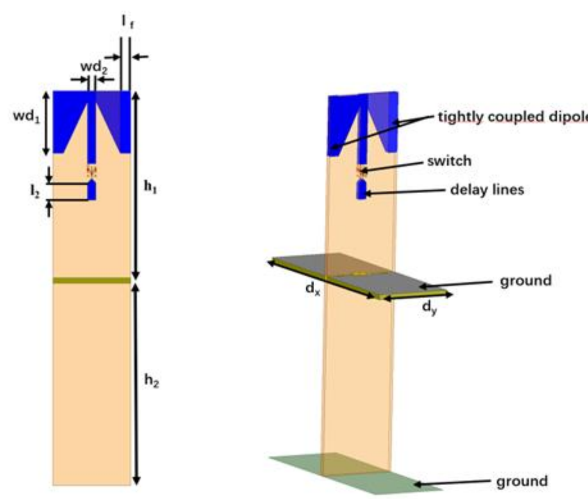
In this paper, a broadband one-bit element for the wideband reflectarray is proposed, of which the bandwidth is from 1.84 to 7.23 GHz. In the unit cell, RF switches are integrated into delay lines for realizing one-bit reconfigurable reflection phase. To validate the proposed unit cell, a reflectarray is designed and simulated. Simulated results demonstrate that within the 3.5-5 GHz frequency band, the beam can be scanned from -15° to 15° , with the first sidelobe level below -8 dB.

II. Antenna Design

In this part, the configuration of the unit is described. The reflectarray which is based on the proposed element is shown as well.

A. Unit Cell

The structure of the proposed element is shown in Fig. 1. It consists of a tightly coupled dipole printed on the substrate, a pair of transmission lines, two RF switches, and two delay lines. The transmission lines connect the dipole and the RF switches. Two delay lines are employed to adjust the element's reflection phase. The status of the unit cell is controlled through the switches. With different statuses, the reflection phase of the element is different. Additionally, the ground plane is printed on the FR4 substrate. The parameters of the elements are shown in Table I.



(a) (b)

Fig. 1. The configuration of the proposed unit (a)front view, (b)side view.

TABLE I

PARAMETERS OF THE ELEMENT

Parameter	wd_2	l_f	wd_1	h_1	d_x	d_y	h_2
Value(mm)	1.2	1.5	6	18	23	7.5	20

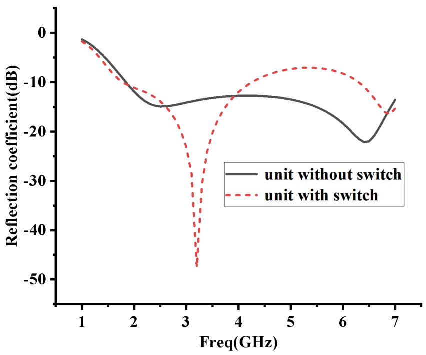


Fig. 2. The reflection coefficient of the element.

The simulated reflection coefficient of the unit cell is shown in Fig. 2. It can be seen when the switches are introduced to the element, the working band of the element is from 1.78 to 7.26 GHz.

The length of the delay lines of the unit is l_2, which adjusts the reflection phase of the unit. The reflection phase with diverse l_2 is shown in Fig. 3. It can be observed that when the switch is OFF, the l_2 almost does not affect the reflection phase. When the switch is ON, the changing l_2 has effects on the reflection phase.

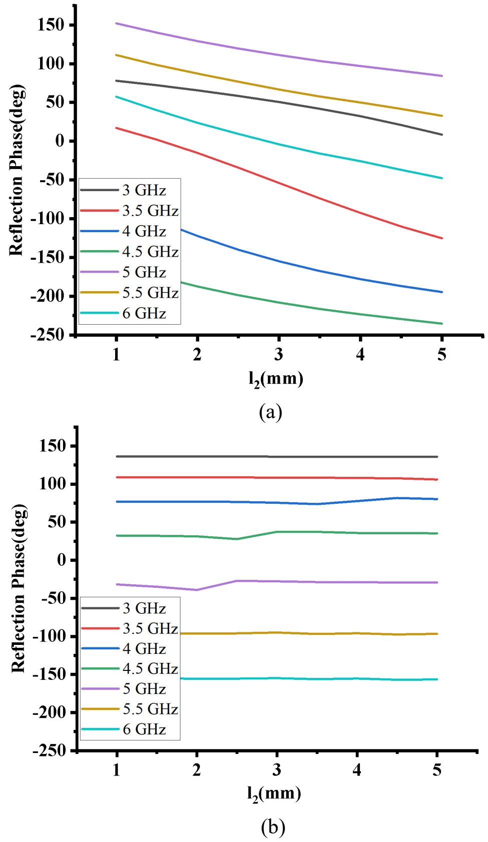


Fig. 3. The reflection phase of the element when the switch is (a)ON, (b)OFF

B. *Structure of the Reflectarray*

Based on the proposed element, a reflectarray antenna is designed to validate the proposed unit for beam scanning.

The designed one-bit broadband beam-scanning reflectarray antenna is shown in Fig. 4. The reflecting surface comprises 27x9 units, and the size of the reflecting surface is 207mm x 202.5mm. The feeding antenna is an LPDA. The distance between the feeding antenna and the top plane of the reflecting surface is Ph_2, which is 111mm. And the distance between the phase center of LPDA and the top plane of the reflecting surface is Ph_1, which is 144mm.

The needed reflection phase is calculated at 4 GHz. The required reflection phase is shown in Fig. 5. Based on the required reflection phase, The status of the switch is determined by the required reflection phase according to (1),

$$Status = \begin{cases} ON, \varphi > \varphi_{off}/2 \\ OFF, 0 < \varphi < \varphi_{off}/2 \end{cases}, \tag{1}$$

where φ is the required reflection phase of the reflecting surface. φ_{off} is the reflection phase of the element when the switch is OFF. In this paper, φ_{off} is 184.14° .

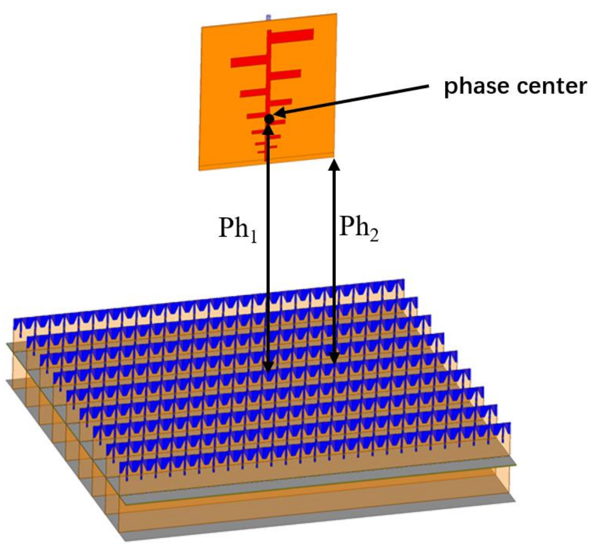


Fig. 4. Configuration of the reflectarray.

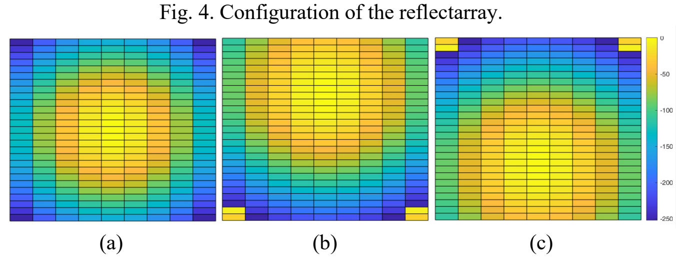
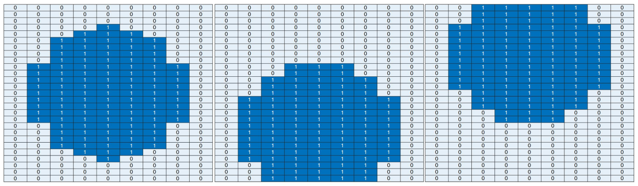


Fig. 5. The required reflection phase when scan angle is(a)0° , (b)15° and(c)-15° .

The status is shown in Fig. 6, where 0 means the switch is OFF and 1 means the switch is ON.



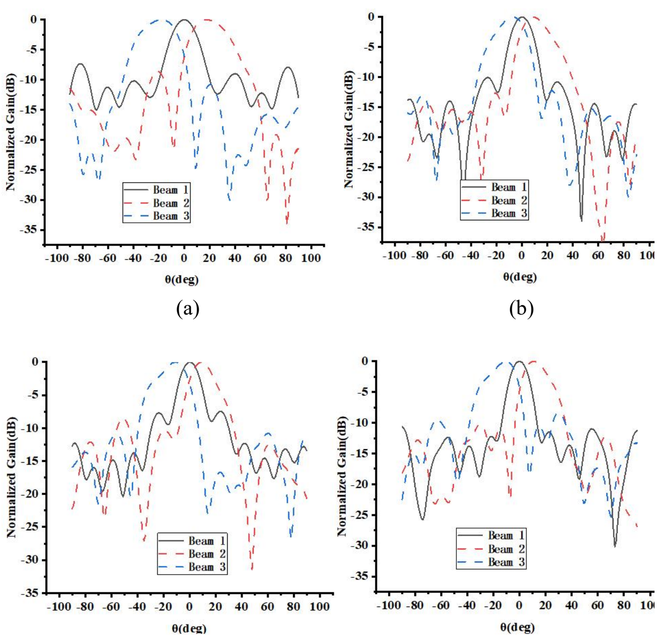
(a) (b) (c)

Fig. 6. The status distribution when scan angle is(a)0° ,(b)15° and(c)-15° .

III. Simulated Results

The reflectarray is simulated for scanning angles being 0° , 15°, and -15° from 3.5 to 5 GHz. The simulated radiation patterns are shown in Fig. 7. It can be observed that the scanning angle of the main beam is between -15° and 15° in the working band.

The beam directions at different frequencies are shown in Table II. The beam directing error is lower than 5° for all scanning angles. The sidelobe level is less than -8 dB, from 3.5 to 5 GHz, as well.



(a) (b) (c) (d)

Fig. 7. Simulated radiation patterns at (a)3.5 GHz, (b)4 GHz, (c)4.5 GHz and(d)5 GHz.

TABLE II

THE BEAM POINTING ERROR

Beam direction(deg)\Freq(GHz)	3.5	4	4.5	5
Beam 1	0°	0°	0°	0°
Beam 2	+3°	-5°	-5°	-4°
Beam 3	+3°	-5°	-5°	-4°

IV. Conclusion

This paper presents a novel element for a broadband beam-steerable reflectarray antenna. The unit integrates RF switches on its delay lines to realize one-bit reconfigurable reflection phase modulation. To verify the proposed element, a reflectarray consisting of 27x9 units is designed. The reflectarray is simulated for beam scanning angles being 0° , 15° and-15° . The simulated results demonstrate that the main beam directing error is less than 5° , and the SLLs are below -8 dB, which demonstrates that the proposed unit cell is resultful in the design of beam scanning reflectarray.

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