A Reconfigurable Beam-Scanning Partially Reflective Surface (PRS) Antenna

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***Abstract*— A novel reconfigurable partially reflective surface (PRS) antenna is presented in this paper. The beam scanning ability is realized by employing a reconfigurable PRS structure and a phased array as the source. The design achieves a beam switching between -15°, 0°, to 15° with respect to the broadside direction from 5.5 GHz to 5.7 GHz with the realized gains over 12 dBi. Good agreement between the simulated and measured results is achieved.**

Index Terms— reconfigurable PRS antenna, beam scanning, phased array antenna..

I. INTRODUCTION

A high-gain, low-profile beam scanning antenna has many applications, such as cellular base stations and satellite communications. A conventional way to realize beam steering is to utilize a phased array antenna, but it has the drawbacks of high cost and bulky structure [1]. Pattern reconfigurable antennas can provide a low-cost alternative to phased arrays and they have attracted significant attention from both academia and industry [2]. However, most of the reported designs suffer from low realized gains. It is well known that a partially reflective surface (PRS) antenna can achieve a high gain with a fixed broadside beam. It would be more useful if its beam can be reconfigured. Recently, a few PRS antennas have been presented that have the capabilities to switch the main beam direction [3-4].

This paper proposes a new pattern reconfigurable beam-scanning PRS antenna which employs a reconfigurable PRS and a 2-element microstrip patch phased array as the source. The antenna can steer its beam between -15º, 0º, and 15º from 5.5 GHz to 5.7 GHz (beam steering range of 30°) with a realized gain over 12 dBi. It employs a simple biasing network and its phase shift network for the array source is integrated into the antenna, leading to a compact structure.

II. ANTENNA GEOMETRY

A. Design of a PRS antenna with a phased array source

A conventional PRS antenna is composed of a source antenna embedded between a ground plane and a dielectric superstrate employed as the PRS. The PRS is usually placed about half a wavelength above the ground plane with a reflection coefficient $\Gamma = R \cdot \exp(j\varphi)$. The electromagnetic waves radiating from the source experience multiple reflections within the cavity. According to the ray theory [5], a maximum directivity at the broadside can be calculated as a function of the reflection magnitude of the PRS as following

$$D_{emax} = \frac{1-R}{1+R} \qquad (1)$$

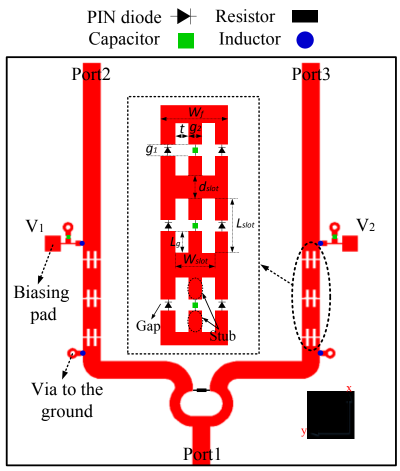

Fig. 1. Structure of the feed network

Generally, a center-fed PRS antenna produces a broadside beam. In this design, a phased array patch antenna is utilized as the source of the PRS antenna to realize beam steering. To obtain phase shifts between the array elements, reconfigurable defected microstrip structure (RDMS) based phase shifter [6] are incorporated in the feed network as shown in Fig.1. Each phase shifter consists of 3 identical RDMS units, as shown in the inset of Fig. 1. Each unit consists of a rectangular slot with a size of $L_{slot} \times W_{slot}$; two gaps etched on the edges for inserting the PIN diodes; and two metallic stubs located in the middle of the slots as mounting pads for the capacitors not only to realize RF continuity, but to provide DC isolation for the PIN diodes as well. The dimensions of the RDMS unit are listed in Table I. The phase shift is achieved by controlling the states of the PIN diodes of the RDMS unit. The current path for the off- state of the PIN diodes is longer than that of the

TABLE I DIMENSIONS OF THE RDMS UNIT

Parameter	W_f	L_{slot}	W_{slot}	L_g
Value (mm)	3.4	3.5	2.0	1.55
Parameter	d_{slot}	g_1	g_2	t
Value (mm)	4.2	0.4	0.7	0.65

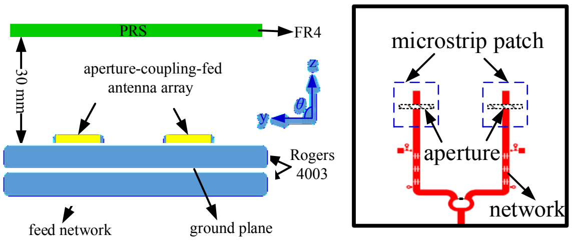

Fig. 2. Phased array fed PRS antenna (a) side view, and (b) top view

on-state. For this design, the off-state generates a 30º phase delay with respect to the on-state for a single unit. By cascading three RDMS units, a 90º phase shift can be obtained.

The schematics of the entire phased array PRS antenna are shown in Fig. 2. The dimensions of the antenna are 170 mm × 170 mm. The phased array source is a two-layer structure. For the first layer, two square microstrip patches with a size of 13.2 mm are placed at one side of a 1.524-mm-thick Rogers4003 substrate and aligned symmetrically along the y direction. The spacing between them is 43 mm. On the other side of the substrate, two slots coupling are etched on the ground at the position of the patch center. For the second layer, the feed network is printed on the lower side of another 1.524-mm-thick Rogers4003 substrate. A 6.5-mm-thick FR4 substrate is used as the PRS structure which is located 30 mm from the patch array.

By employing the reconfigurable phased array as the source, the PRS antenna can steer its beam towards 0°, −10°, and 10° when the PIN diodes are "all on", "left branch on with right off", "left branch off with right on", respectively.

B. The reconfigurable PRS structure

To further increase the beam-tilted angle and to improve the realized gain, the PRS structure employs 6 × 6 reconfigurable cells. Each reconfigurable cell is composed of a 20.5 mm × 20.5 mm microstrip patch etched on a 24 mm × 24 mm × 0.8mm FR4 substrate. A 1 mm slot is inserted in the middle of the patch. PIN diodes are placed at the two sides of the slot (Fig.3(a)). The reflection phase of the cell element can be varied by switching the states of the diodes to produce a reflection phase inconsistency between the two parts of the entire PRS structure, which in turn switches the beam of the PRS antenna. When the PIN diodes are switched off, the two halves of the patch disconnect from each other, which results in a surface with a high reflectivity and a small phase. When the PIN diodes are switched on, a larger phase value is obtained compared to that of the off-state. As shown in Fig.3 (b), the entire PRS structure composed of such reconfigurable elements is divided into two halves with opposite orientation of PIN diodes.

The above reconfigurable PRS structure can realize an additional ±5° beam tilting on the basis of the previous phased array fed PRS antenna. By the combination of the reconfigurable PRS structure and the phased array source, the proposed antenna can realize a ±15° beam tilting with respect to the broadside direction. Moreover, instead of using a separate power divider and a reconfigurable matching network [4], the proposed antenna employs an integrated aperture-feed network for the phased array source and does not require an extra impedance matching network; leading to a more compact structure.

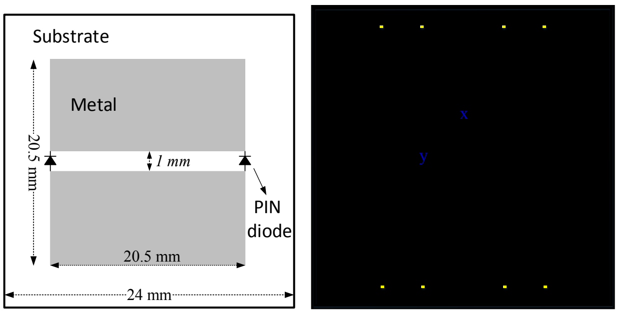

Fig. 3. Reconfigurable PRS (a) cell, (b) entire structure

III. Antenna Performance

Based on the analysis and results shown in Sections II, a PRS antenna with a reconfigurable PRS structure and a phased array source has been designed, fabricated, and measured. The reconfigurable PRS structure is the same as that shown in Fig. 3(b), which consists of 6 × 6 reconfigurable cells, with dimensions of 20.5 mm × 20.5 mm, printed on the lower side of a 0.8-mm-thick FR4 substrate. The structure of the phased array source and its feed network are the same as that shown in Fig. 2. However, the size of the array elements is changed to 12.2 mm after optimization. In this design, $\varphi = -145.5°$ for an off-state is chosen as an initial value to calculate Lr. After optimization, Lr is set to be 30 mm.

A prototype as shown in Fig.4 was built to verify the proposed design. In this work, we examine three states: State 1 refers to the state in which the diodes in the PRS cells are all switched off while those in the feed network are all turned on, to realize a broadside beam. State 2 represents the case when the diodes on the left half of both the PRS and the feed network are switched on while the diodes on the right half are turned off, to realize a beam tilted towards −y direction. State 3 is opposite to State2 and it realizes a beam titled to +y direction.

Fig.5 shows the measured reflection coefficients. It is seen that an overlapped impedance bandwidth from 5.5 GHz to 5.74 GHz is achieved. The radiation patterns in the H-plane (y-z plane) at 5.5 GHz are shown in Fig. 6. The simulated and measured results are seen to be in good agreement with each other. It is observed that a broadside radiation is obtained at

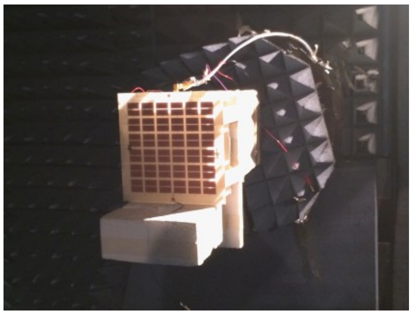
Fig. 4. Prototype of the proposed antenna

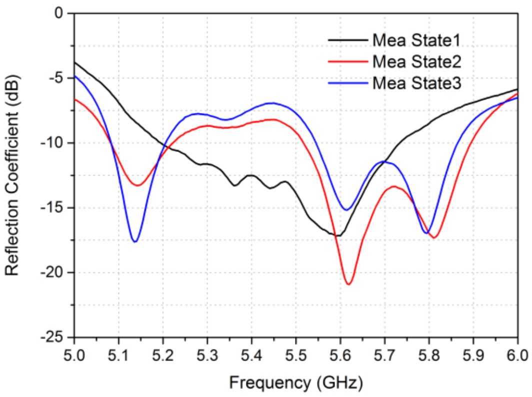

Fig. 5. Measured reflection coefficient.

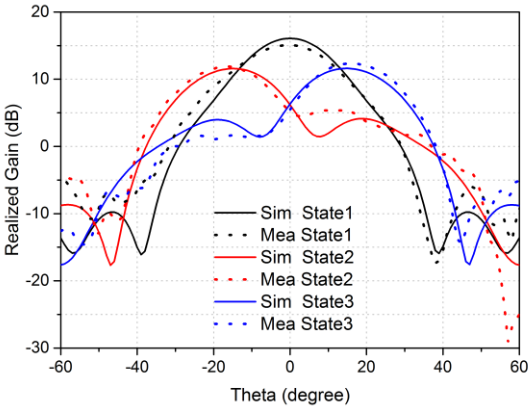

Fig. 6. Radiation patterns of the proposed antenna at 5.5GHz.

State 1. For State 2 and State 3, the beam directions are tilted towards -15º and 15º from the broadside. The measured realized gain is over 12 dBi for these three states.

IV. Conclusion

A novel reconfigurable beam scanning PRS antenna has been proposed in this paper. It is composed of a reconfigurable PRS structure and a phased array antenna as its source. Its beam direction can be tilted between -15°, 0°, and 15° from 5.5 GHz to 5.7 GHz. Compared to other pattern reconfigurable PRS antennas, the proposed antenna exploits two reconfiguration mechanisms to achieve a larger beam tilt angle without sacrificing the realized gains. A prototype has been fabricated and measured to validate the proposed design.

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