Pattern Reconfigurable Fabry-Perot Cavity Antenna

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***Abstract*—A newly designed pattern reconfigurable Fabry-Perot cavity antenna is presented in this paper. The reconfigurability is achieved by employing a phased array with a reconfigurable feed network as the source of the FPC antenna. The design can switch its main beam direction between -10° and 10° with respect to the broadside direction from 5.36 GHz to 5.76 GHz. The realized gain of the proposed antenna is over 11.6 dBi. Good agreement between the simulated and measured results is achieved.**

Keywords—FPC antenna, pattern reconfigurability, phased array, reconfigurable feed network.

I. INTRODUCTION

Pattern reconfigurable antennas are of particular interest due to their capability to avoid noise source by altering the null positions, to save energy by directing the signal toward intended users, and to provide larger coverage by steering the main beam [1-2]. While there have been substantial advances in the design of pattern reconfigurable antennas, it is found that most of the reported designs have a low realized gain. The goal of this work is to achieve a high gain pattern reconfigurable antenna with a relatively compact structure.

Among many types of high gain antennas, Fabry-Perot cavity (FPC) antennas have been found to be more competitive due to their simple structure, low profile and ease of realizing high gains. Generally, FPC antenna radiates a broadside direction pencil-beam. There are mainly two approaches for FPC antennas to realize pattern reconfigurability. The first one is to employ phase-varying metamaterial surfaces as the PRS structure in order to realize a variable reflection phase distribution. Another way to reconfigure the pattern is to utilize a phased array as the source antenna [3]. In [4], a two-element patch antenna array using a separate Wilkinson power divider and phase shifters was exploited to excite the PRS to reconfigure the radiation pattern. Its beam can be tuned from -10º to 10º with a gain greater than 13 dBi at 2 GHz.

In this paper, we use the second method mentioned above to design a compact pattern reconfigurable FPC antenna by employing a 2-element phased array source with an integrated reconfigurable feed network and a biasing network. The antenna can switch its beam between -10° to 10° with respect to the broadside direction from 5.36 GHz to 5.76 GHz. Its maximum realized gains are over 11.6 dBi for all beam directions.

II. ANTENNA GEOMETRY

A conventional FPC antenna is composed of a source antenna embedded in a cavity made by a ground plane and a metallic or dielectric superstrate which is known as the partially reflective surface (PRS). The PRS is located approximately about half a wavelength above the ground plane with a reflection coefficient Γ=R·exp(jφ). The electromagnetic waves radiating from the source experience multiple reflections within the cavity. According to the ray theory described in [5], a maximum directivity at the broadside is obtained when the cavity height Lr satisfies (1) below,

$$L_r = \left(\frac{\varphi}{\pi} - 1\right)\frac{\lambda}{4} + N\frac{\lambda}{2} \quad N = 0, \pm1, \pm2\ldots \qquad (1)$$

where λ is the free-space wavelength at the resonant frequency. And the maximum directivity can be calculated as a function of the reflection magnitude of the PRS as following

$$D_{max} = \frac{1-R}{1+R} \qquad (2)$$

It is well known that a single center-fed FPC antenna can radiate a broadside direction pencil-beam. In our design, a 2-element phased array patch antenna is utilized as the source of the FPC antenna to realize pattern reconfigurability. To obtain phase shifts between the two array elements, reconfigurable defected microstrip structure (RDMS) based phase shifter [6] are incorporated in the feed network as shown in Fig.1. The feed network is comprised of two phase shifters etched on each branch of a Wilkinson power divider. Each phase shifter consists of 4 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 diodes. 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 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 at the end of the two outputs.

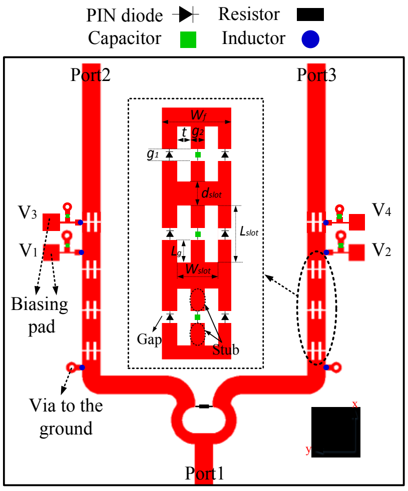


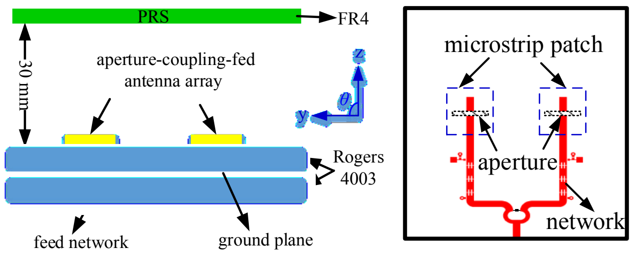
Fig. 1. Structure of the feed network

If the PIN diodes on both branches of the power divider are “all-on”, no phase shift is acquired and this state is referred to “State 1”. When three diodes on the left branch are switched on and other diodes are switched off, the right one can achieve a 90º phase delay with respect to the left one. This state is named “State 2”. When three diodes on the left branch are all switched off and those of the right branch are all switched on, this state is “State 3” and makes the left branch have a 90º phase delay with respect to the right one.

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

The schematics of the entire phased array FPC antenna are shown in Fig. 2. The dimensions of the antenna are 150 mm × 150 mm. The phased array source is a two-layer structure. For the first layer, two square microstrip patches, each with a size of 13.2 mm, are placed at one side of a 1.524 mm thick Rogers4003 substrate and are aligned symmetrically along the y direction. The spacing between them is 43 mm. On the other side of this substrate, two slots with a dimension of 7 mm × 1.5 mm for an aperture 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 mm thick FR4 substrate is used as the PRS structure which is located 30 mm from the source antenna.



(a) (b)

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

By employing the reconfigurable phased array as the source, the FPC antenna can reconfigure its beam towards 0° (State 1), −10° (State 2) and 10° (State 3). The simulation and measurement results are shown in the next section.

III. ANTENNA PERFORMANCE

A prototype as shown in Fig.3 has been designed, fabricated, and measured. The simulation was accomplished using CST. Measured results of reflection coefficient, realized gain and radiation pattern were obtained by an Agilent N5230A network analyzer and a NSI-700s-50 spherical near-field measurement system.

A. Reflection coefficient

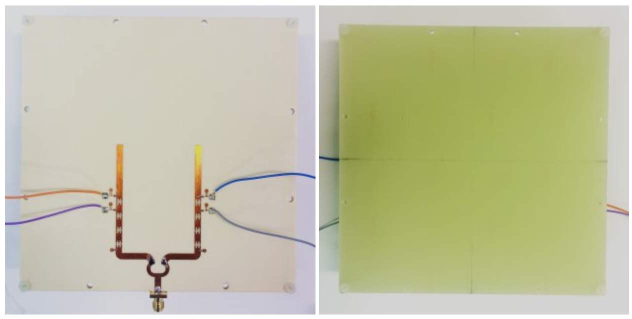
Fig.4 shows the simulated reflection coefficients of the proposed antenna. The simulated results agree reasonably well with the measured ones. It can be seen that the overlapped 10 dB impedance bandwidth of the proposed antenna ranges from 5.36 GHz to 5.76 GHz for all the three operating states. The discrepancies between the simulated and measured results may be caused by the measurement errors or installment errors, such as the air gap between the two substrate layers.

B. Radiation Pattern

For brevity, we only report the radiation patterns of the H-plane (y-z plane) at 5.5 GHz in Fig. 5. 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 State 1. For State 2 and State 3, the beam directions are tilted towards -10º and 10º from the broadside. The maximum measured realized gains for the three operating states are 13 dBi, 11.7 dBi, and 11.6 dBi, respectively.

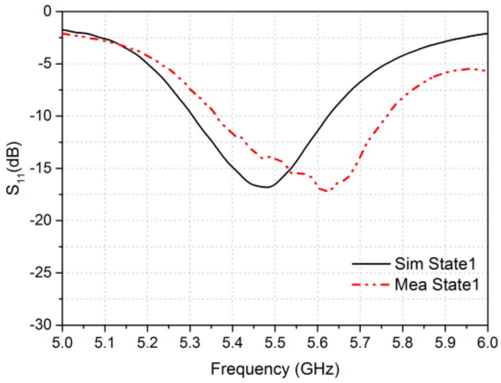
IV. CONCLUSION

A novel pattern reconfigurable FPC antenna has been proposed in this paper. This reconfigurability is realized by a 2-element phased array antenna with reconfigurable feed network as its source. Its maximum beam direction can be reconfigured between -10°, 0°, and 10° from 5.36 GHz to 5.76 GHz. Compared to other pattern reconfigurable FPC antennas, the proposed antenna has a much simpler structure, relatively high realized gains, and highly integrated phase network with no need of using other matching methods. A prototype has been fabricated and measured to validate the proposed design. Good agreements have been found in the comparison between simulated and measured results.

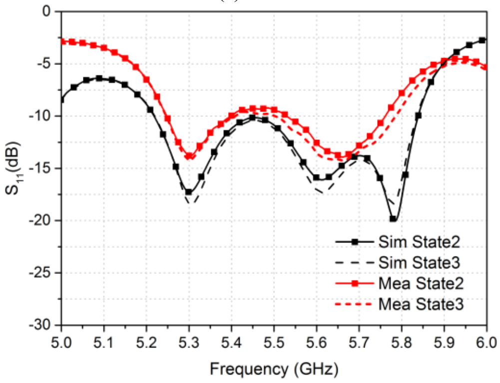


(a) (b)

Fig. 3. Prototype of the proposed antenna (a) reconfigurable feed network, and (b) substrate PRS structure

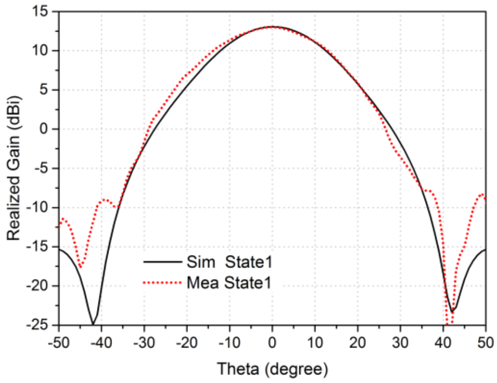


(a)

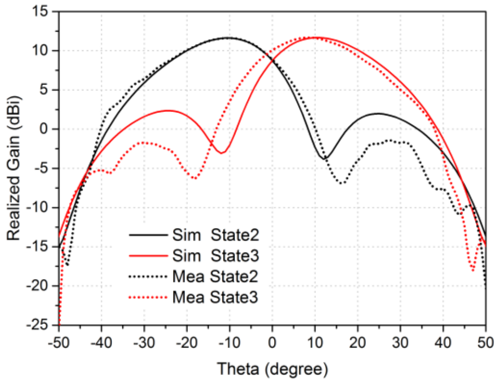


(b)

Fig. 4. Input reflection coefficients of the proposed antenna (a) State 1, (b) State 2 and 3



(a)



(b)

Fig. 5. Radiation patterns of the proposed antenna at 5.5GHz (a) State 1, (b) State 2 and 3

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