A Wideband Fabry-Perot Antenna with Quad-Layer Partially Reflective Surface

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***Abstract*—An Fabry-Perot (FP) cavity antenna with a large 1-dB gain bandwidth is presented in this paper employing a new quad-layer partially reflective surface (PRS). Four layers of metallic square rings are printed on each side of two dielectric substrates separated by an air gap of about λ/27 (λ is the wavelength in the open air) at 5.5 GHz. The total profile of the FP cavity is about λ/2. By properly choosing the dimensions of square rings and the distance between the two substrates, the phase of the reflection coefficient of the PRS increases with the operating frequency, demonstrating a broadband property. In order to validate the performance of the proposed PRS, one single-polarized FP antenna with a size of 2.9 λ × 2.9 λ is designed. It has a measured peak realized gain of 16.9 dBi with a 1-dB gain bandwidth from 5.15 to 5.8 GHz (11.9%).**

Keywords—Fabry-Perot antenna, partially reflective surface (PRS), high-gain antenna, wideband antenna

I. INTRODUCTION

For the current and the next generation (5th generation or 5G) wireless communication systems, low-cost and high-gain antennas are required to achieve high data rate transmissions. Fabry-Perot (FP) cavity antennas have received significant attention due to the compact structure and ease of achieving high gain [1-5]. An FP cavity antenna is composed of a source antenna backed by a ground plane and a periodic structure as the partially reflective surface (PRS) located approximately half a wavelength above the source. Electromagnetic waves radiated from the source experience multiple reflections and transmissions within the cavity formed by the ground plane and the atop superstrate. When certain resonance conditions are satisfied, the waves transmitted through the PRS can be in phase [2], thus enhancing the antenna directivity. Unfortunately, the resonance condition is usually realized in a small bandwidth, thereby narrowing the impedance and radiation bandwidths of FP antennas. Compared to the conventional microstrip antenna arrays, they do not require complex feeding networks, leading to a lower design complexity, lower loss and cost.

Recently, a few FP antennas have been developed with an improved gain bandwidth [3-5]. However, most of the FP antennas are focused on a 3-dB gain bandwidth enhancement. For many applications such as wireless communications for high-speed railways, however, 1-dB gain bandwidth and a -15 dB input reflection coefficient are required in order to ease the design of the transceiver and to guarantee a reliable communications link. The key challenge of achieving the aforementioned high performance is to develop a novel PRS structure, the gradient of whose reflection phase curve is not only positive but match well with the ideal phase curve from theoretical calculation in a relatively wide band. For many of the reported wideband FP antennas, the reflection phase gradient is positive across a wide band but there are significant deviations from the ideal one. As a result, although the 3-dB bandwidth can be very wide, the improvement of 1-dB bandwidth is limited. Moreover, generally, the magnitude of the reflection coefficient *R* cannot be maintained stable across the operating frequency band because a resonance is needed to generate a positive phase gradient. Therefore, the changing of the magnitude *R* must be considered for the PRS unit cell design.

In this paper, a single-polarized wideband FP antenna is proposed by employing a new PRS structure. The PRS structure consists of two dielectric substrates with square rings printed on both sides of each substrate. The distance between the two substrates is only λ/27 (λ is the wavelength in the open air) at 5.5 GHz. Due to the strong couplings between the total four layers of periodic arrays, a positive reflection phase gradient is achieved that matches very well with the ideal one, demonstrating a wide gain bandwidth. The 1-dB gain bandwidth for the antenna is larger than 10% with peak gain around 16.9 dBi, and the input reflection coefficient is lower than -15 dB for the operating band overlapped with the 1-dB gain bandwidth.

II. FABRY-PEROT ANTENNA WITH QUAD-LAYER PRS

The unit cell of the proposed PRS structure is shown in Fig. 1. The cell size *P* is 13 mm (about 0.24 λ at 5.5 GHz). It consists of two layers of 0.8-mm-thick FR4 substrates (dielectric constant 4.4). The distance between two substrates *Ht* is 2 mm. Metallic square rings are printed on each side of the two substrates. The dimensions of the square rings are given in Table I. Full-wave simulations of the reflection coefficients of the unit cell are calculated using the Frequency Domain Solver of CST Microwave Studio [6]. The phase and the magnitude of the input reflection coefficient are shown in Fig. 2. It can be observed that the reflection phase increases with frequency and the reflection magnitude is from -1.6 dB to -3.5 dB for the range between 5.05 GHz to 5.6 GHz. Since the phase gradient of the proposed unit cell agrees very well with the ideal one (the distance between PRS and the ground is 29.5 mm) and the variation of the reflection magnitude is reasonably small (less than 1.9 dB), a wide gain bandwidth of an FP antenna using the proposed cell element can be obtained.

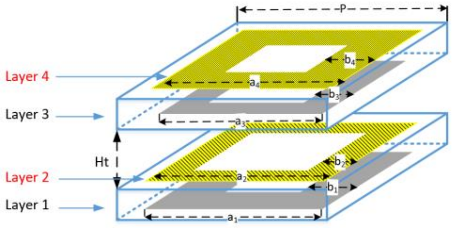


Fig. 1. Configuration of the PRS unit cell

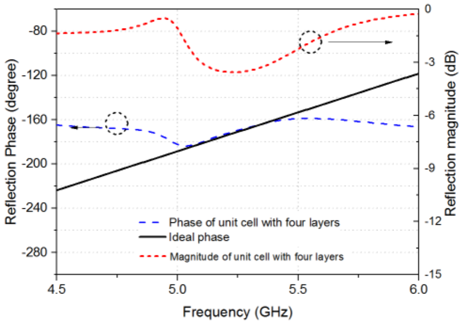


Fig. 2. Simulated reflection coefficient versus frequency of the unit cell

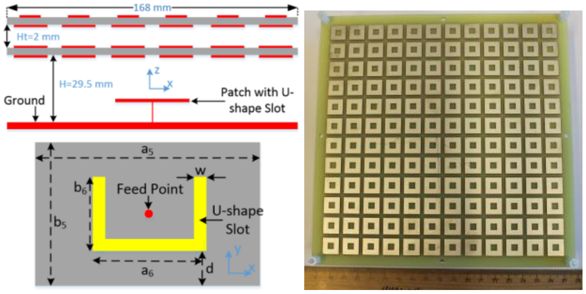
TABLE I

DIMENSIONS AND PARAMETERS OF THE SINGLE-POLARIZED ANTENNA

Parameter	a_1	b_1	a_2	b_2	a_3	b_3	d
Value (mm)	11.7	2.24	12	0.93	11.1	2.24	2.6
Parameter	a_4	b_4	a_5	b_5	a_6	b_6	w
Value (mm)	10.5	3.2	38.2	17.3	13.1	12.1	1.58

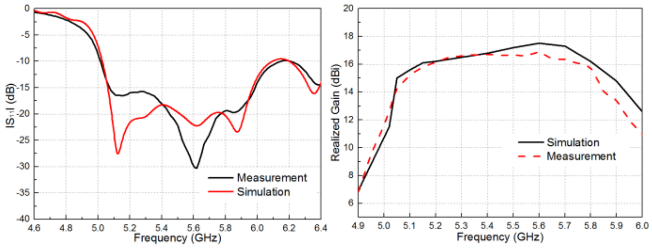
By using the proposed quad-layer PRS structure, one single-polarized FP antenna is presented in this section. The PRS structure is shown in Fig. 3 (a) and is composed of 12 × 12 unit cell elements, corresponding to 156 mm × 156 mm (2.9 λ × 2.9 λ at 5.5 GHz). But the overall dimensions of the antenna are 168 mm × 168 mm in order to accommodate eight M3 nylon bolts to support the PRS structure along its four sides above the ground plane. The distance between PRS and the ground is 29.5 mm. A rectangular metal patch inserted with a U-shape slot [7] is used as the source of the FP antenna. There is no dielectric substrate below the metal patch in order to have a wide impedance bandwidth of the source antenna. The structure and the dimensions of the patch antenna are shown in Fig. 3 (a). The dimensions of the patch antenna will mainly affect the input reflection coefficient of the FP antenna and it has been optimized to achieve a -15-dB impedance match across the operating band. The photograph of the entire FP antenna is given in Fig. 3 (b).

The input reflection coefficients of the single-polarized FP antenna are given in Fig. 4 (a). The measured result agrees reasonably well with the simulated one. The measured -15 dB input impedance bandwidth is from 5.05 GHz to 6 GHz (about 16.6%). The radiation patterns and realized gains of the antenna were measured using a spherical near-field (SNF) antenna measurement system NSI-700s-50. As seen in Fig. 4 (b), the simulated and measured peak realized gains occur at 5.6 GHz which are 17.5 dBi and 16.9 dBi, respectively. The measured 1-dB gain bandwidth is 5.15 GHz to 5.8 GHz (11.9%). The radiation patterns of the antenna will be presented in the conference.



(a) (b)

Fig. 3 (a) Configuration of FP antenna; (b) Photograph of the antenna



(a) (b)

Fig. 4 (a) Input reflection coefficients of the antenna; (b) Simulated and measured gains of the antenna

III. CONCLUSION

A novel quad-layer PRS unit cell element is presented for low-profile wideband FP cavity antennas. The gradient of the reflection phase of the proposed element is found to match the ideal one very well, leading to a wide 1-dB gain bandwidth. Moreover, the proposed PRS structure can employ more than two dielectric substrate layers to further increase the 1-dB gain bandwidth of the FP antenna, which will be studied in our future work.

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