A Partial-Reflective-Metasurface-Based Fabry-Pérot Cavity Antenna

Jiaran Qi, Shanshan Xiao, Chang Liu
Dept. of Microwave Engineering, School of Electronics and Information Engineering
Harbin Institute of Technology
Harbin, China, 150086
qi.jiaran@hit.edu.cn

***Abstract*—A Fabry-Pérot cavity antenna with extended 3dB gain bandwidth is presented in this paper. The proposed structure consists of a rectangular-patch microstrip antenna, on top of which a planar partial reflective surface (PRS) is mounted. Two periodic planar structures, i.e. metasurfaces, with different unit cells are printed on both sides of a 1.5mm-thick Rogers 5880 substrate, forming a novel PRS. It is then confirmed by simulation and experimental results that the proposed antenna operates at around 12GHz with a relative bandwidth of 19.77%. The measured gain can reach 16dB with a 3dB gain bandwidth of 11.23%, much more than a Fabry-Pérot Cavity antenna with a traditional PRS.**

Keywords—Fabry-Pérot cavity antenna; wide bandwidth; PRS; high gain

I. INTRODUCTION

Recently, high gain and low profile antennas have received increasingly more attention since they can feasibly be implemented in various applications, such as satellite transceiver systems and point to point wireless communications [1, 2]. The array arrangement can easily provide relatively high gain and other appealing properties, e.g., beam-steering. It will, however, complicate the feeding network [3]. Alternatively, Fabry-Pérot cavity antennas provide an option to enhance the antenna gain without complicating the feeding network, and it becomes gradually a hot research interest [4]. A Fabry-Pérot cavity (FP) antenna, also known as a partial reflective surface (PRS) antenna, is usually composed of a planar feeding antenna, with a PRS mounted half-wavelength on top of it. In 2005, Feresidis implemented an artificial magnetic conductor (AMC) surface onto the substrate of the feeding microstrip antenna, greatly reducing the antenna profile by a quarter wavelength [5]. By introducing a two-element array as the feeding source, the PRS antenna with independent beam steering and beamwidth control properties was realized [6]. A conformal FP antenna to cylindrical objects was presented in [7]. By employing a double-sided PRS placed above an anisotropic high-impedance-surface ground plane, a high gain circularly polarized FP antenna with a linearly polarized primary source was constructed [8]. However, the 3dB gain bandwidths of the abovementioned antennas are relatively low, no more than 2%. Thus, by introducing a specifically designed PRS, we in this paper present a FP antenna with improved 3dB gain bandwidth operating at around 12 GHz, suitable for, e.g., X-band satellite communication. Moreover, the factor limiting the FP antenna gain bandwidth is analyzed. Finally, the proposed antenna is fabricated, and experimental results confirm our design procedures.

II. THEORETICAL BASIS

The brief operating principle of a Fabry-Pérot cavity antenna is illustrated in *Fig. 1*. The PRS is parallel placed above the primary source at a distance h. If the multiply reflected waves, marked with number 0, 1, 2, etc., are in phase, the antenna can achieve a noticeable gain enhancement.

The directivity of the feeding antenna can be depicted as $f(\alpha)$, where α is the angle between beam and normal directional to the feeding antenna plane. The reflection coefficient of PRS is $re^{j\varphi}$, and the transmission coefficient is $(1-r^2)^{1/2}e^{j\varphi}$. The reflection coefficient of the ground plane is $e^{j\pi}$. Suppose that transmission loss is negligible, we can then get

$$G=\frac{1-r^2}{1+r^2-2r}f\left(0\right)^2=\frac{1+r}{1-r}f\left(0\right)^2 \tag{1}$$

where G represents the antenna gain and r is the magnitude of reflection coefficient of the PRS. Apparently, it can be observed from (1) that one should increase r in order to realize an antenna with as high gain as possible.

On the other hand, multiply reflected waves have to be in phase to ensure the gain enhancement. It thus requires

$$\varphi+\pi-\frac{4\pi}{\lambda}h=2n\pi \tag{2}$$

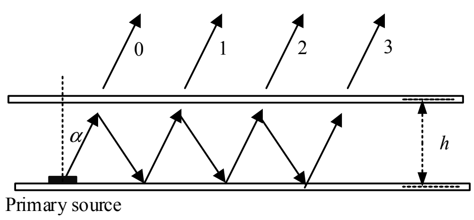
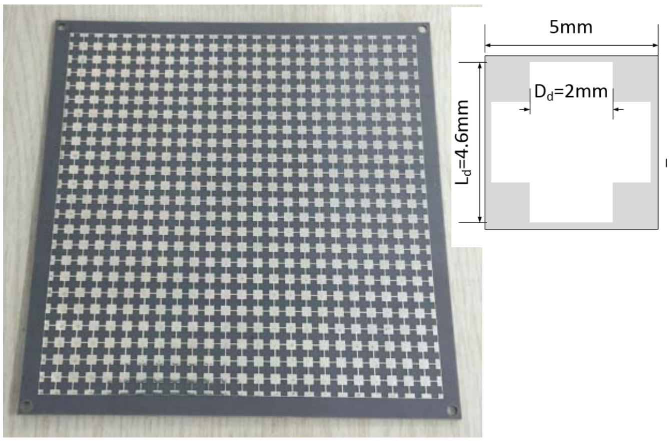
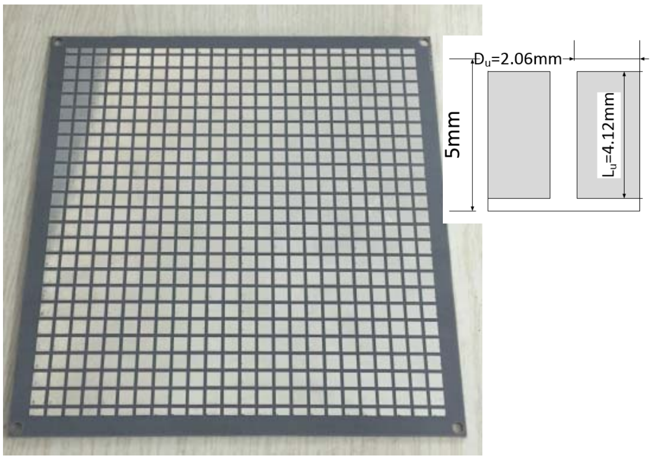


Fig. 1. Working principle of a Fabry-Pérot cavity antenna



(a) Lower-layer structure of the PRS



(b) Upper-layer structure of the PRS

Fig. 2. Geometry of the proposed PRS structure

where in (2) φ denotes the phase of reflection coefficient of the PRS, and λ is the free space wavelength corresponding to the operating frequency. Note that for a certain h (2) holds strictly at only one frequency sample. When the height h of Fabry-Pérot cavity is fixed, the wavelength becomes smaller with increasing frequency. In order to make (2) hold, the reflection phase of PRS is supposed to increase as the frequency grows. However, traditional single-sided PRS doesn`t satisfy this requirement, which in turn limits the 3dB gain bandwidth. By analyzing the working principle of Fabry-Pérot cavity antenna, we could figure out that firstly reflection magnitude of the PRS needs to be large enough to ensure high gain, and secondly reflection phase of the PRS should increase with growing frequency to broaden the 3dB gain bandwidth.

III. Antenna Configuration

The PRS of the proposed antenna is fabricated on a double-sided dielectric slab of relative permittivity ε_r (=1.5) occupying a volume of 120×120×1.5mm^3. As shown in *Fig. 2(a)*, a periodic capacitive structure with cross-slot-shaped unit cell is etched on the lower side of the slab. Another periodic inductive structure with square metallic unit cell, shown in *Fig. 2(b)*, is etched on the upper side of the same slab.

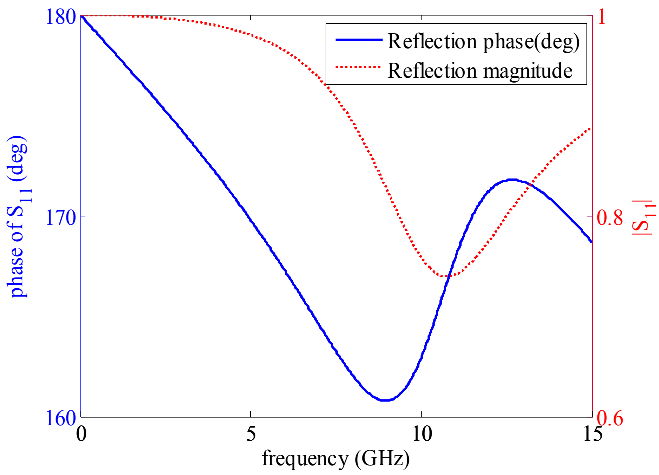
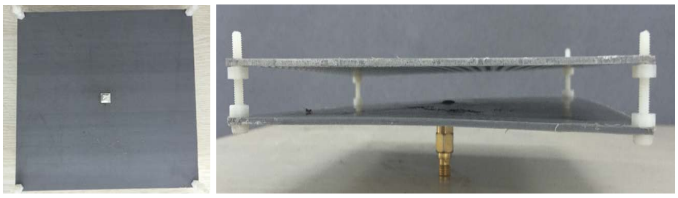


Fig. 3. Magnitude and Phase of the reflection coefficient of the proposed PRS



(a) Primary source (b) Fabry-Pérot cavity antenna

Fig. 4. Construction of the proposed Fabry-Pérot cavity antenna

The reflection phase variation of the PRS with increasing frequency is illustrated in *Fig. 3*. It can be observed that the proposed PRS structure meets simultaneously the two design requirements within the operating frequency band, i.e., relatively high reflection magnitude (larger than 0.74) and the growing reflection phase with increasing frequency. It should be noted that either periodic structure cannot provide a growing reflection phase with increasing frequency. However, the careful implementation of a capacitive and an inductive structures could make the reflection coefficient display a resonant behavior shown in *Fig. 3*.

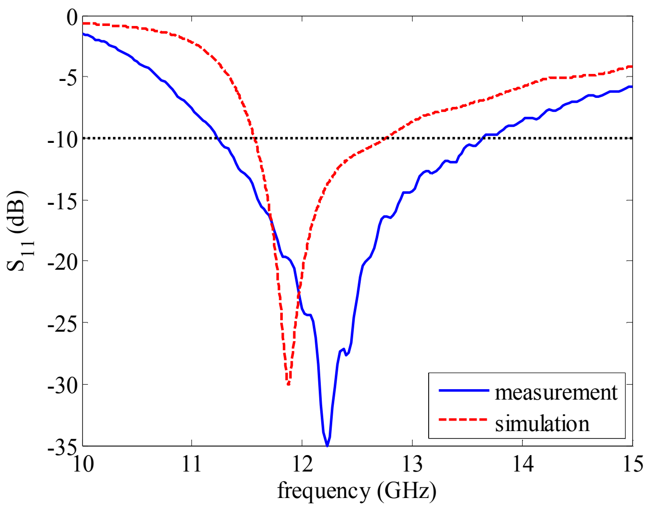


Fig. 5. Simulated and Measured return losses of the proposed FP antenna

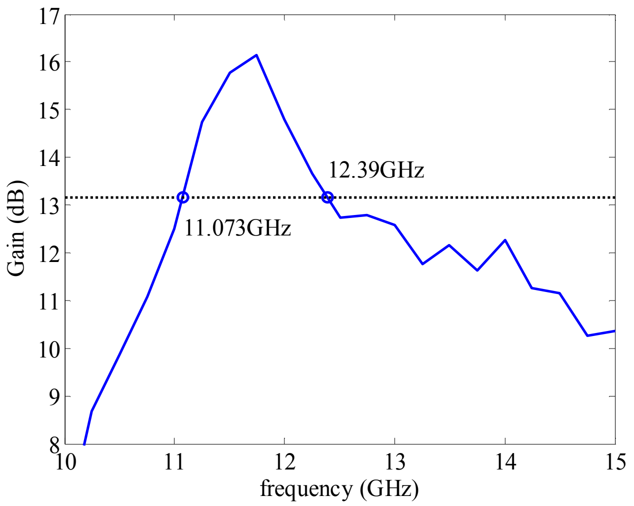


Fig. 6 . Measured gain of the proposed Fabry-Pérot cavity antenna

It is shown in *Fig. 4* the feeding antenna structure and complete configuration of the proposed Fabry-Pérot cavity antenna. We adopt a 1.5mm thick Rogers 5880 dielectric-slab. According to classic theories regarding microstrip patch antennas, the size of rectangular-patch of the feeding microstrip antenna is determined as 7.1mm×7.1mm, while the ground is 120mm×120mm. The height between PRS and the feeding antenna is 12.3mm (approximately half a wavelength of the operating center frequency).

IV. Measurement Results and Discussion

The simulated and measured return losses of the proposed FP antenna are shown in *Fig. 5*. It can be seen that the simulated operating frequency band spans from 11.57 to 12.77GHz with a center frequency of 11.88 GHz, which implies a nearly 9.8% relative bandwidth. The measurement shows that the –10dB impedance bandwidth is from 11.24 to 13.7GHz with a center frequency of 12.26GHz, nearly a 19.77% relative bandwidth.

The measured gain of the proposed Fabry-Pérot cavity antenna is showed in *Fig. 6*. The maximum gain reaches 16.16dB at around 11.8 GHz, and the –3dB gain bandwidth spans from 11.073 to 12.39GHz, nearly an 11.23% relative bandwidth.

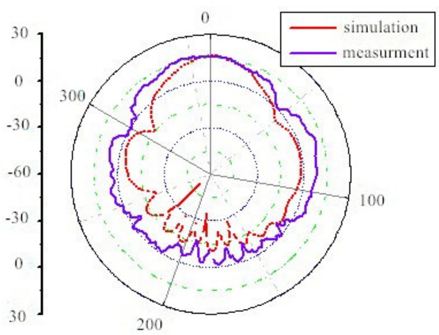


Fig. 7. Measured and simulated radiation pattern of the proposed Fabry-Pérot cavity antenna at 12GHz.

In comparison with the feeding antenna, we notice that the polarization remains after installing the PRS on top of the primary source. The cross polarization level is still low, but the gain increases from 7.26dB to 16.16dB, and the main lobe width was reduced from 81.4° to 24.6°. The side lobe level increases from –21.8dB to –17.2dB, as shown in *Fig. 7*. The feeding antenna alone has a relative –10dB impedance bandwidth of 8.24%. The Fabry-Pérot cavity antenna then has a broader relative –10dB impedance bandwidth of 19.77%, and a –3dB gain bandwidth is 11.23%. Compared with the traditional FP antennas in [5–8], the 3dB gain bandwidth increase almost 6 times, from 2% to 11.23%.

V. Conclusion

In the paper, we propose a FP antenna with broaden 3dB gain bandwidth. The antenna prototype is fabricated, and measurement results confirm that the –10dB impedance bandwidth ranges from 11.24 to 13.7GHz. The maximum gain reaches 16.16dB, and the –3dB gain bandwidth spans from 11.07 to 12.39GHz (relative bandwidth of 11.23%). Moreover, the proposed FP antenna has a rather low profile of half a wavelength (12.33mm). It is thus suggested that the proposed Fabry-Pérot cavity antenna is a good candidate for wireless or satellite communication systems.

Acknowledgment

This work was supported by National Natural Science Foundation of China under Grant No. 61301013, and Research Initialization Funding of Harbin Institute of Technology for employed young talents. S. Xiao and C. Liu contributed equally to this work.

References

[1] A. Feresidis and J. Vardaxoglou, “High gain planar antenna using optimised partially reflective surfaces,” IEE Proceedings-Microwaves, Antennas and Propagation, vol. 148, pp. 345-350, June 2001.

[2] J.Vardaxoglou, A. Robinson, and R. Seager, “Towards a new class of waveguiding structures and lightweight horn antennas using passive arrays,” Proceedings of IEEE International Conference on Electro-magnetics in Aerospace Applications, ICEAA, Torino, Italy. 1993.

[3] G. Gottwald and W. Wiesbeck, “Influence of mutual coupling and feed network on directivity and gain [Array Patch Antennas],” IET Eighth International Conference on Antennas and Propagation, 1993.

[4] G. Trentini, “Partially reflecting sheet arrays,” IRE Transactions on Antennas and Propagation, pp. 666-671, April 1956.

[5] A. Feresidis, G. Goussetis, S. Wang, and J. Vardaxoglou, “Artificial magnetic conductor surfaces and their application to low-profile high-gain planar antennas,” IEEE Transactions on Antennas and Propagation, vol. 53, pp. 209-215, January 2005.

[6] T Debogović and J. Perruisseau-Carrier, “Array-fed partially reflective surface antenna with independent scanning and beamwidth dynamic control,” IEEE Transactions on Antennas and Propagation, vol. 62, pp. 446-449, January 2014.

[7] D. Germain, D. Seetharamdoo, S. Burokur, and André de Lustrac, “Thin conformal directive Fabry–Pérot cavity antenna,” IEEE Antennas and Wireless Propagation Letters, pp. 926-929, December 2013.

[8] R. Orr, G. Goussetis, and V. Fusco, “Design Method for Circularly Polarized Fabry–Perot Cavity Antennas,” IEEE Transactions on Antennas and Propagation, vol. 62, pp. 19-26, January 2014.