Wideband High-Gain Low-Profile 1D Fabry-Perot Resonator Antenna

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***Abstract*-Wideband high-gain low-profile Fabry-Perot resonator antennas (FPRAs), composed of a single superstrate and a PEC ground, are proposed in this paper. Two thin dielectric slabs are used to construct the superstrate that exhibits increasing reflection phase at the designated frequency band, making the Fabry-Perot cavity resonate at a wider band and hence leading to a wideband low-profile FPRA. The design example validates the design principle. By truncating the size of the superstrate to about 1.3λ×1.3λ, the 3dB-gain directivity bandwidth of the antenna can be extended from 12.6% to 34.8%, with a peak gain of 15.7 dBi.**

I. INTRODUCTION

Fabry-Perot (FP) resonator, originally used in optical region, was first applied to enhance the gain of radiators in 1956 [1]. Afterwards, dielectric Fabry-Perot resonator antennas (FPRAs) were well studied [2]. In the recent decade, progress in photonic band-gap (PBG) and electromagnetic band-gap (EBG) materials inspired the study on FPRAs. High-gain, wideband and multiband directive FPRAs were developed [3-6] using various EBG materials in the microwave region.

One of the crucial properties of FPRAs concerned by researches is the bandwidth, due to the inherent narrowband resonant cavity. Several methods have been developed to overcome the problem. An active reconfigurable FPRA is designed to obtain an operating bandwidth of about 13.5% [4]. An FPRA with dual-resonator configuration and patch array feeding can achieve a bandwidth of 13.2% [5]. A tapered FSS can be designed to form a wideband FPRA. Theoretically, the increasing reflection phase with frequency of the EBG can be utilized to design wideband FPRAs. This principle has been utilized in practice to develop wide FPRAs. Recently, a single dielectric layer with dual dipole arrays etched on the two sides is developed to form wideband FPRAs [6], due to its increasing reflection phase in the operating frequency band.

To the best of the author's knowledge, most EBG or partially reflective surface (PRS) structures forming FPRAs published in literatures are multiple-layer, which will result in the increase of the antenna size and side-lobes at higher frequencies. Another problem, as mentioned in [6], the radiation pattern will deteriorate at higher frequencies, due to out-of phase at the surface of the EBG/PRS structure, though the antenna gain is still within the 3-dB gain bandwidth.

In this paper, a wideband high-gain low-profile 1D FPRA is proposed. The increasing reflection phase is generated by two stacked dielectric layers with no air gap. To overcome the deteriorated radiation pattern, the PRS is truncated to have a size of about 1.3λ×1.3λ. This will further enhance the effective 3-dB gain bandwidth of FPRAs. Example shows that a bandwidth of about 34.8% and a peak gain of 15.7 dBi can be achieved.

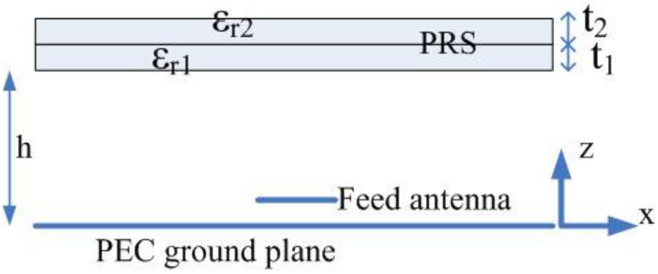


Figure 1. Configuration of the 1D Fabry-Perot resonator antenna.

II. 1D PRS FOR WIDEBAND FABRY-PEROT CAVITY

Most wideband Fabry-Perot resonator antennas have multiple superstrates, which increase the antenna size. In [6], a single superstrate and a PEC round are applied for a wideband FPRA, making the antenna structure simple and low-profile. In the superstrate, periodic resonant elements are printed on its two sides to generate the increasing reflection phase for wideband operation. In this paper, a single superstrate without loading any resonant elements is proposed for wideband FPRAs.

The general geometry of the FPRA under consideration is shown in Figure 1. The structure is ideally infinite in the *x*-*y* plane. The superstrate is composed of two dielectric slabs and there is no air gap between the two slabs. Each dielectric layer is assumed lossless, homogeneous, and isotropic. A horizontal Hertzian dipole feeds the Fabry-Perot cavity, and the separation area between the PEC and the superstrate is considered free space. By following the same derivation procedure described in [1], the total far-field pattern of the FPRA is

$$E = f(\alpha)\sqrt{\frac{1-\Gamma^2(\theta)}{1-2\Gamma(\theta)\cos\left(\varphi-\pi-\frac{4\pi}{\lambda}\cos\theta\right)+\Gamma^2(\theta)}} \tag{1}$$

where Γ, φ, and θ are reflection coefficient, reflection phase and orientation angle, respectively. *f(α)* is the radiation pattern of the horizontal Hertzian dipole. The reflection coefficient, reflection phase of the superstrate can be calculated by using the cascade ABCD network, as detailed in [7]. The far-field pattern can be approximately calculated by

$$E = \sqrt{\frac{1-\Gamma^2(\theta)}{1-2\Gamma(\theta)\cos\left(\varphi-\pi-\frac{4\pi}{\lambda}\cos\theta\right)+\Gamma^2(\theta)}} \tag{2}$$

This analytical model is based on the ray-tracing method and accurate in calculating the far-field pattern of the FPRA.

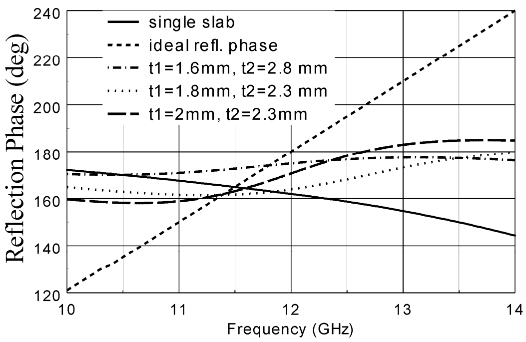


Figure 2. Reflection phases from the single dielectric slab and various dual dielectric slabs.

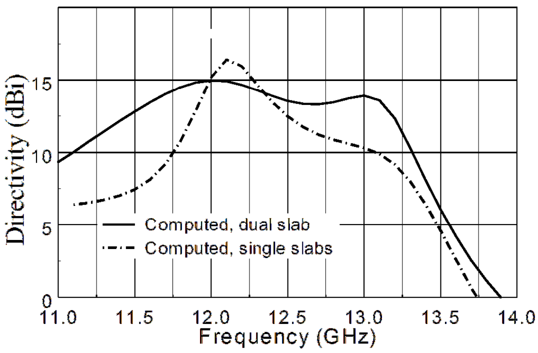


Figure 3. Directivities vs frequency.

It is well known that the reflection phase of a single dielectric slab decreases with frequency, as can be shown in Figure 2. The superstrates made out of dual slabs with no air gap, as shown in Figure 1, were investigated and the results show that increasing phase with frequency can be obtained. Parameters of such superstrate examples presented here are ε_{r1}=25 and ε_{r2}=4.4. Other parameters like cavity height *h* and the thickness of the two slabs t_1 and t_2 are adjustable for better performance. Figure 2 gives some results of the investigation. The reflection phases of the proposed superstrate with three sets of values of t_1 and t_2 are plotted. It can be seen that all three results have the increasing phase within a frequency range, demonstrating the potential feasibility of wideband Fabry-Perot resonator antennas. The ideal increasing phase needed to maintain the resonance at the corresponding Fabry-Perot cavity is also plotted in Figure 2, for reference.

The superstrate with $t_1=1.8$ *mm* and $t_2=2.3$ *mm* is applied to construct an FPRA to verify the design principle. Formula (2) is employed to calculate the directivity and the radiation patterns, which are shown in Figure 3 and Figure 4 respectively. For comparison, the directivity obtained from the FPRA based on a single-slab superstrate is also plotted in Fig. 3. It can be seen that the antenna with dual-slab superstrate exhibits a much wider 3-dB directivity bandwidth. The radiation patterns shown in Figure 4 have a proper main lobe and low side lobes at 12 GHz and 13 GHz, demonstrating the effectiveness of the design of wideband high-gain low-profile FPRAs, together with the results in Figure 3.

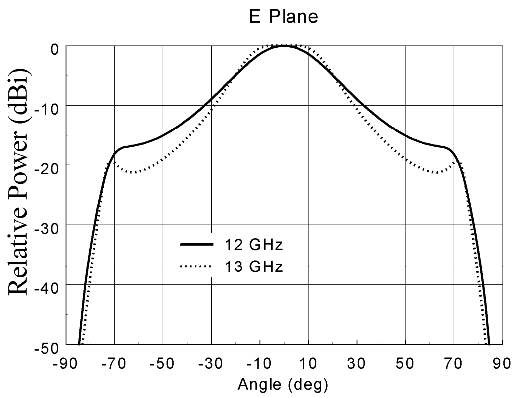


Figure 4. Far-field patterns in E plane of the proposed FPRA at 12 GHz and 13 GHz.

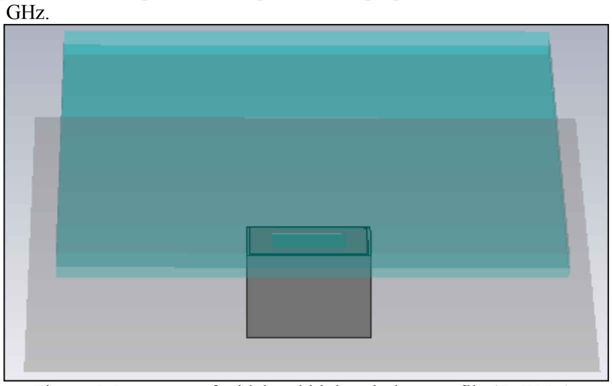


Figure 5. Prototype of wideband high-gain low-profile 1D FPRA.

III. 1D Wideband Fabry-Perot Resonator Antenna

The structure of the final design of the wideband high-gain low-profile FPRA is shown in Figure 5. It is composed of a dual-slab superstrate and a PEC ground and fed by a WR75 rectangular waveguide. The design parameters of the dual-slab superstrate are $\varepsilon_{r1}=25$, $\varepsilon_{r2}=4.4$, $t_1=1.8$ *mm* and $t_2=2.6$ *mm*. The cavity height *h* is *14 mm*. The sizes of the superstrate and the ground are $80\times80\ mm^2$ and $90\times90\ mm^2$, respectively. The aperture size of the feeding WR75 waveguide is $19\times9.5\ mm^2$. To improve the impedance matching of the feeding waveguide, thin metallic irises are added at the radiating aperture of the waveguide. Therefore, the aperture size on the ground surface is $12\times5\ mm^2$. Ansoft HFSS is employed to simulate the designed FPRA.

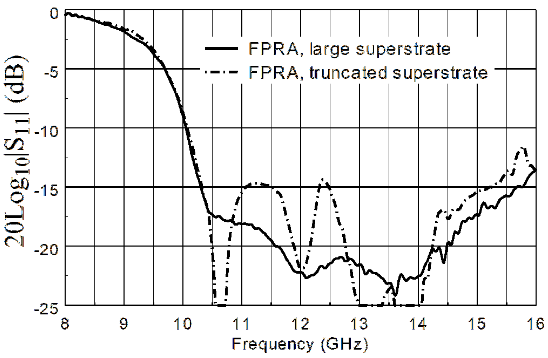


Figure 6. Reflection coefficient.

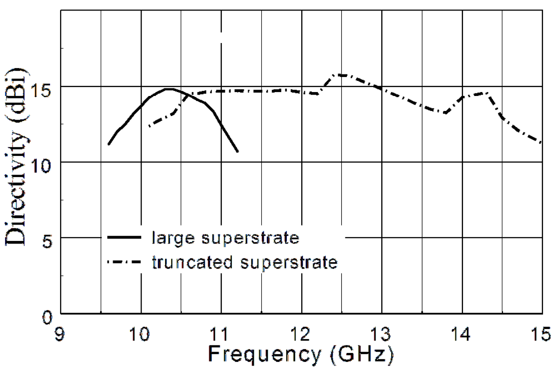
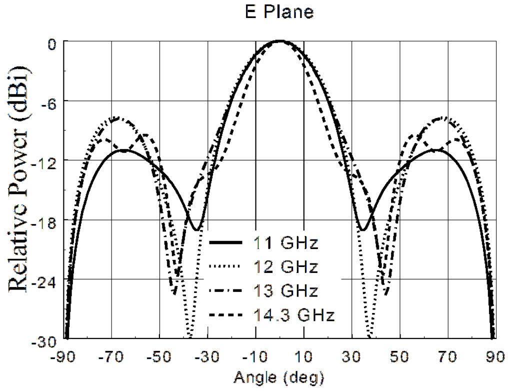


Figure 7 Directivities vs frequency.

The computed reflection coefficient is shown in Figure 6. It can be seen that good impedance matching is obtained from 10.1 GHz to over 16 GHz. The calculated directivity is shown in Figure 7. The peak directivity is about 15 dBi and the 3-dB directivity bandwidth is about 12.6%. To further investigate the FPRA, the size of the dual-slab superstrate is truncated to be about 1.3λ×1.3λ. The simulation results, also plotted in Figures 6, and 7, respectively, show that the similar impedance matching can be obtained, while the peak directivity and the 3-dB directivity bandwidth become 15.7 dBi and 34.8%, showing a much improved bandwidth performance with a much smaller size and without compromising any other performance. The computed radiation patterns of the truncated FPRA at 11 GHz, 12 GHz, 13 GHz and 14.3 GHz are plotted in Figure 8. All patterns at the four frequencies are similar except that higher sidelobe level is obtained at higher frequencies.



F Hz.

IV. Conclusion

A superstrate composed of two thin dielectric slabs with no air gap has been successfully designed to give increasing reflection phase within a designated frequency band. This superstrate is then applied to construct Fabry-Perot resonator antennas. Simulations show that the antenna achieves a 3-dB gain bandwidth of 12.6%., with a peak directivity of 15 dBi. By truncating the size of the superstrate to 1.3λ×1.3λ and then constructing an FPRA, a bandwidth of 34.8% is obtained, with a peak directivity of 15.7 dBi. Thus, a compact, low-profile, wideband, high-gain Fabry-Perot resonator antenna is successfully developed.

Acknowledgment

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