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Wideband Fabry-Perot Resonator Antenna with Single-Layer Partially Reflective Surface

Yuan Xu, Ruina Lian, Zedong Wang, and Yingzeng Yin

Abstract—A single-layer partially reflective surface (PRS) structure is presented to design single-feed Fabry-Perot resonator antennas (FPRA) with a large gain bandwidth and compact size. The design of the PRS structure applied in this antenna is based on the theory of tightly coupled antenna arrays. Owing to strong mutual coupling between the overlapped patches, the proposed antenna obtains a wider bandwidth and more compact size. Experimental results show that the antenna obtains a 32% 3-dB gain bandwidth from 8.8 GHz to 12.2 GHz, with a peak gain of 13.5 dBi. Moreover, the relative impendence bandwidth is 40.9% for the voltage standing wave ratio (VSWR) less than 2 from 8.45 GHz to 12.8 GHz.

1. INTRODUCTION

Fabry-Perot resonator antennas (FPRA) have attracted a lot of interest in the communication field due to their merits of high gain, high radiation efficiency, and especially simple feeding networks. In the last decade, one of the most urgent challenges in the design of FPRA is to improve the operating bandwidth for return loss and 3-dB gain bandwidth. These characteristics are mainly determined by the property of the PRS and feeding source. In 2007, an unprinted multilayer dielectric electromagnetic bandgap (EBG) superstructure excited by a 4×8 slot array obtained an enhanced 3-dB gain bandwidth of 12.6% [1]. But a complex feeding network is indispensable when an antenna array is used as the excitation to feed the FPRA instead of a simple antenna. In consequence, choosing a simple feeding source with satisfactory performances, as the proposed antenna in [2] and giving the suitable design on PRS structure, are what antenna engineers should do. Some 1-D EBG resonator antennas with two layers dielectric slabs or multilayer superstrates as PRS achieved a 30% 3-dB gain bandwidth which was notable [3, 4]. But the thicknesses of the superstrates are one quarter guided wavelength, which is too thick for antenna application. A new concept for designing FPRA is introduced which achieves 18.3 dBi directivity with 8% bandwidth in [5], and the antenna is based on two double-sided periodic arrays printed on either side of a 1.5-mm-thick dielectric substrate.

In recent years, many ultra-wideband tightly coupled antenna arrays are implemented by utilizing coupling characteristics of the adjacent elements to achieve extended bandwidth [6–8]. In this paper, we present a novel PRS structure, which is constructed by two identical triangular metal patches with overlapped section printed on the opposite sides of a 1-mm-thick dielectric substrate. Putting the patches with overlapped section produces strong mutual coupling, which obtains a 32% 3-dB gain bandwidth.

2. WIDEBAND FPRA DESIGN AND CONFIGURATION

Geometry of the proposed antenna is shown in Fig. 1. The antenna is formed by a PRS layer and a feed antenna with Perfect Electric Conductor (PEC) ground plane. Top view of the PRS layer is shown in

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* Corresponding author: Yuan Xu (15829669033@163.com).
The authors are with the Science and Technology on Antenna and Microwave Laboratory, Xidian University, Xi'an, Shaanxi 710071, China.

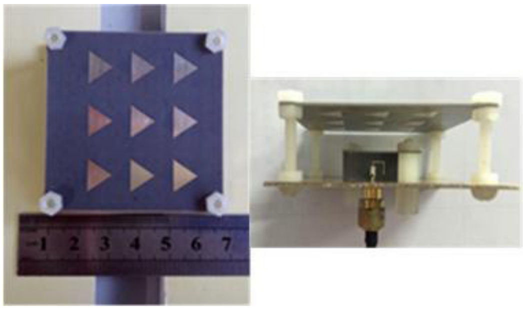
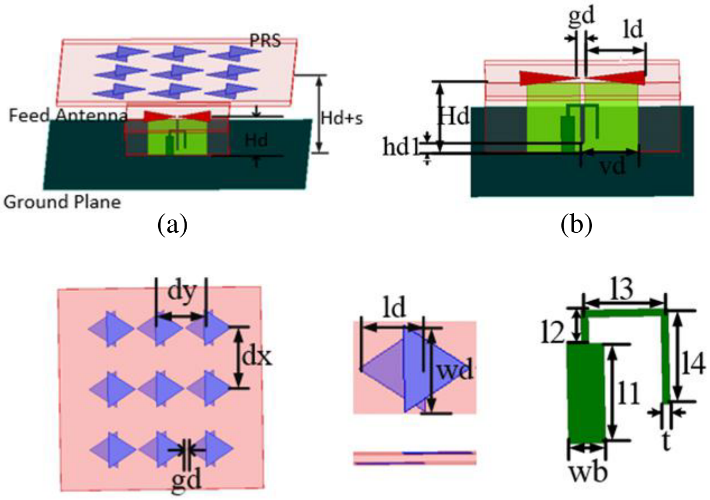


Figure 1. Photograph of the fabricated antenna.



(a) (b)

(c) (d) (e)

Figure 2. Antenna configuration. (a) The geometry of the proposed antenna. (b) Feed antenna. (c) Top view of the PRS layer. (d) Unit cell dimension of the PRS layer. (e) Integrated balun of the feed antenna.

Fig. 2(c). It uses a thin substrate which only has a thickness $h = 1\,\text{mm}$ and permittivity $\varepsilon_r = 2.2$. The unit-cell of the PRS structure is composed of two triangular metal patches with their edges overlapped. The feed antenna in this design is developed by the printed dipole antenna proposed in [4], and in order to facilitate the assembly, the triangular patches are printed on the top side of the horizontal substrate symmetrically instead of connecting to the vertical rectangular patches. All substrates of the feed antenna use a 0.508-mm-thick RogersRT/duroid5880 with permittivity $\varepsilon_r = 2.2$. The configuration is presented in Fig. 2(b), and the details of the integrated balun are shown in Fig. 2(e). Dimensions are specified as follows (unit: mm): $hd = 7.8$, $s = 10$, $gd = 0.5$, $dx = 15$, $dy = 12$, $wd = 9$, $ld = 6.8$, $hd = 7.8$, $hd1 = 1$, $vd = 6$, $l1 = 4.2$, $l2 = 1.4$, $l3 = 3$, $l4 = 4$, $wb = 1.53$, $t = 0.3$.

3. ANALYSIS AND ANTENNA PERFORMANCE

To study the influence of the mutual coupling between the overlapped patches, we have full-wave analysis on PRS structure. The variations of reflection magnitude and phase against frequency of PRS with patches overlapped ($dy = 12\,\text{mm}$) and without patches overlapped ($dy = 16\,\text{mm}$) are presented in Fig. 3. It can be observed that the magnitude of reflection coefficient is enhanced about 1.5 dB in the whole operating band, which means that a higher directivity can be generated by coupling between the overlapped patches. To study it further, we choose a feed antenna shown in Fig. 2(b) to form a FPRA.

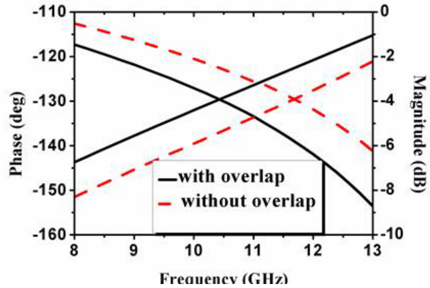


Figure 3. Reflection magnitude and phase of PRS with patch overlapped and without patch overlapped.

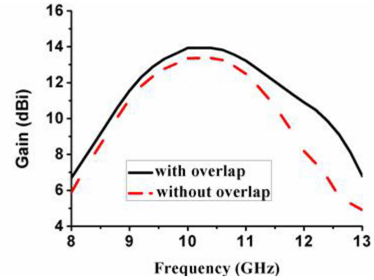


Figure 4. Variations of gain against frequency with and without patches overlapped.

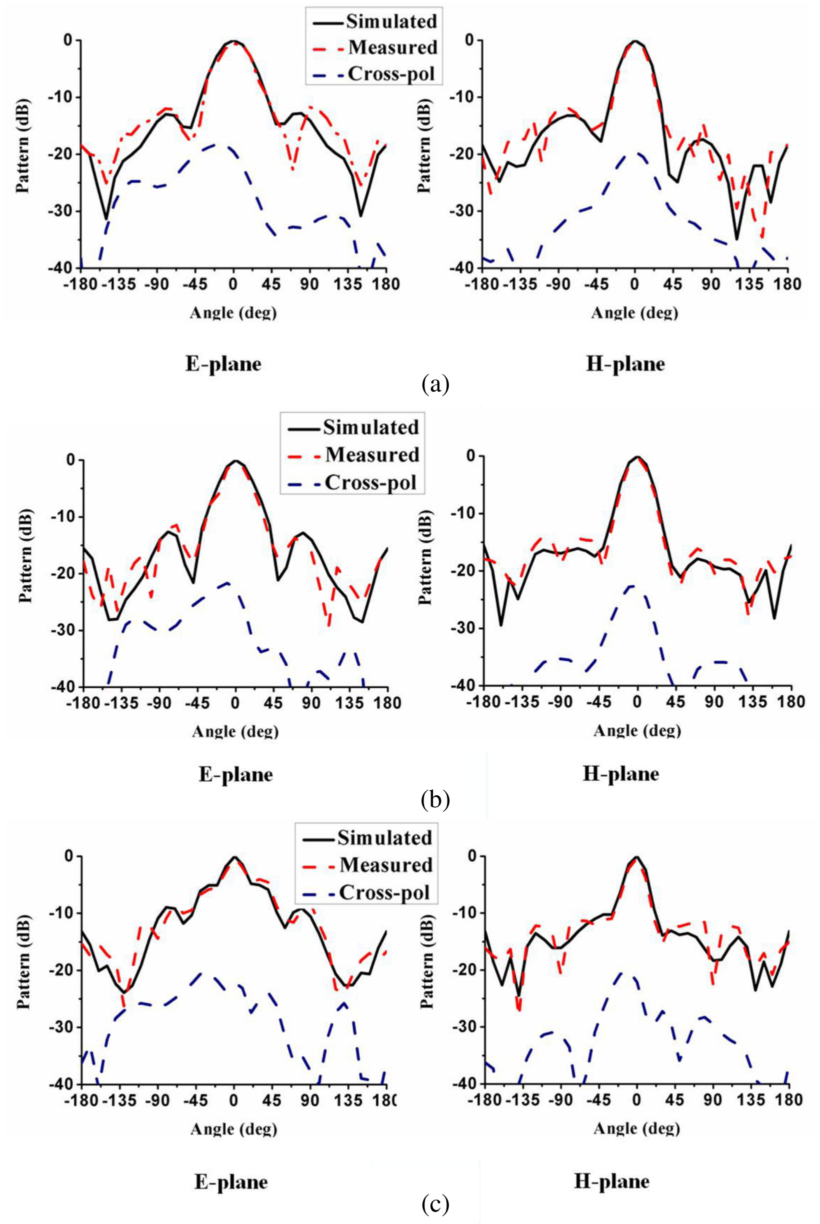


Figure 5. 2-D radiation patterns at 9.3, 10.3, 11.3 GHz. (a) 9.3 GHz. (b) 10.3 GHz. (c) 11.3 GHz.

The total height of the antenna $hd+s$ should satisfy the following formula (1),

$$hd+s=\left(\frac{\varphi_{PRS}}{2\pi}-\frac{1}{2}\right)\frac{\lambda_c}{2}+N\frac{\lambda_c}{2},\quad N=0,1,2,\ldots \tag{1}$$

where λ_c is the resonance wavelength, and phase (φ_{PRS}) is reflection coefficient of the PRS which is presented in Fig. 3.

The overall design of the proposed antenna is simulated using the ANSYS-HFSS V15.0. A comparison between the simulated results of gain when the wideband FPRA is with and without the patches overlapped is presented in Fig. 4. It can be seen that with coupling between the patches the gain increases about 0.6 dBi in the band 9–11 GHz and even more in the higher operating band. At the same time, the 3-dB gain bandwidth of wideband FPRA increases about 7.6%.

The simulated and measured E-plane and H-plane radiation patterns at 9.3, 10.3, 11.3 GHz are presented in Fig. 5. The measured patterns have low SLL values less than -10 dB, and the cross-polarization is less than -20 dB in operating band. It can be seen that the patterns are not symmetrical in H-plane, especially in the lower operating band, which may be caused by the SMA connector not at the center of the antenna.

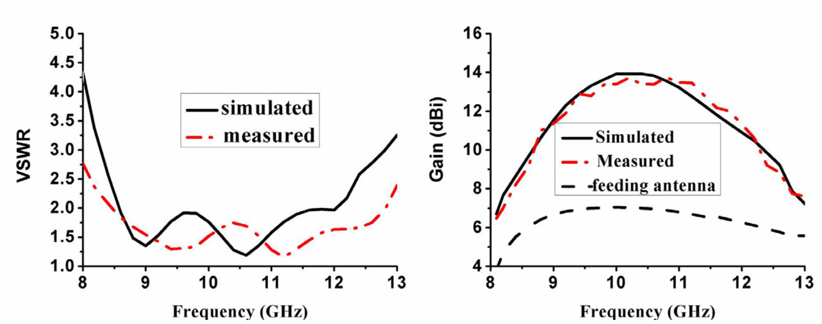


Figure 6. Simulated and measured results of VSWR and gain.

Figure 6 shows the simulated and measured VSWRs of the wideband FPRA. The measured results indicate that the antenna obtains good impedance matching for VSWR less than 2 from 8.93 GHz to 12.22 GHz. It has a slight frequency shift compared to the simulated results, which may be caused by measurement uncertainty and fabrication tolerance. The simulated and measured gains against frequency of the wideband FPRA are also shown in Fig. 6. It can be seen that the two curves agree well with each other. A broadband performance is obtained with the 3-dB gain bandwidth of 32% and a peak gain of 13.5 dB. Compared with the feed antenna, the gain of the wideband FPRA is increased about 7 dBi.

4. CONCLUSION

We present a wideband FPRA with a novel single-layer PRS according to the theory of tightly coupled antenna design. Two triangular metal patches with their edges overlapped are used as the unit-cell of the PRS structure. Compared to the patches without their edges overlapped ($dy = 16$ mm), a wider bandwidth can obtained owing to the strong coupling, and size of the PRS structure can be reduced by 27%. The proposed FPRA has a 32% 3-dB gain bandwidth with a measured peak gain of 13.5 dBi. The proposed antenna can be a good candidate for wireless community application since its impendence bandwidth can cover the 3-dB gain bandwidth well.

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