Study on Fabry-Pérot Antennas Using Dipole Exciters

Yong Zhang [1], Wenhua Yu [1], and Wenxing Li [2]

[1] 2Comu, INC., VA 22030, USA
robeyzhang@gmail.com, wenyu@2comu.com

[2] Harbin Engineering University, Harbin, Heilongjiang 150001, China
liwenxing@hrbeu.edu.cn

Abstract **─** Fabry-Pérot (F-P) cavity antennas with Artificial Magnetic Conductor (AMC) ground planes and Frequency Selective Surface (FSS) superstrates have been investigated in this paper. The method of periodic imaging is used to analyze the cavity antennas, and we can calculate the working frequency and quality factor. One or two dipole antennas are utilized to excite the cavity antennas. The results demonstrate that the gain will be enhanced with the increase of the cavity size, and two exciters in the cavity will improve radiation efficiency obviously.

Index Terms **─** AMC, F-P cavity antennas, FSS superstrate.

I. INTRODUCTION

F-P cavity antennas have attracted a lot of interests for requirements of high-directivity, low-cost and simple-feeding radiation problems [1-4]. The antenna usually consists of a partial reflection surface that is a superstrate, a ground plane and one or several exciters. Therefore, complexity of a traditional feeding network can be significantly reduced.

In order to get a high directivity, the height of a cavity formed by the superstrate and metal ground plane is about one-half wavelength. AMC, which can generate a reflected wave with a zero phase, is utilized to replace the metal ground plane. The height of cavity will be reduced by half while retaining the peak performance of the antenna [5].

Patch FSS superstrate investigated in this paper is used as not quite a band-stop filter, which is just a partially reflecting surface. Substrates with a high electric permittivity are also used for superstrate, while high loss and not high enough reflection coefficients will reduce the directivity.

Excitation in a cavity antenna plays an important role because it's a cavity and the boundary conditions are changed. It is difficult to generate the desired cavity mode with a high directivity and low return loss. Dipole, patch or slot antennas have been used as the exciters for such cavity antennas.

In the following sections, square patch cells are used for AMC ground planes and FSS superstrates. A method of periodic imaging is utilized to analyze the cavity. One and two dipole antennas are used as the exciters for different size cavity antennas.

II. F-P ANTENNA DESIGN

We begin with the design process by choosing the AMC ground plane and superstrate. The simulations have been carried out by GEMS [6], which is an efficient 3-D parallel electromagnetic simulator for modeling complex EM systems. For an AMC unit, a square patch is printed on a metal-backed substrate, whose height and relative permittivity are 1.6 mm and 2.55, respectively. The dimensions of the element unit are $2.6\times2.6\times1.6$ mm^3, and the patch size is 2.5×2.5 mm^2. The reflection phase of AMC is shown in Fig. 1, and the zero reflection phase occurs at 11.4 GHz. We set the height of cavity to be 7 mm that corresponds to about one quarter of wavelength at 11.4 GHz.

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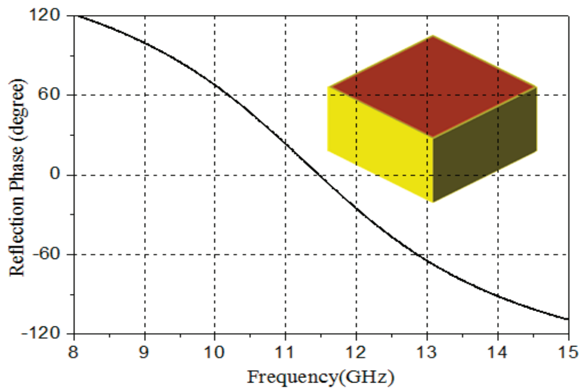
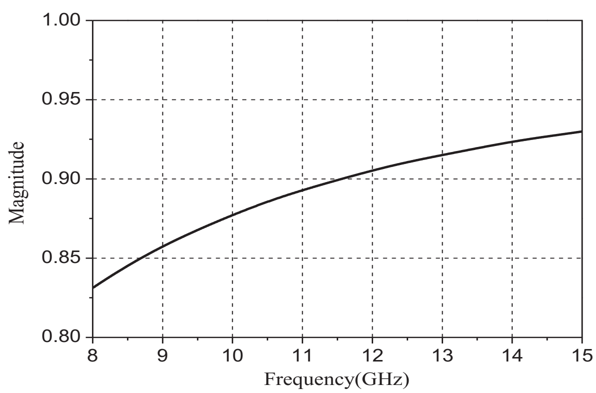
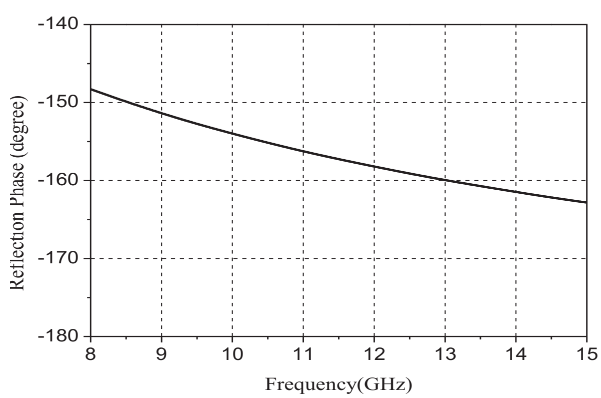


Fig. 1. Reflection phase of the patch AMC.

We use an FSS layer as the superstrate, while the dielectric layer is the same as those used in AMC. The square patches are printed on one side of the dielectric layer. The dimensions of element unit and the patch are 7.8×7.8×1.6 mm^3 and 7×7 mm^2, respectively. The reflection coefficients of superstrate are plotted in Fig. 2. The reflection magnitude is about 0.9 and the phase is -157 degrees at 11.4 GHz.



(a) Magnitude



(b) Phase

Fig. 2. Reflection characteristics of the patch FSS.

We use the method of periodic imaging to get the characteristics of the cavity [2-3]. This method is effective to analyze the working frequency and get the field distribution inside the cavity. As shown in Fig. 3, one unit cell of the cavity consists of one FSS unit cell and nine AMC unit cells. The unit cell is truncated by using the Periodic Boundary Conditions (PBCs); therefore, we only need to simulate a single cell to get the solution. The metal ground is replaced by an imaging of the AMC and superstrate. The plane wave is incident along the -z-axis direction, and the reflection and transmission coefficients are calculated as shown in Fig. 4. The cavity works at around 11.7 GHz, and the Quality Factor (Q) of the cavity is 58.5. The field distribution in one cutting plane in the cavity is presented in Fig. 5.

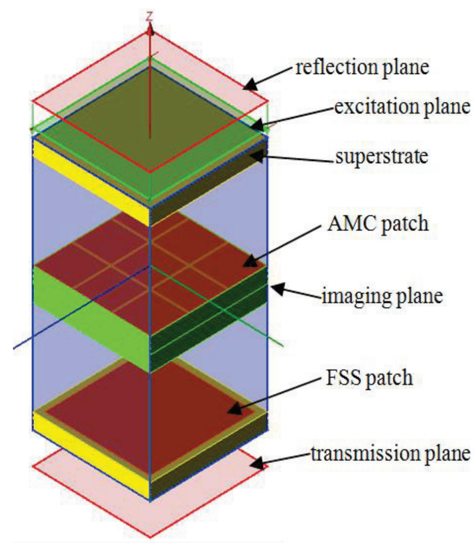


Fig. 3. Configuration of periodic imaging.

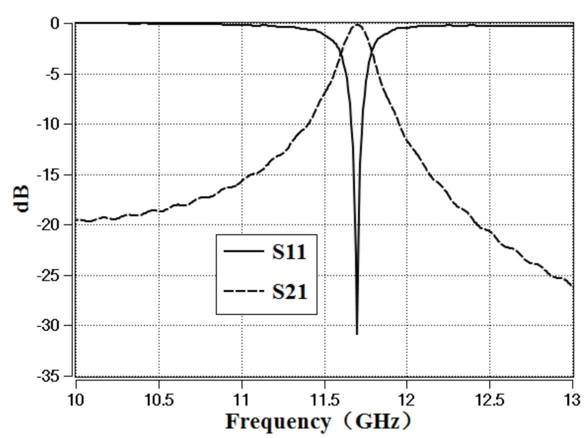


Fig. 4. S-parameters of the F-P cavity.

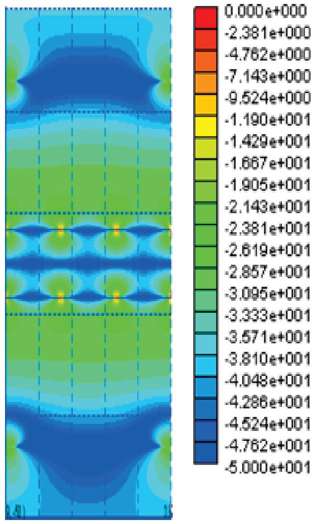


Fig. 5. Field distribution of one cutting plane inside the cavity.

The resonant frequency is a little different from the AMC design since the reflection phase of FSS is not -180 degrees. By increasing the height of the cavity, the frequency can be modified as well for the AMC case. Therefore, the periodic imaging method is very important for the F-P antennas design, and it can be used to modify the parameters of cavities. In this case, we will still choose the height of 7 mm.

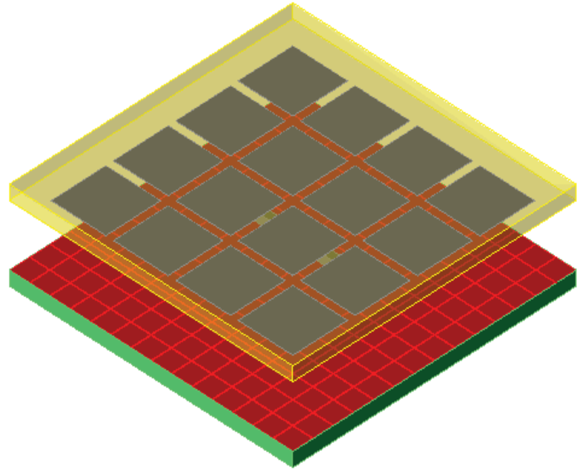
Next, two antenna cavities with different sizes but same height are constructed, shown in Table 1.

Table 1: Cavities geometry information

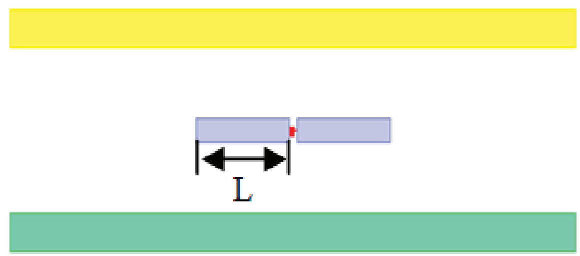
Cavity	AMC Cells	FSS Cells	Size (mm)
1	14x14	4x4	36.4x36.4
2	39x39	13x13	101.4x101.4

III. RESULTS AND DISCUSSION

In Fig. 6, a dipole antenna with L=6 mm is located at the center of the cavity. For the cavity configuration 1, the S_{11} and gain can be plotted in Fig. 7. The maximum gain is 13.3 dB at 12.35 GHz, and the S_{11} is -12dB. The working frequency shift for the cavity is small, while periodic imaging method is just used to simulate an infinite case.



(a) 3D view



(b) Side view

Fig. 6. Configuration of the F-P antenna.

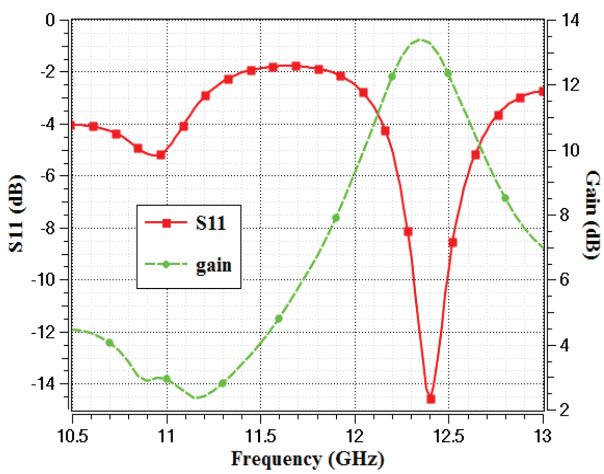


Fig. 7. Performance of cavity 1 with one dipole.

The results for the cavity 2 with one dipole excitation at the center of the cavity are shown in

Fig. 8. The antenna works at 11.75 GHz, the gain is around 19 dB and the S_{11} is -13 dB. We observe from Fig. 8, that the antenna gain will be improved with the increase of the cavity size. At the same time, the working frequency will approach to the resonant frequency in Fig. 4.

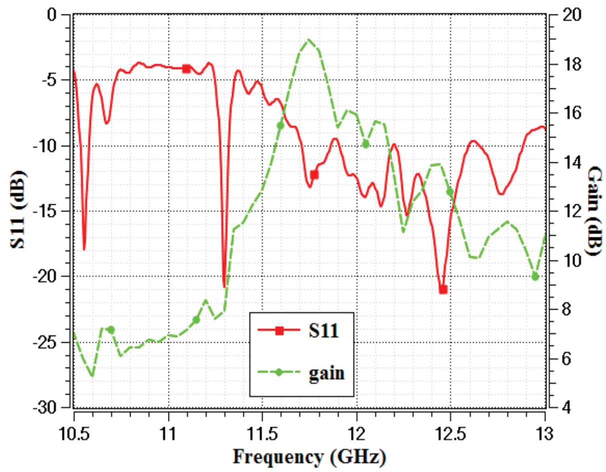


Fig. 8. Performance of cavity 2 with one dipole.

Next, we consider two dipole antennas in the case of the cavity 2 shown in Fig. 9. They are arranged symmetrically along the x-axis, and centrally along the y- and z-axis inside the cavity. The simulation results are presented in Fig. 10. The antenna works at 11.75 GHz, the antenna gain is around 21 dB and the S_{11} is -15 dB. The 2-D and 3-D radiation patterns are presented in Fig. 11.

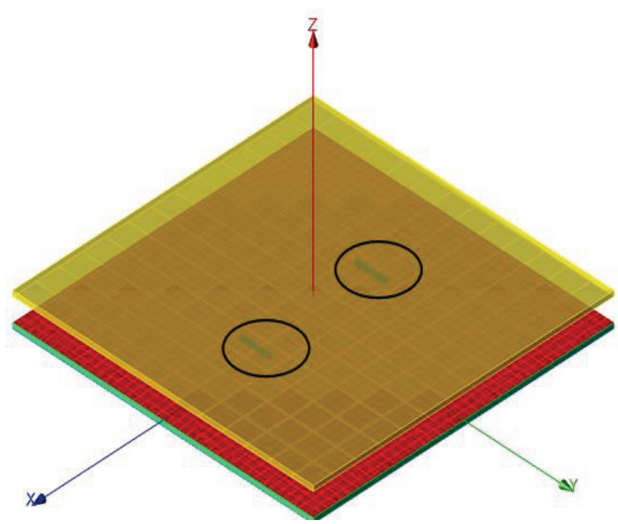


Fig. 9. Configuration of the F-P antenna with two dipoles.

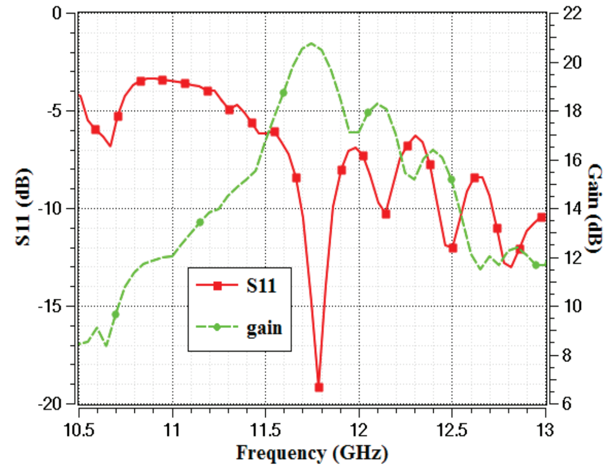
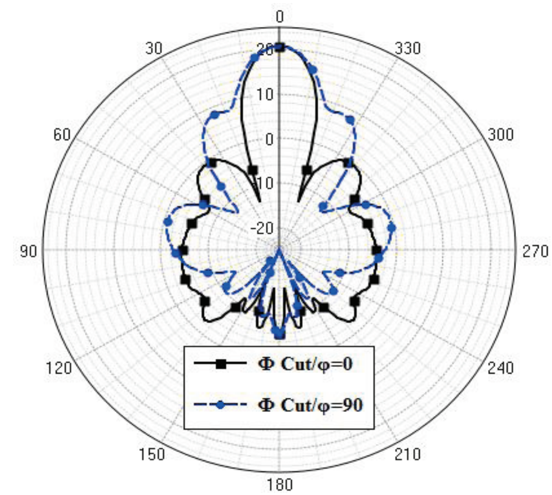
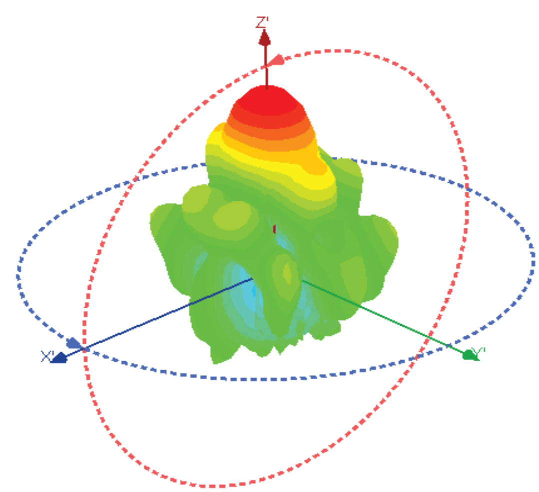


Fig. 10. Performance of cavity 2 with two dipoles.



(a) 2D patterns



(b) 3D patterns

Fig. 11. Radiation patterns of cavity 2 with two dipoles.

The theory of effective aperture field for array antennas can be used as a reference for the performance of the F-P antennas. As shown in Fig. 7, the cavity 1 with one dipole has good radiation efficiency. The effective aperture of the cavity 2 is almost eight times larger than the cavity 1. For one dipole exciter, the directivity of cavity 2 antenna increases about 5.5 dB than the cavity 1. Two dipole exciters increase the directivity about 7.5 dB. Therefore, for large size F-P antennas, more exciters, even small arrays are necessary for high directivity.

IV. CONCLUSION

In this paper, AMC ground planes and an FSS superstrate are used to construct the F-P cavities. The method of periodic imaging is used to analyze the working frequency and quality factor of the cavity. The dipole antennas are utilized to excite the cavity. The simulation results demonstrate that the F-P antennas have good radiation efficiency with simple excitations. The future work will focus on characteristics analysis of larger F-P antennas, including beam scanning, beam forming, and array excitation.

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Yong Zhang received his M. Sc. and Ph. D. degrees in Radio Physics from the University of Electronic Science and Technology of China (UESTC), Chengdu, China, in 2006 and 2011, respectively. He was a Visiting Scholar in the Electromagnetic Communication Laboratory, at Pennsylvania State University in 2008. His research interests include the reconfigurable antenna technique, AMC applications and high directivity antenna design.

Wenhua Yu received his Ph.D. degree in Electrical Engineering from the Southwest Jiaotong University in 1994. He worked at Beijing Institute of Technology as a Postdoctoral Research Associate from February 1995 to August 1996. He has published over 100 technical papers and several books. He is CEO of Computer and Communication Unlimited Company. He is a Senior Member of the IEEE. He is currently a Professor with the College of Information and Communication Engineering, Harbin Engineering University, China. He is also a Visiting Professor and Ph.D. Advisor with the Communication University of China. Yu's research interests include computational electromagnetic, parallel computational techniques, and the theory and design of parallel computing systems.

Wenxing Li received his B.S. and M.S. degrees from Harbin Engineering University, Harbin, Heilongjiang, China, in 1982 and 1985, respectively. He is currently a Full Professor with the College of Information and Communication Engineering, Harbin Engineering University, China. He is also the Head of Research Centre of EM Engineering & RF Technology since 2010. He is also the organizer of the 30th Progress in Electromagnetics Research Symposium (PIERS), IEEE International Workshop on Electromagnetics (iWEM), the TPC of 2012 Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC 2012) and 2012 Global Symposium on Millimeter Waves (GSMM 2012). His recent research interests are mainly on computational electromagnetic, microwave engineering, modern antenna design and microwave and millimeter wave circuits.