Design and Simulation of a Miniature Thick-Screen Frequency Selective Surface Radome

Bao-Qin Lin, Fan Li, Qiu-Rong Zheng, and Yue-Seng Zen

***Abstract*—In this letter, we present a miniature conical thick-screen frequency-selective surface (FSS) radome at C-band and investigate the effect of the miniature FSS radome located in close proximity of a monopole antenna. The unit cell of the thick-screen FSS radome is designed according to the concept of artificial puck plate (APP), and its strict periodic array mounted on sharp conical surface is indicated in detail. The FSS radome, together with a monopole antenna, is simulated using the software HFSS both at the pass- and stopbands. Simulated results show that the miniature thick-screen FSS radome has a narrow band-pass response and could be useful for out-of-band radar cross-section (RCS) control.**

***Index Terms*—Artificial puck plate (APP), frequency-selective surface (FSS), radome.**

I. Introduction

FREQUENCY-SELECTIVE SURFACES (FSSs) have attracted considerable attention in telecommunications, antenna design, and electromagnetic compatibility for several decades [1]–[8]. FSSs were proposed to be used as polarizers, space filters, and subreflectors in dual-frequency antennas and as antenna radomes for radar cross-section (RCS) control [3].

As an antenna radome, the FSS is curved and has nonplanar illumination. Because the FSS radome is often designed as a large structure, the approximate locally planar technique (LPT) method has been used to determine the scattering from a large FSS radome [4], The LPT involves dividing the surface into a number of subarrays, each of which is assumed to be a segment of an infinite planar surface, and the infinite FSS theory with a plane wave illumination is applied to analyze each subarray.

In this letter, we propose a miniature FSS radome at C-band that is mounted on sharp conical surface. The proposed FSS radome is constructed on a perfectly conducting thick screen according to the concept of artificial puck plate (APP), and its strict periodic array mounted on a sharp conical surface is indicated in detail. The miniature FSS radome, together with a monopole antenna, is to be analyzed. Because it is located in close proximity of a monopole antenna, the whole structure is not too large and can be effectively simulated using the Ansoft software HFSS. The influence of the miniature FSS radome on the radiation of the monopole antenna is investigated through the comparison of the antenna radiation when the FSS radome is present or not.

II. Design

The miniature FSS radome in design is a periodic array mounted on a sharp curved surface. As a perfect FSS radome, the FSS radome is first required to be transparent within the frequency range of the enclosed antenna and reflective otherwise. In addition, it is expected to be a reinforced structure.

In the process of the FSS radome's design, the configuration of its unit cell is to be decided at first. To be a reinforced structure, the known band-pass FSS: APP is chosen as a reference [8]. The unit cell of the APP consists of a circular aperture in a conducting thick screen, and there are high dielectric ceramic pucks filled in the aperture and one circular patch lain at the aperture on each side of the screen. The chosen unit cell of the FSS radome is just like that of the APP, while for an APP structure at C-band, the conducting thick screen must be thicker than 10 mm; it is too thick for the miniature FSS radome in design. To thin the conducting thick screen, one patch perforated with six small circular apertures is introduced to be sandwiched medially by the dielectric ceramic puck in its circular aperture.

After the unit cell is chosen, the periodic array is to be established. For a miniature FSS radome, a strict periodic array mounted on its sharp curved surface is difficult to be constructed. After much thought, we choose the FSS radome as a conical structure. This design is based on a novel axi-symmetric planar FSS. The geometry of the devised axi-symmetric planar FSS, as well as the chosen unit cell, are shown in Fig. 1.

For the axi-symmetric planar FSS, the area of one unit cell is fan-shaped. Its size is defined by two parameters: one is the length of the center arc l, the other is the radius r_0, as shown in Fig. 1(b). To keep the axi-symmetry of the FSS, the ratio of the radius r_0 to the center arc l shall be chosen as some fixed values. Now, we select it as

$$\frac{r_0}{l} = \frac{3}{\pi}.$$

In this way, the made-up FSS is just an axi-symmetric structure that is made up of six large pie slices, as shown in Fig. 1(a).

Now, a novel axi-symmetric conical FSS radome can be constructed when one or two large pie slices of the axi-symmetric planar FSS are taken out, and the left structure is circled around the center axis. When one large pie slice is taken out, the obtained FSS radome is named as FSS radome A; when two large pie slices are taken out, a much sharper FSS radome B is obtained.

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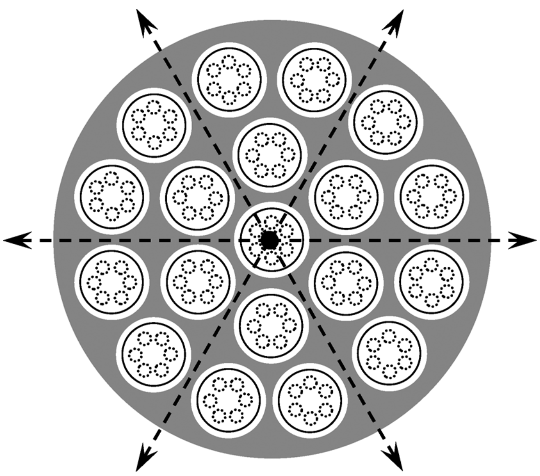
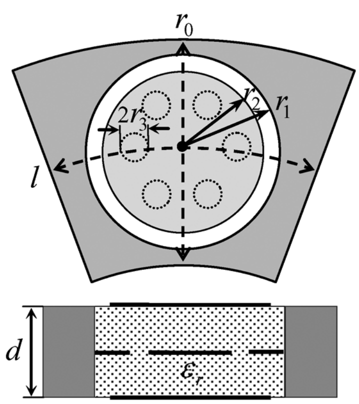
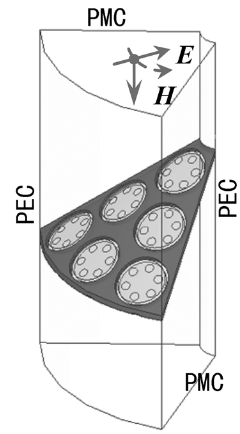


(a)

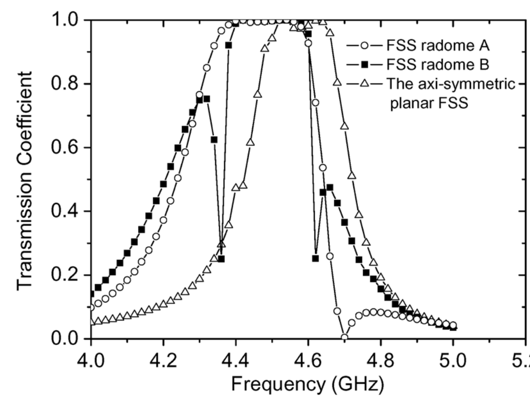


(b)

Fig. 1. Geometry of an axi-symmetric planar FSS using the chosen unit cell. (a) Top view. (b) Unit cells.



(a)



(b)

Fig. 2. Three-dimensional simulated model of (a) the FSS radome and (b) the simulated transmission coefficients.

III. Simulated Results

As an axi-symmetric structure, the miniature conical FSS radome can be calculated by finite-differend time domain (FDTD) method in three-dimension cylindrical coordinates, while we use the Ansoft software HFSS to simulate it as a simple method.

After a series of calculations, we choose the structural parameters of the unit cell as the following: the radius of fan-shaped cell is $r_0 = 20.0$ mm, and that of the circular aperture in the thick screen and the circular patches lain at the aperture are $r_1 = 9.0$ mm, $r_2 = 8.0$ mm, respectively. The small circular apertures on the sandwiched patch deviate from the center of the circular aperture by 5.5 mm, and their radius is $r_3 = 1.45$ mm. The thickness of the conducting thick screen is $d = 1.5$ mm, the dielectric constants of the dielectric ceramic pucks filled in the apertures are chosen as $\varepsilon_r = 5.5$.

First, we have analyzed the band-pass response of the conical FSS radome. According to its axi-symmetry, we pose the FSS radome into a large coaxial cable and only choose one large pie slices as the simulated structure, as shown in Fig. 2(a). The analyzed transmission coefficients of the axi-symmetric planar FSS and the conical FSS radome are all shown in Fig. 2(b). It is shown that the desired narrow band-pass response is kept well when the planar FSS is changed as the conical FSS radome A or B.

The conical FSS radome together with an antenna is simulated in succession. To keep the axi-symmetry of the whole structure, a monopole antenna is selected and laid on the center axis of the conical FSS radome. In this way, we can separate one large pie slice from the whole structure using perfect magnetic conductors (PMCs) as the simulated structure.

First, for the FSS radome A, the simulated structure is shown in Fig. 3(a). The radiation of the monopole antenna has been simulated individually when the FSS radome is presented or not. Now, we define the ratio of the radiation in the presence of FSS radome to that of the same antenna in the absence of the radome as a contrastive result α. The analyzed frequency has been selected as 4.5, 3.8, and 5.0 GHz successively. As the simulated results, the radiate electric fields in the middle longitudinal dissected plane of the simulated structure, as well as the contrastive result α, are shown in Fig. 3(b)–(d).

At frequency 4.5 GHz, which is in the pass-band of the FSS radome, the length of the monopole antenna is 14.1 mm. The data in Fig. 3(b) show that the FSS radome has little effect on the radiation of the antenna, and the contrastive result α is all close to 1.0 when the angle θ varies from 0° to 180°. At frequencies 3.8 and 5.0 GHz, which are both in the stop-band of the FSS radome, the length of the monopole antenna is changed to 17.7 and 12.8 mm, respectively. The simulated results in

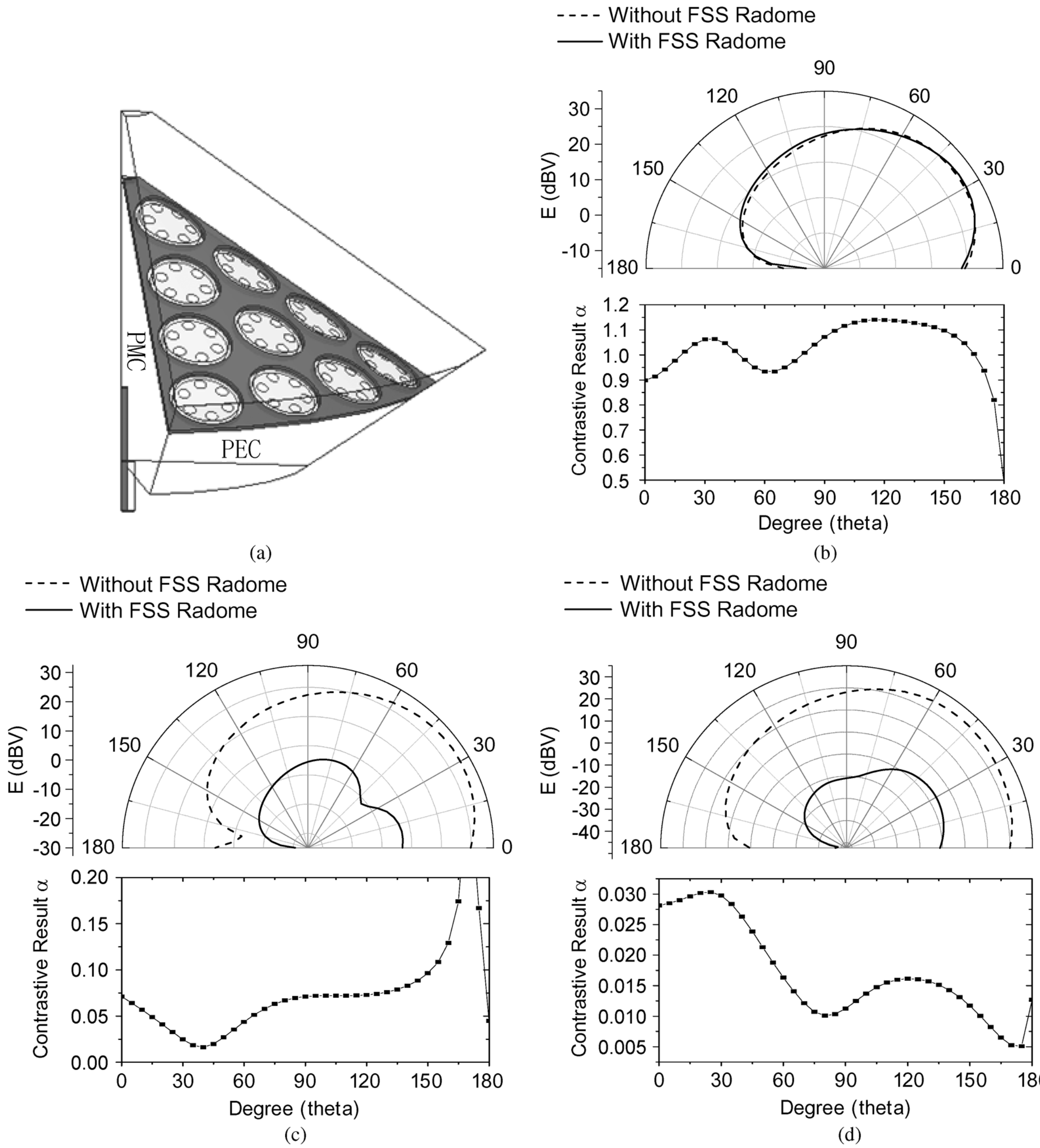


Fig. 3. (a) Three-dimensional simulated model of the FSS radome A with monopole antenna and the simulated results at three frequencies: (b) 4.5, (c) 3.8, and (d) 5.0 GHz.

Fig. 3(c) and (d) show that the radiation of the monopole antenna have been controlled in all directions because of the presence of the FSS radome. The contrastive result α is reduced to $-20 \sim -40$ dB. It is verified that the FSS radome A has a desired band-pass response and is prospectively useful for out-of-band RCS control.

A series of the same simulated processes has been implemented using the FSS radome B, and similar simulated results have been obtained.

Finally, we combine the conical FSS radome A with a cylindrical FSS as a novel FSS radome. The unit cell of the cylindrical FSS is the same as that of the conical FSS. The longitudinal period is kept as 20.0 mm, while the transverse periods is changed to 23.68 mm to keep the axi-symmetry of the whole structure.

The novel FSS radome combined with a monopole antenna is shown in Fig. 4(a), and the simulated results at three frequencies—4.5, 4.0, and 5.0 GHz—are shown in Fig. 4(b)–(d), respectively. The desired band-pass response of the novel FSS radome has been effectively verified.

IV. Conclusion

A miniature conical thick-screen FSS radome at C-band is proposed in this letter. Its design is based on a novel axi-symmetric planar FSS, and its structure is described in detail. The proposed structure is effectively simulated together with a monopole antenna using the software HFSS. The simulated results expressed that the miniature thick-screen FSS radome has a narrow band-pass response and is prospectively useful for out-of-band RCS control.

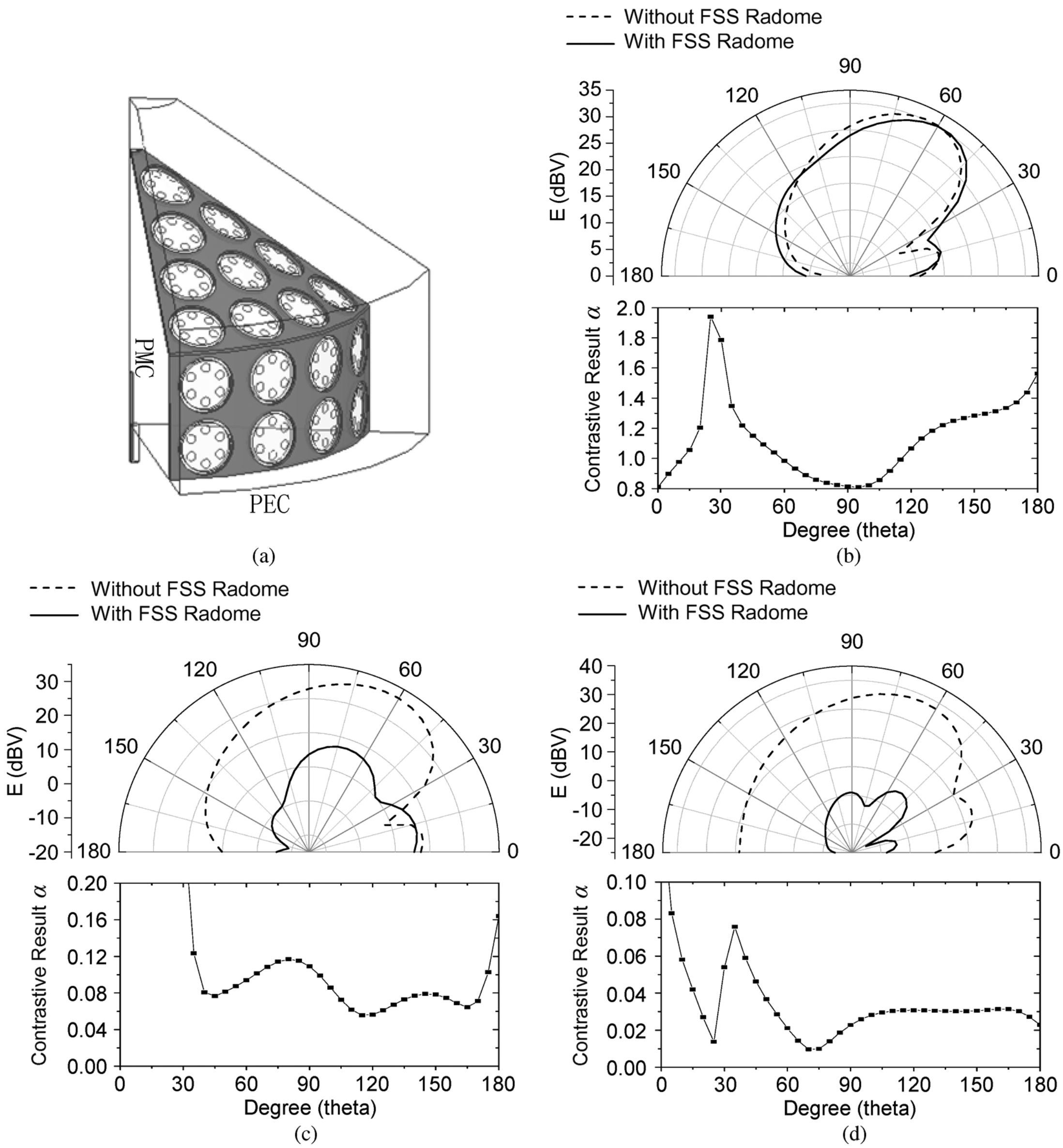


Fig. 4. (a) Three-dimensional simulated model of the novel FSS radome with monopole antenna and the simulated results at three frequencies: (b) 4.5, (c) 4.0, and (d) 5.0 GHz.

REFERENCES

[1] T. K. Wu, *Frequency Selective Surface and Grid Array*. New York: Wiley, 1995.

[2] B. Munk, *Frequency Selective Surfaces: Theory and Design*. New York: Wiley, 2000.

[3] R. Mittra, C. C. Chan, and T. Cwik, "Techniques for analyzing frequency selective surfaces: A review," *Proc. IEEE*, vol. 76, pp. 1593–1615, Dec. 1988.

[4] A. Caroglanian and K. J. Webb, "Study of curved and planar frequency selective surfaces with nonplanar illumination," *IEEE Trans. Antennas Propag.*, vol. 39, no. 2, pp. 211–220, Feb. 1991.

[5] A. A. Tamijani, K. Sarabandi, and G. M. Rebeiz, "Antenna filter antenna arrays as a class of band pass frequency-selective surfaces," *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 8, pp. 1781–1790, Aug. 2004.

[6] A. Roberts and R. C. McPhedran, "Bandpass grids with annular apertures," *IEEE Trans. Antennas Propag.*, vol. 36, no. 5, pp. 607–611, May 1988.

[7] B. Widenberg, S. Poulsen, and A. Karlsson, "Scattering from thick frequency selective screens," *J. Electromagn. Waves Appl.*, vol. 14, pp. 1303–1328, Jul. 2000.

[8] R. G. Schmier, "The artificial puck frequency selective surface," in *Proc. URSI Radio Sci. Meeting*, Ann Arbor, MI, 1993, pp. 266–272.