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A High-Gain Filtering Antenna Based on Folded Reflectarray Antenna and Polarization-Sensitive Frequency Selective Surface

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***Abstract*—In this paper, the concept of high-gain multifunctional antenna based on folded reflectarray antenna (FRA) and polarization-sensitive frequency selective surface (FSS) is proposed. Antenna with multiple functions can be realized by using a polarization-sensitive FSS as the subreflector of FRA instead of the traditional polarizing grid. To validate this concept, a high-gain filtering antenna designed at *Ka* band is presented as a design example. Good filtering performance of the antenna has been achieved due to the frequency selective characteristics of FSS. Besides, the relationship between the focal-length-to-diameter (F/D) ratio of FRA and the size of FSS element has also been discussed.**

***Index Terms*—Multifunctional antenna, filtering antenna, folded reflectarray antenna (FRA), polarization-sensitive frequency selective surface (FSS).**

I. Introduction

THE last few decades have witnessed an increasing interest in the microwave and millimeter wave multifunctional antenna design [1]-[5]. The multifunctional antenna usually integrates multiple functions such as radiation, filtering, power splitting and other functions into a single module. It is possible to make the entire microwave and millimeter wave system to be more compact with a reduced component number and improve the system performance with the filtering or other augmented characteristics of the antenna.

The need of high-gain antennas is usually unavoidable in most long-distance radar and communications systems [6]. The folded reflectarray antenna (FRA) is one of the attractive candidates for high-gain antenna due to its advantages as high efficiency, low profile, low cost, etc [7]-[11]. The losses caused by the complex feeding network of array antenna can be avoided in the reflectarray antenna design due to its space-feeding principle. Compared with the reflectarray antenna, the folded reflectarray antenna can achieve an effective reduction of aperture blockage and antenna height. The FRA is usually consisted of a printed reflectarray with hundreds of patches distributed over an elliptical or square region and a polarizing grid placed parallel to the printed reflectarray with a certain distance. The printed reflectarray functions as the phase compensator to properly focus or shape the electromagnetic wave, meanwhile twisting the wave polarization with 90degree. The polarizing grid is transparent to one polarization while reflecting the wave with corresponding orthogonally polarized polarization over a very wide frequency band [6]. Thus, the frequency selective characteristics of the antenna are mainly determined by the printed reflectarray.

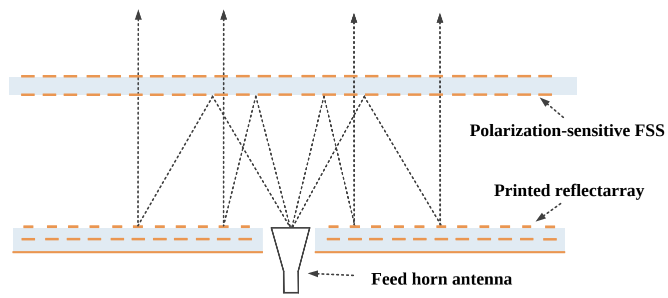

Fig. 1. Side view of the high-gain filtering antenna: folded reflectarray antenna with polarization-sensitive FSS as its subreflector.

Meanwhile, the frequency selective surface (FSS) is a 2D or 3D periodic structure with the functionality of manipulating the spatial electromagnetic wave, which has been widely used in a variety of applications such as spatial filter, reflector, polarization converter, absorber and so forth [12]. Therefore, a high-gain multifunctional antenna can be achieved through using the polarization-sensitive FSS as the subreflector of FRA instead of the traditional polarizing grid.

In this paper, a high-gain filtering antenna based on folded reflectarray antenna and polarization-sensitive frequency selective surface (FSS) is presented to validate the antenna design concept. A polarization-sensitive FSS realized in

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substrate integrated waveguide (SIW) technology is adopted as the subreflector of the folded reflectarray antenna instead of polarizing grid. The SIW FSS is designed to pass the linearly polarized incident wave in its passband as a spatial filter while reflecting the corresponding orthogonally polarized incident wave as a reflector. Besides, the relationship between the focal-length-to-diameter (*F/D*) ratio of FRA and the size of FSS element has also been discussed.

The presented paper is organized as follows. Section II mainly presents the concept of high-gain filtering antenna based on folded reflectarray antenna and the design of polarization-sensitive SIW FSS. The high-gain filtering antenna prototype is exemplified and its corresponding results are discussed in Section III. Finally, the work is summarized in a brief conclusion.

II. Design of High-Gain Filtering Antenna

A. Concept of the high-gain filtering antenna

The side view of the proposed high-gain filtering antenna is shown in Fig. 1. The whole antenna is mainly consisted with a polarization-sensitive frequency selective surface, a feed antenna and a printed reflectarray. The linearly polarized wave radiated from the feed antenna propagates towards the polarization-sensitive FSS and is almost totally reflected backward to the printed reflectarray. Then the reflectarray shapes the wave with proper phase compensation and rotates the wave polarization with 90degree. Finally, the wave reflected from the reflectarray passes through the FSS in its passband and radiates into the free space. The polarization-sensitive FSS is required to function as the spatial reflector and filter under the incident wave with different polarizations.

B. Design of polarization-sensitive FSS

An FSS based on SIW technology is adopted as the subreflector of FRA. The planar SIW FSS is made up of a 2-D periodic array of SIW cavities with parallel slots etched on their front and back sides. The metalized via array of SIW cavity serves to suppress the parallel plate mode excitations. The periodic element of the SIW FSS is depicted in Fig. 2, with its geometrical parameters listed in Table 1. Taconic TLY-5 with a thickness *h* of 0.508mm is adopted as the substrate in the SIW FSS design.

The full-wave EM simulation results of the polarization-sensitive SIW FSS are shown in Fig. 3 and 4. Fig. 3 shows the transmission and reflection coefficients of the FSS under oblique incidence with TM polarizations. It can be observed that the FSS reflects almost all the incident wave at the incidence angle from 0° to 60° over the *Ka* band. Fig. 4 illustrates the frequency selective response of the FSS under normal incidence with TE polarization. It can be easily seen that the FSS functions as a spatial filter with its passband from 31.7 to 36.3GHz. Moreover, better frequency selectivity of the SIW FSS can be achieved with the multimode resonance or multilayer structure [13], [14].

The lowest frequency f_{g0} where a grating lobe is encountered by the FSS can be determined by the incident angle θ and the FSS element size *w* as follows [12]:

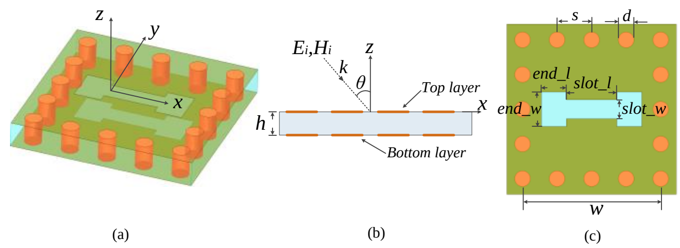

Fig. 2. Periodic element of the SIW FSS. (a) Perspective view, (b) Side view, (c) Structure of periodic element.

TABLE I
DIMENSIONS OF PERIODIC ELEMENTS OF SIW FSS

Symbols	Values in this design [mm]
w	4.4
slot_w	0.6
slot_l	1.6
end_w	1.1
end_l	0.8
s	1.1
d	0.5

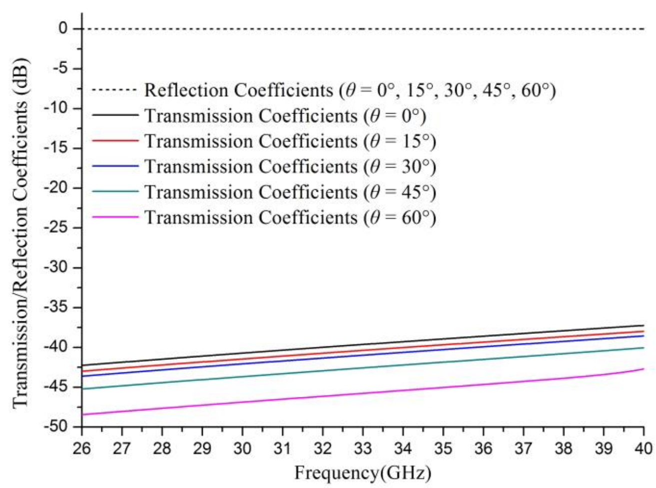

Fig. 3. Simulated results of the SIW FSS under incidence with TM polarization.

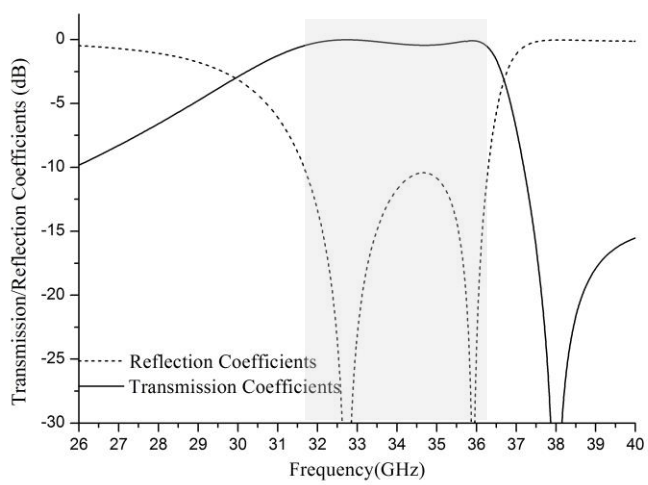

Fig. 4. The bandpsss performance of the SIW FSS under normal incidence with TE polarization. (Gray area: the designed passband of FSS)

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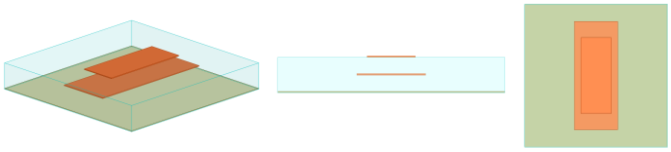


(a) (b) (c)

Fig. 5. Illustration of two-layer periodic element of printed reflectarray. (a) Perspective view, (b) Side view, (b) Top view.

$$f_{g0} = \frac{c_0}{w(\sin\theta + 1)} = \frac{c_0}{w\left(\sin\left(\arctan\left(D/2F\right)\right)+1\right)}, \quad (1)$$

where c_0 is the speed of light in vacuum, D and F are the diameter and focal length of folded reflectarray antenna, respectively. As the FSS element size w is chosen to be 4.4mm, the focal-length-to-diameter (F/D) ratio of the folded reflectarray antenna should be larger than 0.5 to avoid the appearance of grating lobe in the passband of FSS.

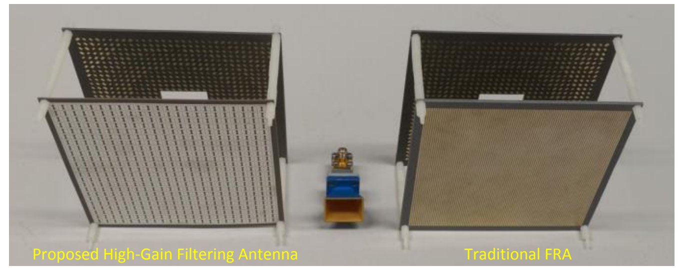
C. Other parts of the high-gain filtering antenna

The printed reflectarray is consisted of hundreds of variable-sized two-layer stacked patches distributed over a square region. Smooth phase compensation can be obtained by using the stacked patches as the reflectarray element, and thus the operating bandwidth of the reflectarray antenna is enhanced [6]. The reflectarray is designed to operate at the center frequency of 34GHz and fabricated on a two-layer Taconic TLY-5 substrate (ε_r = 2.2, tanδ = 0.0009 @ 10GHz) with the total thickness of around 1.1mm. The element structure of the printed reflectarray is shown in Fig. 5. The size of reflectarray element is 3.3mm × 3.3mm and the size coefficient between metal patches of first-layer and second-layer is chosen to be 0.7. A pyramidal horn antenna is used as the feed antenna in the high-gain filtering antenna design due to its outstanding characteristics as low loss, wide operating bandwidth, etc.

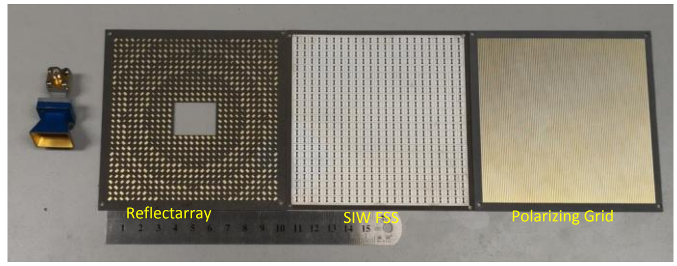
III. Results and Discussion

A folded reflectarray antenna with the polarization-sensitive SIW FSS as its subreflector operating at *Ka* band has been investigated in both the simulation and measurement. As illustrated in Fig. 6, antenna prototypes with size of around 99mm × 99mm are fabricated. The focal-length-to-diameter (F/D) ratio of the folded reflectarray antenna is chosen to be 1 in the FRA design, i.e., $F = D = 2H$ = 99mm, to avoid the effect of grating lobe. Besides, high radiation efficiency of the FRA could be achieved with a large focal-length-to-diameter ratio [15]. A *Ka*-band pyramidal horn antenna is adopted as the feed antenna. Good mechanical stability of the whole antenna structure can be achieved by inserting some plastic pillars between the printed reflectarray and the FSS.

All the simulation results of the filtering antenna design are obtained with CST Microwave Studio. The antenna radiation patterns have been measured with the far-field method in the anechoic chamber. The simulated and measured radiation patterns in *E*-plane and *H*-plane at its center frequency of 34GHz are shown in Fig. 7. Good agreement between the simulations and measurements has been achieved. Both of the measured 3dB beamwidth in *E*-plane and *H*-plane are 5.3 °. The measured side lobe levels (SLLs) in the *E*-plane and *H*-plane are under -14.7 and -14.4dB, meanwhile the cross-polarization

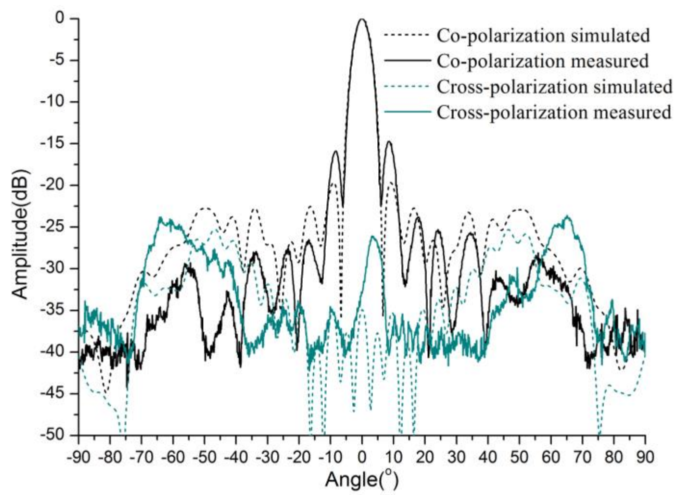


(a)

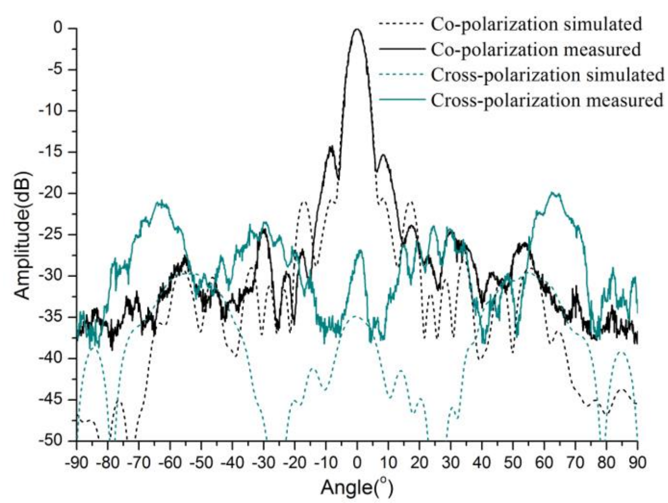


(b)

Fig. 6. Photograph of the folded reflectarray antennas. (a) Proposed high-gain filtering antenna and traditional FRA, (b) Main components of the two FRAs.



(a)



(b)

Fig. 7. Normalized radiation patterns of the proposed filtering antenna at 34 GHz. (a) *E*-plane, (b) *H*-plane.

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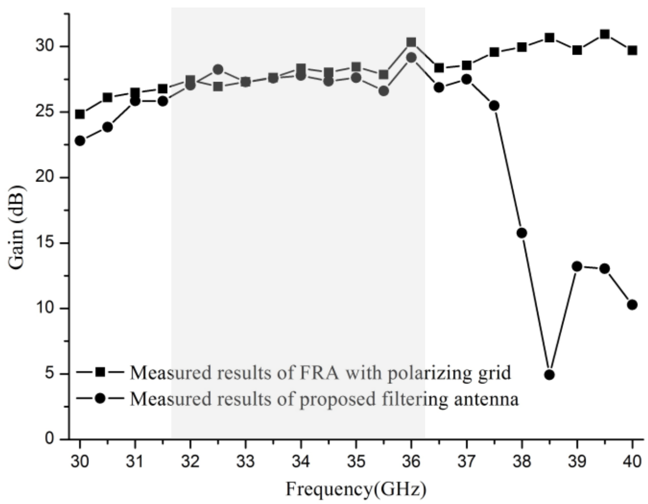

Fig. 8. Measured gains of the high-gain filtering antenna and the traditional FRA. (Gray area: the designed passband of FSS)

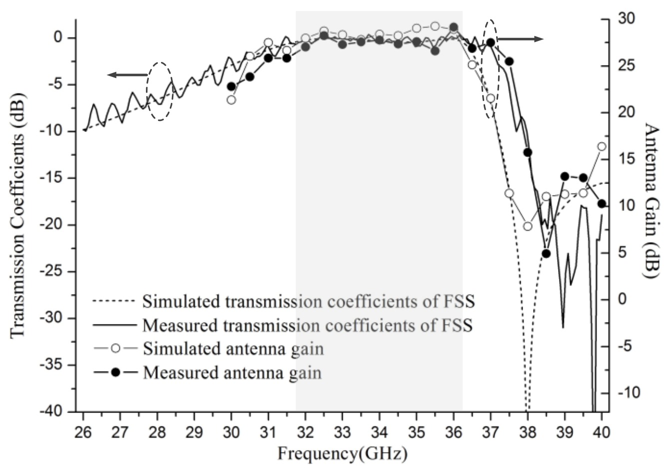

Fig. 9. Transmission coefficients of SIW FSS and gains of proposed filtering antenna in simulation and measurement. (Gray area: the designed passband of FSS)

levels are less than -22.0dB in both the *E*-plane and *H*-plane. Moreover, the radiation pattern of the filtering antenna is stable in the FSS passband.

Comparison has been done between the proposed filtering antenna and the traditional FRA with polarizing grid as its subreflectors. The printed reflectarray and feed horn antenna of these two antennas are totally the same. As depicted in Fig. 6(b), the polarizing grid was manufactured on a Taconic TLY-5 substrate with a thickness of 1.5mm. The metal strip width and gap width of the polarizing grid are 0.6mm and 0.4mm, respectively.

Fig. 8 shows the comparison of measured gains between these two FRAs. The measured results of the two FRAs are almost the same in the designed FSS passband. Compared with the traditional FRA, good frequency selective characteristics has been achieved by the proposed filtering antenna, especially at the upper stopband of the filtering antenna. Fig. 9 shows the transmission coefficients of SIW FSS and gains of proposed filtering antenna in simulation and measurement. It can be seen from Fig. 9 that the filtering performance of proposed antenna is mainly determined by the frequency selective characteristics of SIW FSS in both simulation and measurement. The measured antenna gains of the filtering antenna are larger than the simulated values at the frequencies range from 37GHz to 38GHz. This phenomenon of measured results should be attributed to the imperfect fabrication of the SIW FSS, which leads to a little wider passband than the simulation.

IV. Conclusion

To verify the concept of high-gain multifunctional antenna based on the folded reflectarray antenna and polarization-sensitive frequency selective surface, a high-gain filtering antenna has been proposed and verified at *Ka* band with the polarization-sensitive FSS functions as the spatial filter and reflector at the same time under incidence with different polarizations. Good filtering performance of the FRA has been achieved with the polarization-sensitive FSS used as the subreflector of FRA instead of the traditional polarizing grid. The proposed filtering antenna retains the advantages of FRA as low profile, easy fabrication, etc. It can be further expected that other multifunctional antennas can also be obtained through the integrated design of polarization-sensitive frequency selective surface and folded reflectarray antenna.

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