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A Dual-Frequency Single Layer Circularly Polarized Reflectarray with Frequency Selective Surface Backing

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Abstract—The design of a dual-frequency single-layer circularly polarized reflectarray with frequency selective surface (FSS) backing is presented in this paper. The proposed reflectarray consists of rotated cross dipole elements etched on an FSS-backed substrate. Compared with the conventional design, the FSS layer reduces the mutual effect between the elements of two bands between the elements of two frequencies. The technique of element rotation ensures the proposed reflectarray obtain excellent performance of circular polarization. A dual-frequency circularly polarized reflectarray with FSS backing is fabricated and tested. All the simulated and measured results demonstrate these advantages.

1. INTRODUCTION

A reflectarray [1] is an antenna consisting of a flat reflecting surface with many radiating elements and an illuminating feed antenna. Reflectarray has become an attractive alternative to the parabolic reflectors and phased array antennas in radar and satellite systems because of the advantages of low profile, flat surface and ease of manufacturing. However, one of the severe drawbacks for the reflectarray is its narrow bandwidth. Several approaches have been developed to increase the bandwidth of reflectarray antenna [2–4]. Moreover, a dual-frequency reflectarray antenna has been proposed to cover two narrow bands [5].

In previous works, most dual-frequency reflectarrays were proposed to realize linear polarized operation [6–8]. By contrast, the design of dual-frequency circularly polarized reflectarray has attracted increasing attention in recent years. A dual-frequency dual-layer circularly polarized reflectarray antenna with microstrip ring elements has been designed in [9]. However, using this configuration leads to blockage of lower-band reflectarray to the higher-band reflectarray, despite the small mutual effect of elements at different bands. Besides, the multilayer design will increase the weight, loss and additional manufacturing complexity. A dual-band single-layer circularly polarized reflectarray with cross dipoles of variable size has been proposed in [10, 11], but the mutual coupling between the higher and lower band elements cannot be ignored. When operating at higher band, part of the energy radiated by feed antenna is also reflected from lower band elements and has a bad effect on the higher band elements. Similar situation happened at lower band. To overcome this shortcoming, a dual-band reflectarray with split loop elements was introduced in [12], but it can only realize linear orthogonal polarization.

The goal of this paper is to present the design and fabrication process of a dual-frequency, single-layer circularly polarized reflectarray with frequency selective surface (FSS) backing. The conception of FSS-backed reflectarray was suggested in [13–15] to realize dual-frequency linear polarization and reduce the mutual effect between the elements of two bands. Compared with the previous design, the proposed reflectarray uses a single-layer structure to ensure easy fabrication and light weight. The FSS is used as the ground plane, which greatly reduces the coupling of two frequencies. Besides, the approach

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using angular rotation of elements ensures the reflectarray to obtain excellent circular polarization (CP) performance and high gain at both frequencies. All the simulated and measured results demonstrate a small mutual effect and CP performance at both frequencies.

2. ELEMENT DESIGN

The dual-frequency reflectarray consists of orthogonal dipoles, which are printed on an FSS-backed substrate. The elements at both frequencies are arranged in a square lattice with periodicity of $d = 14\,\text{mm}$, equivalent to 0.65λ at 14 GHz (centre frequency of the higher band) and 0.37λ at 8 GHz (centre frequency of the lower band). The configurations of the designed elements at two bands are illustrated in Fig. 1. The relative permittivity of the substrate is 2.65, and the thickness is 3 mm. Instead of metallic ground plane backing, a square loop and a cross dipole loop as the FSS element are used at higher and lower frequencies respectively to reduce the coupling of two frequencies.

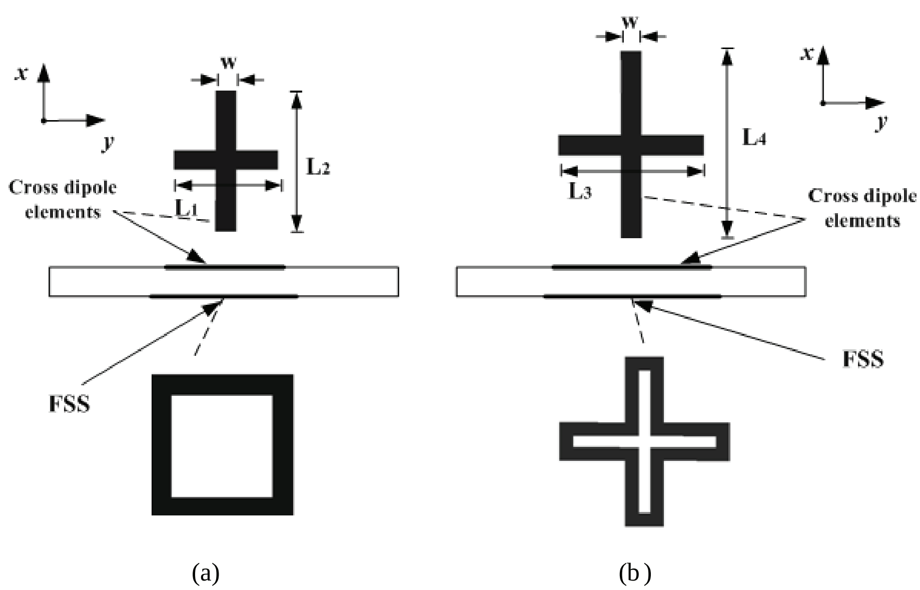


Figure 1. Geometry of the elements. (a) Higher band element. (b) Lower band element.

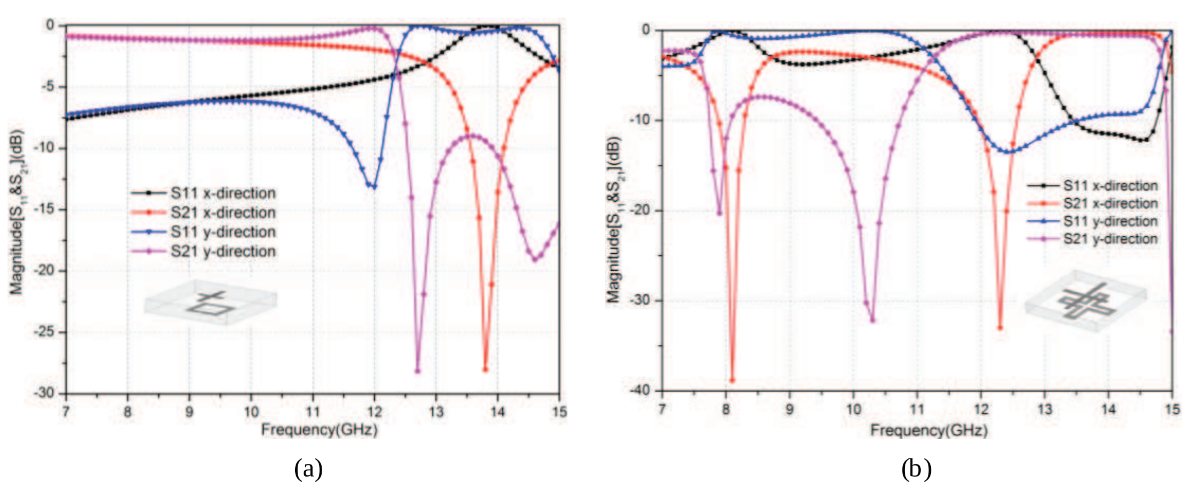
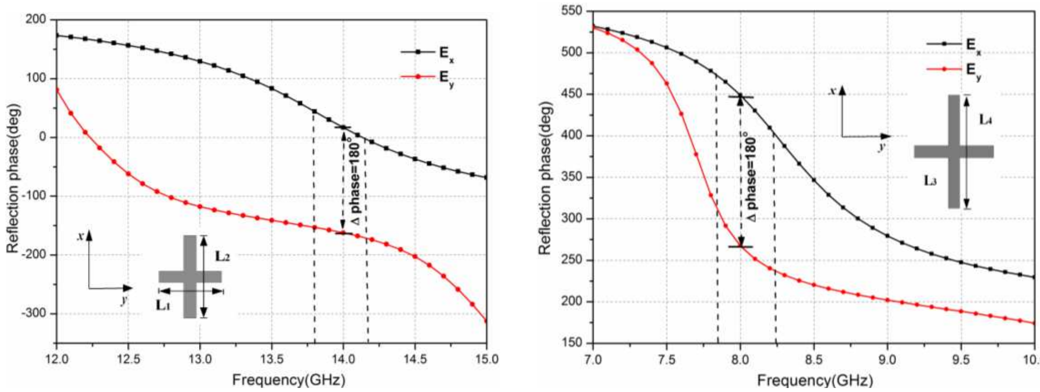


Figure 2. (a) Magnitude of reflected and transmitted waves versus frequency for the higher band element. (b) Magnitude of reflected and transmitted waves versus frequency for the lower band element.



(a) (b)

Figure 3. (a) Phase of the E_x and E_y versus frequency for the higher band element ($L_1 = 4\,\text{mm}$, $L_2 = 7.2\,\text{mm}$). (b) Phase of the E_x and E_y versus frequency for the lower band element ($L_3 = 8.5\,\text{mm}$, $L_4 = 11\,\text{mm}$).

Table 1. Design parameter of feed antennas.

Parameter	The feed operating at higher band	The feed operating at lower band
Pitch	5 mm	8 mm
Ground size	30 mm × 30 mm	30 mm × 30 mm
Number of turns	12	11
Wire diameter	1.2 mm	1.2 mm
Co-polarization	LHCP	LHCP

The elements are analyzed using Ansoft HFSS. Fig. 2 shows the magnitude of S_{11} and S_{21} versus frequency for the elements at higher and lower bands. It can be seen from Fig. 2(a) that S_{11} in both x- and y-directions are close to 0 dB at 14 GHz for the higher band element, which ensures a total reflection at higher band. Similar results are obtained for the lower band element in Fig. 2(b). Hence, FSS-backing has a similar reflection effect as metallic ground plane. Moreover, it can be observed in Fig. 2(a) that the S_{21} of both directions are about -1 dB at 8 GHz, which indicates that energy illuminated from feed antenna is transmitted at lower band. Therefore, the mutual effect on the higher band elements is greatly reduced when operating at higher band. A similar conclusion can also be obtained at lower band from Fig. 2(b). So the FSS-backed reflectarray can decrease the coupling of two frequencies.

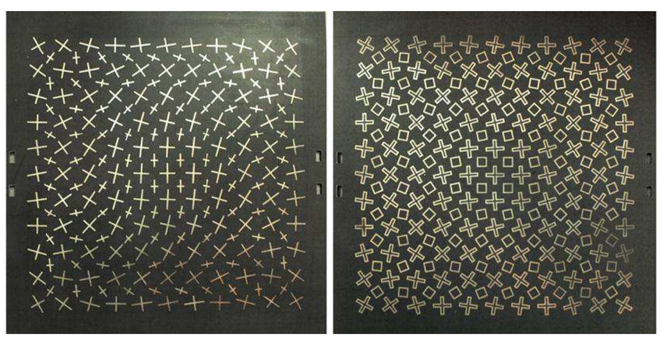
In the case of circularly polarized reflectarray with rotated elements, each cell element should satisfy the condition that the x- and y-polarized reflected electric fields differ in phase by 180°. In fact, it is essential to adjust the orthogonal dimensions of the cross dipole element to maintain the phase difference. Fig. 3 presents the phase of two orthogonal electric fields versus frequency for the elements at two bands. For higher band element, a phase difference of 180° is maintained at 14 GHz when $L_1 = 4\,\text{mm}$ and $L_2 = 7.2\,\text{mm}$. For lower band element, $L_3 = 8.5\,\text{mm}$ and $L_4 = 11\,\text{mm}$ can produce the phase difference of 180° at 8 GHz. The element rotation angle can be adjusted to compensate the phase delay caused by the spatial path difference between the feed and elements in the reflectarray. More details about the design of circularly polarized reflectarray with rotated elements can refer to [16].

3. REFLECTARRAY REALIZATION AND PERFORMANCE

A prime-focus reflectarray using proposed radiating elements has been designed and fabricated. Photographs of the reflectarray prototype are given in Fig. 4. It consists of 100 higher frequency and 121 lower frequency cross dipoles on the top surface. On the bottom surface, the corresponding FSS elements are etched. Both the size of the reflectarray prototype D and focal distance F are 154 mm, thus giving a F/D ratio equal to 1. Two axis-mode helix antennas with the main polarization of left-hand circular polarization (LHCP) are chosen as the feed antennas. One of the helix antennas operates at higher band and the other at lower band. The prototype of two helix antennas is shown in Fig. 5, and the design parameters of the feed antennas are show in Table 1. The radiation patterns of feed antennas at 14 GHz and 8 GHz are given in Fig. 6. As can be seen from figure, the measured radiation patterns of feed antennas are consistent with the simulated results at both frequencies, and the sidelobe levels are 11.2 dB down from the main beam for the higher band feed and 11.7 dB down for the lower band feed. Besides, both of the higher and lower band feed antennas have a 3 dB beamwidth about 35°, which are both perfect to be the feed antenna.

To verify the validity of the proposed design, a dual-frequency circularly polarized reflectarray with metallic ground plane is also designed. The metallic ground plane reflectarray also uses angular rotation technique to compensate the phase delay caused by the spatial path difference between the feed and elements in the reflectarray. Except the metallic ground plane, other design parameters, including design frequencies, feed antennas, relative permittivity and thickness of the substrate, dimensions of higher and lower band cross dipoles, are the same as the FSS-backing reflectarray. The simulated radiation patterns of these two reflectarrays at 14 GHz and 8 GHz are shown in Fig. 7. Compared with the FSS-backing reflectarray, the severe cross-polarization level at both frequencies is produced in the metallic ground plane reflectarray to show the strong mutual effect between two frequencies. More detailed comparison of antenna performance between two reflectarrays is given in Table 2. All these results indicate that the performance of reflectarray with the metallic ground plane is obviously not as good as that of the FSS-backing reflectarray. Therefore, the proposed design can greatly reduce the coupling of two frequencies and obtain excellent CP performance.

The measured radiation patterns of the proposed reflectarray at 14 GHz and 8 GHz are presented

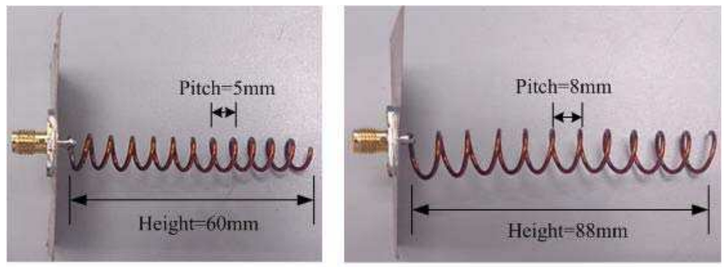


(a) (b)

Figure 4. Photograghs of the dual band CP reflectarray. (a) Front view. (b) Back view.

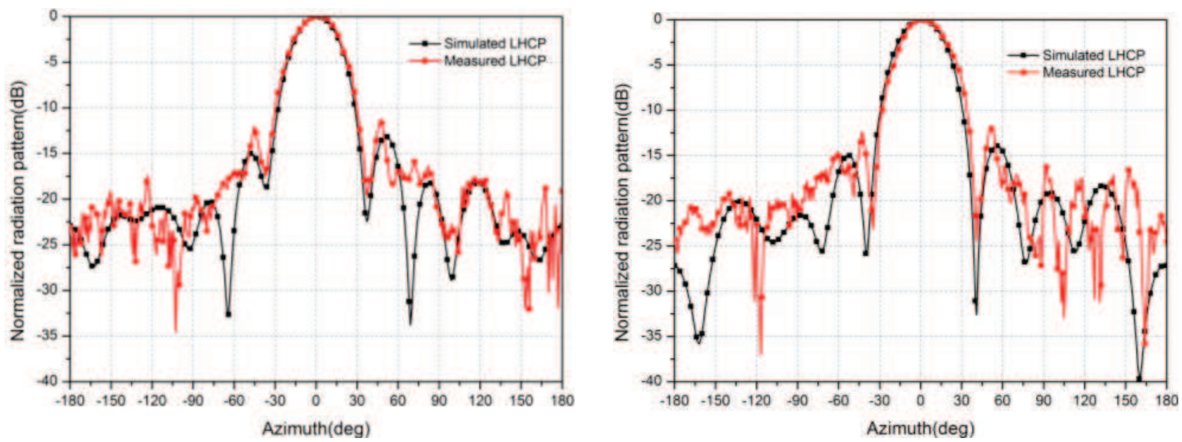
Table 2. Simulated results of two reflectarrays at design frequencies.

Parameter	**FSS-backed reflectarray**		**Solid metallic ground plane reflectarray**	
Frequency	8 GHz	14 GHz	8 GHz	14 GHz
LHCP gain	18.65 dBi	23.12 dBi	16.45 dBi	22 dBi
Peak sidelobe level	−13.4 dB	−16.4 dB	−7 dB	−13.3 dB
Axial ratio	2.2 dB	2.1 dB	8.4 dB	4.5 dB
3 dB beamwidth	12.9°	9°	12.9°	9.2°
Efficiency	34.6%	38.3%	20.9%	29.6%



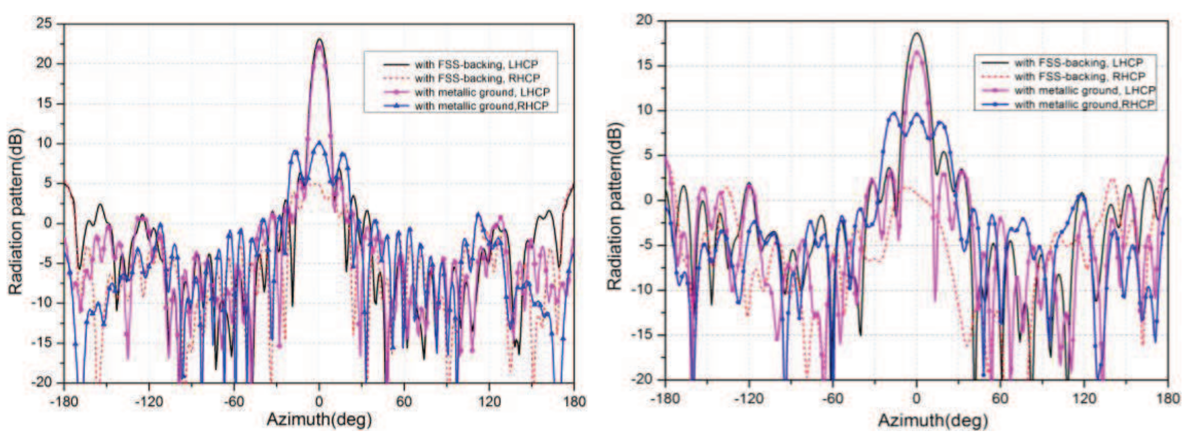
(a) (b)

Figure 5. (a) Helix antenna operating at higher band. (b) Helix antenna operating at lower band.



(a) (b)

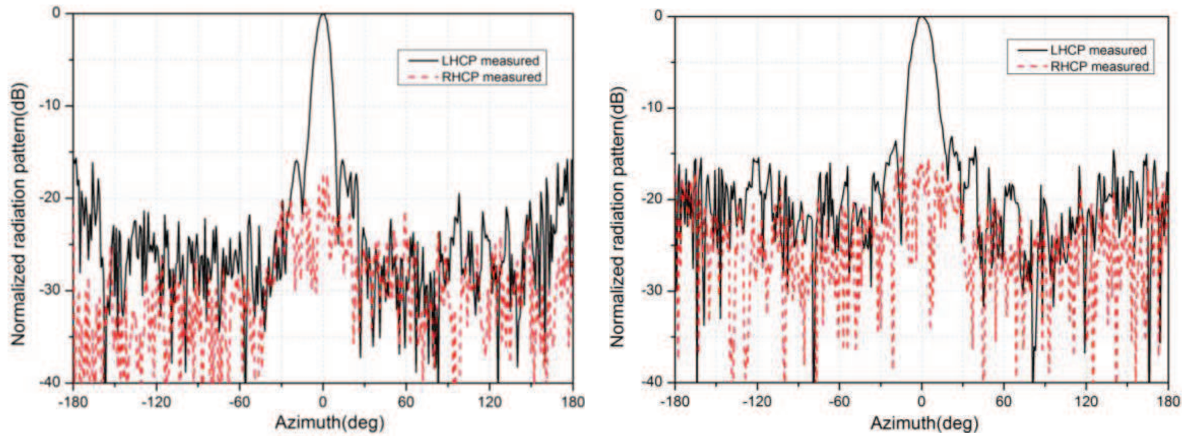
Figure 6. The radiation patterns of feed antennas operating (a) at 14 GHz, (b) at 8 GHz.



(a) (b)

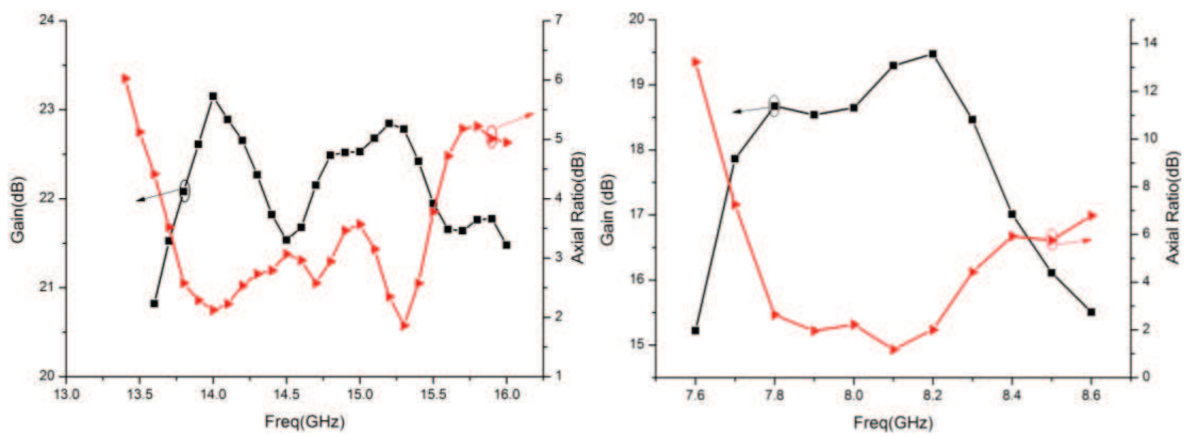
Figure 7. The simulated radiation pattern of two reflectarrays (a) at 14 GHz, (b) at 8 GHz.

in Fig. 8. At 14 GHz, the RHCP gain is 18 dB lower than the LHCP gain at the main beam direction, and the peak sidelobe level is −15.5 dB. At 8 GHz, the RHCP level is −17 dB below the peak LHCP gain in the broadside direction, and the peak sidelobe level is −13 dB. The gain and axial ratio of the reflectarray in the broadside direction at both bands are shown in Fig. 9. At higher band, the maximum gain is 23.1 dB; antenna efficiency is about 38.3% at 14 GHz; 3-dB axial ratio bandwidth is 16.3% (from 13.6 GHz to 16 GHz); 1-dB gain bandwidth is 4.2% (from 13.8 GHz to 14.4 GHz). At lower band, the



(a) (b)

Figure 8. The measured radiation pattern of proposed reflectarray (a) at 14 GHz, (b) at 8 GHz.



(a) (b)

Figure 9. Gain and axial ratio of the reflectarray (a) at higher band, (b) at lower band.

reflectarray has the maximum gain of 19.4 dB and obtains aperture efficiency of 41.8% at 8.2 GHz, and the 3-dB axial ratio bandwidth and 1-dB gain bandwidth are 6.3% (from 7.8 GHz to 8.3 GHz) and 7.5% (from 7.8 GHz to 8.4 GHz), respectively.

4. CONCLUSION

A dual-frequency single-layer circularly polarized reflectarray with FSS backing has been designed and analyzed in this paper. The proposed elements with FSS offer a good reflection and transmission at both frequencies, which greatly reduce the mutual effect between two bands. In addition, by adjusting the rotation angle of the cross dipole and FSS elements, the reflectarray can achieve good CP performance at both frequencies. The simulated and measured results demonstrate excellent performance of the proposed reflectarray.

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