Progress In Electromagnetics Research Letters, Vol. 26, 115–123, 2011

RCS REDUCTION FOR A FSS-BACKED REFLECTARRAY USING A RING ELEMENT

L.-S. Ren*, **Y.-C. Jiao, J.-J. Zhao, and F. Li**

National Laboratory of Antennas and Microwave Technology, Xidian University, Xi'an, Shaanxi 710071, P. R. China

Abstract—A novel RCS (radar cross section) reduction configuration for a reflectarray antenna, employing the appropriate FSS (frequency-selective surface) as a ground, is proposed. The performance of a reflectarray element backed either by a solid metal ground plane or a frequency-selective surface is compared. To optimize the performance of the designed frequency-selective surface, a parametric study is carried out using Ansoft HFSS. Then, a prime-focus FSS-backed reflectarray is fabricated and tested. The measurements demonstrate that the gain of a FSS-backed reflectarray is about 0.5 dB lower than its counterpart backed by a solid ground plane. The RCS is nearly the same at the operating band of 10 GHz, while out of this band the FSS-backed reflectarray reduces the RCS strongly, especially at 1 GHz with the reduction up to 20 dB. Compared with the RCS reductions obtained in the other papers, the FSS-backed reflectarray using a ring element can also obtain a good result.

1. INTRODUCTION

A microstrip reflectarray antenna is an attractive alternative to conventional parabolic reflectors for many communication applications. It has a number of advantages, such as low profile, mass, and volume; easy manufacturing process; and possibilities for beam shaping and electric beam control [1–3]. The most severe drawback for the reflectarray is its narrowband performance, and intense efforts have been made in recent years to overcome this shortcoming.

Elements with linear phase response can be used to improve the antenna bandwidth. Linearization of phase response may be done in several ways including using a thick substrate, multiple stacked

Received 12 July 2011, Accepted 29 August 2011, Scheduled 4 September 2011

* Corresponding author: Li-Shi Ren (renlishi007@126.com).

patches [4], and phase-delay lines [5], etc.. Many novel designs, e.g., microstrip elements composed of rectangular patch and rectangular ring [6], have been proposed for enhancing the reflectarray bandwidth.

The reduction of radar cross section (RCS) is of great interest from the point of view of enhancing the stealth performance of antennas in military applications [7, 8]. RCS reduction of reflectarray antennas is very useful in many applications, which plays an important role in the design of objects with reduced detectability, such as ships, aircrafts and so on. By taking a kind of dual-petal element reflectarray antenna as an example, a new method is presented to reduce its RCS. Compared with the RCS reductions obtained in these papers [10–12], our method can reduce the RCS so strongly out of the operating band that the RCS is lowered by 20 dB at 1 GHz.

In this paper, we demonstrate that a significant reduction in the RCS of a reflectarray antenna is possible when the solid conducting ground plane is replaced with a bandstop frequency-selective surface (FSS). Simulated results show that the reflection phase and amplitude of the two structures are similar when the FSS is designed to resonate at the centre operating frequency of the antenna. And also the measured radiation patterns of the reflectarray which employs the FSS as a ground at 10 GHz almost remain the same as its counterpart backed by a solid ground. The FSS-backed reflectarray reduces the RCS strongly out of the operation band, especially at 1 GHz, the RCS is lowered by 20 dB.

2. ELEMENT DESIGN

The dual-petal elements are operating around resonance with grid spacing of the order of 15 mm. Periodic boundary conditions are introduced to take into account interactions with the neighbor elements. In Figure 1, the dual-petal patches and FSS cells are printed on the substrates A and C with the relative permittivities of $\varepsilon_1 = 2.65$ and $\varepsilon_3 = 4.6$. B is a substrate of foam as a support substrate, $\varepsilon_2 = 1.07$. Based on the previous research, the structure parameters of the reflectarray element are chosen as follows: $H_1 = 2\,\mathrm{mm}$, $H_2 = 3\,\mathrm{mm}$, $H_3 = 2\,\mathrm{mm}$, $L_2 = L_1 * 0.66$ [9]. The elements are all separated with the same spacing in x- and y-directions. It is essential to note that the FSS-backed structure should be as reflective as possible in its operating band. Here, using the same period with the reflectarray top element, the period of the FSS is assumed 15 mm. The FSS element is a ring as shown in Figure 1. The sizes of the outer and inner rings are R_1 and R_2, respectively. The relation between R_1 and R_2 is assumed to be $R_2 = R_1 * K$. Then extensive numerical simulations were

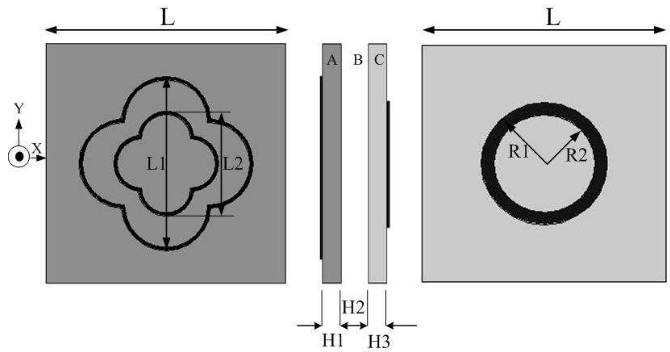


Figure 1. Geometries of the ring element of FSS and the top reflectarray element.

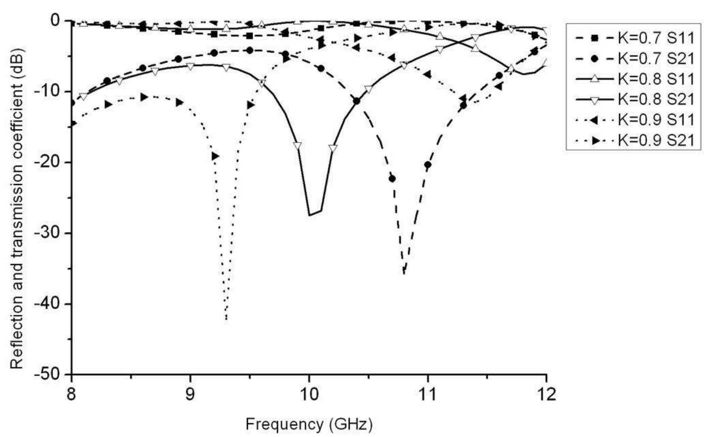


Figure 2. Reflection and transmission coefficients of the ring element of FSS with different K.

performed to optimize the FSS cell. Figure 2 shows the reflection and transmission coefficients of the FSS cell with different K. It can be concluded that when $R_1 = 3.88\,\mathrm{mm}$, $R_2 = 3.1\,\mathrm{mm}$ and $K = 0.8$, the reflection coefficient presents a maximum and the transmission coefficient a minimum at the target frequency of 10 GHz, which means that the FSS scatters the beam only at the desired frequency, but is transparent to other frequencies.

Compared with the ring element of FSS in Figure 1, this reflectarray element with different types of FSS elements are also analyzed. Geometries of the split-ring and C-ring are shown

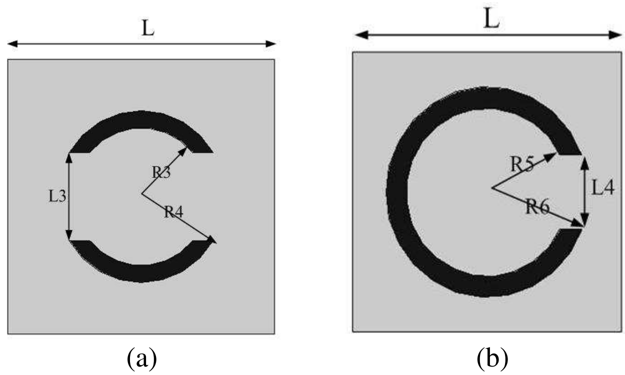


Figure 3. Geometries of (a) the split-ring and (b) C-ring.

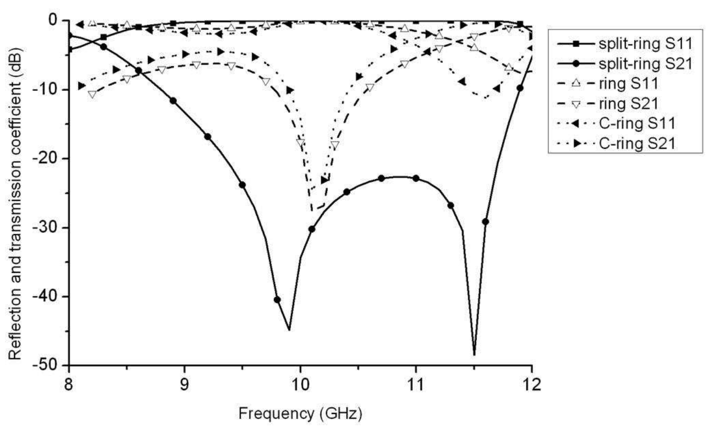
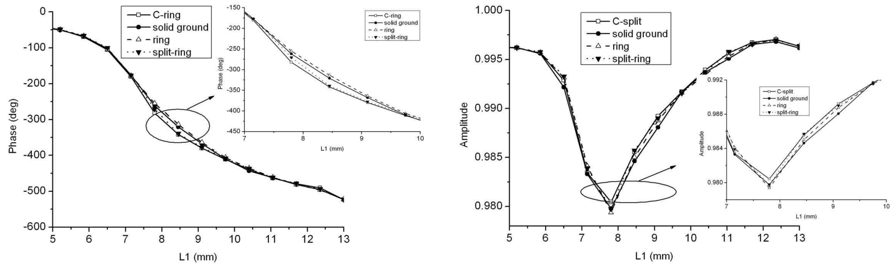


Figure 4. Reflection and transmission coefficients of the three types of FSS elements.

in Figure 3. Several important parameters of the cell element are investigated using the Ansoft HFSS software. The structure parameters are chosen as follows: $L = 15\,\text{mm}$, $R_3 = R_4 * 0.8$, $R_4 = 4.7\,\text{mm}$, $L_3 = 4.8\,\text{mm}$, $R_6 = 5.64\,\text{mm}$, $R_5 = R_6 * 0.8$ and $L_4 = 4\,\text{mm}$. Figure 4 illustrates the reflection and transmission coefficients of the three types of FSS elements. It can be noticed that the reflection coefficients are all at maximum and the transmission coefficients are at minimum at the target frequency of 10 GHz. The computed reflection phases and amplitudes of the three types of FSS elements at normal incidence are shown in Figure 5. It can be concluded that the phase and amplitude of the ring element keep nearly the same when the FSS



(a) (b)

Figure 5. (a) Phase and (b) amplitude of the reflectarray element with the three types of FSS elements.

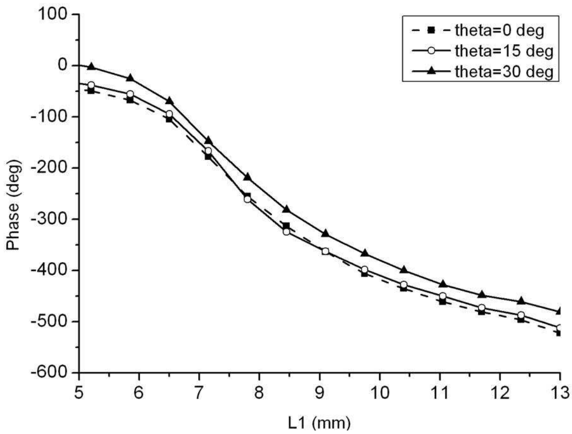
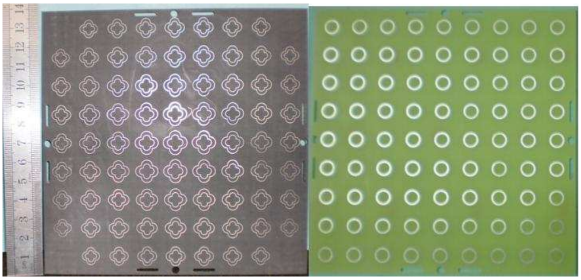


Figure 6. Phase responses of reflectarray element with FSS ground for different angles of incidence.

ground is replaced by a solid ground plane at the operating frequency of 10 GHz. But when the FSS ground is split-ring or C-ring FSS element, there are some differences between the two types of FSS elements and solid ground. To keep the 'in-band' performance unchanged and reduce the 'out-of-band' RCS effectively. So the best FSS element is the ring as shown in Figure 1. Figure 6 describes phase shifts of this reflectarray element with the ring cell of FSS under oblique incidence. The minor discrepancies between the curves indicate that the effect of the oblique incidence on the reflected phase is small. In fact, the dimensions of the patch can be adjusted to achieve the required phase shifts for the minor discrepancies between the curves.

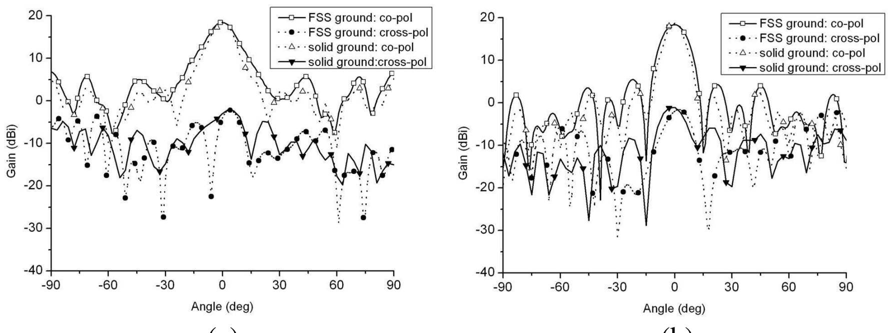
3. ARRAY REALIZATION

In order to validate the phase data of the elements, we design a prime-focus reflectarray operating at 10 GHz, which is composed of the reflectarray and FSS-backed structure. Its photograph is shown in Figure 7, where Figure 7(a) is the top surface composed of 77 dual-petal elements, Figure 7(b) is the bottom surface composed of 81 ring elements with the same parameters described in the element configuration. Here, both the size and focal distance of the considered array are 140 mm, thus giving a ratio equal to 1. Since a horn would seriously block the reflected wave from the reflectarray, a Vivaldi antenna is chosen as the feed. Considering the radiation pattern of the feed and the configuration of the reflectarray, the illumination levels near the centers of four borders are all about -5 dB. Moreover, the



(a) (b)

Figure 7. Photograph of the designed 77-element reflectarray and 81-element FSS ground.



(a) (b)

Figure 8. Measured radiation patterns for the reflectarray with FSS ground. (a) E-plane. (b) H-plane.

cross-polarization level in the broadside direction is 28 dB below the peak gain. The sidelobe levels are 14 dB down from the main beam.

Compared with its counterpart backed by a solid ground plane, the measured radiation patterns of the reflectarray with FSS ground at 10 GHz for both E- and H-planes are presented in Figure 8. The half-power beamwidths in E- and H-planes are about 14° and 12°, respectively. The cross-polarization gain is 23 dB below the peak gain in the broadside direction. The sidelobe levels are 14 dB down from the main beam. The gain of a FSS-backed reflectarray is about 0.5 dB lower than its counterpart backed by a solid ground plane. The minor difference in the gain value for both E- and H-planes demonstrates the effect of the FSS-backing on the antenna performance. In other words, the FSS-backing very closely emulates ground plane in the operating band. The maximum gain is 18.7 dBi at 10 GHz. The antenna efficiency, calculated by comparing the measured copolarized gain to the directivity based on the physical aperture area, is about 35% at 10 GHz. Also, some factors, such as random phase errors, blockages of the feed, primary feed losses, losses in the substrate, and nonuniform illumination across the aperture, may reduce the antenna efficiency. And also, the proposed type of reflectarray element may also result in the low antenna efficiency. Figure 9 displays the simulated RCS of the two as a function of frequency for normal incidence, and it is a representative of the overall performance for a whole range of angles of incidence. As observed, the RCS is nearly the same at the operating band of 10 GHz, while out of this band FSS-backed reflectarray reduces the RCS strongly, especially at 1 GHz with the reduction up to 20 dB.

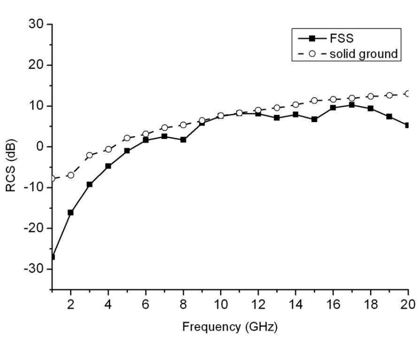


Figure 9. Comparison of simulated RCS of two reflectarrays with solid ground and FSS ground.

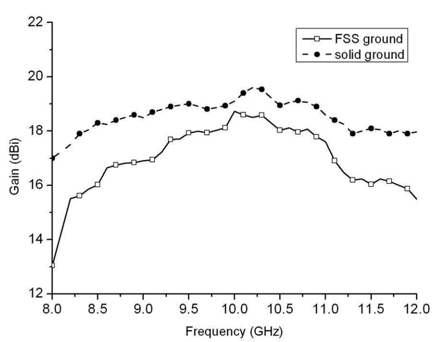


Figure 10. Measured gain versus frequency.

Figure 10 depicts the measured gain bandwidth of the two reflectarrays. The gain of a FSS-backed reflectarray is about 0.5 dB lower than its counterpart backed by a solid ground plane at 10 GHz. It also can be observed that the 1-dB gain bandwidth of the FSS-backed reflectarray is 17% (9.3–11 GHz), which has a moderate discrepancy compared to the original antenna (25%, 8.7–11.2 GHz).

4. CONCLUSION

A novel low RCS microstrip reflectarray is presented. This is accomplished by using an appropriate FSS that replaces the ground plane. Compared with the three types of FSS elements and the RCS reduction obtained in the other papers, we select a proper one. A reflectarray prototype is designed and measured to demonstrate this concept. It gives nearly the same performance as the conventional reflectarray at the operating frequency. The RCS characteristics of the proposed reflectarray are also studied and compared with the conventional reflectarray with a solid ground. It is shown that by using a FSS as a ground plane, the RCS of the reflectarray can be significantly reduced in a wide frequency band.

REFERENCES

1. Zubir, F., M. K. A. Rahim, O. B. Ayop, and H. A. Majid, "Design and analysis of microstrip reflectarray antenna with Minkowski shape radiation element," *Progress In Electromagnetics Research B*, Vol. 24, 317–331, 2010.
2. Tahir, F. A., H. Aubert, and E. Girard, "Equivalent electrical circuit for designing MEMS-controlled reflectarray phase shifters," *Progress In Electromagnetics Research*, Vol. 100, 1–12, 2010.
3. Li, H., B.-Z. Wang, and W. Shao, "Novel broadband reflectarray antenna with compound-cross-loop elements for millimeter-wave application," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 10, 1333–1340, 2007.
4. Encinar, J. A. and J. A. Zornoza, "Broadband design of three-layer printed reflectarrays," *IEEE Trans. Antennas Propag.*, Vol. 51, No. 7, 1662–1664, Jul. 2003.
5. Hasani, H., M. Kamyab, and A. Mirkamali, "Broadband reflectarray antenna incorporating disk elements with attached phase-delay lines," *IEEE Antennas Wireless Propag. Lett.*, Vol. 9, 156–158, 2010.

6. Li, Q. Y., Y. C. Jiao, and G. Zhao, "A novel microstrip rectangular patch/ring-combination reflectarray element and its application," *IEEE Antennas Wireless Propag. Lett.*, Vol. 8, 1119–1122, 2009.
7. Euler, M. and V. F. Fusco, "RCS control using cascaded circularly polarized frequency selective surfaces and an AMC structure as a switchable twist polarizer," *Microwave Opt. Technol. Lett.*, Vol. 52, 577–580, 2010.
8. White, M. O., "Radar cross-section: Measurement, prediction and control," *Electron. Commun. Eng. J.*, Vol. 10, 169–180, 1998.
9. Ren, L.-S., Y.-C. Jiao, F. Li, J.-J. Zhao, and G. Zhao, "A novel dual-petal loop element for broadband reflectarray," *Progress In Electromagnetics Research Letters*, Vol. 20, 157–163, 2011.
10. Misran, N., R. Cahill, and V. F. Fusco, "RCS reduction technique for reflectarray antennas," *Electronics Lett.*, Vol. 39, 1630–1631, 2003.
11. Li, H., B.-Z. Wang, G. Zheng, W. Shao, and L. Guo, "A reflectarray antenna backed on FSS for low RCS and high radiation performances," *Progress In Electromagnetics Research C*, Vol. 15, 145–155, 2010.
12. Li, L., Q. Chen, Q.-W. Yuan, K. Sawaya, T. Maruyama, T. Furuno, and S. Uebayashi, "Frequency selective reflectarray using crossed-dipole elements with square loops for wireless communication applications," *IEEE Trans. Antennas Propag.*, Vol. 59, 89–99, 2011.