Progress In Electromagnetics Research Letters, Vol. 47, 119–124, 2014

A Reflectarray Based on the Folded SIR Patch-Slot Configuration Backed on FSS for Low RCS

Mohammad M. Fakharian*, Pejman Rezaei, and Ali A. Orouji

Abstract—In this letter, a reflectarray antenna based on the folded stepped impedance resonator (SIR) patch-slot configuration with variable size is presented. A novel frequency selective surface (FSS) in the reflectarray as a ground plane for reducing radar cross section (RCS) level is applied. The FSS is based on the folded SIR configuration. Two prime-focus 15×15 reflectarray antennas backed on the folded SIR FSS ground and a conventional ground are designed and manufactured. The radiation performance of a reflectarray element backed either by a solid ground plane or a band-stop FSS structure is compared. The measured results demonstrate that the radiation pattern and gain of the FSS-backed reflectarray are almost same to its counterpart backed by a conventional ground plane at the operating band of 11.5 GHz. The RCS is effectively reduced in the out of this band when compared with the reflectarray with a solid metal ground plane of the same dimension.

1. INTRODUCTION

A reflectarray antenna is an attractive alternative to conventional parabolic reflectors with the best features of phased array antennas and reflector antennas. It has a number of advantages, such as flat, light weight, low volume, low cost, high gain, and possibilities for beam shaping and electric beam control [1, 2]. However, it is well known that the use of high-gain antennas on military platforms increases radar cross section (RCS) levels and platform detectability. So, RCS reduction of reflectarray is very useful in many applications, which plays an important role in the design of objects with reduced detectability, such as aircrafts, ships, and so on.

There are common methods for RCS reduction, including coating with radar absorbing materials [3], employing passive and active cancellation technology [4, 5], antenna shaping [6], and using frequency selective surfaces (FSS) [7–10] as the reflector. The use of an FSS ground plane based on the folded stepped impedance resonator (SIR) configuration is considered in this study. Compared with the previous works, our method can reduce the RCS so strongly the out-of-band and the antenna radiation performances are almost same in the inner-of-band when the solid conducting ground plane is replaced with a band-stop FSS.

On the other hand, several reflectarray approaches are presented to control the phase characteristic of them in the literature. For example, the using identical microstrip patches with different-length phase-delay lines, variable-size patches, dipoles, or rings have been proposed over the last decade [11, 12]. To overcome the shortcoming of narrow bandwidth of the reflectarrays, multi-layer reflectarrays using variable patch size are also being developed [13]. Indeed, the elements with linear phase response can be used to improve the antenna bandwidth.

In this letter, two 15×15 reflectarray antennas based on the folded SIR patch-slot configuration backed on a band-stop FSS and a conducting ground plane are designed and fabricated. The element is capable of presenting an almost linear behavior and a phase range that well exceeds 400° for a broadband reflectarray design. Simulated results show that the reflection phase of the two structures is

---

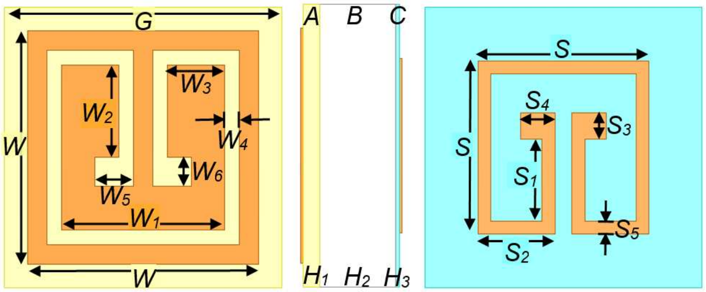
Received 18 June 2014, Accepted 29 July 2014, Scheduled 7 August 2014

* Corresponding author: Mohammad M. Fakharian (m_fakharian@sun.semnan.ac.ir).
The authors are with the Faculty of Electrical and Computer Engineering, Semnan University, Semnan, Iran.

similar when the FSS is designed to resonate at the centre operating frequency of the antenna. And also the measured patterns of the reflectarray which employs the FSS as a ground at 11.5 GHz almost remain the same as its complement backed by a solid metal ground. The FSS-backed reflectarray reduces the RCS strongly out of the operation band, especially at 19 GHz, the RCS is lowered more than 13 dB.

2. DESIGN OF THE PROPOSED REFLECTARRAY ELEMENT

The novel element based on the folded SIR patch-slot configuration is shown in Fig. 1. The phasing element is operating around resonance with grid spacing of the order of 0.5 wavelengths (λ). Periodic boundary conditions with the full wave electromagnetic software Ansoft HFSS are applied to take into account interactions with the neighbour elements. As shown in Fig. 1, the patches and FSS cells are printed on the substrates A and C with the relative permittivities of $\varepsilon_1 = 3.55$ and $\varepsilon_3 = 2.2$, respectively. Substrate B is a foam as a support substrate, $\varepsilon_2 = 1.07$. Based on the parametric study, the structure parameters of the reflectarray element are chosen as follows: $G = 13\,\mathrm{mm}$, $H_1 = 0.8\,\mathrm{mm}$, $H_2 = 3.5\,\mathrm{mm}$, $H_3 = 0.13\,\mathrm{mm}$, $W_1 = W \times 0.85$, $W_2 = W \times 0.4$, $W_3 = W \times 0.25$, $W_4 = W \times 0.06$, $W_5 = W \times 0.17$, and $W_6 = W \times 0.12$. The elements are all separated with the same spacing of G 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 $0.5\,\lambda$. The FSS element is a folded SIR as shown in Fig. 1(c).



(a) (b)

Figure 1. Configuration of (a) the top view, (b) the side view, and (c) the back view of the proposed reflectarray element on the folded SIR element of FSS.

The sizes of folded SIR are $S = 8\,\mathrm{mm}$, $S_1 = 3.8\,\mathrm{mm}$, $S_2 = 3.6\,\mathrm{mm}$, $S_3 = 1.2\,\mathrm{mm}$, $S_4 = 1.6\,\mathrm{mm}$, and $S_5 = 0.6\,\mathrm{mm}$. Numerical simulations are performed to optimize the FSS cell. Fig. 2 shows the reflection and transmission coefficients of the FSS cell. It can be seen that the reflection coefficient presents a maximum and the transmission coefficient a minimum at the target frequency, which means that the FSS scatters the beam only at the desired frequency, but is transparent to other frequencies.

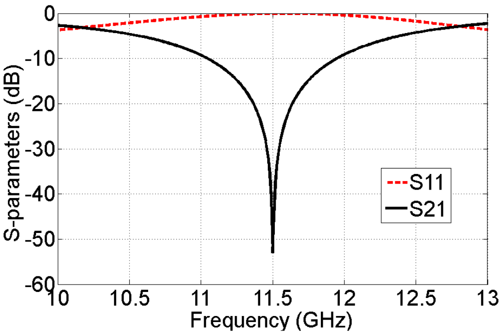


Figure 2. Reflection and transmission coefficients of the folded SIR element of FSS.

Figure 3(a) describes phase shifts versus W of this reflectarray element with the folded SIR cell of FSS-backed under normal incidence and compared with solid ground plane at frequency of 11 GHz. Based on the results presented in this figure, by simple adjustment of the elements size, we obtain a phase variation in the range of around 400° and quasi-linear reflection phase variation with element size, which could help to expand the bandwidth.

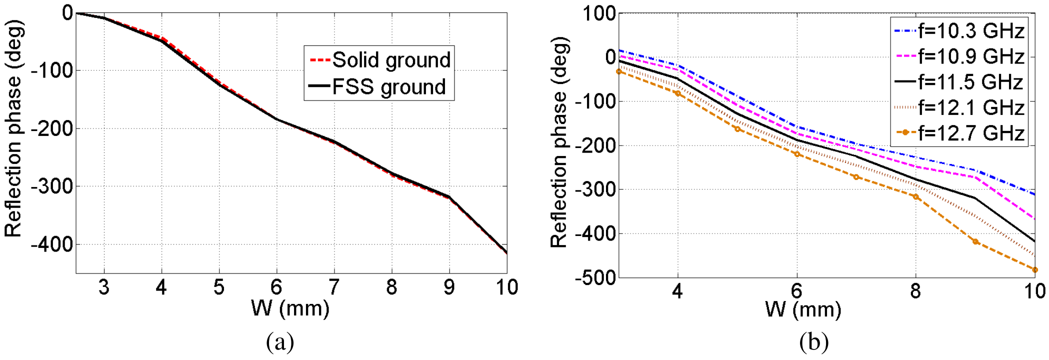


Figure 3. (a) Comparison of reflection phase response versus width W at $f = 11.5$ GHz for solid and FSS grounds and (b) reflection phase response versus width W for different frequencies.

The phase of reflected wave against width W over a frequency range of 10.3, 10.9, 11.5, 12.1, and 12.7 GHz for the proposed reflectarray element with the mentioned parameters is shown in Fig. 3(b). As shown in this figure, it can be observed that the phase curves are approximately parallel. This is the required property for the phase characteristic of reflectarray having broad bandwidth.

The reflection phase for the folded SIR, conventional square patch, and loop elements are shown in Fig. 4. Note that the folded SIR element obtained wider phase ranges than its square- and loop-patch counterparts with approximately 250° and 172° of additional phase variation, respectively. The folded SIR element had a wider phase range, due to its larger inductance compared to the loop and square patches, while they had nearly identical gap capacitances. This property led to greater phase variation for the case of the folded SIR element, for the same element-size variation in the three elements.

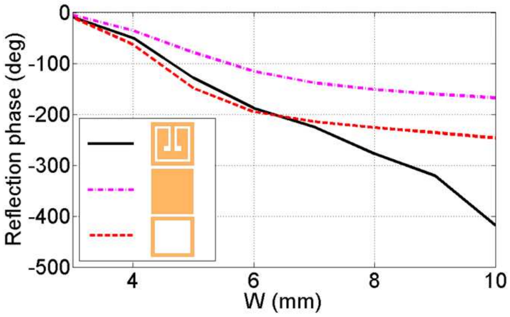


Figure 4. The reflection phases for the folded SIR, square and loop elements at 11.5 GHz.

3. RESULTS AND DISCUSSIONS

In order to examine the validation of replacing the solid metal ground with the proposed FSS structure, two 15 × 15 reflectarrays are carefully manufactured. The reflectarrays are centre fed by a linearly-polarized horn located at a distance $F = 19.5$ cm $(F/D = 1)$ in the normal direction of the array plane. The photograph of proposed reflectarrays is shown in Fig. 5 in which the top surface composed of 225 reflectarray elements, and the bottom surface composed of 225 folded SIR FSS elements with the same parameters described in the element configuration.

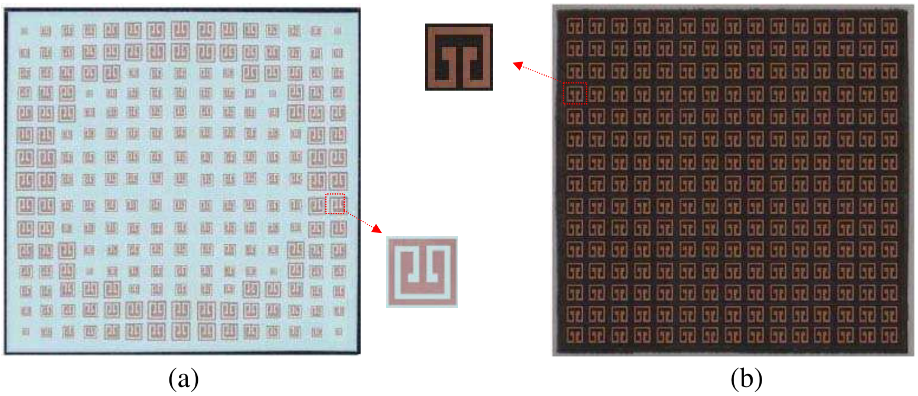
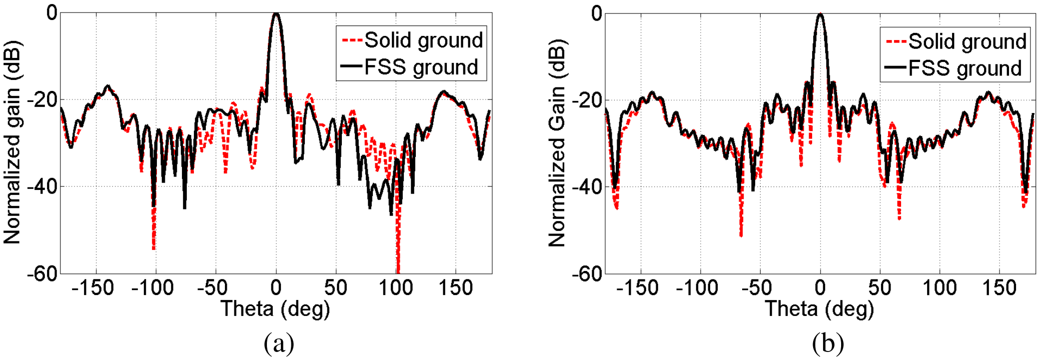

(a) (b)

Figure 5. The photograph of the 15 × 15 proposed reflectarray, (a) top surface and (b) bottom surface.



(a) (b)

Figure 6. Measured radiation patterns of two reflectarray antennas (a) *E*-plane and (b) *H*-plane.

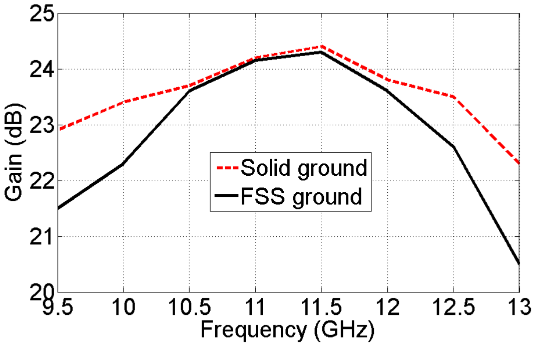


Figure 7. Measured gain versus frequency of two reflectarrays with solid and FSS grounds.

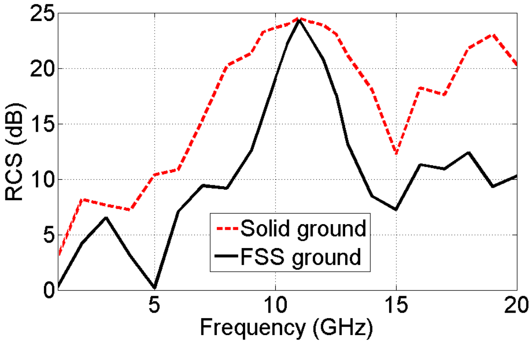


Figure 8. Comparison of simulated RCS of two reflectarrays with solid and FSS grounds.

The radiation patterns are measured at 11.5 GHz which is in the stop-band of the proposed FSS structure. Fig. 6 shows the comparison of the measured radiation patterns of two reflectarrays with solid and FSS grounds. Due to the slot design of antenna ground, some energy radiates in the backward direction. Therefore, the back lobe of the reflectarray with FSS ground increases by about 0.91 dB compared to the original antenna. However, the 3 dB beamwidth of the reflectarray with FSS ground increases from 6.5° to 6.7°, and the sidelobe level also decreases by about 3.4 dB. The gain of a FSS-backed reflectarray is about 0.1 dB lower than its counterpart backed by a solid ground plane.

In addition, Fig. 7 depicts the measured gain bandwidth of the two reflectarrays. It can be observed that the 1-dB gain bandwidth of the reflectarray backed on FSS is 17% (10.3–12.2 GHz), which has a moderate discrepancy compared to the original antenna 23% (10–12.6 GHz). However, the peak gain are slightly reduced for the reflectarray designed in the presence of the FSS ground, which resulted in almost same gain through the frequency band than out-of-band.

Figure 8 shows the simulated RCS of the two as a function of frequency for normal incidence. As observed, the RCS is negligibly reduced at the operating band of 11.5 GHz, while out of this band FSS-backed reflectarray reduces the RCS strongly, especially at 19 GHz with the reduction up to 13 dB. For the 'in-band' frequencies, the FSS works almost as a solid ground, and the RCS level decreases slightly.

4. CONCLUSION

A novel element has been analyzed to design a broadband microstrip reflectarray antenna. Element phase response shows an almost linear behavior within a wide range of frequency band. The integration of novel FSS into the reflectarray for low RCS has been shown and validated with measurement. This is accomplished by using an FSS based on the folded SIR configuration that replaces the ground plane. 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.

ACKNOWLEDGMENT

This work has been financially supported by the Office of Brilliant Talents at the Semnan University. The authors would like to thank all the members of the Antenna Laboratory at Iran Telecommunication Research Center (ITRC), for their cooperation.

REFERENCES

1. Huang, L. and J. A. Encinar, *Reflectarray Antennas*, John Wiley and Sons, Inc., Hoboken, NJ, USA, 2007.
2. Carrasco, E., M. Barba, J. A. Encinar, and M. Arrebola, "Design, manufacture and test of a low-cost shaped-beam reflectarray using a single layer of varying-sized printed dipoles," *IEEE Transactions on Antennas and Propagation*, Vol. 61, 3077–3085, 2013.
3. Fakharian, M. M. and P. Rezaei, "Numerical analysis of mushroom-like and uniplanar EBG structures utilizing spin sprayed Ni (-Zn) -Co ferrite films for planar antenna," *European Journal of Scientific Research*, Vol. 73, No. 1, 41–51, 2012.
4. Zheng, Q.-R., Y.-M. Yan, X.-Y. Cao, and N.-C. Yuan, "Hign impedance ground plane (HIGP) incorporated with resistance for radar cross section (RCS) reduction of antenna," *Progress In Electromagnetics Research*, Vol. 84, 307–319, 2008.
5. Fakharian, M. M., P. Rezaei, and A. A. Orouji, "Microstip antenna with a reconfigurable Dumbbell-shaped defected ground plane for DCS-1800 and PCS-1900," *International Symposium on Antennas and Propagation Society (APSURSI)*, 576–577, 2013.
6. Fakharian, M. M. and P Rezaei, "Parametric study of UC-PBG structure in terms of simultaneous AMC and EBG properties and its applications in proximity-coupled fractal patch antenna," *International Journal of Engineering-Transactions A: Basics*, Vol. 25, No. 4, 347–354, 2012.
7. Fakharian, M. M., "Multiple fork-like EBG structure and its analysis as artificial magnetic conductor," *6th European Conference on Antennas and Propagation (EUCAP)*, 1–4, 2012.
8. Misran, N., R. Cahill, and V. F. Fusco, "RCS reduction technique for reflectarray antennas," *Electron. Letters*, Vol. 39, 1630–1631, 2003.
9. 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.

10. Ren, L.-S., Y.-C. Jiao, J.-J. Zhao, and F. Li, "RCS reduction for a FSS-backed reflectarray using a ring element," *Progress In Electromagnetics Research Letters*, Vol. 26, 115–123, 2011.
11. Wang, Q., Z. Shao, P. Li, L. Li, and Y. Cheng, "A dual polarization, broadband, millimeter-wave reflectarray using modified cross loop element," *Microwave and Optical Technology Letters*, Vol. 56, No. 2, 287–293, 2014.
12. Zhao, M.-Y., G.-Q. Zhang, X. Lei, and J.-M. Wu, "Design of new single-layer multiple-resonance broadband circularly polarized reflectarrays," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 356–359, 2013.
13. Radi, Y., S. Nikmehr, and A. Pourziad, "A novel bandwidth enhancement technique for X-band RF MEMS actuated reconfigurable reflectarray," *Progress In Electromagnetics Research*, Vol. 111, 179–196, 2011.