In-band and Out-of-band RCS Reduction of a Patch Antenna Using Anisotropic Unit Cell

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***Abstract*—In this paper, both in-band and out-of-band radar cross section (RCS) reduction as well as gain enhancement of a conventional probe-fed microstrip patch antenna around 10 GHz is presented. Anisotropic unit cell which has 180°±27° phase difference between its x- and y-polarized reflected components is used and arranged in a chessboard-like surface. The central part of the chessboard surface is replaced by the microstrip patch antenna. The simulated results show that the proposed antenna possesses remarkable in-band and out-band monostatic RCS reduction from 9 GHz to 16 GHz (60%). The RCS reduction is more than 5dB with maximum RCS reduction is about 24dB for normally impinging both x- and y-polarized waves. Furthermore, the radiation characteristics of the antenna have been well kept and the antenna gain is improved by about 1.16dB. The proposed antenna is being fabricated now the measured results will be presented during the conference.**

***Index Terms*—Microstrip antenna, radar cross section reduction, chessboard, metasurface.**

I. INTRODUCTION

RADAR cross section (RCS) reduction of metallic objects and antennas using metasurface attracts much attention in recent years [1]-[2]. Because of its small volume, low fabrication cost, low profile, light weight, and ease of integration with other RF/microwave components, microstrip patch antennas have extensively been used in wireless communication systems for both military and commercial applications. However, microstrip patch antenna is one of the scattering sources in any communication system and contributes to the over all RCS of the system and highly affects the stealth characteristics of a platform. Several techniques have been introduced so far to improve the scattering characteristics and reduce antenna radar cross section. In [1] the RCS reduction of a patch antenna was achieved by using loading metamaterial technique. In [3] RCS reduction of a 2×2 slot array antenna is achieved by using holographic metamaterial.

In this paper, in-band and out-of-band RCS reduction of a conventional microstrip patch antenna with gain enhancement is presented. The mechanism of the RCS reduction and gain enhancement are analyzed in details. The in-band and out-of-band monostatic RCS reduction is achieved for normally impinging both x- and y-polarized EM-waves using a ultrathin metasurface composed by anisotropic unit cell. The radiation characteristics (such as S_{11}, E- and H-plane radiation patterns, realized gain…etc) of the microstrip patch antenna are well preserved at the design frequency.

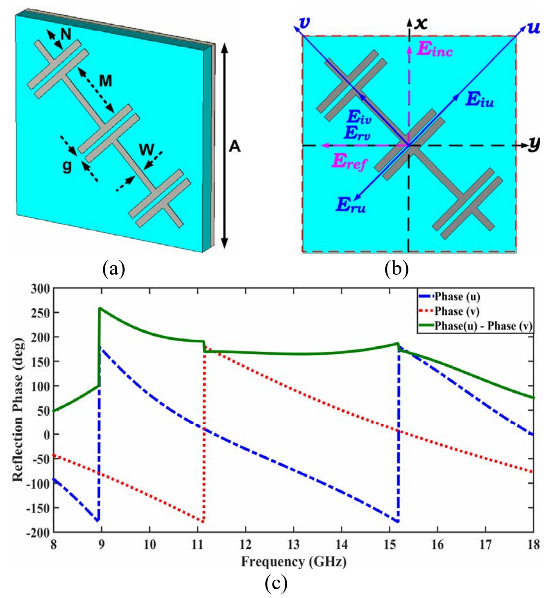

Fig. 1. Layout of the (a) anisotropic unit cell: M=3.5 mm, A=9.1 mm, g=0.2 mm, W=0.2 mm, N=0.4 mm, thickness=3.04 mm, and ε_r=3.38 and. (b) Incident and reflected field components. (c) Reflection phase characteristics of the unit cell.

II. UNIT CELL DESIGN

The geometry of the proposed anisotropic unit cell is shown in Fig.1. The unit cell has a sub-wavelength size of $0.27\lambda_{9GHz}$, $0.39\lambda_{13GHz}$, $0.48\lambda_{16GHz}$. The optimized dimensions of the anisotropic unit cell are depicted in the caption of Fig.1. The unit cell has a copper resonator of "capacitor symbol" shape on the upper side of a PEC backed dielectric material. The relative permittivity and thickness of the dielectric substrate are ε_r=3.38 and 3.04 mm, respectively. The full numerical simulations have been performed using the Frequency solver of CST Microwave Studio to obtain the reflection phase characteristics of the proposed unit cell. The incident and reflected field components are presented in Fig.1 (b). The reflection phase versus frequency curves of E_{rv} and E_{ru} which are named as Phase (v) and Phase (v), respectively, are illustrated in Fig.1 (c). As can be seen the phase is continuous and varies from +180° to –180°. The phase difference versus frequency curve is also presented in Fig.1 (c). It can be seen that the phase difference (Phase (u) – Phase (v)) of the unit cell is in the range 180°±27° from 10 GHz

III. RCS REDUCTION INVESTIGATION

RCS reducer surfaces based on the proposed unit cell as "0"

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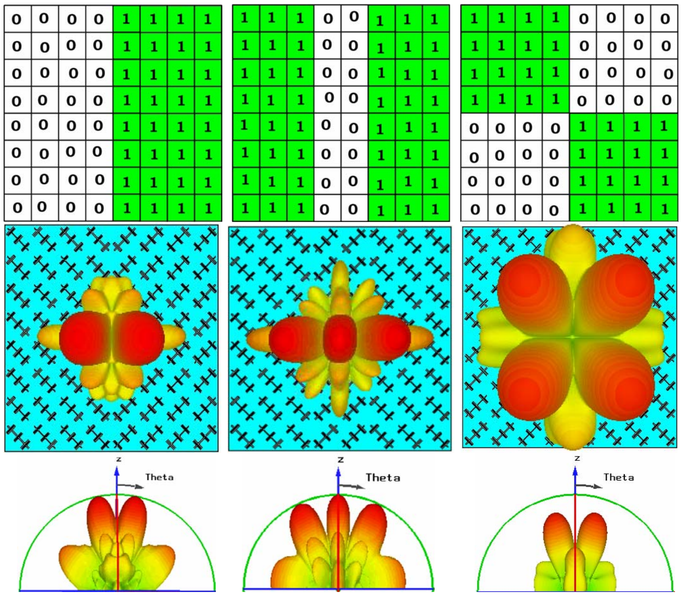
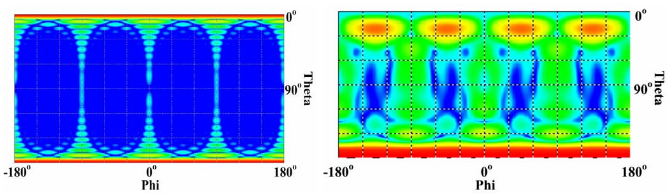


(a) (b) (c)

Fig. 2. Layout of the RCS reducer surfaces and their scattering patterns. (a) two beams, (b) three beams, and (c) four beams (chessboard-like surface).



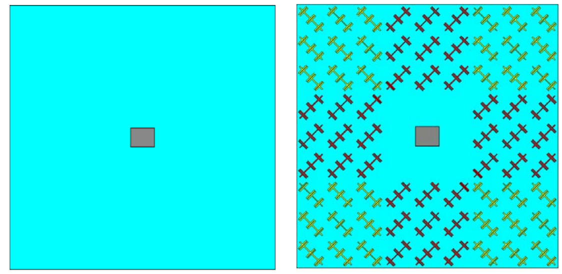
(a) (b)

Fig. 3. 2D field distribution on front of (a) bare PEC plate and (b) Surface#4.

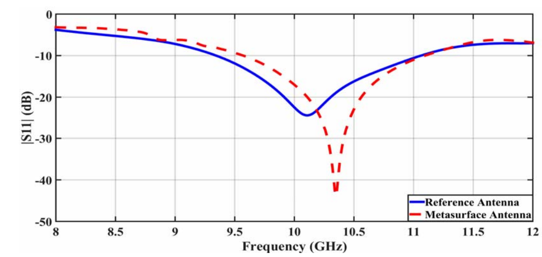
to 16 GHz. This phase difference is a result of the anisotropic geometry of the unit cell with respect to x- and y-axis.

element and its mirrored unit cell as “1” element are constructed as shown in Fig.2. As the unit cell has a phase difference of about 180°±27° between its u- and v-axis, using the unit cell and its mirrored one in one surface can ensure the required phase difference across the surface aperture for passive cancellation and RCS reduction. As can be seen in Fig.2, various kinds of backscattered RCS patterns (2-beams, 3-beams, and 4-beams) are achieved based on the arrangement of the unit cells. All surfaces have the same dimensions of 81.8×81.9 mm^2. In Fig.2 (c) the backscattered RCS Patterns takes the form of 4-beams with significant RCS reduction near z-axis in the boresight direction. The reflected energy is directed as four-lobes along the diagonals. The 2D field distribution of the backscattered energy is presented in Fig.2 for both a bare PEC plate and a chessboard-like surface.

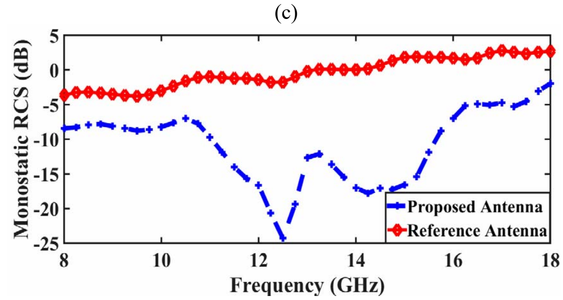
The RCS reduction of a probe-fed patch antenna is achieved by inserting the patch antenna at the central part of the chessboard-like surface as shown in Fig.4. As both the patch antenna and the metallic resonators are etched on the same surface, some space is left around the patch antenna to reduce the unwanted coupling between them. The width and length of the patch antenna are 7.4mm and 6mm, respectively. Simulated S_{11} of both the reference antenna and the proposed antenna in Fig.4 (a) and (b) is given in Fig.4 (c) and the resonance frequencies of both antennas are very close to each other. However, the resonance frequency of the proposed antenna is



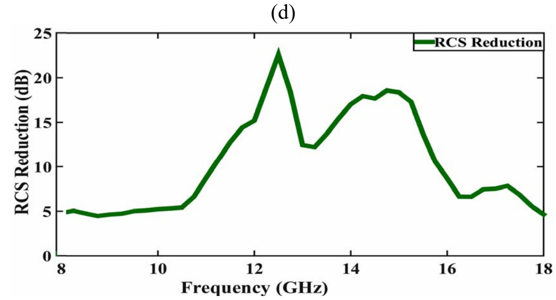
(a) Reference Antenna (b) Proposed Antenna



(c)



(d)



(e)

Fig. 4. (a) and (b) are the layout of the reference and proposed antennas and (c) is their $|S_{11}|$. (d) Computed monostatic RCS curves. (e) RCS reduction versus frequency curve.

shifted a little bit as a result of the coupling and the radiation characteristics of the antenna is preserved. It has noticed that the gain of the patch antenna is improved by about 1.16 dB.

The monostatic RCS response curves of the reference antenna and the proposed antenna are computed using the T-solver of CST Microwave Studio and presented in Fig.4 (d). It can be seen that a remarkable monostatic RCS reduction is obtained from about 9 GHz to 16 GHz which includes both in-band and out-of-band frequencies. It’s important here to mention that the in-band monostatic RCS reduction is more than 5dB and the maximum RCS reduction is about 24.2dB around 12 GHz as shown in Fig.4 (e). The presented idea is extended to RCS reduction of a 2×2 microstrip antenna array as shown in Fig.5. The configuration of the proposed design shows that all antennas are inserted at the center of the chessboard-like surface and the radiation patches surrounded by the anisotropic unit cells. The traditional 2×2 microstrip antenna array is regarded as the reference antenna array. As the insertion of the radiating patches will not affect their radiation characteristics as

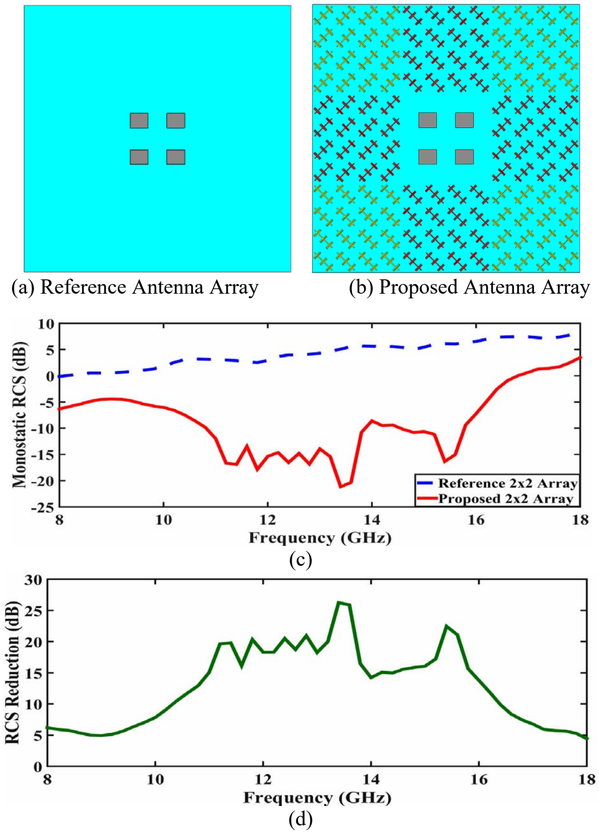


Fig. 5. (a) and (b) are the layout of the reference and proposed antennas and (c) Computed monostatic RCS curves. (d) RCS reduction versus frequency curve.

shown previously, here only the monostatic RCS reduction performance is investigated for brevity. The distance between any adjacent antennas is about λ/2 and the total dimension of the antenna array is 109.2×109.2 mm^2. The computed monostatic RCS of both the reference antenna array and the proposed one is presented in Fig.5 (c) and (d) with normally impinging plane wave. It can be seen that the monostatic RCS of the proposed array is obliviously lower than that of the reference one and the RCS reduction is more than 5dB from about 8.5 GHz to 16 GHz with maximum reduction of 26 dB at about 13.8 GHz. The 3D plots of the scattered field of the single antenna and the antenna array are illustrated in Fig.6. It can be seen that the proposed antennas have lower RCS compared to that of the reference antennas as the backscattered energy along the boresight is reduced and redirected to other directions.

IV. Conclusion

Monostatic RCS reduction with radiation characteristics preservation of a single patch antenna and a 2×2 microstrip antenna array are presented in this article. The scattered energy is redirected to various angles with low-level and the radiation characteristics are persevered.

Acknowledgement

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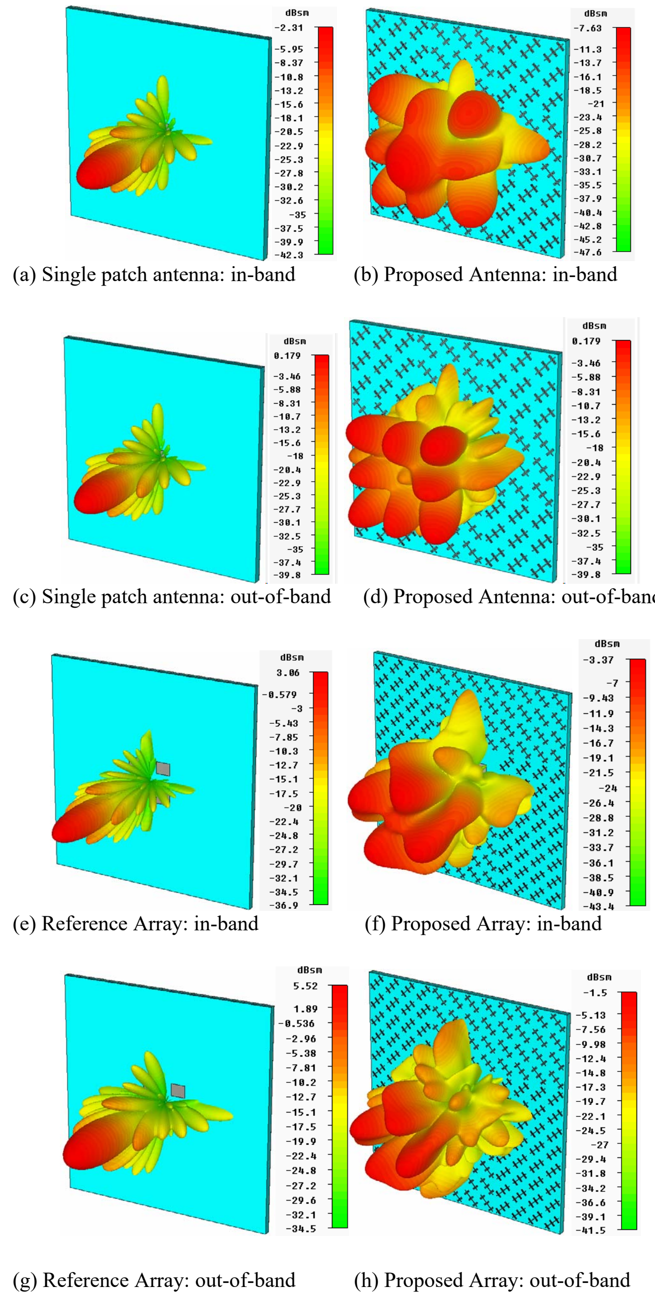

Fig. 6. 3D RCS patterns of the reference and proposed antennas.

References

[1] Y. Zheng *et al*., “Metamaterial-based Patch Antenna With Wideband RCS Reduction And Gain Enhancement Using Improved Loading Method,” *IET Microwaves, Antennas & Propagation*, vol. 11, no. 9, pp. 1183-1189, 2017.

[2] Y. Liu, K. Li, Y. Jia, Y. Hao, S. Gong and Y. J. Guo, “Wideband RCS Reduction of a Slot Array Antenna Using Polarization Conversion Metasurfaces, ” *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 1, pp. 326-331, 2016.

[3] Y. Liu, et al., “Wideband and Polarization-Independent Radar Cross Section Reduction Using Holographic Metasurface, ” *IEEE Antennas Wireless. Propagation Letters*, vol. 15, pp. 1028–1031, 2016.

[4] X. Kang, J. Su, H. Zhang, Z. Li and Y. Yang, “Ultra-Wideband RCS Reduction of Microstrip Antenna Array By Optimised Multi-Element Metasurface, ” *Electronics Letters*, vol. 53, no. 8, pp. 520-522, 2017.