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Ultra-Wideband radar cross section reduction by thin AMC metasurface

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***Abstract-* An ultra-wideband thin metasurface is designed and fabricated to reduce the radar cross-section (RCS) from 9.72 GHz to 26.77 GHz (93% bandwidth) more than 10 dB. The proposed metasurface is composed of two different artificial magnetic conductor (AMC) tiles with about 180° reflection phase differences to destruct the reflected wave over ultra-wideband frequency. Although the designed tiles have similar unit cell configuration, their reflected phase responses are properly tuned by changing the dimensions. The comparison between the proposed AMC metasurface and some sate of the art references clearly proves the high RCS reduction bandwidth with very low thickness of the designed AMC metasurface rather than the references. The measured results are in good agreement with the simulation ones which prove the idea.**

Index Terms- Artificial Magnetic conductor, RCS, wideband

I. INTRODUCTION

The ability of a radar target to reflect the signals in the transceiver direction is measured by its radar cross section (RCS) which is an important index in the radar system design. Since we don't have enough information about the enemy radars, the RCS reduction should be done at the wide frequency bandwidth. Different ways such as target shaping, radar absorbing materials, and passive or active cancellation have been proposed in the literatures to achieve low radar visibility which is required in the military applications. The passive cancellation by combination of artificial magnetic conductor (AMC) and perfect electric conductor (PEC) tiles in periodic chessboard like configuration has been proposed in [1, 2].

In this method, the adjacent AMC and PEC tiles achieve in-phase and out-phase wave reflections, respectively which produces the destructive phase cancellation and reduces the radar target RCS, consequently. Since the in-phase reflection of the AMC metasurface is achieved at its resonance, the frequency bandwidth of this structure is narrow. To deal with this problem, two different AMC tiles

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with 180° phase difference have been used in the chessboard like configurations instead of using AMC-PEC tiles to achieve higher bandwidth RCS reduction [3-4]. Several studies have been performed in the literatures to enhance the bandwidth of this chessboard like configuration by optimal design of the AMC unit cells. The patch-patch and loop-cross unit cells have been designed and implemented in [5] by using two stacked substrates with different heights resulted in 50% RCS reduction bandwidth. Two different AMC unit cells have been designed on RO4003-air substrates in [6] to enhance the RCS reduction bandwidth up to 73%. Recently, 95% RCS reduction has been achieved by using two different stacked substrates, also [7]. Rather than these references with two stacked substrates and high thickness which limit their applications, the one substrate E-shaped patches and saltire cross arrows AMC unit cells have been proposed in [8] resulted in 85% RCS reduction bandwidth. In this paper, an ultra-wideband, polarization independent, thin and simple two layers (one substrate) AMC metasurface is designed and fabricated for RCS reduction. The proposed metasurface is composed of two different AMC tiles in chessboard like configuration with about 180°±30º phase reflection differences from 9.72 GHz to 26.77 GHz (93% bandwidth) which results in more than 10-dB RCS reduction in this bandwidth. These two AMC tiles are composed of similar unit cell structure with different dimensions tuned to achieve desired reflection phase differences. Since the proposed unit cell has symmetrical configuration, it works with properly with TE and TM polarization of the incident waves. The proposed thin and simple two layers metasurface is fabricated and tested which prove its good specifications rather than the references, properly. Based on the best author knowledge, the proposed metasurface has highest RCS reduction bandwidth compared with the references except the recently published one in [7] which has only 2% higher bandwidth in expense of triple thickness enhancement.

II. UNIT CELLS DESIGN

The proposed ultra-wideband AMC metasurface is composed of two different unit cells with out-phase reflection but similar configuration. In fact, the out phase scattered fields from these unit cells cancel each other which results in RCS reduction if they are arranged in chessboard like surface. The RCS reduction of this surface can be estimated by

$$\text{RCS Reduction}=10\log\left|\frac{\Gamma_1+\Gamma_2}{2}\right|^2 \quad (1)$$

where $\Gamma_1=|\Gamma_1|e^{j\angle\Gamma_1}$ and $\Gamma_2=|\Gamma_2|e^{j\angle\Gamma_2}$ are the reflection coefficients of two different AMC unit cells. While 180° reflection phase difference between unit cells achieve infinite RCS reduction, 180°± 37° phase difference results in more than 10-dB RCS reduction within the bandwidth in this relation [9-12].

The general configuration of the proposed unit cell is depicted in Fig. 1 which is composed of one

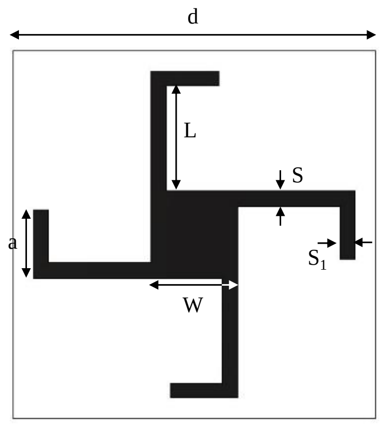


Fig. 1 The proposed AMC unit cell.

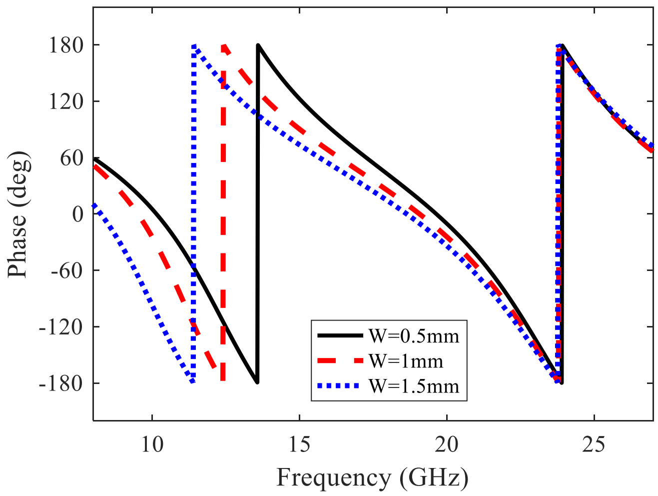


Fig. 2 The reflection phase of the proposed unit cell with different patch sizes.

square patch connected to four L-shaped sequentially 90° rotated arms. Two different AMC unit cells with 180°± 37° phase difference in wideband frequency range should be designed to achieve wide band RCS reduction. This unit cell is able to achieve different reflection phase responses by tuning its design parameters.

To evaluate the design parameters effects, the unit cell is designed on RO4003 substrate with ε_r = 3.35 and h = 60 mil thickness. The simulation of this unit cell is performed by using frequency domain solver of the commercial software CST Microwave Studio where the 2D periodic boundary conditions are imposed in x and y directions and it is excited with Floquet ports. These conditions simulate the infinite AMC metasurface conditions to obtain the unit cell reflection phase versus frequencies.

The arm lengths can be used to shift the reflection phase response while the square patch size only affects the first resonance of the unit cell as shown in Fig. 2. In more details, increasing the patch size reduces the first unit cell resonance frequency. Notice that the other design parameters of the unit cell are tabulated in the first column of Table. 1.

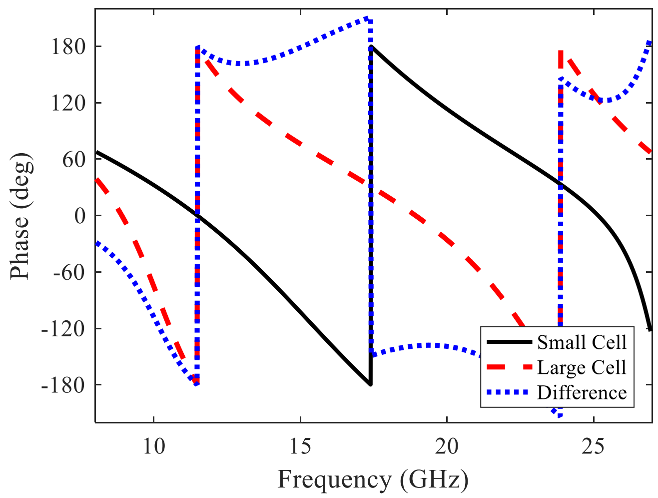


Fig. 3 The reflection phase of the proposed unit cells and their differences.

Table. 1. The unit cell dimensions.

Dimensions (mm)	**d**	**L**	**a**	**S**	**S1**	**w**
Small unit cell	5	0.64	1.05	0.2	0.42	0.42
Large unit cell	6	1.7	1.12	0.26	0.24	1.44

To achieve the destructive phase cancellation in the reflected waves, the dimensions of the required two unit cells should be properly tuned to reach 180° reflection phase difference between them over wideband frequency. The proposed unit cells named as small and large with the dimensions tabulated in Table 1.

The reflected phase responses of these unit cells and their phase difference are depicted in Fig. 3, also. As it can be seen, the unit cells phase difference stay in 180°±37° from 10.6 GHz to 26.3 GHz. Therefore, these proposed unit cells can be used in chessboard like configuration to achieve the phase cancellation and RCS reductions, consequently.

III. Design and Fabrication

A chessboard like of the proposed unit cells which provide ultra-wideband phase cancellation is formed by two different tiles with 3cm × 3cm dimensions arranged in 5×5 configuration as shown in Fig. 4. In this structure, one tile is composed of 5 × 5 large unit cells while the other one is composed of 6 × 6 small unit cells.

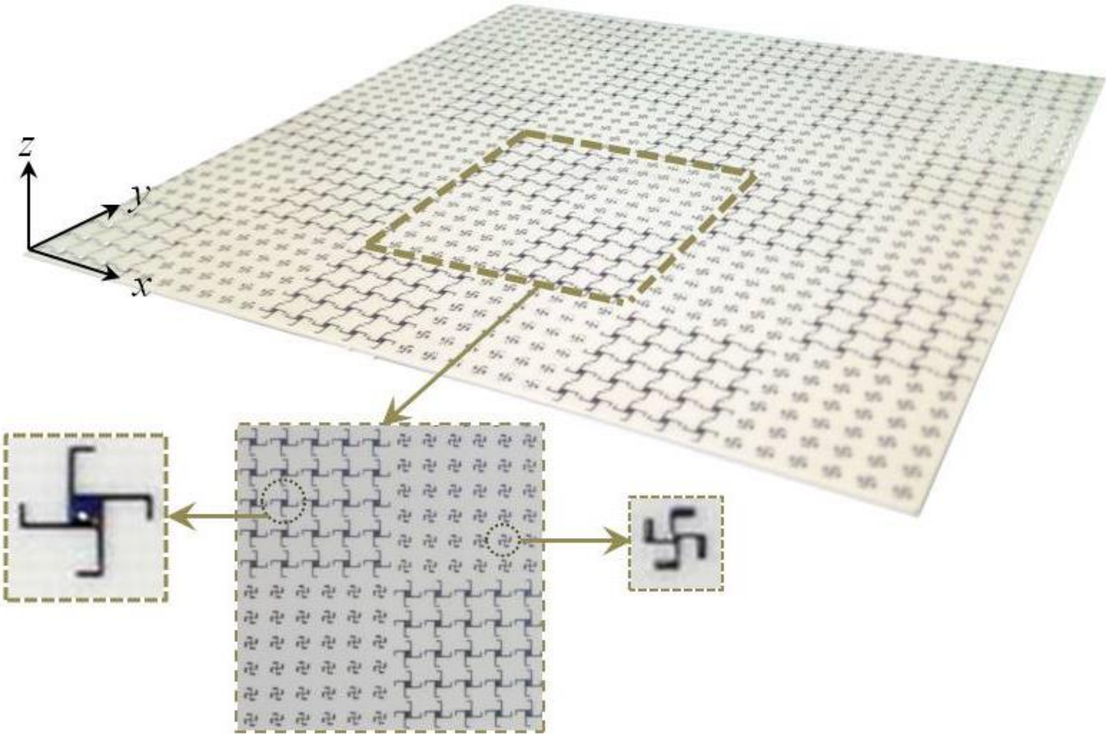
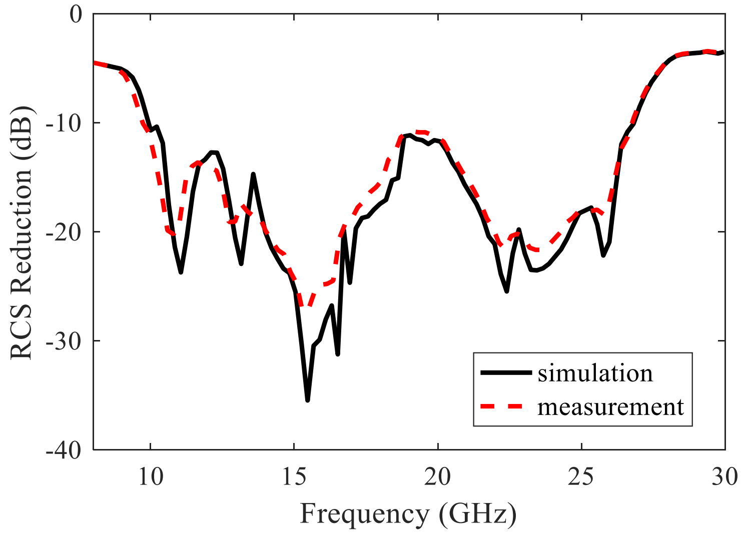


Fig. 4 The fabricated AMC structure.

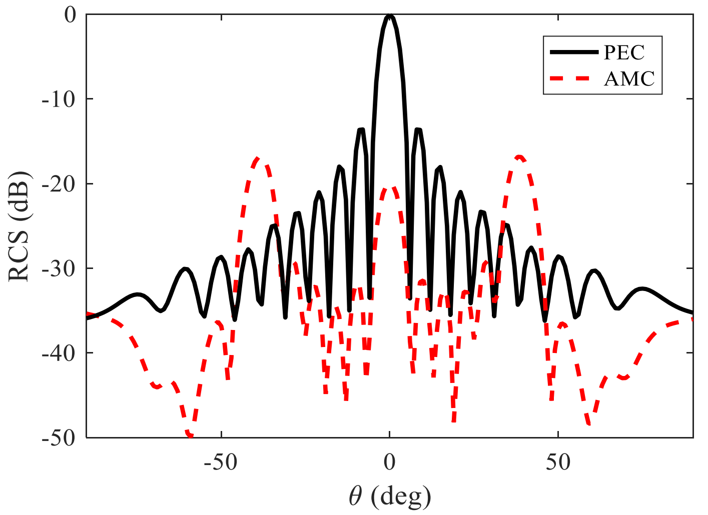
The simulation result of the monostatic RCS of the proposed 5×5 tiles AMC metasurface is compared with the measurement one in Fig. 5(a) versus frequency which shown a very good agreement. The fabricated metasurface is tested with normal incidence of plane wave in an anechoic chamber. These monostatic RCS results are normalized respect to a metallic plate with similar physical dimensions. The fabricated AMC metasurface reduce the RCS more 10 dB from 9.72 to 26.77 GHz (93% bandwidth). Notice that this bandwidth is wider than the bandwidth of 180°±37° unit cells reflection phase difference which is 10.6 GHz to 26.3 GHz.

Fig. 5(b) depicts the simulation scattered patterns of the proposed metasurface for the normal incidence compared with a PEC plane with similar dimensions at 15 GHz. As it can be seen, the phase cancellation between the reflected waves from the tiles redirects the main PEC lobe in the other directions and achieves effective RCS reductions. A simple set-up for monostatic RCS measurements is used as shown in Fig. 6 to verify the numerical results. In this setup, it used from the six emitting standard antennas operating from 5 to 30 GHz are used as transmit and receive antennas at both side of the structure.

A comparison between the proposed AMC metasurface and some sate of the art references is presented in Table. 2 which clearly proves the high RCS reduction bandwidth with very low thickness of the designed AMC metasurface rather than the references.



(a)



(b)

Fig. 5 The results of the proposed AMC metasurface (a) Simulation and measurement RCS reduction results (b) Scattered pattern for the normal incidence at 15 GHz.

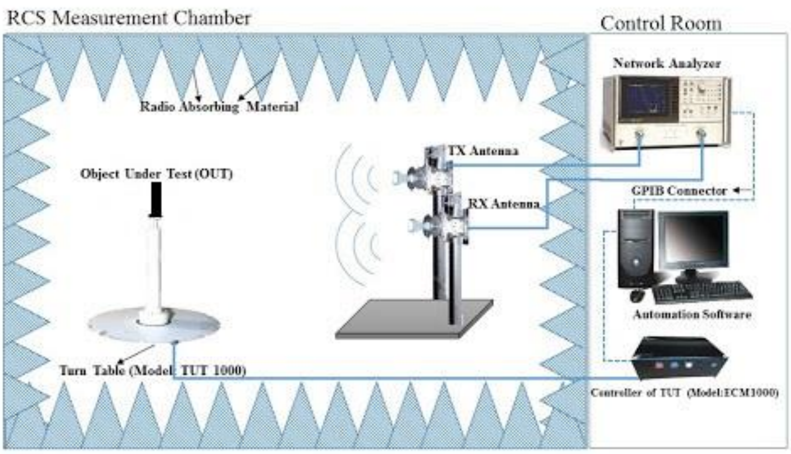


Fig 6. The RCS measurement test setup.

Table 2. Comparison of the proposed AMC with the references

Ref.	**Thickness (mm)**	**Frequency range (GHz) (<−10 dB), B**	**Bandwidth (%)**
[5]	3.3	9-15	50
[6]	4.81	5.9-12.7	73
[7]	6.80	3.8-10.7	95
[8]	2.28	9.4-23.28	85
This work	2.28	9.72- 26.77	93

IV. CONCLUSION

An ultra-wideband thin metasurface has been designed and fabricated for RCS reduction applications. The proposed metasurface was formed by two different AMC unit cells arranged in chessboard like configuration. The simulation and measurement results proved the ability of the proposed metasurface to redirect the scattered field and achieve more than 10dB RCS reduction over 9.72 GHz to 26.77 GHz (93 % bandwidth).

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