Broadband RCS Reduction using a Composite AMC Structure

Ali Azarbar[1], Mostafa Mashhadi[2]
1- Department of Computer and Information Technology Engineering, Islamic Azad University Parand Branch, Tehran, Iran
Email: azarbar@ee.sharif.edu
2- College of Electrical Engineering, Iran University of Science and Technology, Tehran, Iran
Email: mashhadi@elec.iust.ac.ir (Corresponding author)

Received: June 17 2015 Revised: August 12 2015 Accepted: August 24 2015

ABSTRACT:
A composite artificial magnetic conductor (AMC) surface with magneto-dielectric substrate is presented for wide band radar cross section (RCS) reduction. It is shown that using of magneto-dielectric substrate can increase the in-phase reflection bandwidth of AMC structures. The composite surface consists of two kinds of AMC cells that operates at different resonance frequencies. The phase difference between these two different AMC are tuned to be close to $\pm\pi$ over a wide bandwidth so that the reflections from them cells cancel each other. The results show that RCS reduction more than 13 dB was achieved with a 93% bandwidth.

KEYWORDS: Radar Cross Section, Composite AMC Structure, Magneto-dielectric substrate, Broadband RCS Reduction

1. INTRODUCTION

Radar Cross Section reduction (RCS reduction) has received a lot of attention in stealth technology for many years. The goal of RCS reduction is to reduce the scattered electromagnetic field when an incident wave is illuminating to the object-of-interest. Three remarkable different solutions are proposed for RCS reduction that consist of the use of Radar Absorbing Material (RAM), object shaping, and object coating.

RAM materials [1, 2], widely used in antenna and RCS measurement facilities to suppress echoes in floor and walls and transform the electromagnetic energy into heat. The main disadvantages of RAMs are their weight, cost and size [3]. Another approach for RCS reduction is object shaping. The aim of shaping is to design the platform's surfaces and edges to avoid reflection in the direction of the incoming wave [4]. This technique usually requires a trade-off between operational features and RCS reduction specifications. The third technique for RCS reduction is objects' coating [5, 6], the creation of phase difference between the various reflections canceling each is its operational basis.

Salisbury screen is one of implementations of RAM coating [7]. The geometry consists of a lossy resistive dielectric sheet placed $\lambda/4$ above a perfect electric conductor (PEC). The main drawbacks of the Salisbury screens are the overall thickness and the frequency angular dependence. In [8] it is shown that the overall thickness can be reduced by placing a sheet on a magnetic surface. In that case, $\lambda/4$ spacing is not required anymore. Engheta [9] presented a sketch of an idea for implementation of magnetic surface. Using the artificial magnetic conductor (AMC) the overall thickness of Salisbury screen is remarkably reduced. In contrast with an ordinary metal ground plane that operate as a low impedance surface with reflectivity -1, an AMC have a very high impedance and reflectivity +1 that means it acts as a magnetic conductor.

AMC surfaces also can be used to control the electromagnetic scattering from targets based on shaping. The principle is to reflect the electromagnetic waves away from the direction of incoming waves. In [10-12] a composite surface of AMC and PEC cells are proposed for this purpose. The cancellation of the reflection contributions from PEC and AMC parts are the basis of RCS reduction ability of the composite surface. The PEC and the AMC cells were arranged in a chessboard like configuration. In the absence of any lossy components, the energy is scattered in offset directions. The main drawback of this structure is narrowband RCS reduction that just is created around the frequency where the AMC reflectivity is +1. For solving this problem, in [13-18] new structures are introduced that in which metal cells are substituted by another AMC structure working at different frequencies than other AMC cells. Using this configuration the maximum operational bandwidth of 60% has been reported.

In this work, we use magneto-dielectric materials to increase RCS reduction bandwidth of chessboard configurations. In [20] it is shown that materials with permeability higher than one can be used to increase the in-phase reflection bandwidth of AMC. Therefore, in this work we study the AMCs chessboard configurations with magneto-dielectric substrate and show that this surface has a broadband RCS reduction in comparison with PEC one's.

In this work, firstly it is shown that using of substrate with permeability higher than one, results in wider in-phase reflection bandwidth in AMC structure. Then, in Section 3, using this technique a composite AMC structures are designed so that the phase difference between two AMCs are close to $\pm\pi$ over a wide bandwidth. Therefore this structure can reduce RCS over a wide bandwidth.

2. AMC DESIGN

It was demonstrated in [20] that AMC can be modeled with a parallel LC circuit model and in-phase reflection bandwidth for a parallel LC circuit is proportional to $\sqrt{L/C}$. Therefore to increase the in-phase reflection bandwidth we must increase L. To increase L we use magneto-dielectric materials where the relative permeability μ_r is greater than one. An increase in L, for a specific resonance frequency leads to reduction of the size of patch since smaller capacitance would be needed to fix the resonant frequency. In this work the usable bandwidth of an AMC, has been considered to be the frequencies over which the phase of the reflection coefficient is bounded by 45 degree.

To verify the idea, a unit cell of an AMC which is a square patch and is shown in Fig. (1) is simulated for different permeability values. To see the effect of permeability, the proposed structure with the following dimensions, $W = 7.3\,mm$, $L = 8\,mm$, $h = 1.6\,mm$, $\varepsilon_r = 1$, and with different values of permeability are considered. The structures are simulated with CST STUDIO SUITE using plane wave excitation with normal incidence. The simulation results are shown in Fig. 2. The simulation results for different value of permeability are summarized in Table I. This table shows the in-phase reflection bandwidth, the center frequency corresponding to a reflected phase of zero and percentage bandwidth of AMC cell. As shown in this table, by increasing of the permeability the percentage bandwidth increases and center frequency decreases.

As observed, by increasing of permeability the in-phase reflection bandwidth of AMC is also increased. This property can be used to increase the bandwidth of RCS reduction of composite AMC structure. Therefore, we adopted two AMC cells with different resonance frequencies and chose the resonant frequencies of these two AMCs so that the phase difference between them are close to $\pm\pi$ in a much wider frequency range.

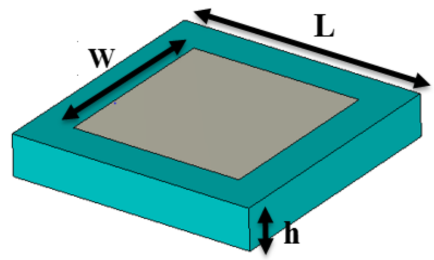


Fig. 1. A configuration of unit cell AMC structure.

Table 1. Simulation Results for AMC with Different Permeability

μ_r	In-phase Reflection Bandwidth (GHz)	Center Frequency (GHz)	Percentage Bandwidth
1	10.3-11.95	11.1	%14.9
2	7.1-8.8	7.9	%21.5
4	5-6.5	5.7	%26.5
6	4.2-5.7	4.9	%30.6

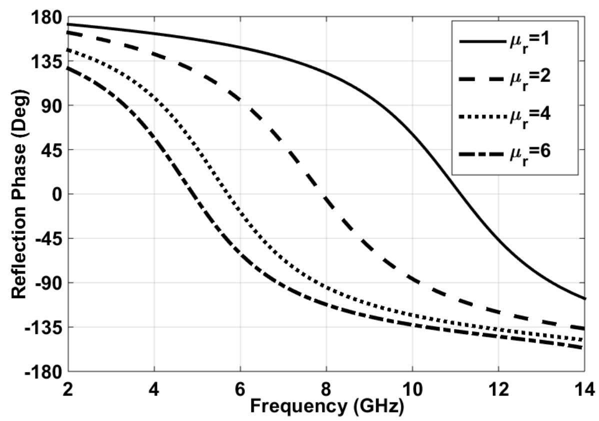


Fig. 2. Phase of the reflected plane wave for the AMC structure for different value of permeability

For this purpose, in order to reducing the RCS in the frequency ranges of 8-20[GHz] the dimensions of two AMCs are optimized which resulted to $W = 7.3\,mm$, $L = 8\,mm$ for the first AMC structure (structure A) and the second AMC (structure B) dimensions are $W = 1\,mm$, $L = 2\,mm$. The relative permeability of substrate is also considered to be $\mu_r = 4$. The reflection phases of two AMCs to normal incident waves are shown in Fig.3, while the difference between both curves is shown in Fig. 4. If we assume that a phase difference of 180º±20º is acceptable, it is expected that in the frequency range of 7.2 GHz -18.6 GHz (88.4%) a remarkable RCS reduction occurred.

3. CHESSBOARD CONFIGURATION

A 2×2 chessboard configuration composed from two proposed AMCs is shown in Fig. 5. This structure is simulated in CST STUDIO SUITE and the result is shown in Fig. 6.

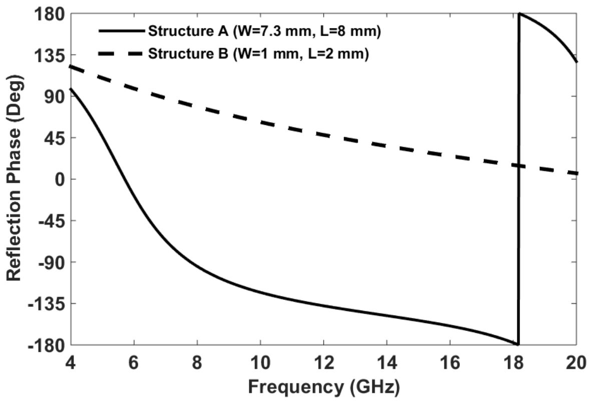


Fig. 3. Reflection phase variation versus frequency for the two types of square patches AMCs

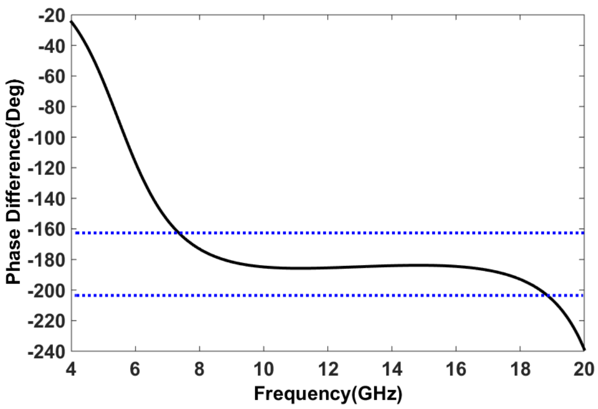


Fig. 4. Phase difference versus frequency between both square patches AMCs

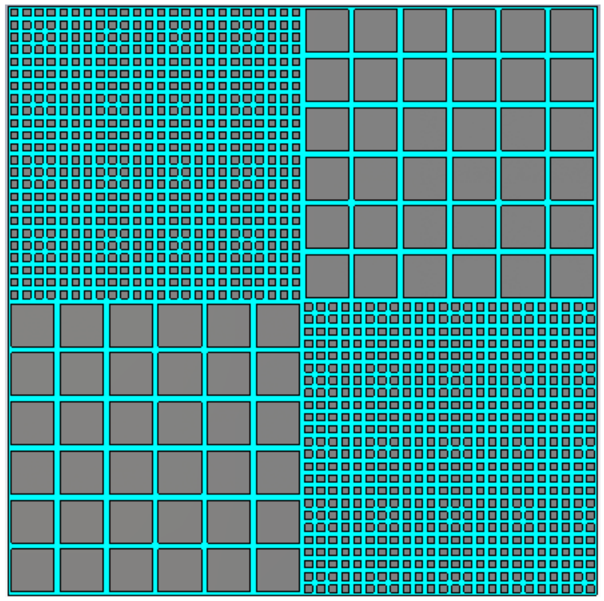


Fig. 5. AMCs combinations in 2×2 chessboard-like configurations

The RCS reduction compared to a metallic plate with the same dimension is observed that is more than 13 dB between 7.1 GHz and 19.5 GHz (93.2%). It is observed that there are good agreement between predicted band given by phase difference and chessboard RCS reduction range. 0º and 45º cuts of a normalized bistatic RCS of composite AMCs structure and a PEC surface versus θ for frequencies of 8, 12, 16 and 19GHz are shown in Fig.7.

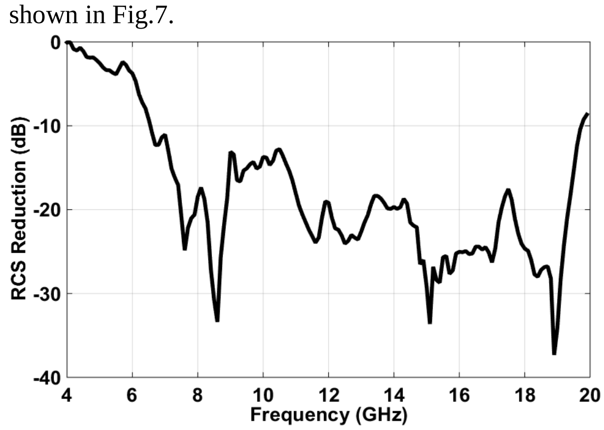
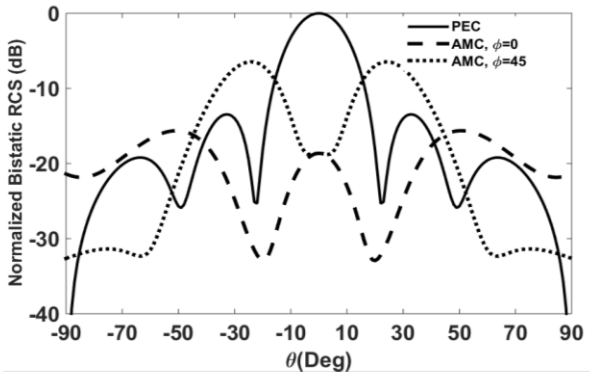
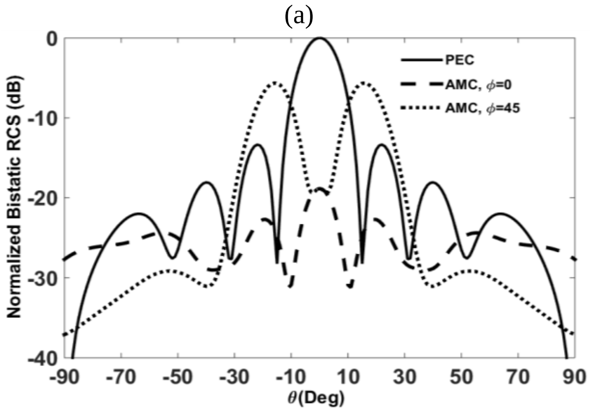


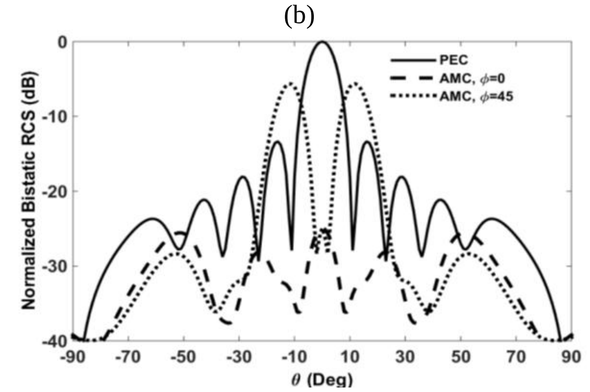
Fig. 6. Normalized RCS of the composite AMCs structure respect to a metallic plate.



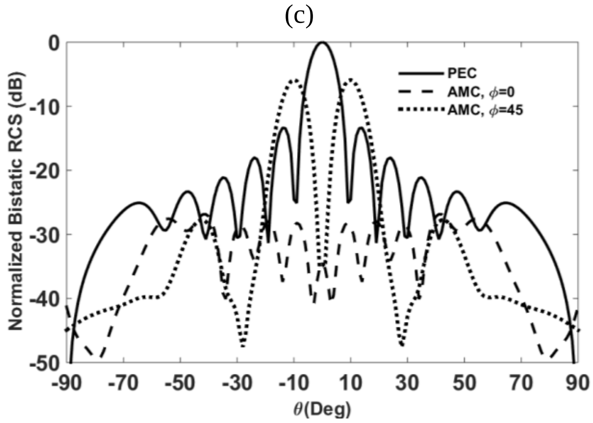
(a)



(b)



(c)



(d)

Fig. 7. Normalized bistatic RCS of composite AMC surface and metal surface at different frequencies: (a) 8GHz, (b) 12 GHz, (c) 16GHz, and (d) 19GHz.

4. CONCLUSION

A magneto-dielectric substrate can increase the in-phase reflection bandwidth of AMC. This property can be used in chessboard AMC configurations to enhance bandwidth of RCS reduction of a surface. In this work a wide band low RCS composite surface with magneto-dielectric substrate was designed. The surface was composed of two kinds of AMC cells with different resonant frequencies so that their reflection coefficient phase difference is close to $\pm\pi$ over a wide bandwidth. Therefore, the reflection waves have opposite phases and cancel each other. The results shows that composite AMC configurations can achieve to more than 13 dB RCS reduction in the normal direction over a 93.2% bandwidth.

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