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Entire X-band region metamaterial absorber and reflector with a microstrip patch switch for X-band applications

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ABSTRACT

A metamaterial structure capable of operating as a wide band absorber as well as an AMC reflector is presented in this report. A microstrip patch copper was used as a switch to switch between the two modes. An FR4 substrate was used and the incidental wave angles were varied from 00 to 600. Simulations results showed that the absorber was able achieve 96% absorption at 13.05 GHz and 100% absorption at 10.00 GHz and 12.00 GHz. Furthermore, it archived over 85% absorption for the entire X-band frequency range. The AMC reflector also was able to achieve 84.97%, 82.88% and 78.69% for incident angles 00, 200 and 400 respectively. Unfortunately, the structure is polarization sensitive.

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1. INTRODUCTION

Since the establishment of the theories and concept behind exotic properties of metamaterials (MTM) [1], The name MTM has been ringing in the minds of researchers especially those in (EM) electromagnetic field. MTM are unique structures which were purposely engineered to exhibit properties not found naturally in nature. Several Scholars and researchers in the fields of EM are at took to their heels to max-out and exploit all the benefits MTM can offer.

The unique properties of this structures have proved to be useful for many applications such as low-profile ground plane [2], phase-shifter [3], band-rejection [4], filter [5], focusing antenna beam [6], beam steering [7], and surface waves suppression [8]. An excellent experimental work on metamaterial was demonstrated by N. I. Landy et. al in 2008 [1]. They designed an EM wave absorber based on electric ring resonator over a cut wire separated by a lossy dielectric material.

EM Waves absorbers are structures that neither reflect nor transmit EM waves but instead they minimize reflection by maximizing energy loss within the structure’s substrate. While AMC reflector, reflects the remnants of EM waves after Minimum conduction or transmission. A simple application that will benefit from structure that offers both reflection and absorption at same resonance frequency is stealth mode for fighter jets.

The basic principle and concept of metamaterial absorber is to have layers that are perfectly matched, where the magnitude of the surface impedance, Z(ω) is made to be the same with that of the free space impedance, η0. Achieving the perfectly match layers, involves having the effective permittivity, ε(ω) and permeability μ(ω) to have the same magnitude. In addition to that, the imaginary part of both parameters needs to be as large as possible in order to maximize absorption. [10]

On the other hand, it is worth mentioning that initially perfect electric conductors (PEC) were used before the discovery of Artificial Magnetic conductor (AMC) or Perfect Metallic Conductor (PMC). AMC or PMC are characterised by unusual boundary conditions. These boundary conditions result in having the magnitude of the reflection coefficient to be +1 while its phase is 0°. It has high surface impedance (Zs) and it reflects the external electromagnetic waves without the phase reversal.

In contrast, the PEC has a reflectivity of -1 and has electromagnetic waves out of phase with the incident waves. As the metallic plate, the AMC also can be used as a ground plane to redirect the back radiation and provide shielding to the antennas [11].

2. PROPOSED DESIGN AND SIMULATION

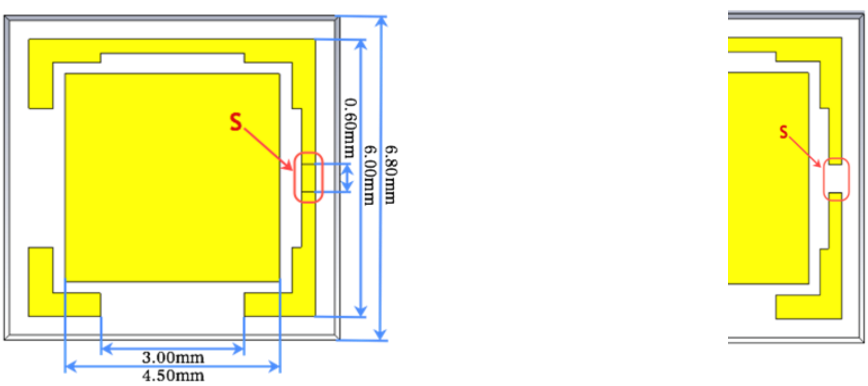
In this paper, the proposed structure was designed using an FR4 substrate with thickness 1.6mm. other properties of this substrate include dielectric constant of 4.6 and loss tangent of 0.019. The entire structure measures 6.80mm by 6.80mm while the patch measures 6.00mm by 6.00mm. Basic antenna equations were used to calculated approximate substrate size for the resonance frequency. The structure consists of a square shaped major patch which is cornered or caged by four (4) L-shaped patches. Three of the L-shaped patches were interlinked by two bridges. One of which of the bridges beds a switch (S) whose function is switch between modes.

When the switch (S) is activated, the structure functions as MTM absorber while when the switch is deactivated it functions as an AMC reflector. Activating switch S enables the flow of current towards the topmost and rightmost part of the structure. This current furthermore interacts with the current at the edges of the large center square patch. The interactions between these two surfaces current gives rise to two neighboring resonances which helps in expanding the absorber's bandwidth to cover almost the entire x-band range.

Deactivating Switch S, breaks down the current flow, thus cutting down the current interactions. This leaves the center square patch to be the most active portion. With that, it is worth mentioning that in this design, the large square patch is solely responsible for the reflectance properties demonstrated by the structure. The four L-shaped patches help in slightly compressing the resonance frequency of the reflector, and on the other hand the generate absorbance properties when interlinked together. The bottom side of the structure is fully covered by the ground plane, thus making transmittance to be zero (0). Reflectance is taken to be S11 whereas absorbance is calculated using (1). Figure 1a below shows the top view of the structure while Figure 1b shows the deactivated section of switch (S). Simulations were done using Microwave Studio of Computer Simulation Technology CST® 2015.

$$\text{Absorbance: } A(\omega) = 1 - R(\omega) - T(\omega) \quad (1)$$

where:
$R(\omega) = |S11|^2$
$T(\omega) = |S21|^2$



(a) (b)

Figure 1. (a)MTM absorber switch "S" activated; (b) MTM absorber switch "S" deactivated

3. SIMULATED RESULTS AND DISCUSSIONS

3.1. Parametric Study on the Bridges and Switch Position

Parametric study was conducted to identify the most optimum size for the bridge bedding the switch as well as an optimum position for the switch. Frist the thickness of the bridge was considered and from the simulations, it was noted that as long as the thickness of the bridge is less than that of the L-shaped patch and greater than 0.6mm then there is no effect on the performance of the AMC reflector. It should not be forgotten that once the L-shaped patches are interlinked by the bridge, the structure functions as MTM absorber.

Similarly, the switch position on the bridge, has less or no significant effect on the performance of AMC reflector, but it somehow introduced a little notch when the switch is horizontally moved to the bottom. A few positions were used to determine the effect. Position (Y = 0) being the center of the right-hand side bridge was used as reference point. Next the switch was moved to Y=0.3, Y=0.6, Y= -0.3 and Y=-0.6. It was noted when the switch is moved up towards positive values, the notch almost disappeared but the shift in resonance frequency increases. When the switch is moved downwards towards negative values, the notch increases but the shift in resonance frequency reduces. Therefore, in order to balance between reflection rate, size of notch and shift in resonance frequency, the position Y= 0 was chosen and used for rest of the simulations. Figure 2a and 2b shows the results for switch position.

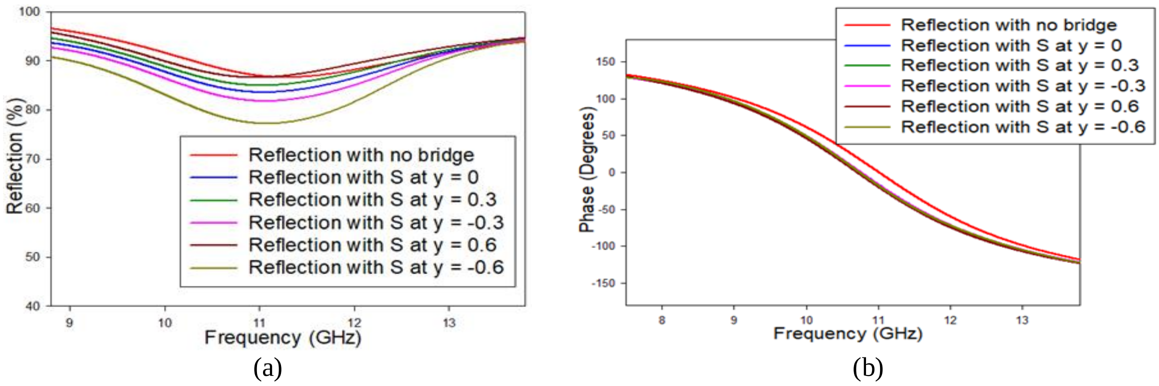


Figure 2. (a) S11 of Parametric study on switch position; (b) Phase of Parametric study on switch position

3.2. TE Mode Performance of the MTM Absorber

Over here, switch (S) was activated, thus the structure's operation was turned into absorber mode. Under this operation mode, the structure was simulated for various polarizations and incident angles (0^0, 20^0, 40^0, and 60^0). The structure was able to achieve more than 80% absorption for the frequency range from 9.0 GHz to 13.50 GHz. For the first two (2) incident angles ($0^0$and 20^0), the waveforms are identical and they both achieved 96% absorption at 13.05 GHz and 100% absorption at 10.00 GHz and 12.00 GHz.

For incident angle 60^0 the structure demonstrated less absorption (93%) at 11.00GHz. Furthermore, this incident angle has the smallest bandwidth 10.05 GHz to 13.00 GHz and demonstrated the most least absorption at 12.80 GHz.

3.3. TM Mode Performance of the MTM Absorberß

Similarly, maintaining the switch position as (S) activated, the polarization was changed to TM, and the structure was tested for the same incident angles (0^0, 20^0, 40^0 and 60^0). The waveforms were similar to that of the TE mode with slight difference. Over here, overall performance of all the incidence angles seemed improved when compared to that of the TE Mode. Figure 3a and Figure 3b shows the TE and TM modes waveforms.

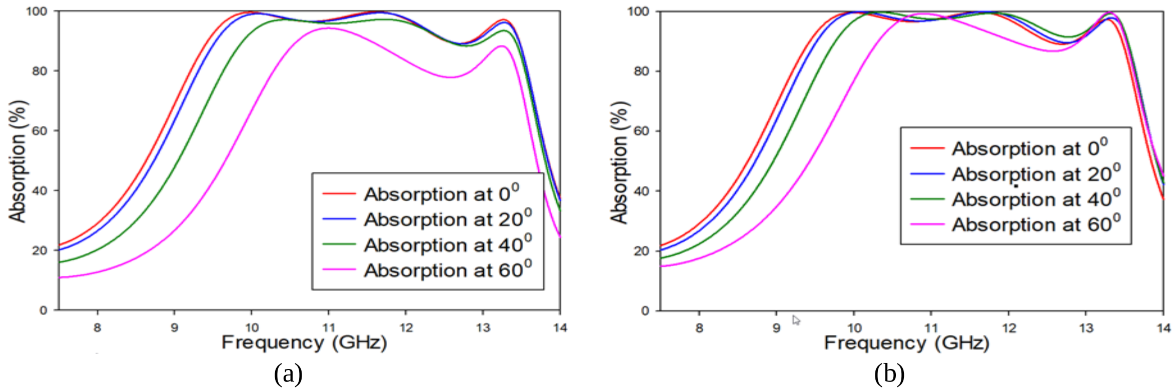


Figure 3. (a) TE mode performance of the MTM absorber; (b) TM mode performance of the MTM absorber

3.4. Performance of the AMC Reflector (Reflection Rate and Reflection Phase)

After reporting on the performance of the MTM absorber at previous section, over here, the performance of the AMC reflector is being reported. Firstly, the structure was designed to work at 10.74 GHz as an AMC reflector. In order for the structure to perform as an AMC reflector, the switch (S) needed to be deactivated. As mentioned, deactivating the switch cuts down the surface current flow between the topmost and the rightmost patches. This furthermore reduces the interaction between the side and the center large square patch.

With respect to reflection rate, the structure was tested for the same incident angles (0^0, 20^0, 40^0, and 60^0). The waveforms demonstrated a reflection of 84.97% for incident angle 0^0, followed by 82.88% and 78.69% for incident angles 20^0 and incident angle 40^0 respectively. This is shown in Figure 4a.

On the other hand, the reflection phase showed there is shift in resonance frequency as the incident angle is increased. The shift is considered large, since it shifted from 10.74 GHz at incident angle 0^0 to 11.30 GHz at incident angle 60^0. In addition to that, the structure was only able to perform as a reflector for TE mode only. Bearing the large shift in resonance frequency and polarization sensitivity in mind, it is best or better for this structure to serve as an absorber rather than an AMC reflector. Figure 4b shows the phase waveform.

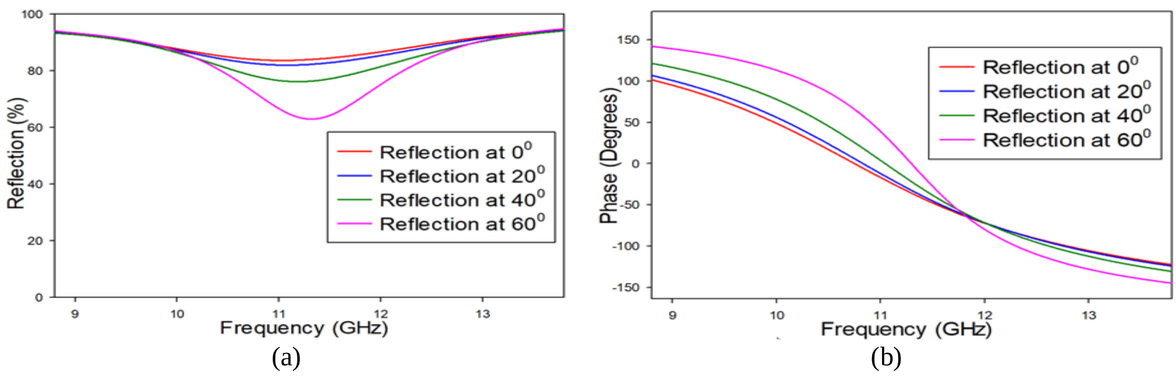


Figure 4. (a) AMC's Reflection Phase; (b) AMC's Reflection Phase

4. CONCLUSION

In this report, an electromagnetic wave metamaterial structure is presented. The structure was able to switch between an absorber and a reflector. The performance of the structure for under TE and TM modes were observed. The absorber operated across the entire X-band region and demonstrated 96% absorption at 13.05 GHz and 100% absorption at 10.00 GHz and 12.00 GHz. Whereas the reflector demonstrated 84.97%, 82.88% and 78.69% reflection for incident angles 0^0, 20^0 and 40^0 respectively.

Unfortunately, the structure is polarization sensitive which can be fixed by making it symmetry. Furthermore, it is advisable for such structure to be used as an absorber rather than a reflector since the TE mode of the AMC reflector demonstrated poor performance. Nevertheless, this structure has features and can be used for X-band applications because it is believed the TE poor performance and be fixed by symmetrizing the structure.

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