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Polarization insensitive switchable metamaterial absorber/reflector for X-band applications

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ABSTRACT

A unit cell of squared shaped polarization-insensitive switchable metamaterial absorber/reflector is presented. The structure operates at 10.20 GHz under both absorber mode and reflector mode configurations. Copper wire bridging the gaps to form a circular shape structure were used as switches for operation mode selections. The structure was designed on an FR4 substrate, and the incidental wave angles were varied from 0 to 50 degrees. The structure demonstrated almost 100% absorption at resonance, 3.314 GHz percentage bandwidth at 80% as an absorber. On the other hand, as reflector, it demonstrated almost a 90% reflection and a usable bandwidth of 3.327 GHz.

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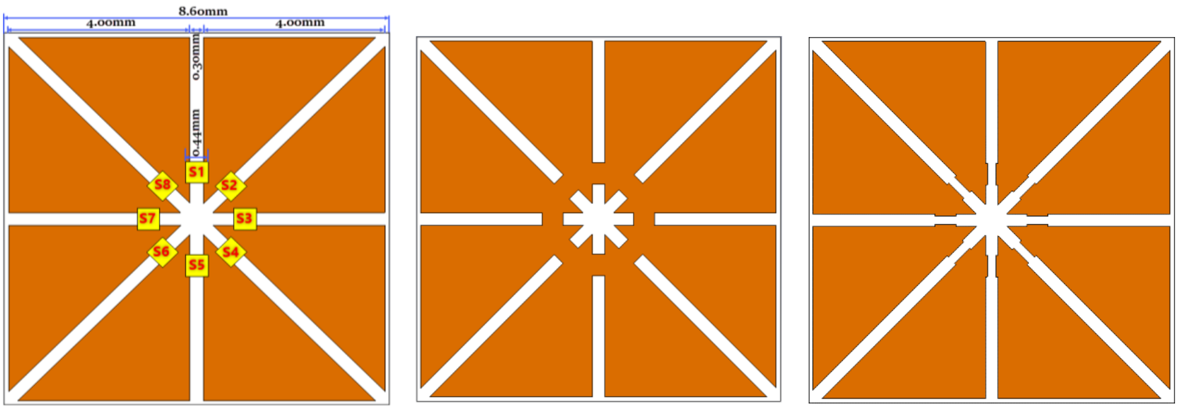
1. INTRODUCTION

The metamaterial (MTM) as defined, are structures artificially engineered to have properties not found in nature [1-3]. MTMs are divided into classes and subclasses. In the field of electromagnetic, the most important is left-handed metamaterial (LHM) [4], double negative (DNG) [5-7], backward media (BWM) [8] or negative index materials (NIM) [9]. Materials in this class exhibit negative permittivity and permeability simultaneously. This class is desirable in the electromagnetic field because in this class, waves can propagate in opposite directions which can be manipulated to increases the focusing/directivity of the propagated waves [10]. Other applications that can benefit from metamaterials are cloaking [11], reflectors [12], sensing, EM filters [13], focus antenna beam [14], low profile ground plane, phase shifting [15], etc.

Electromagnetic waves (EMW) absorber is defined as a structure that is capable of absorbing incidental waves by minimizing reflection and transmission through maximizing energy loss within the structure. In contrast, electromagnetic wave reflector or artificial magnetic conductor (AMC) are structures designed with unusual boundary conditions that are "selective" in supporting surface wave currents. Before the discovery of planar structures for absorbers and reflectors, Conventional absorbers and reflectors were in existence, but they all have their drawbacks, take, for instance, the Salisbury [16] and Dallenbach [17] have limitations of being narrowband and electrically thick. In addition to that, also, they can only operate in quarter wavelength [18]. Similarly, the conventional reflectors, known as perfect electric conductor (PEC) mainly used for antenna ground planes, have drawbacks. These drawbacks include the production of out of phase image currents and propagation of surface current. In this paper, replacing PEC with AMC counters these drawbacks and improves gain by reducing back radiation is presented.

2. RESEARCH METHOD

The proposed MTM structure is based on the designs presented in [12, 19, 20-25]. It is made up of four-square patches diagonally dissected to form two back-facing triangles each. In addition to that, the structure has eight copper wire switches labelled S1 to S8 which are used in selecting operation modes between absorption and reflection mode. The structure was designed on an FR4 substrate measuring 8.60 mm by 8.60 mm with a thickness of 1.60 mm. Other properties of the substrate include relative permittivity of 4.4 and loss tangent of 0.019. The structure has a full ground plane to minimize transmission. Figure 1(a) shows the proposed structure with the copper wire switches (S1 to S8), while Figure 1(b) shows the structure with absorber configuration while Figure 1(c) shows it with reflector configuration. The structure's primary resonance for both absorber mode and reflector mode configuration is at 10.20 GHz.



(a) (b) (c)

Figure 1. Proposed structure showing, (a) Switches S1–S, (b) Absorber mode configuration, (c) Reflector mode configuration

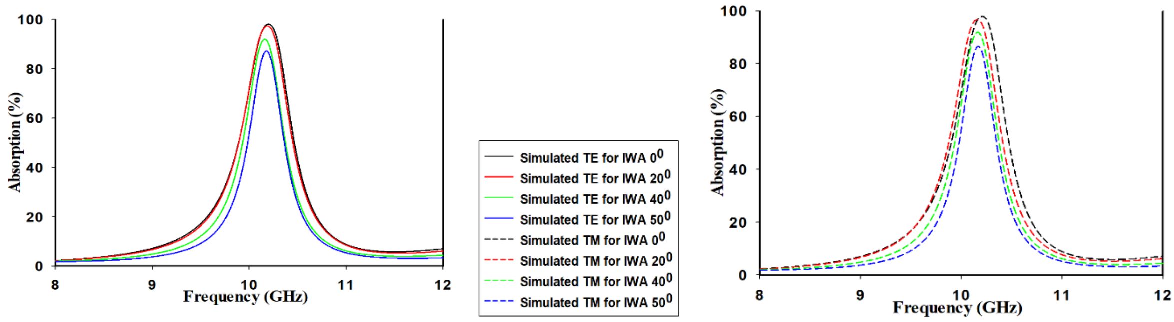
The simulations of the proposed structure were carried out using Microwave Studio of Computer Simulation Technology CST® 2019. For both absorber and reflector configurations, boundary conditions were set to "unit cell" while Z_{min} & Z_{max} were set to "open add space". Reflector's reflection was taken from the return loss S_{11} while absorbance, A(ω) was calculated using A(ω)= -R(ω)-T(ω). Where reflectance, R(ω) is $|S11|^2$ and transmittance, T(ω) is $|S21|^2$. Transmittance was zero $|S21|^2=0$ since the structure has a full ground plane. As mentioned, the structure's primary resonance for both absorber mode and reflector mode configuration is 10.20 GHz. In addition to that, the incident wave angle was varied from 0 to 50 degrees, and the results were reported.

3. RESULTS AND DISCUSSION

3.1. Absorber's operations analysis and absorption mechanism

As mentioned earlier, the structure can performer as an absorber or a reflector, depending on the selected configurations. Over here, the structure is set to work as an absorber where it resonates at 10.20 GHz. The absorber configuration is accomplished by activating the copper switches. Activating the copper switches results in the formation of circular ring-like shape at the centre of the structure. This disrupts the diagonal surface current; thus, creating a pendulum moment around the newly made circular shape structure. With this regard, the switch tends to be the primary absorption mechanism as it establishes a new path for the surface current and thus giving rise to the resonance.

The TE and TM absorption performance of the structure is discussed here. Due to the nature of the design, the structure is polarization insensitive. Therefore, both TE and TM modes analysis were identical. It was observed that for incident wave less than 20 degrees, the structure achieved not less than 99% absorption. As the incident angle was increased, between 21 and 40 degrees, the structure demonstrated more than 93% absorption. As the incident wave angle was further increased to above 40 degrees, the performance of the structure dropped even further to 87%. The waveforms obtained from the TE and TM mode simulations are shown in Figures 2(a) and (b) respectively.



(a) (b)

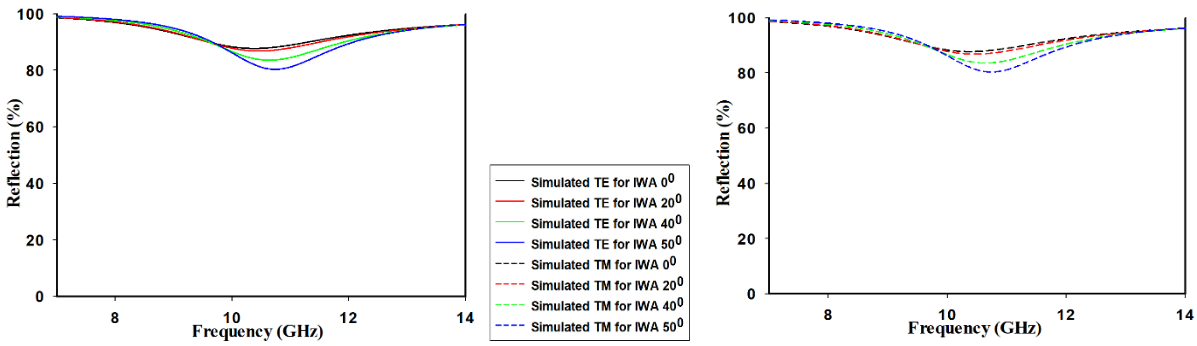
Figure 2. The waveforms simulation at different incident wave angles, (a) TE-mode absorption, (b) TM-mode absorption

3.2. Reflector's operations analysis

Over here, the structure was configured to work as a reflector. This configuration is achieved by removing or deactivating the switches S1 to S8. This action results in creating a free flow path for the surface current and thus reducing the electromagnetic coupling at the centre of the structure as in the case of the absorber. This also, in addition, breaks down the circular-shaped structure formed by the switches. This makes the capacitance at the edge of the structure to be more active and thus results in displaying reflection characteristics.

3.2.1. TE and TM reflection performance at different incident wave angles

Similarly, in this case, the TE and TM performance are identical. For both TE and TM mode, the structure demonstrated not less than 89% reflection for incident wave angles between 0 degrees and 20 degrees. As the incident angle was increased to 40 degrees, the performance slightly dropped to 83% while the resonance shifted to the right (from 10.20 to 10.209 GHz). Furthermore, as the incident wave angle was increased to 50 degrees, the reflection dropped to 79%. Similarly, the resonance shifted further to 10.221 GHz). The reflection waveforms are shown in Figures 3(a) and (b) respectively.



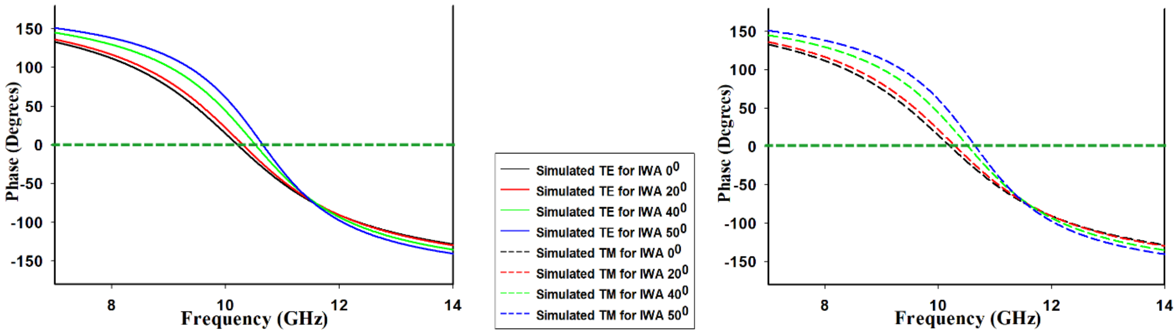
(a) (b)

Figure 3. The reflection performance waveforms at different incident wave angles (a) TE-mode reflection, (b) TM-mode reflection

3.2.2. TE and TM reflection phase at different incident wave angles

Over here, the reflection phase of the structure is discussed. It is worth mentioning that for a reflector, the reflection phase is vital. That is because the in-phase image is only produced within the phase (-180 to +180 degrees), at angle 0 degree, whereas the usable bandwidth of the structure is taken from (-90 to +90 degrees).

Having that in mind and recalling that the structure is polarization insensitive. It is expected that the TE and the TM mode simulations results will be identical. For the incident wave angle 0 and 20 degrees, the structure demonstrated a usable bandwidth of 3.327 GHz (from 8.628 to 11.955 GHz) and 3.196 GHz (from 8.781 to 11.977 GHz) respectively. For incident wave angles 40 and 50 degrees, the structure demonstrated usable bandwidth of 2.688 GHz (from 9.210 to 11.898 GHz) and 2.273 GHz (from 9.533 to 11.806 GHz) respectively. It was noted that the drop-in reflection and shift in resonance results in reduction of the usable bandwidth. The reflection phase waveforms are shown in Figures 4(a) and (b) respectively.



(a) (b)

Figure 4. The reflection phase waveforms at different incident wave angles, (a) TE-mode reflection, (b) TM-mode reflection

4. CONCLUSION

A polarization-insensitive switchable metamaterial Absorber /Reflector for X-band application is presented. The structure's performance was tested with varied incident wave angle from 0 to 50 degrees, and the results were reported. The structure under absorber mode configuration achieved almost a 100% absorption with a minimum of 87% absorption at incident wave angle 50 degree. It demonstrated a percentage bandwidth of 3.314 GHz at 80%**.** On the other hand, under reflector mode configuration, the structure demonstrated almost a 90% reflection with usable bandwidth of 3.327 GHz. The structure has potentials for X-band applications such as stealth and visibility modes for military

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