On the “Absorption” Mechanism of Metamaterial Absorbers

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***Abstract*— Several papers have appeared in the literature where periodic structures known as metamaterials are being used as RF absorbers. However, these structures lack enough lossy materials to absorb the electromagnetic energy in the same way that traditional RF absorbers do. Traditional RF absorbers convert electromagnetic energy to thermal energy. Since the first law of thermodynamics must hold, where does the energy carried as power in the electromagnetic wave go? In this paper it is shown that rather than absorb, the metamaterial structure redirects the energy away from the specular directions. Understanding how the power is reflected is key to being able to use these materials as RF absorbers in antenna ranges or to treat structures to reduce the RCS.**

***Index Terms*—RF Absorbers, metamaterials.**

I. Introduction

The use of metamaterial structures as absorbers has been reported in the literature in recent years [1,2]. These materials show reflectivity levels of -10 to -20 dB and claim absorptions of over 90%. Some of these materials can exhibit reflectivity at certain angles of -40 dB. However, these materials do not have the high loss tangents found in traditional RF absorber [3] that would account for the dissipation of the electromagnetic wave. In traditional RF absorber, the electromagnetic waves power is dissipated as heat [4]. It should be noted that not all Metamaterials are designed to be RF absorbers. In this paper, the metamaterial absorber presented in [2] is further analyzed to understand better the absorption mechanism for these types of RF absorbers.

II. Absorption in Metamaterial Absorbers

In [1], The absorption is computed using the following equation.

$$A(f) = 1 - |S_{11}(f)|^2 - |S_{21}(f)|^2 \qquad (1)$$

Where S_{11} is the reflected power and S_{21} is the transmitted power. For structures like the one presented in [2] the transmitted power is close to zero, as it is a material backed by a continuous copper layer. Hence the absorption as defined in (1) reduces to the incident wave minus the reflected wave. However. The reflected wave accounted for is that of the first mode of the Floquet port, thus, only the specular reflection is accounted for in the absorption equation.

A higher order basis function method of moments (HOBF-MoM) computational EM package is used to model the absorber presented in [2]. Figure 1 shows the model of a single cell. The lateral boundaries are periodic boundaries, and the top is a Floquet port. The bottom layer is also a Floquet port. However, the bottom of the metamaterial structure is a PEC layer. Hence, no energy reaches the bottom port.

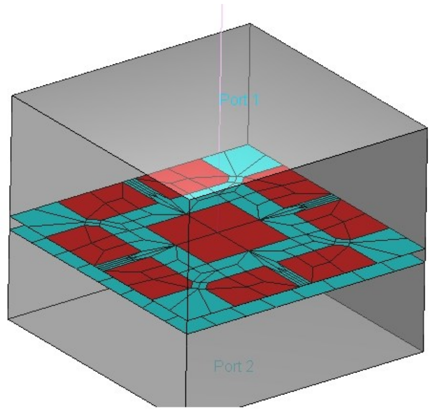

Figure 1. The single cell of the periodic boundary HOBF-MoM model of the metamaterial in [2]

The model in Fig. 1 is slightly different than the model in [2], the difference is mainly the use of PEC for all the metallic parts, and also the metallization is assumed to have zero thickness, that is, these are 2D layers. The use of 2D versus thick layers effectively reduces the size of the metallization, thus the frequency behavior is slightly offset. Despite those differences the results from the HOBF-MoM code is similar to what was presented in [2].

The numerical code employed (WIPL-D) allows the user to plot the total power crossing the Floquet port by adding the power from multiple modes of the port that correspond to surface waves the propagate along the periodic structure. If the total power is plotted, the reflectivity shows is close to 0dB, that is, there is no absorption since most of the energy is reflected, since in this model the only loss mechanism is the lost tangent of the felt used as the dielectric substrate (ε_r=1.4-j0.028). Figure 2 shows the results of this computation with the reflectivity for the bi-static mode.

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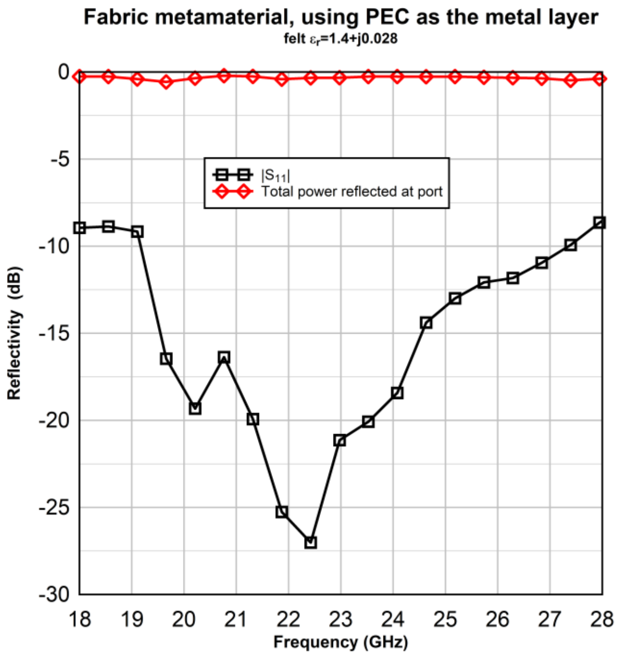

Figure 2. Reflectivity of the first mode (bistatic) and the total power reflected.

The results in fig. 2 seem to imply that there is no absorption from the material. The power incident onto the metamaterial periodic structure is reflected in directions that do not correspond to the bi-static or specular direction. The HOBF-MoM method allows the user to create larger, non-infinite structures. Hence a 36 cm by 36 cm metamaterial section is analyzed.

III. Finite Absorber Analysis

The finite model is analyzed at 22 GHz, which as shown on fig. 2 corresponds to the lowest bistatic reflectivity. At 22 GHz the wavelength is 1.363 cm. hence the finite metamaterial absorber section is 26.42λ. Figure 3 shows the meshed structure being analyzed.

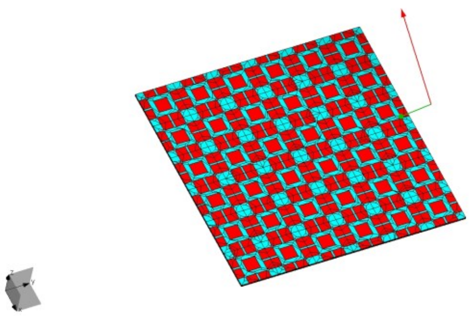

Figure 3. a 26.4λ by 26.4λ (36 cm by 36 cm) Metamaterial absorber section analyzed.

The radar cross section (RCS) of a metallic (PEC) plate can be approximated, for the normal incidence case by the following equation,

$$\sigma = 4\pi \frac{a^4}{\lambda^2} \tag{2}$$

Where a is the side of the square plate in meters and λ is the wavelength in meters. For the given size metamaterial structure, the Monostatic RCS for the normal incidence case is 1136.6 m^2 or 30.55 dBsm. Figure 5 shows the RCS for a metal (PEC) 36 cm by 36 cm object and for the metamaterial section of the same size. The results are shown for the normal incidence case (top of the figure) and for the case where the angle of incidence θ=30° (bottom of the figure. The simulated results for the normal incidence on the PEC plate show an RCS of 30.55 dBsm, thus agreeing with equation (2).

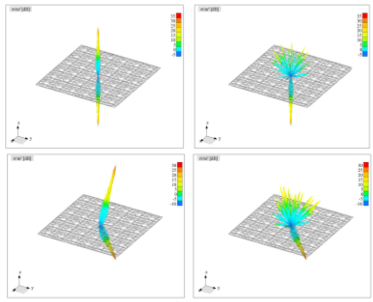

Figure 4. RCS of the 36 cm by 36 cm square plate (left side) and for the Metamaterial shown on Fig. 4 (right side). For θ=0° (top) and θ=30° (bottom)

Figure 5 shows that rather than absorption, these metamaterial absorbers work by redirecting the reflected power in different directions away from the specular direction

IV. Conclusions

The results have shown that the proposed metamaterial absorber in [2] works by minimizing the specular bounce, spreading the power into higher modes of propagation in the periodic structure. The work presented in this paper shows that equation (1) is not sufficient to compute the absorption if only the S_{11} for the first mode of the Floquet port is used. It is important to compute higher order modes, especially if the unit cell of the metamaterial is larger than λ at the frequencies of interest, since at those frequencies the higher order modes propagate.

References

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