Ultra-thin Electromagnetic Bandgap Absorbers Synthesized via Genetic Algorithms

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Abstract
A design methodology is presented for utilizing electromagnetic bandgap meta-materials, also known as artificial magnetic conductors, to realize ultra-thin absorbers. One approach that has recently been proposed is to place a resistive sheet in close proximity to a frequency selective surface acting as an artificial magnetic conductor. However, we demonstrate that incorporating the loss directly into the frequency selective surface can eliminate the additional resistive sheet, thereby further reducing the overall thickness of the absorber. A genetic algorithm is used to optimize the geometrical structure and corresponding resistance of the lossy frequency selective surface in order to achieve the thinnest possible design. Two examples of genetically engineered electromagnetic bandgap meta-material absorbers will be presented and discussed.

I. Introduction

A typical method of reducing the Radar Cross Section (RCS) of a structure is to coat the surface with some type of lossy material that can increase the absorption of electromagnetic waves at the operating frequency of the radar [1, 2]. To this end, there has been a considerable amount of interest over the years in the development of new design methodologies for lightweight, ultra-thin absorber coatings.

One of the most popular classical electromagnetic absorber design techniques is based on the use of so-called Salisbury screens [3]. This structure consists of a resistive metallic screen placed a quarter wavelength above a ground plane, separated by a dielectric. One advantage to such a design is the simplicity of the structure, while the main disadvantage is the relatively large thickness of a quarter wavelength, which can severely limit the physical applications of the absorber. Therefore it is highly desirable to find alternative design approaches that would lead to much thinner absorbers with comparable performance characteristics.

Recently it has been shown by Engheta [4] that the absorber thickness can be considerably reduced with respect to that of a standard Salisbury screen by using a Gangbuster Frequency Selective Surface (FSS) and a resistive sheet placed above the ground plane. When the FSS is placed close to the conductor backing, the structure acts as a High Impedance Frequency Selective Surface (HZ FSS) or Artificial Magnetic Conductor (AMC) over a narrow frequency band. In this case, a resistive sheet was placed just above the FSS screen to provide the necessary loss.

The designs presented here demonstrate the ability to reduce the complexity and thickness of the Gangbuster FSS [5] design by replacing the resistive sheet and Gangbuster FSS with a single lossy HZ FSS screen. These new HZ FSS absorber designs combine the advantages of an AMC structure with those of a thin resistive screen for considerably thinner absorber designs.

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II. Genetic Algorithm Approach

In this section an optimization methodology is introduced for synthesizing ultra-thin electromagnetic bandgap absorbers via lossy HZ FSS. Due to the complex nature of the problem, conventional optimization methods were not considered in favor of a more robust Genetic Algorithm (GA) approach. A similar GA technique was previously employed in [6] to successfully synthesize optimal HZ FSS designs for multi-band AMC surfaces. The result is a robust optimization procedure that can be used to design an ultra-thin resistive FSS structure with AMC and absorbing properties at the desired frequency. Due to the rather long convergence time that would be required for a conventional GA, a micro-GA was used in the actual optimization procedure [7]. The Fitness Function (FF) used in the micro-GA for synthesizing a lossy HZ FSS is given by

$$FF = \frac{1}{0.2\left|\phi_{\mathbf{max}} / 180\right| + 0.8\left|\Gamma_{\mathbf{max}}\right|} \tag{1}$$

where $|\Gamma_{max}|$ and ϕ_{max} are the maximum reflection coefficient magnitude and phase respectively.

III. Ultra-thin Absorber Design Examples

Two examples of genetically engineered ultra-thin electromagnetic bandgap absorbers will be presented and discussed for a normal incidence plane wave. The objective in the first case is to design an absorber centered at 6 GHz with a maximum dielectric substrate thickness of 5 mm, or about a tenth of a wavelength. The GA was used to synthesize a design with a unit cell size of 2.73 cm by 2.73 cm, a screen resistance of about 84 ohms, and a substrate permittivity of $\varepsilon_r = 6$. The FSS structure, including unit cell and screen geometry, is shown in Fig. 1. The magnitude and phase of the reflection coefficient for this lossy HZ FSS are shown in Fig. 2 assuming a normally incident electromagnetic plane wave. It can be seen from Fig. 2b that the phase of the reflection coefficient at 6 GHz is zero degrees indicating a high-impedance behavior.

While the tenth of a wavelength thickness yielded very good absorbing characteristics at the desired operating frequency, for certain applications this structure may still be considered too thick. As such, a second design example was synthesized via the GA, again for operation at 6 GHz. This time, however, the maximum substrate thickness was fixed at 1 mm, approximately one fiftieth of a wavelength. The optimal unit cell size in this case was found to be 3.54 cm by 3.54 cm, with a permittivity of $\varepsilon_r = 1.044$. The actual substrate thickness of the optimized structure was 0.952 mm, with an FSS screen resistance of 0.7 ohms. The unit cell and FSS screen geometry are shown in Fig. 3. The reflection coefficient magnitude and phase plots for this design are shown in Fig. 4. A comparison of Fig. 4 with Fig. 2 indicates that the thinner of the two absorbers has the narrower bandwidth.

IV. Conclusion

A robust GA optimization approach is presented for the synthesis of ultra-thin electromagnetic bandgap meta-material absorbers. Two examples of these genetically engineered absorbers have been shown which are considerably thinner than more conventional absorber designs, such as Salisbury screens. It has also been demonstrated that incorporating the loss directly into the FSS rather than placing a separate resistive sheet in close proximity to the FSS can reduce the overall thickness of the metamaterial absorber.

V. References

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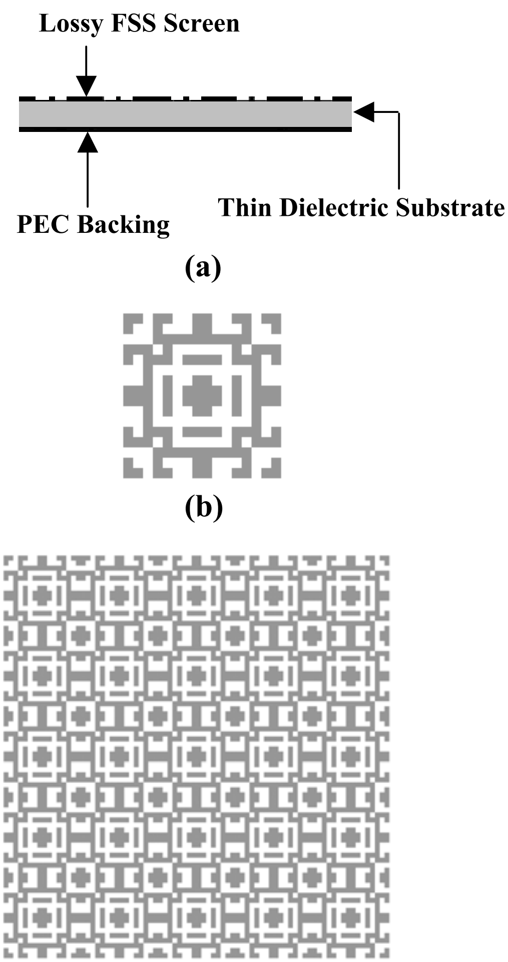
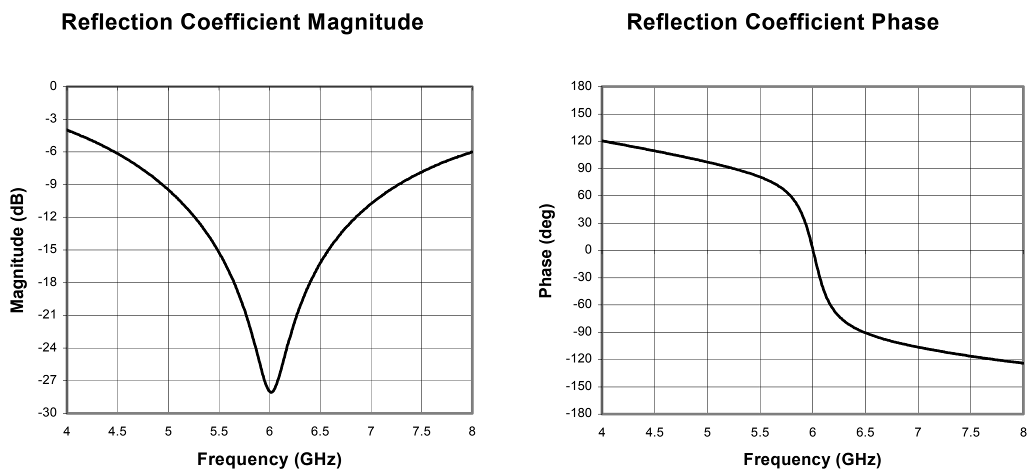


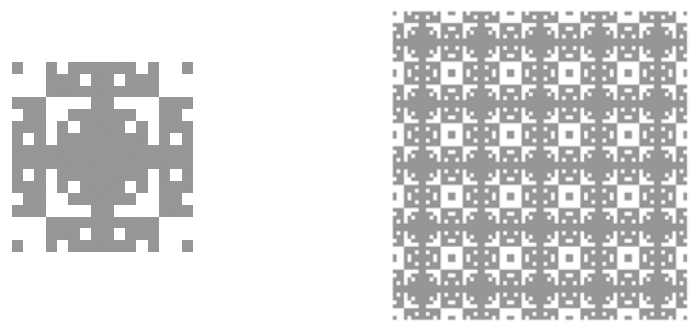
(c)

Fig. 1: Resistive FSS absorber structure and screen geometry for operation at 6 GHz. General resistive FSS absorber configuration (a), unit cell geometry for $\lambda/10$ design (b), and FSS screen geometry for $\lambda/10$ design (c).



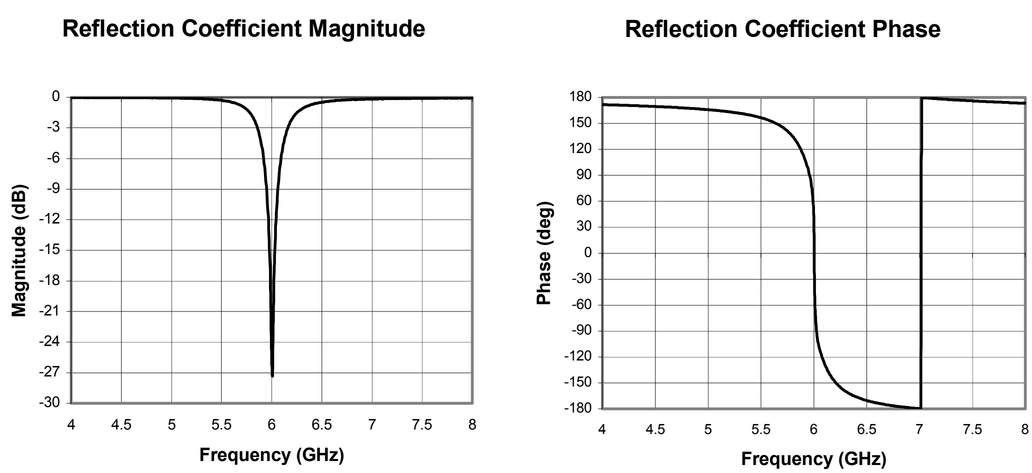
(a) **(b)**

Fig. 2: Reflection coefficient frequency response for λ/10 design. Magnitude of the reflection coefficient versus frequency (a), and reflection coefficient phase versus frequency (b).



(a) **(b)**

Fig. 3: Resistive FSS geometry for λ/50 design. Unit cell geometry for λ/50 design (a), and resistive FSS screen geometry for λ/50 design (b).



(a) **(b)**

Fig. 4: Reflection coefficient frequency response for λ/50 design. Magnitude of the reflection coefficient versus frequency (a), and reflection coefficient phase versus frequency (b).