A Robust GA-FSS Technique for the Synthesis of Optimal Multiband AMCs with Angular Stability

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Abstract – A Genetic Algorithm (GA) design methodology is presented for synthesizing multiband Artificial Magnetic Conductors (AMCs) with angular stability. The GA is used to optimize the Frequency Selective Surface (FSS) screen geometry and other design parameters for both multiband operation and stability with respect to the angle of illumination at each operating frequency. The design example presented demonstrates the multiband angular stability for a dual-band AMC at a GPS frequency of 1.575 GHz and a cell phone frequency of 1.96 GHz.

I. Introduction

Electromagnetic Bandgap (EBG) structures have recently been investigated for their use in the design of metamaterials that act as AMCs over a narrow frequency band with the ability to mitigate surface waves [1, 2]. Such a structure is useful in reducing the overall thickness of a conformal antenna design, as well as improving the performance of a printed antenna above the AMC [3]. More recently, robust GA techniques have proven very useful for designing AMC surfaces with optimal performance characteristics. In [4], a GA optimization scheme has been demonstrated for the synthesis of multiband AMC surfaces, including GPS and cell phone dual-band designs, among others. The specific AMC designs reported in [4] utilized a High-impedance Frequency Selective Surface (HZ-FSS) geometry consisting of a single substrate layer between the FSS screen and PEC ground plane, with no superstrate layer. In this case, the multiband GA-FSS design parameters include the unit cell geometry, the corresponding unit cell size, as well as the dielectric constant and thickness of the substrate material. An alternative approach to improving the AMC response is the use of a GA optimization procedure to ensure angular stability with respect to the incident angle of illumination over a single frequency band. By incorporating additional superstrate layers and optimizing each one individually, an angularly stable design can be achieved which maintains a nearly constant reflection phase with an incident angle as large as 80 degrees [5, 6].

This paper demonstrates that the advantages of both a multiband and an angularly stable design can be combined to achieve an AMC surface that is both multiband and angularly stable at each band by means of GA-optimized HZ-FSS structures. The specific structure to be used for this GA design process consists of a single FSS screen placed above a PEC ground plane, separated by a single substrate layer. Since no superstrate layer is used the resulting angularly stable multiband AMC designs reported here are relatively thin as well as capable of effectively suppressing surface waves.

II. Genetic Algorithm Strategy

Each parameter has been coded in a binary string to form a chromosome, representing the whole structure. The basic cell is subdivided into elementary pixels coded as 1s or 0s depending on whether they are covered by a printed metal element or not; the choice between symmetric or asymmetric shape is allowed. To evaluate the frequency and angular properties of the surface, an electromagnetic solver based on the Method of Moments (MoM) has been used. The evaluation criterion of the structure performance has been chosen as the root mean square difference between the actual

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and the desired electric field reflection coefficient for TE and TM modes; *i.e.,* $\Gamma_{E\ \mathrm{des}}$ = 1+j0, imposing separately this condition on both real and imaginary part. To improve angular stability, two analyses are performed, one in the frequency domain, and the other by varying the incidence angle at the central frequency for each band. A weighted mean is then performed between the relative fitness data, to get the global fitness value of the structure. This process is repeated for each band, and then the resulting fitness values are averaged to evaluate the global chromosome fitness. We can use both a standard single point crossover, and a new multi-point strategy that seems to be more efficient in the case of the multi-band optimizing operation, with a fixed probability *pcross* = 80%.

The specific GA adopted for use in this work employs a standard proportionate selection also called the weighted roulette wheel selection scheme. Moreover, to improve the algorithm speed of convergence, we can use a strong elitist strategy, building the initial population by using the best chromosomes of several trial populations; once the evolution has started, the next generations are created by inserting only new chromosomes showing fitness values lower than the older ones. Since a faster convergence might result in a loss of 'genetic information', prematurely removing overall unfit chromosomes that might however contain good genes, a linear variable mutation probability has been applied. The mutation operator is rarely present in the initial evolution stages, when crossover acts maximally to achieve a fast improvement of the populations; however, it begins to act when the fitness value settles. In our implementation, mutation probability *pmut* increases if two successive generations show the same fitness value. In particular, *pmut* increases linearly between a minimum value of 1% to a maximum value of 20% in 1% steps. If an improvement has been observed, *pmut* returns to its lower value.

III. Numerical Results

In this section the numerical results and the corresponding design are presented. The design specifications call for a positive unity reflection coefficient for the electric field in each frequency band, implying *in phase* total reflection for an incident plane wave impinging upon the surface. A symmetric shape, together with equal dimensions along the periodicity directions have been chosen for the FSS unit cell, ensuring nearly equal performance for TE and TM polarizations. The structure is composed by an FSS screen with a dielectric substrate placed on a PEC ground plane; a maximum value of 3 cm for the FSS unit cell dimensions and 0.5 cm for the substrate thickness have been imposed. The presence of the FSS as a top layer results in the limiting of surface wave propagation, an additional advantage of such a solution. An equal weight is assigned to the angular stability and frequency response in evaluating the fitness function. The operating frequencies for this design are 1.575 GHz and 1.96 GHz. A sample of the genetically optimized FSS screen obtained is shown in Fig. 1. The dimensions of the unit cell are $t_x = t_y = 2.6254$ cm. The dielectric substrate permittivity has been fixed to a value of $\varepsilon_r = 13$, and the dielectric thickness obtained by the GA is t = 0.4548 cm. The frequency performance of the dual band AMC structure is shown in Fig. 2. The relative bandwidths (defined as the frequency range in which the phase of the reflected field lies between ±90°) are 8.5% in the first band and 2.14% in the second. This design also exhibits a good angular stability with very low phase values up to an incidence angle of about 80° at each resonant frequency, as shown in Fig. 3. By examining the current distributions of the unit cell shown in Fig. 4, it can be noted that in the lower frequency band the "loaded" square loops that appear in the center of the unit cell are the main resonant elements, while for the higher band the contribution of the side elements is the dominant factor. Finally, to emphasize the robustness of the optimization, it should be noted that the GA was able to reach convergence in 850 generations, using linearly variable mutation probability, a multi-point crossover and a strong elitist strategy, for a computing time of about 12.4 hours on an Athlon™ XP 2000+ processor PC.

IV. Conclusions

The design presented in this paper demonstrates the ability to successfully combine angular stability and multiband performance to achieve a practical AMC design. The GA optimization is robust in that the selection strategies and mating techniques are continuously altered as the optimization proceeds. An example was presented that demonstrates how the GA-FSS technique can be used to successfully obtain a multiband solution that exhibits angular stability without imposing any additional physical complications to the design of an EBG surface.

Acknowledgements

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V. References

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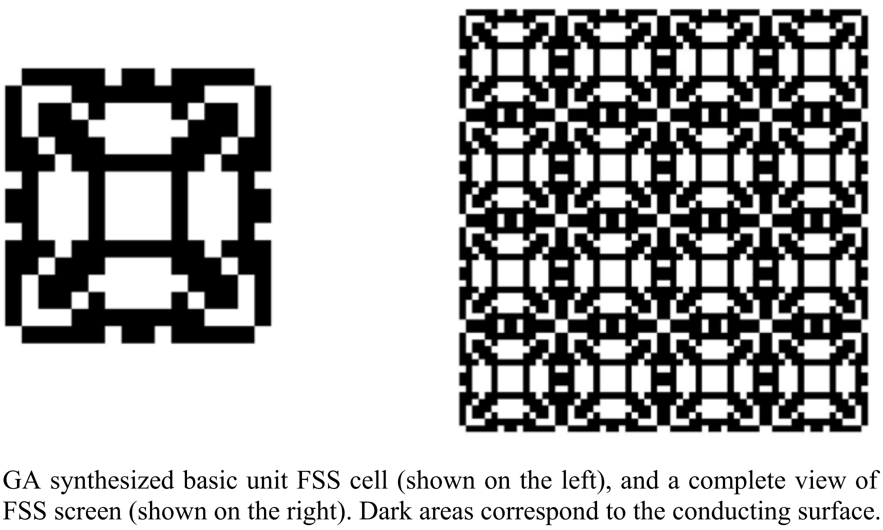

Fig. 1: GA synthesized basic unit FSS cell (shown on the left), and a complete view of the FSS screen (shown on the right). Dark areas correspond to the conducting surface.

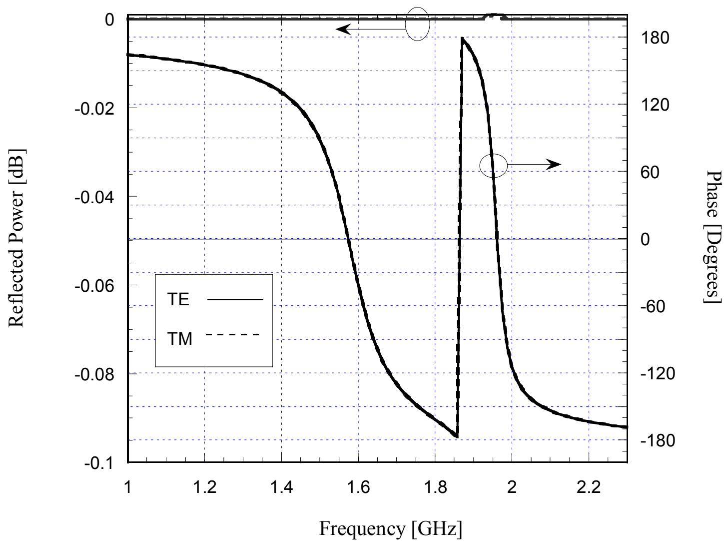

Fig. 2: Frequency response of the synthesized structure shown in Fig. 1. Frequency analysis is performed near normal incidence (θ=ϕ=3°).

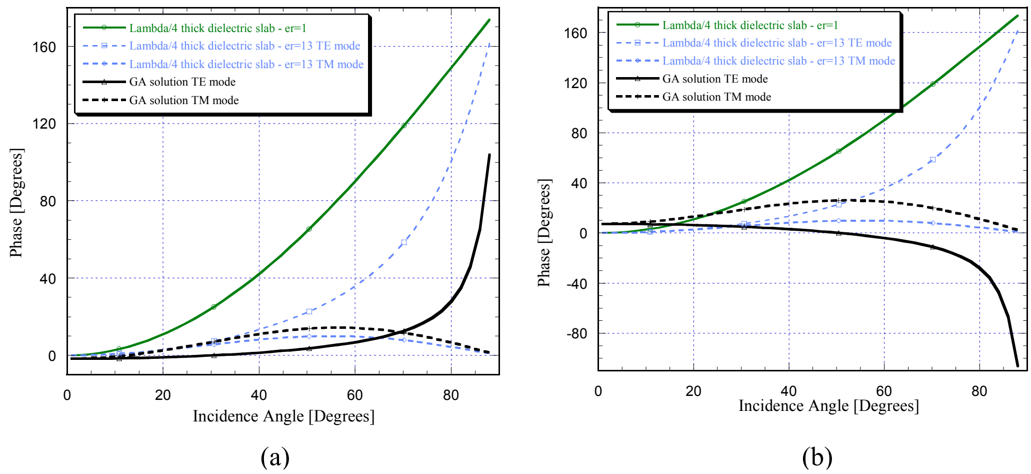

Fig. 3: Angular properties of the synthesized structure shown in Fig. 1, at f_1=1.575 GHz (a) and f_2=1.96 GHz (b). Both of these analysis are performed for an azimuth angle ϕ = 3°. A comparison is made between GA solution and two λ/4 dielectric slabs backed by a PEC with permittivity ε_r=1 and ε_r=13, respectively.

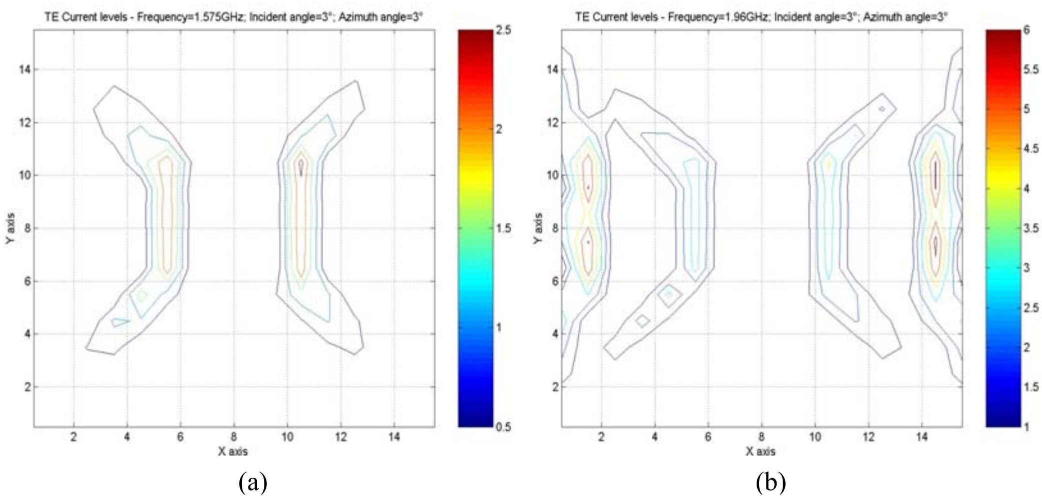

Fig. 4: Current distributions for TE case at 1.575 GHz (a) and at 1.96 GHz (b).