ADVANCES IN EBG DESIGN CONCEPTS BASED ON PLANAR FSS STRUCTURES

D. H. Werner [(1)], D. J. Kern [(1)], and M. G. Bray [(1)]

[(1)] Department of Electrical Engineering
The Pennsylvania State University
University Park, PA, USA 16802
dhw@psu.edu, djk189@psu.edu, mgb144@psu.edu

Abstract
This paper presents an overview of the various applications of planar Frequency Selective Surfaces (FSS) to the synthesis of Electromagnetic Bandgap (EBG) structures that act as metamaterials, such as Artificial Magnetic Conductors (AMCs). Over the past few years, many designs such as single- and dual-band AMC surfaces, tunable AMC surfaces, angularly stable AMC surfaces, ultra-thin EBG absorbers, and EBG metaferrite materials, to name a few, have been investigated and developed successfully at the Pennsylvania State University (PSU) Computational Electromagnetics and Antennas Research Lab (CEARL) [1]. Additionally, the most current research presented here examines the ability to utilize an EBG AMC surface to realize a low-profile conformal antenna system that is tunable over an octave bandwidth from 1.2 to 2.3 GHz. An overview of both the previous work and the current EBG with antenna designs will be presented here.

I. Introduction
Over the past few years, much of the research conducted at CEARL has focused on the area of Genetic Algorithm (GA) optimization as it applies to the design of antennas and other novel electromagnetic devices. Another area of active research has been the incorporation of planar FSS structures in the design of electromagnetic metamaterials. Of particular interest here is the class of metamaterials known as Electromagnetic Bandgap (EBG) surfaces. Such structures have an intrinsic narrowband region where the overall response of the device mimics that of a Perfect Magnetic Conductor (PMC), with a reflection coefficient magnitude and phase of 1 and 0° respectively. This surface is also called an AMC because it is a metamaterial that exhibits the properties of a magnetic conductor at the resonant frequency of the FSS structure.

Recently, it was demonstrated how a GA could be used as a powerful tool for the design optimization of FSS in order to synthesize a metamaterial with a desired EBG AMC behavior [2]. For instance, a GA was used to optimize the geometry of an FSS to obtain single- or dual-band AMC ground plane designs. These results prompted the inclusion of the GA into the FSS design process for many different applications, several of which are detailed below. The dual-band AMC ground plane design was particularly interesting because it demonstrated the ability to optimize for multiple resonances from a single FSS structure. The first design presented in this paper illustrates the GA optimization procedure applied to evolving a dual-band AMC ground plane that operates at the frequencies of 1.575 GHz and 1.96 GHz, for potential use in GPS and cellular applications [2].

Many variations on the theme of multi-band or broadband AMC operation have been designed using EBG surfaces. Another application is the use of EBG optimization to create angularly stable structures, such that the EBG surface retains its AMC reflection properties over a wide range of incidence angles [3]. The optimization procedure can be taken a step further, to create a tunable EBG surface through the introduction of tunable dielectric substrate materials. Additionally, it has been shown that by including relatively large ohmic and/or dielectric losses into the structure it is possible to design an electromagnetic absorbing surface [4]. Furthermore, by utilizing a GA optimization procedure, the thickness of the absorbing structure can be reduced to as thin as λ/100 or more, resulting in an ultra-thin, lightweight electromagnetic absorber.

The GA optimization procedure has also been expanded to include magnetic loading of the substrate in the EBG design. By allowing for a magnetic substrate material, previous designs could be revisited to determine what benefits such a substrate could provide. Many previous designs were resimulated with magnetically loaded substrates, such as the single- and dual-band AMC surfaces, as well as ultra-thin electromagnetic absorbers [5]. It became evident that by introducing a certain degree of magnetic permeability into the substrate, an increase in the operating bandwidth could be achieved [6]. Similarly, investigations where a small amount of magnetic loading was introduced into the design of electromagnetic absorbers have determined that it is possible to reduce the thickness of the absorbers even further than before, thus allowing for lighter weight and even thinner designs.

The GA optimization procedure was further generalized to include the design of metamaterial ferrites, which we call metaferrites. Metaferrites are EBG structures that act as thin PEC-backed ferrite or magnetic substrate materials over a particular bandwidth of operation [7]. The GA has proved to be an essential tool in the design synthesis of metaferrite materials. Finally, EBG surfaces have also been considered for use as AMC ground planes for low-profile and tunable antenna applications [8]. The second design that will be discussed in this paper consists of a broadband linearly polarized antenna optimized via a genetic algorithm, and placed above a tunable AMC ground plane.

II. Genetic Algorithm Optimization

A Genetic Algorithm is a robust optimization procedure based on natural selection and survival of the fittest [9]. In the case of the EBG structures, the use of a GA allows for simultaneous optimization of the FSS unit cell size and geometry as well as the dielectric constant and thickness of the substrate material. Furthermore, multiple frequency points can be incorporated easily into the optimization, as well as ohmic and dielectric losses. Multiple FSS layers can also be incorporated into the GA procedure to create a very robust and flexible process for EBG optimization.

III. Dual-band EBG AMC Surface

The first example presented is a dual-band GPS/cellular EBG AMC FSS ground plane synthesized using a GA. This design was optimized for operation at 1.575 GHz and 1.96 GHz, the GPS L1 frequency and an arbitrary cellular frequency. This structure, which was also fabricated and tested, represents the first example of GA-designed high impedance FSS to achieve such a dual-band response. The fabricated EBG surface is shown in Fig. 1. A plot of the simulated versus measured reflection phase for this design, as well as the unit cell geometry, is shown in Fig. 2. The reflection phase plot illustrates that the targeted resonant frequencies were achieved, with a percent bandwidth of 4.43% at 1.575 GHz and 2.2% at 1.96 GHz. The phase plot also shows very good agreement between the Periodic Moment Method (PMM) simulation and the measurements of the actual fabricated surface. It should be noted that the GA-designed high impedance FSS must transition from a PEC to a PMC condition and back again over a small frequency range, thus effectively limiting the PMC bandwidth. In this case, however, there is still sufficient separation between the bands, as the surface will act as a PEC between about 1.65 and 1.9 GHz.

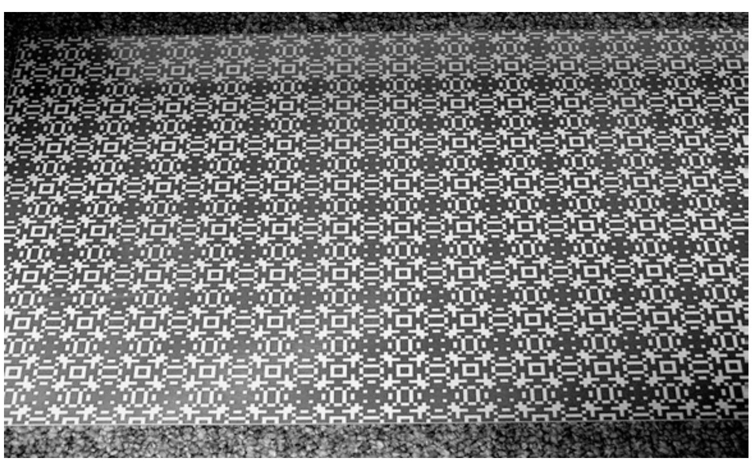

Figure 1: A photograph of the actual GA-designed high impedance FSS ground plane that was fabricated and tested for GPS and cellular operation.

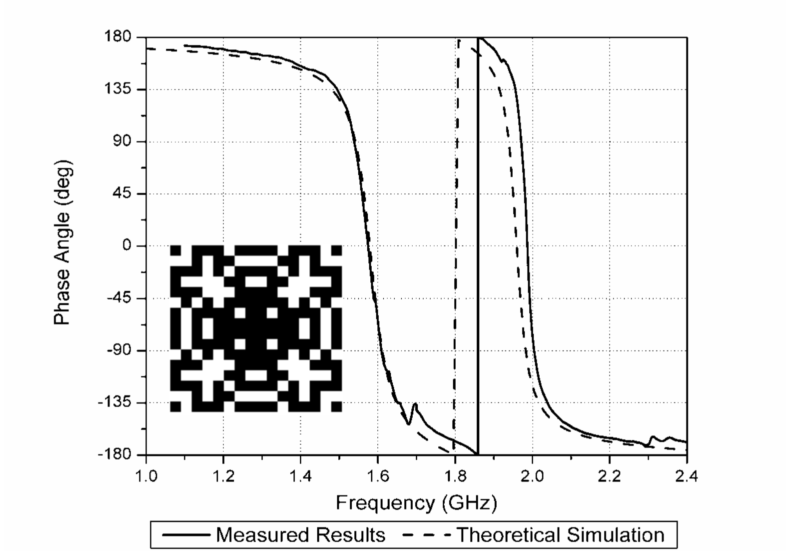

Figure 2: Simulated versus measured reflection coefficient phase for the dual-band GPS and cellular GA-designed high impedance FSS. The FSS unit cell geometry is shown as an inset on the reflection phase response plot.

IV. Varactor-tuned EBG Design with Antenna

A design using a varactor-tuned EBG surface together with a broadband planar antenna is presented next [10]. A planar version of the conventional open-sleeve cylindrical wire dipole was used for a broadband linearly polarized antenna element. Fig. 3 shows the geometry of the planar open-sleeve dipole placed in free space 5 mm above a tunable EBG surface. The tunable EBG surface consists of a 6x6 array of metal patches on top of a 3.6 mm thick PEC-backed dielectric substrate with $\varepsilon_r = 13$. Thin metal wires with a radius of 0.16 mm connect the metal patches with tunable capacitors located at the center of each wire. The placement of the antenna above the EBG surface was chosen by tuning the surface to 2.0 GHz and evaluating the return loss for several different antenna positions. A height of 5 mm was found to provide the best compromise between return loss and antenna system thickness.

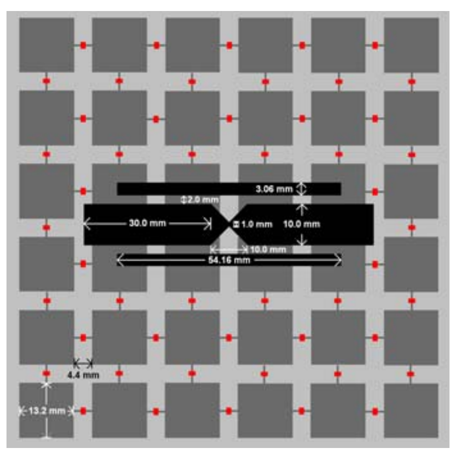

Figure 3: Geometry of the broadband open-sleeve dipole over a narrowband tunable EBG.

Fig. 4 shows the return loss of the entire antenna system (including the EBG AMC ground plane) in combination with the reflection phase of the EBG surface for several different capacitive loads. For comparison purposes, the reflection phase has the 10 dB bandwidth of the corresponding return loss superimposed on each curve. The antenna is tunable from 2.3 GHz down to 1.2 GHz, resulting in an octave bandwidth. It is interesting to note that the best match for the antenna/EBG system occurs in the region from –100° to –150° at the upper frequency limit and then shifts up from 100° to 25° at the lower frequency limit (not shown).

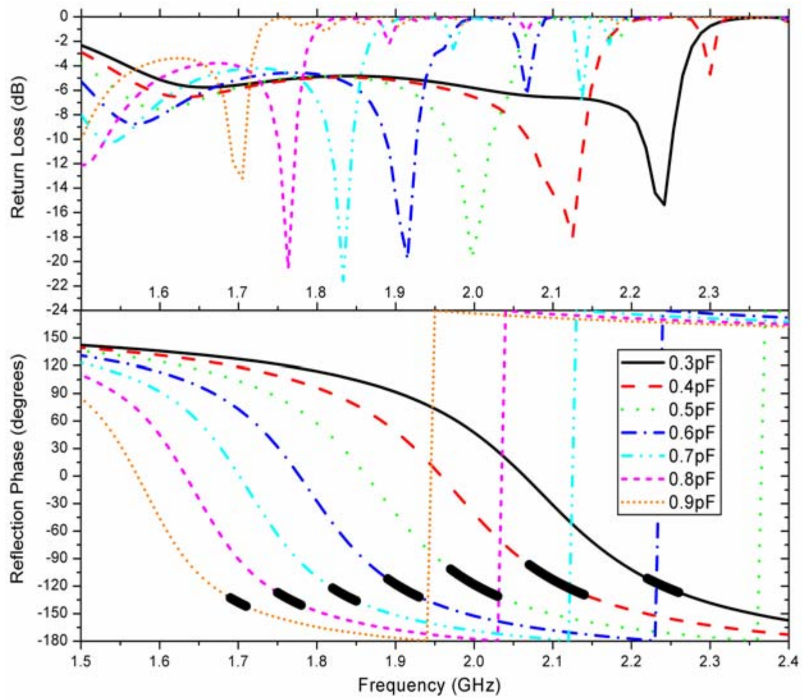

Figure 4: Antenna return loss and EBG surface reflection phase.

V. Conclusions

The designs presented in this paper demonstrate the flexibility of using planar FSS to create many different types of EBG metamaterials, whose performance can be optimized using a GA. Various applications of EBG FSS structures were discussed including multi-band designs, angularly stable designs, tunable EBG surfaces and AMC ground planes, ultra-thin absorbing structures, magnetic loading of EBG surfaces, and metaferrites.

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