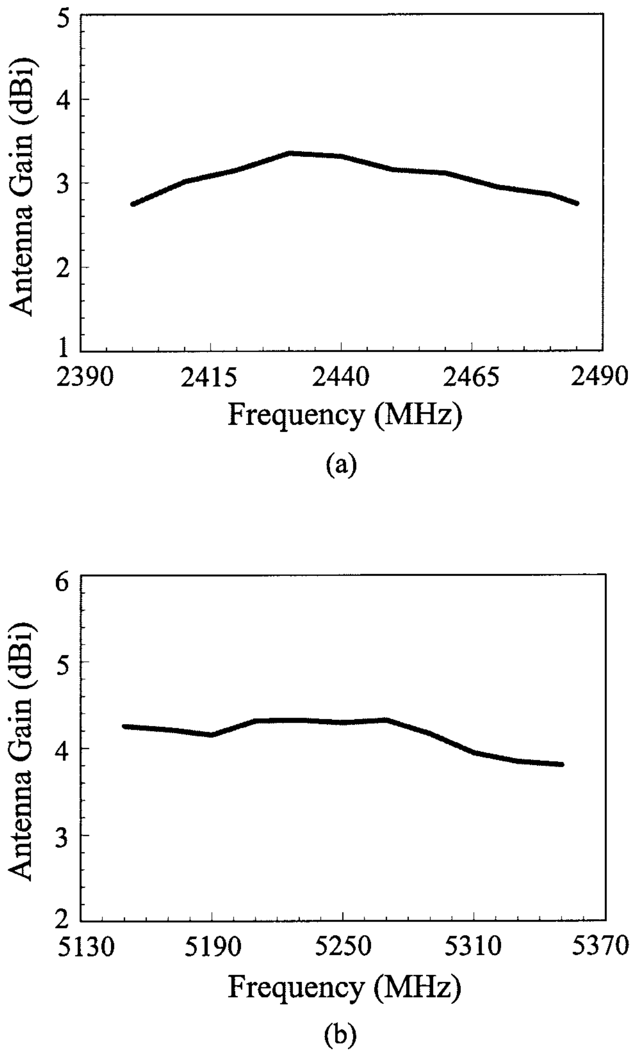

Figure 5 Measured peak antenna gain: (a) 2.4-GHz band (2400–2484 MHz); (b) 5.2-GHz band (5150–5350 MHz)

structed prototype has been obtained. The proposed antenna is very suitable to fit in any possible narrow space inside the housing of a wireless communication device, thus leading to an internal antenna for WLAN operation.

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GENETICALLY ENGINEERED MULTIBAND HIGH-IMPEDANCE FREQUENCY SELECTIVE SURFACES

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ABSTRACT: *A methodology is presented for the design synthesis of metamaterials that act as thin multifrequency artificial magnetic conductors. These structures are realized by placing a frequency-selective surface above a conventional prefect electric conductor, separated by a thin dielectric layer. The frequency-selective surface design is optimized using a micro-genetic algorithm to operate at multiple, narrow frequency bands. Two examples of genetically engineered multiband high-impedance frequency-selective surfaces (that is, artificial magnetic conductors) are presented and discussed.* © 2003 Wiley Periodicals, Inc. Microwave Opt Technol Lett 38: 400–403, 2003; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11073

Key words: *artificial magnetic conductor; electromagnetic bandgap material; frequency-selective surface; genetic algorithm; high-impedance surface; metamaterials*

1. INTRODUCTION

Recently, there has been an interest in developing materials that exhibit novel electromagnetic properties not found in nature. Such structures, known as metamaterials, are deliberately designed to function in ways that ordinary bulk-scale materials cannot. Some examples of microwave metamaterials include left-handed materials [1], electromagnetic bandgap materials [2], and chiral media [3]. The focus of this paper will be on the development of a design synthesis methodology for thin multiband artificial magnetic conductors (AMCs), which represent an important subclass of electromagnetic bandgap metamaterials.

An ideal AMC, or perfect magnetic conductor (PMC), is a surface that exhibits a reflectivity of $+1$, as opposed to a perfect electric conductor (PEC), which has a reflectivity of -1. Strictly speaking, the AMC condition is characterized by the frequency or frequencies where the phase of the reflection coefficient is zero degrees (that is, where the reflected wave is in phase with the incident wave). By placing a frequency-selective surface (FSS) very close to a PEC ground plane, the structure will exhibit a high impedance at certain narrow frequency bands, and will function as a multiband AMC. The geometry for one of the first high-impedance FSS (HZ FSS) designs considered by Yang et al. [2] is shown in Figure 1. In this case, the HZ FSS was designed for an AMC condition at approximately 18 GHz. The potential applications of such an HZ FSS include use as ground planes for low-profile conformal antennas [4], suppression of undesirable surface waves [3], enhancement of the performance of waveguide structures [5], or even use as thin absorbing screens [6].

The multiband AMC structures introduced here have application in the communications sector as critical components in low-profile multiband antenna systems. In many cases, when a single antenna is required to cover multiple bands, it is preferable to have an antenna frequency response consisting of multiple narrow bands as opposed to a single wideband response, in order to meet system-selectivity requirements. By combining multiband AMC

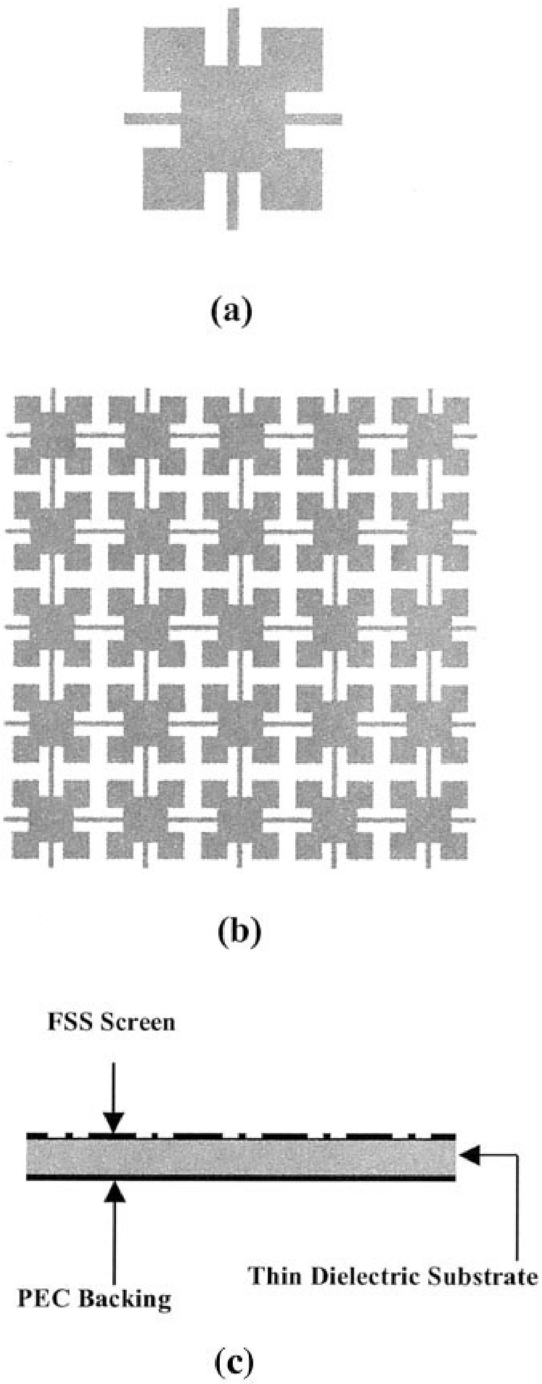

Figure 1 Original high-impedance surface design proposal by Yang et al. [2]: (a) unit cell geometry for original HZ FSS design; (b) doubly periodic HZ FSS screen; (c) composite HZ FSS structure consisting of a PEC ground plane, thin dielectric layer, and FSS screen

technology with a multiband or wideband antenna, it becomes possible to realize designs for thin low-profile multiband antenna systems that exhibit out-of-band (OOB) rejection capability.

2. UNIT CELL GEOMETRY

The equivalent circuit model for the structure shown in Figure 1 can be explained by examining the geometry of the unit cell. The thin conducting lines connecting adjacent cells give rise to an inductive component. The capacitive component consists of the one central square patch with four additional patches connected to the corners of the center patch. Thus, the structure can be viewed as behaving like a parallel-tuned LC circuit, with a resonant frequency given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}, \tag{1}$$

where L and C are the equivalent inductance and capacitance, respectively, associated with the FSS screen. This resonant frequency is precisely where the high-impedance and AMC conditions occur. By altering the unit cell geometry, the values for L and C, the resonant frequency can be modified accordingly. Previous research has been concerned with the primary resonant frequency for various cell geometries. However, by using a method of moments (MoM) code to simulate the structure in Figure 1, higher resonant frequencies were shown to exist. The frequency response, along with the active region of the unit cell geometry, is shown in Figure 2. As can be seen in the figure, the original structure actually has three resonant frequencies. Each frequency corresponds to a different capacitive portion of the unit-cell geometry. At the lowest frequency, the entire unit cell contributes to the overall capacitance. However, at the higher frequencies, only portions of the unit cell contribute to the capacitance of the structure, as shown in Figure 2. Investigation of this effect leads to the important question of whether a unit cell can be synthesized that will resonate at multiple desired frequencies chosen by the designer. Such a task is well suited to a genetic algorithm (GA), as it involves optimization of the cell geometry, as well as the dielectric constant and thickness of the substrate material.

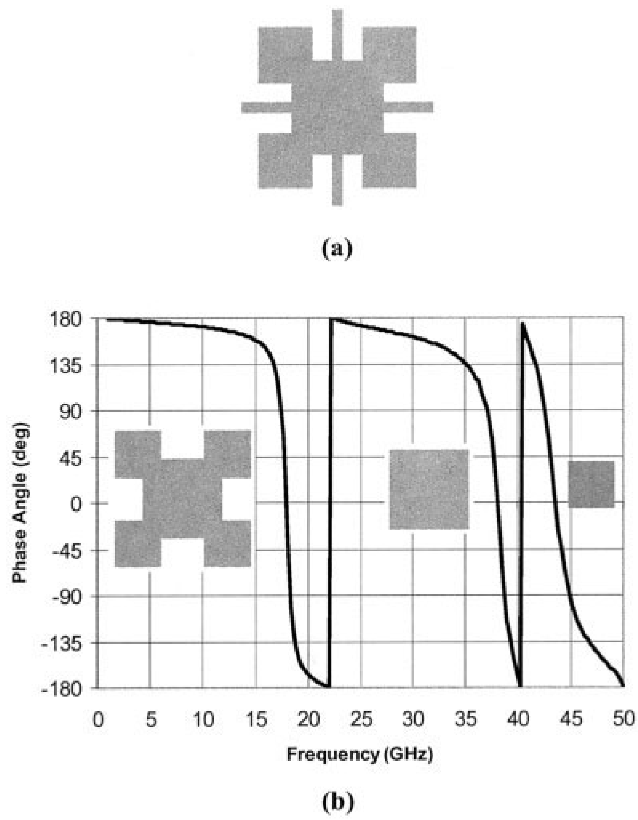

Figure 2 Reflection-coefficient phase response of original high-impedance surface design: (a) unit cell geometry; (b) reflection-coefficient phase response showing corresponding active region of unit cell capacitance for each resonant frequency

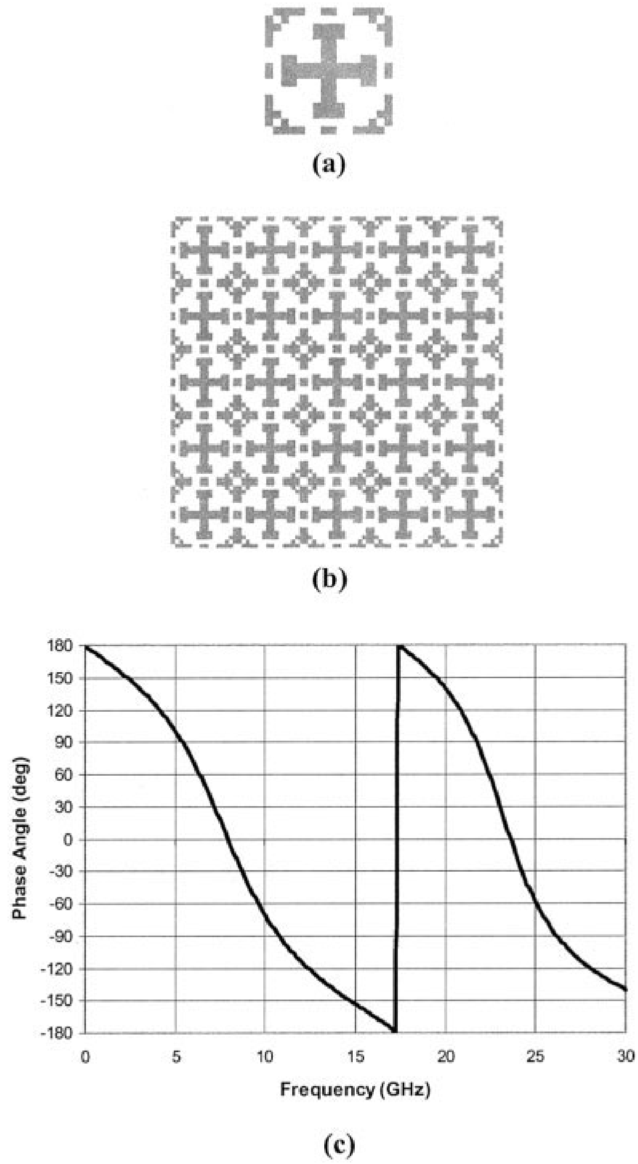

Figure 3 Dual-band HZ FSS design for operation at 8 and 23 GHz: (a) dual-band HZ FSS unit cell geometry; (b) HZ FSS screen; (c) reflection-coefficient phase response

3. GENETIC ALGORITHM DESIGN

When designing HZ FSS structures, it is possible to synthesize designs by using some physics-based reasoning combined with a trial-and-error approach. However, following this type of procedure does not generally lead to optimal configurations. For this reason, we introduce a GA approach, which is capable of simultaneously optimizing the unit cell size and geometry as well as the dielectric constant and thickness of the substrate material [7]. In fact, the GA approach will result in a much smaller cell size and/or a thinner substrate, as compared to what can be achieved via a trial-and-error approach. The main drawback in such an optimization scheme is the rather long convergence time of a GA as compared to more conventional but less robust optimization schemes. Therefore, to reduce the time it takes to complete the optimization cycle, a micro-GA was used rather than a conventional GA for the designs presented here. A micro-GA operates on a much smaller population of chromosomes, thereby considerably reducing the required computation time [8]. The fitness function evaluates the phase of the reflection coefficient at each frequency of interest, with an optimum phase of zero degrees. The designs utilized an eight-fold symmetric unit cell, thus giving the same response for both TE and TM incident waves. The first design was optimized to act as an AMC for a normally incident plane wave at frequencies of 8 and 23 GHz. The unit cell size was found to be 2.6 mm on each side, with a dielectric constant of 2.98, and a substrate thickness of 5 mm. The unit cell and FSS screen geometries, along with the reflection coefficient phase response, are shown in Figure 3. Next, the micro-GA synthesis technique is applied in order to design a triband HZ FSS. This design is optimized for an AMC condition, again at normal incidence, for frequencies of 3.5, 11, and 18 GHz. The geometry and reflection coefficient phase response are shown in Figure 4, which indicates good correspondence between the desired and actual AMC frequencies. The cell size for this design is 3.4 mm on each side, with a dielectric constant of 14, and a substrate thickness of about 5 mm.

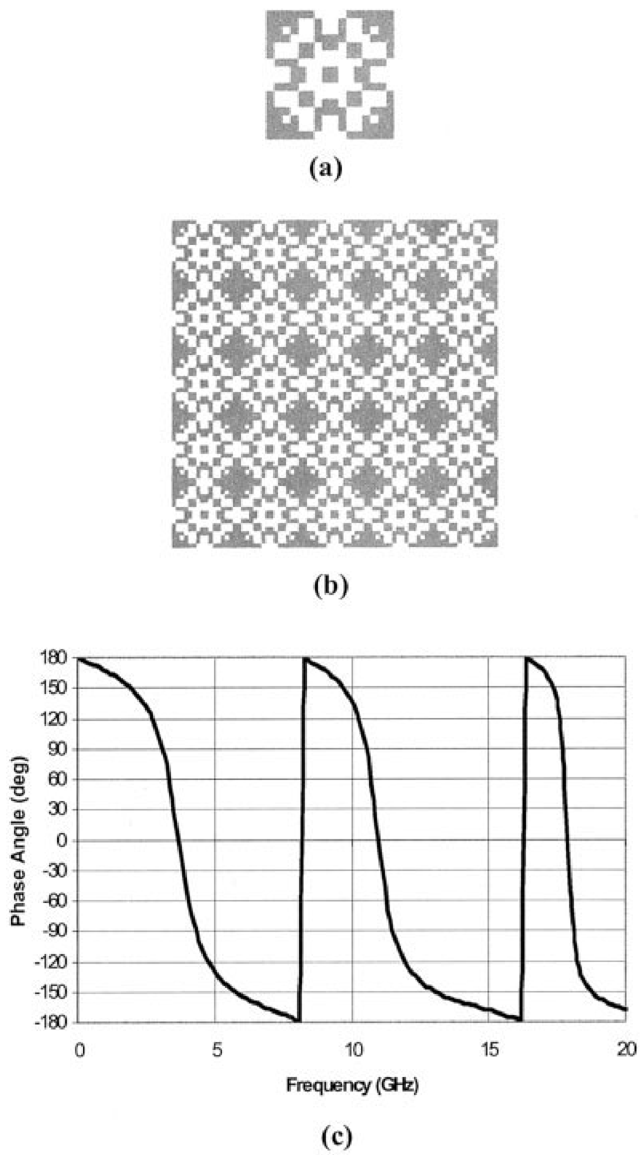

Figure 4 Tri-band HZ FSS design for operation at 3.5, 11, and 18 GHz: (a) tri-band HZ FSS unit cell geometry; (b) HZ FSS screen; (c) reflection-coefficient phase response

4. CONCLUSION

A micro-GA optimization technique has been introduced for the design synthesis of multiband HZ FSS. The micro-GA allows for efficient simultaneous optimization of multiple narrow-frequency bands by modifying the unit-cell size, geometry, dielectric permittivity, and substrate thickness. Two examples have been presented that demonstrate the versatility of the GA optimization technique for thin multiband HZ FSS.

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NEAR FIELDS EVALUATED WITH THE WAVE CONCEPT ITERATIVE PROCEDURE METHOD FOR AN E-POLARISATION PLANE WAVE SCATTERED BY CYLINDRICAL STRIPS

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ABSTRACT: *The wave concept iterative procedure (WCIP), already improved for planar circuits, is developed in this paper for cylindrical structures. The WCIP method has been applied with success to the scattering of an E-polarisation plane wave on cylindrical strips. The results are in good agreement with previous works in the literature, and the calculation time involved is quite reasonable.* © 2003 Wiley Periodicals, Inc. Microwave Opt Technol Lett 38: 403–406, 2003; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.11074

Key words: *scattering from cylindrical strips; WCIP method; development in cylindrical basis*

INTRODUCTION

With the development of inboard antennas, accurate simulations must be made to validate models in order to obtain efficient prototypes. Using this principle the wave concept iterative process (WCIP), already improved for planar circuits [1, 2], has been extended to cylindrical substrate structures [3]. This integral method is based on local tangent-wave interactions and implies the definition of an equivalent circuit of the structure under study [1]. After a brief introduction of its principles, the method is applied in this paper to the example of an E-polarisation plane wave scattered by two circular conducting strips.

WCIP PRINCIPLES

The WCIP, based on local tangent waves [1–3], is defined from the electric and magnetic tangent fields by Eq. (1) as

$$\begin{cases} \vec{A} = \dfrac{1}{2\sqrt{Z_0}}(\vec{E}_T + Z_0\vec{H}_T \wedge \vec{n}) \\ \vec{B} = \dfrac{1}{2\sqrt{Z_0}}(\vec{E}_T - Z_0\vec{H}_T \wedge \vec{n}) \end{cases}, \quad (1)$$

where $\vec{A}$ are waves reflected or emitted from the surface, $\vec{B}$ are waves incident on the surface, Z_0 is an arbitrary impedance (usually chosen as the free space intrinsic impedance when $\varepsilon_r = 1$), $\vec{n}$ is the outward vector normal to the surface, and $\vec{E}_T$ and $\vec{H}_T$ are the fields tangent to the surface.

Two operators achieve the relations between these waves, and both are defined from the structure surface as follows.

The scattering operator is defined in the spatial domain and takes into account boundary conditions. It links the waves between the two different domains separated by the surface considered, for example, the cylinder (C) as shown in Figure 1(b):

$$\begin{pmatrix} \vec{A}_1 \\ \vec{A}_2 \end{pmatrix} = \hat{S}\begin{pmatrix} \vec{B}_1 \\ \vec{B}_2 \end{pmatrix}. \quad (2)$$

The reflection operator is defined in the spectral domain and takes into account the environment reactions. It links the incident and reflected waves in the same domain:

$$\vec{B}_i = \hat{\Gamma}\vec{A}_i. \quad (3)$$

The fast modal transform (FMT) and its inverse (FMT^{-1}) assure the translation from one domain to another. In fact, the WCIP method implies the determination of an equivalent electric scheme of the structure considered, which involves the scattering and reflection operators.

WCIP APPLIED TO CYLINDRICAL SURFACE SCATTERING

Two cylindrical perfectly conducting surfaces in free space, shown in Figure 1(a), are illuminated by an E-polarisation plane wave with an incident angle of $\varphi_{inc} = -90°$, given by