Electromagnetic Modeling of Quasi-Square Open Metallic Ring Frequency Selective Surface Using Wave Concept Iterative Procedure

Mohammed Titaouine, Nathalie Raveu, Alfrêdo Gomes Neto, and Henri Baudrand

ABSTRACT—The wave concept iterative procedure (WCIP) is used to analyze a quasi-square open metallic ring frequency selective surface (FSS). The quasi-square open metallic ring FSS is dual-polarized. When the incident plane wave is polarized in a direction parallel to the FSS' coupled parallel strips, it shows two rejecting bands. Moreover, another rejecting band can be obtained if the source plane wave is perpendicularly polarized with respect to the FSS' coupled parallel strips. The three resonant frequencies are inversely proportional to the length of the FSS' coupled strips to provide an easy fine tuning of the FSS structure. The simulated results obtained using WCIP are compared to the measured results, and a good agreement is reported.

Keywords—WCIP, quasi-square open metallic ring FSS, guide length, FFT, FMT, dual frequency operation.

I. Introduction

A frequency selective surface (FSS) is a planar periodic structure acting as a filter and exhibiting a spectral selectivity that depends on the polarization of the incident wave, the geometry of the planar circuit, and the spacing between the elements within the FSS structure [1]. FSSs find widespread applications in microwave, millimeter wave, and infrared devices. They are employed as bandpass filters related to the design of photovoltaic cells [2], antennas, and radomes [3]. For multiband applications, FSSs may be implemented using concentric rings because a resonant frequency is added for every added ring. A dual-band FSS based on two concentric square metallic rings and a triple-band FSS based on three concentric circular metallic rings are presented in [4] and [5], respectively. If an FSS with a tunable resonant frequency is desired, diodes may be inserted [6].

In this work, the quasi-square metallic ring FSS is presented. It supports dual polarization applications; thus, it can be used for mono-band applications and dual-band applications, and it has the capability of fine tuning the bands. The wave concept iterative procedure (WCIP) detailed in [7] for FSS analysis is used to simulate the FSS electromagnetic behavior. The obtained results are in a good agreement with the measurements performed on an array of 10×10 unit cells.

II. WCIP Formulation

The analysis of an FSS structure is reduced to that of the FSS unit cell because the WCIP considers an FSS a periodic structure in which the unit cells are separated from each other by fictive walls called periodic walls. The quasi-square open ring FSS is shown in Fig. 1. The periodic walls are represented by dashed lines in Fig. 1(b), which shows the FSS unit cell.

The WCIP iterative process is based on transverse waves given in [8] by

$$\vec{A}_i = \left(1/2\sqrt{Z_{0i}}\right)\left(\vec{E}_i + Z_{0i}\,\vec{J}_i\right)\ ,\quad \vec{B}_i = \left(1/2\sqrt{Z_{0i}}\right)\left(\vec{E}_i - Z_{0i}\,\vec{J}_i\right), \tag{1}$$

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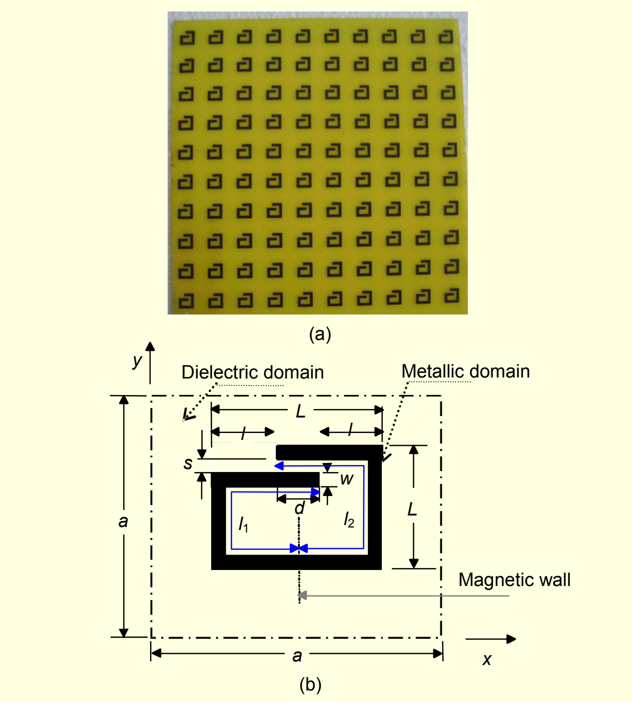

(a)

(b)

Fig. 1. Quasi-square open metallic ring FSS: (a) realized FSS with an array of 10×10 unit cells and (b) FSS unit cell geometry and dimensions.

where $\vec{E}_i$ and $\vec{J}_i$ are, respectively, the tangential electric field and current density at the interface in the side of the medium *i*.

The iterative process converges independently of the planar circuit because bounded operators are involved [8]. With $\vec{A}$ and $\vec{B}$ being the incident waves and the diffracted waves respectively, the iterative process can be summarized into two main steps given as in [7] and [8] by

$$\vec{B} = \hat{S}_\Omega \vec{A} \quad \text{and} \tag{2}$$

$$\vec{A} = \hat{\Gamma} \vec{B} + \vec{A}_0, \tag{3}$$

where $\vec{A}_0$ is the normally incident source plane wave.

The diffraction operator $\hat{S}_\Omega$ is developed from the geometry of the planar structure and the boundary conditions at the interface as explained in [7]. Since the adopted reflection operator $\hat{\Gamma}$ is defined in the modal domain, the diffracted waves must be projected into the complete basis of the periodic walls' box modes. Thus, a fast modal transform (FMT) [7] which permits going from the spatial domain to the modal domain and back to the spatial domain is necessary.

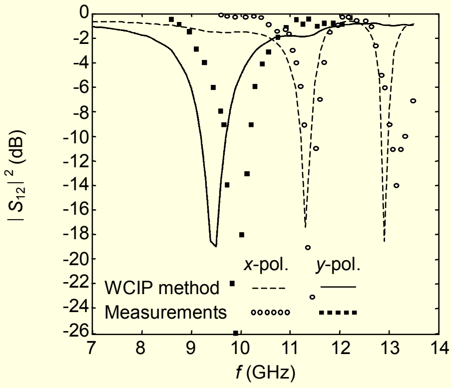
III. Simulation and Measurements

The data acquisition system used for measurements consists of an Agilent two-port microwave network analyzer N5230A and horn antennas with 12 dB gain. The measurements are done on FSSs of arrays with 10×10 unit cells as shown in Fig. 1. The FSS dimensions are a=20 mm, L=10 mm, and w=s=2 mm. The quasi-square metallic rings of the FSS are made of copper and etched on a fiberglass (FR-4) substrate 1 mm thick with a dielectric constant of 4 using printed circuit board (PCB) technology. In all the measurements, all the dimensions are maintained except length d of the parallel coupled strips. Because of the asymmetry of the structure, the FSS can be fed with a normally incident plane wave using x-polarization and y-polarization. The WCIP results are obtained as the interface of the quasi-square open metallic ring FSS unit cell is meshed with a grid of 60×60 square pixels, and the iterative process is stopped after 600 iterations.

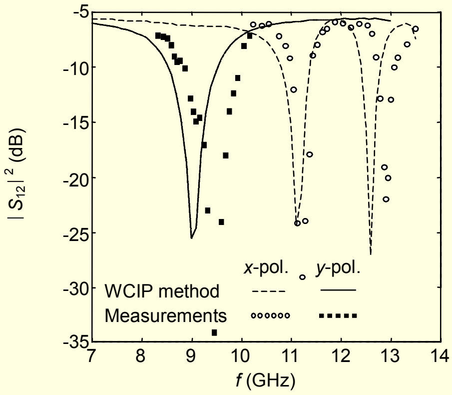
Figure 2 shows the computed and measured transmission power of the quasi-square open metallic ring FSS when an x-polarized normally plane wave is normally incident on the FSS but for different lengths of the coupled strips. When all the FSS dimensions are maintained but the length of the coupled strips is varied from 0 mm to 3 mm, the resonant frequencies are from 11.45 GHz to 10.93 GHz for the lower resonant frequency and from 13.17 GHz to 12.32 GHz for the higher resonant frequency. With x-polarized excitation, the FSS has a y-directed magnetic wall at the quasi-symmetry passing the center point of the coupled strip segment d as shown in Fig. 1(b). Thus, two strips of unequal lengths, l_1 and l_2, are observed to be a function of dimension d. The former controls the higher resonant frequency, and the latter adjusts the lower resonant frequency to lead to the simultaneous tuning of the two rejecting band resonant frequencies.

Figure 2 also shows the transmission coefficient of the quasi-square open metallic ring FSS when a normally incident plane wave source is y-polarized. Increasing parameter d from 0 mm to 3 mm leads to a decrease in the rejecting band resonant frequency from 9.90 GHz to 8.70 GHz in our measured results. This frequency variation represents the spanned band due to the variation of parameter d. In a y-polarized source case, the coupled strips can be viewed as the two armatures of a capacitor in an LC circuit, and increasing their length results in an increased capacitance, which thus decreases the FSS resonant frequency. From the FSS results in the two polarizations, it can be concluded that the rejecting bands central frequencies can be tuned by varying the FSS coupled strips length d. Figure 2 shows that the WCIP results and the experimental results are in a good agreement.

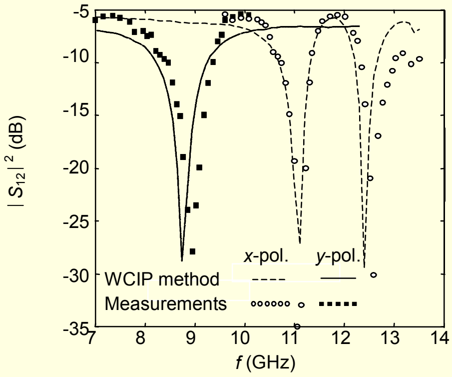
The observed difference between the WCIP results and the measured results can be reduced by incrementing the number of pixels used to describe the FSS interface as shown in Fig. 2(d), in which HFSS results are also plotted. Incrementing



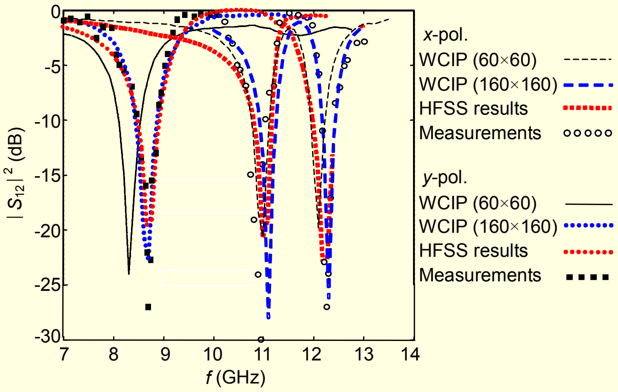
(a) *d*=0 mm



(b) *d*=1 mm



(c) *d*=2 mm



(d) *d*=3 mm

Fig. 2. Transmission power versus frequency for (a) *d*=0 mm, (b) *d*=1 mm, (c) *d*=2 mm, and (d) *d*=3 mm.

the number of pixels leads to a better description of the capacitance formed by the FSS parallel strips. Thus, the WCIP results are greatly improved in the *y*-polarization case.

IV. Conclusion

The quasi-square open metallic ring FSS was analyzed using WCIP. Acting as a dual polarized FSS, the quasi-square open metallic ring FSS can be used for dual-band applications when the source is polarized in the direction parallel to the coupled strips. In the two polarizations, the resonant frequencies of the rejecting bands are inversely proportional to the length of the FSS-coupled strips. Thus, the tuning of the resonant frequencies of the rejecting bands can be insured without a need to change any other FSS dimension. The obtained WCIP method results were compared to the experimental results and a good agreement was achieved.

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