A Novel Metamaterial Unit Cell Using an Interdigital Capacitor with Non-Bianisotropic Property

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Abstract

A novel metamaterial unit cell utilizing an interdigital capacitor (IDC) with non-bianisotropic property is proposed. Due to the induced magnetic resonance of an IDC unit cell, exotic effective constitutive parameters can be realized like a SRR. Furthermore, the proposed unit cell is electrically smaller than a conventional SRR unit cell.

Keywords : Bianisotropy Interdigital Capacitor Metamaterial Negative Magnetic Permeability

1. Introduction

When subwavelength resonant metallic particles such as split ring resonators (SRR) are arranged in a regular lattice, an artificial negative magnetic permeability medium (NMPM) with very high magnetic polarizability can be materialized. A SRR gives rise to a NMPM region in the vicinity of the magnetic resonance frequency [1]. However, an edge-coupled SRR (EC-SRR) initially proposed by Pendry et al. suffers from the cross polarization effect when the wave propagation occurs along an arbitrary direction relative to the principal axes. This phenomenon called bianisotropy can cause undesirable effects such as an additional electromagnetic response. Besides, the electrical size of an SRR cannot be decreased further than a tenth of free-space wavelength due to the edge-coupling between two rings [2]. In order to avoid bianisotropy property, the broadside-coupled SRR (BC-SRR) printed on both side of a dielectric board has been proposed [3]. However, the use of both side of the dielectric board causes a complicated fabrication process. To avoid complicated fabrication, the double-split SRR (2-SRR) was suggested [4], but its resonance frequency is twice higher than that of the same size EC-SRR.

In this paper, a novel metamaterial unit cell consisting of an IDC is proposed. By adopting the inversion symmetric arrangement, the unit cell yields non-bianisotropic property while keeping a uniplanar design. Also, the electrical size of the proposed unit cell is smaller than that of a conventional SRR.

2. Unit Cell Design

The proposed metamaterial unit cell is shown in Fig.1. It is formed by twelve coupled conducting interdigital fingers printed on an FR-4 (ε_r=4.4, tanδ=0.02) slab of thickness h. To avoid bianisotropy, the unit cell has the inversion symmetry with respect to the center of the structure. Additionally, the resonance frequency can be controlled by modifying the length of an arm, *l*, without alteration of the overall cell size. In the proposed design, the unit cell size can be 20% smaller than that of a conventional SRR since large inductance and capacitance of the cell provide a strong magnetic polarizability at the resonance frequency.

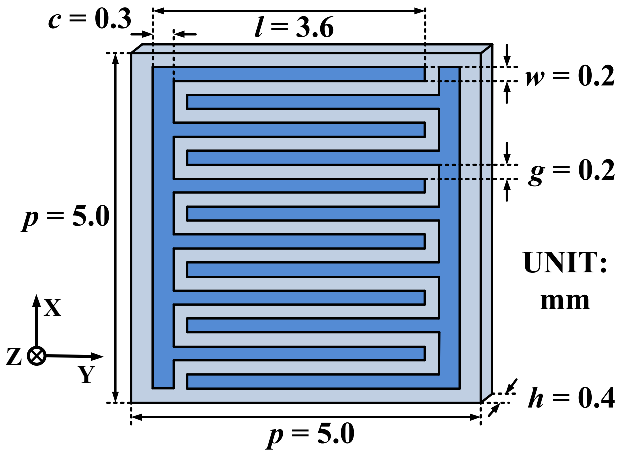


Figure 1: The proposed metamaterial unit cell configuration

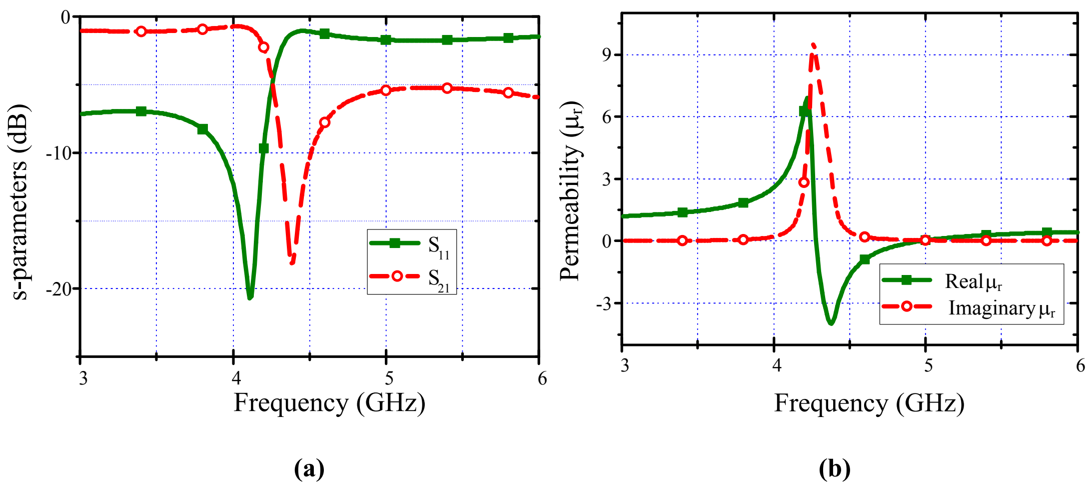


Figure 2: (a) Simulated s-parameters of the unit cell
(b) The real and imaginary parts of the permeability

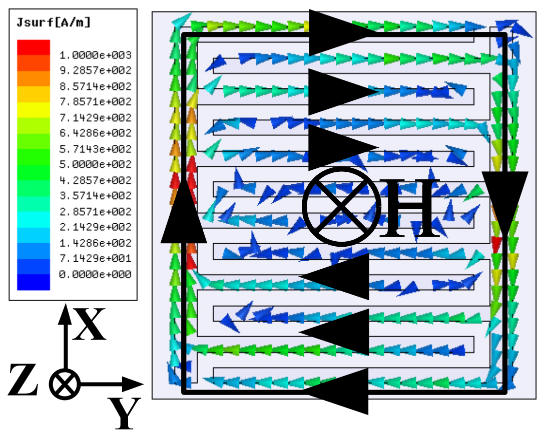
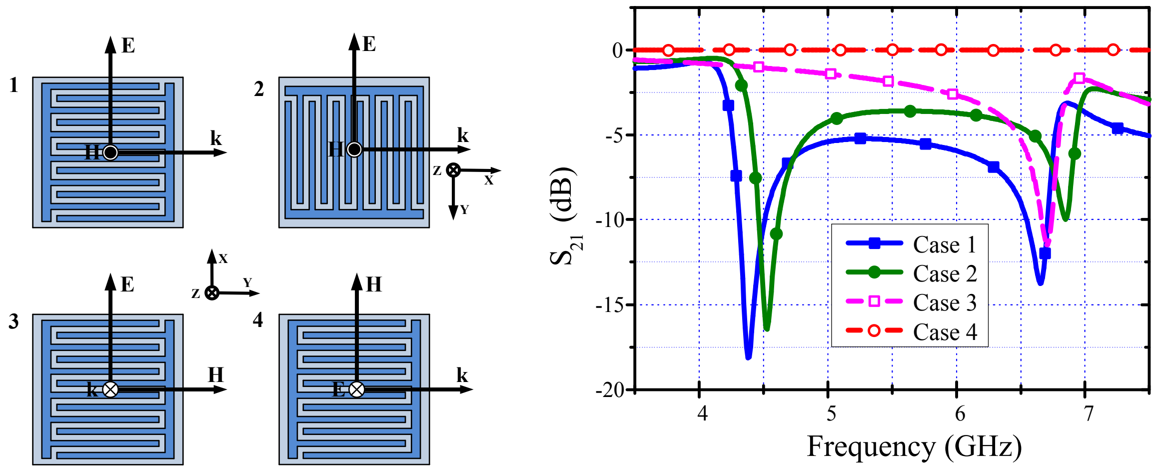


Figure 3: The surface current distribution at magnetic resonant frequency



(a) **(b)**

Figure 4: (a) Unit cell under different propagation directions and incident wave polarizations (b) Transmission responses of the unit cell for four cases

3. Results and Disscussion

The simulation of the proposed metamaterial unit cell was performed by FEM-based commercial software ANSYS HFSS v.12.1.0 [5]. The parameter retrieval technique was used to extract the effective constitutive parameters such as ε_r, μ_r, n, and z from the simulated response [6].

Fig.2 (a) and (b) show simulated s-parameters and the effective permeability for the unit cell, respectively. In Fig.2(a), the notch in S21 indicates the magnetic resonant frequency of 4.42 GHz. Fig.2(b) shows the region of negative permeability around the frequency of resonance of the unit cell.

Fig.3 shows the surface current distribution on the proposed unit cell at the magnetic resonance frequency. When an external magnetic field directed along the *z*-axis is applied, an electromotive force is induced along the interdigital fingers and produces a total magnetic moment in the particle. Since IDC cell has the inversion symmetry with respect to the center of the structure, the charge distribution has bilateral symmetry along the edge of each interdigital finger.

To verify the non-bianisotropic characteristic of the proposed unit cell, numerical simulations were performed for four cases as shown in Fig.4 (a). In cases 1 and 2, both electric and magnetic resonances are induced but electric field directions are different. Otherwise, only electric resonance is induced in case 3 and neither of them is induced in case 4. Fig.4 (b) depicts the transmission property of the proposed metamaterial for four cases. In cases 1 and 2, it is observed that both electric and magnetic resonances occur around 4.5 GHz and 6.6 GHz, respectively, but electric resonance of case 2 is weakened due to the decreased capacitance. In case 3, however, the metamaterial exhibits only electric resonance around 6.6 GHz which means that the electric resonance does not affect the magnetic resonance. Therefore, the cross-polarization effect is avoided in the proposed unit cell. For case 4, neither electric nor magnetic resonance occurs. From these observations, one can conclude that the proposed metamaterial unit cell has non-bianisotropic characteristic even with the smaller electrical size than that of a conventional SRR.

4. Conclusion

In this paper, a novel uniplanar metamaterial unit cell consisting of an IDC is proposed. Large inductance and capacitance of the IDC provide a strong magnetic resonance. Thus, the electrical size of the unit cell can be about 20% smaller than that of a conventional EC-SRR. In addition, the unit cell is non-bianisotropic because of the inversion symmetry.

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Acknowledgments

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