Two-dimensional Cross Embedded Metamaterials

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Abstract—Traditional two dimensional (2D) left-handed metamaterials were composed of honeycomb structures. In this paper, we experimentally realized a 2D S-shaped metamaterial with cross embedded form. We show that metamaterials with cross embedded arrangements exhibit wider left-handed band and lower loss than honeycomb structures.

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1. INTRODUCTION

In 2001, left-handed metamaterial was experimentally realized [1] by using metamaterial fabricated with periodical patterns composed of a unit split-ring resonator (SRR) and conducting wire. Since then, a variety of designs have been proposed and studied, such as the \(\Omega\)-like structure, S-shaped resonators, while transmission line structures and photonic crystals have also been shown to exhibit left-handed properties. The general problem with the one-dimensional (1D) LHM (left handed metamaterials) is the inherent asymmetry of the resulting lattice of structures. R. A. Shelby has achieved 2D isotropy by placing the SRRs along two orthogonal axes in a lattice [2]. And so far the two dimensional LHM are usually realized by arranging the rings into a honeycomb structure as R. A. Shelby did. For this kind of arrangement, the loss is very high and the bandwidth is very small, because the interaction between the rings in two directions is very large. Some authors proposed some embedded SRR to achieve 2D or 3D isotropic resonators. Because the sizes of the rings in the two dimensions are different, it leads to different macroscopic properties of the material. Besides, the arrangements of the rods haven’t been considered, these structures only show negative permeability behavior.

In this paper, we proposed a new type of two dimensional left-handed metamaterial with a cross embedded form of the S-ring resonators. The rings in the two dimensions have the same size, shows more isotropic properties in the two dimensions. The transmission experiment are carried out, and the results are compared with the one realized with honeycomb form. We show a wider bandwidth and a lower loss is achieved, showing the superiority of this arrangement. The reason is that there is less coupling effect between the units in the two dimensions.

2. 2D S-RING STRUCTURES

The elementary cell of the metamaterial is based on an extended S-ring resonator, which is composed of a substrate of height \(L = 49.7\) mm in the \(y\) direction and of thickness \(d = 2\) mm, as shown in Fig. 1. The relative permittivity of the substrate is 4.0. The extended S-shaped metallic strips are printed on both sides of the substrate, and are a mirror image of each other. The geometry is formed by linking two S-shaped structures of the same size, and the other dimensions of the sample are: \(c = 2.1\) mm, \(w_1 = 6.3\) mm, \(w_2 = 13.5\) mm, \(h = 14.7\) mm, \(H = 17.5\) mm.

Firstly, we arrange the one dimensional S-shaped unit cell in a traditional honeycomb structure by placing the S-shaped resonator along two orthogonal axis in a lattice, which forms a two dimensional metamaterial, as shown in Fig. 2(a). The period of each cell is 5 mm. The commercial software CST Microwave Studio has been used for the simulation of the structure, which repeats periodically in \(x\) and \(z\) directions. The electromagnetic wave is incident in \(z\) direction with an electric field polarized in \(y\) direction. The \(S\)-parameters have been extracted for the 0–10 GHz frequency range. From the results obtained using CST and shown in Fig. 3, it can be noted that there is a narrow passband around 2.34 GHz, with a loss of about 10.1 dBm. Using the retrieval
Figure 1: Dimensions characterizing the one dimensional unit cell of the metamaterial ($c$ is constant for all metallization).

Figure 2: (a) The two dimensional metamaterial arranged as a square lattice, (b) Picture of the metamaterial used in the experimental measurements which is arranged in a honeycomb structure.

Figure 3: Simulated $S$-parameters of the two dimensional metamaterial arranged in the honeycomb structure.
method [4], we find the frequency range of 2.325–2.365 GHz is a left-handed passband, in which the effective permittivity and permeability are both negative. The result is shown in Fig. 4, from which a relative bandwidth of 1.7% could be identified.

![Figure 4: Effective permittivity and permeability of the 2D LHM of honeycomb structure by retrieval method using the simulated s parameters.](image)

In comparison, we next arrange the extended one dimensional S-shaped ring in a cross embedded structure to form a two dimensional metamaterial, as shown in Fig. 5(a). The structure is repeated periodically along $x$ and $z$ direction with a period of 5 mm. The electromagnetic wave is incident in $z$ direction with an electric field polarized in the $y$ direction.

![Figure 5: (a) The two dimensional metamaterial arranged in a cross embedded structure, (b) Picture of the metamaterial used in the experimental measurements which is arranged in a cross embedded structure.](image)

The simulated $S$-parameters are shown in Fig. 6. Also the effective permittivity and permeability could be obtained using the retrieval method, and are shown in Fig. 7. Compared with the simulated results of the honeycomb structure, we find that the loss at the peak frequency of the passband is about 1.5 dBm, which is much lower, and the passband is much wider as well, with a relative bandwidth of 11%. The better performance of the cross embedded structure is due to the smaller interaction between the rings.

### 3. EXPERIMENT REALIZATION

In order to measure the transmission properties of the two dimensional metamaterials, we use a rectangular waveguide with a working frequency band from 1.7–2.5 GHz. Fig. 2(b) and Fig. 5(b) are
Figure 6: Simulated S-parameters of the two dimensional metamaterial arranged in a cross embedded structure.

Figure 7: Effective permittivity and permeability of the 2D LHM of cross embedded structure by retrieval method using the simulated s parameters.

the pictures of the samples used in the experiment. The two samples are loaded into the waveguide independently. The S parameters are recorded by an Agilent 8722ES network analyzer.

Using the S parameters measured in the experiment, the effective permittivity and permeability are retrieved, shown in Fig. 8 and Fig. 9. The relative bandwidth of the cross-embedded structure is 13% while the overlapping area of negative permittivity and permeability of the traditional arranged S-ring resonators disappears. This striking phenomenon is caused by the interaction between the rings in the two orthogonal directions, which deteriorates the left-handed properties of the 2D S-ring resonator.

Figure 8: Effective permittivity and permeability of the 2D LHM of honeycomb structure by retrieval method using the measured s parameters.

Figure 9: Effective permittivity and permeability of the 2D LHM of cross-embedded structure by retrieval method using the measured s parameters.
4. CONCLUSION
A new type of two dimensional metamaterial is presented in this paper, of which the rings are cross embedded arranged. This structure leads to a much better performance, which could be seen in the simulation and experiment result.

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REFERENCES