Design of Effective Thin Metamaterial Absorber for 2 GHz Frequency Band

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Abstract

This paper presents a new type of thin absorber exhibiting double negative metamaterial (MTM) characteristics. A MTM unit cell was constructed by a multiple split ring resonator (MSRR). A MSRR structures exhibit negative permeability and negative permittivity, respectively. Simulated results show a high maximum absorption of 95 % at 2.2 GHz.

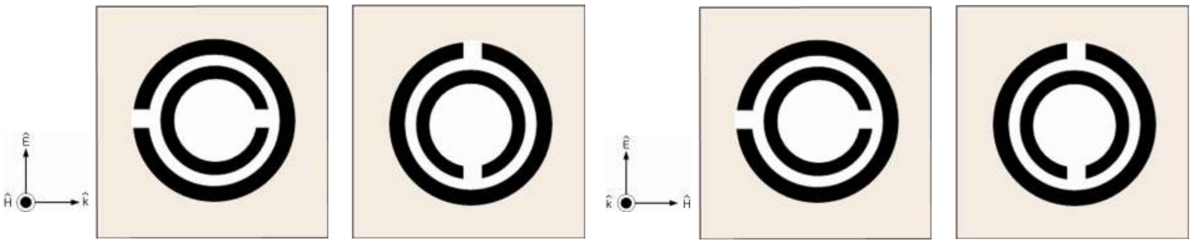
Keywords: Metamaterial, Thin absorber, Multiple split ring resonator, Double negative

1. Introduction

Recently, artificially structured electromagnetic (EM) materials have become an extremely active research area because of the possibility of creating materials which exhibit novel EM responses not available in natural materials. This includes negative refractive index (NRI), superlensing, cloaking, and more generally, coordinating transformation materials. For the most part, these composites, often called metmamaterials (MTM) [1]. The microwave absorbers are used in military and civil application to reduce the electromagnetic interference among microwave components or electronic circuits mounted on the same platform. The absorbers employed in everyday applications are usually backed by a metallic plate. The metallic backing plays two main roles. On one hand, it is used to avoid power transmission on the other side of the absorber. On the other hand, it enables a boundary condition useful to create a reflected component that, combined with the impinging wave, cancels out the reflection from the screen. This phenomenon is well evident in the principle of operation of the Salisbury screen [2], [3]. The dimension of separation between the inclusions are both very small compared to the operating wavelength, it is usually possible to model the macroscopic behaviour of the composite material in terms of the effective permittivity and permeability [4]. Due to the resonance behaviour of the inclusions, also the effective permittivity and permeability exhibit a dispersive behaviour characterized by a resonance and, if the inclusions are properly designed, it is also possible to obtain negative values for the effective constitutive parameters. Moreover, metatmaterials usually exhibit high losses around the resonance frequency and this aspect sometimes limits their employment in practical components requiring high efficiencies. However, as far as absorber is concerned, losses may help to absorb the impinging electromagnetic power [5]. The double negative (DNG) metamaterial structure was realized in 2000 by appropriately depositing split-ring resonators (SRR) and thin-wires on dielectric substrate. Since then, most of reported designs have a 1D or 2D geometry that responds only to one (two) electrical and magnetic components of the electromagnetic fields. Much of the work in MTM has been focused on the real parts of permittivity and permeability to enable the creation of a NRI material. However, they can be manipulated to create a high performance absorber [6], [7]. By varying the dimensions of electric and magnetic components, it is possible to adjust permittivity and permittivity independently. Additionally, by tuning the electric and magnetic resonance a MTM can be impedance matched to free space, resulting reflectivity $R = 0$. The additional multiple layers or metallic back-plate will also ensure transmission $T = 0$. As a result, 100 % absorbance A ($=1 - R - T$) is theoretically possible. In practice, it is difficult to realize excellent absorbing properties and to reduce absorbers electrical thickness at low frequencies. For the design of compact microwave absorbers made by MTM complimentary pairs, we should choose proper unit cell structure which is characterized by oppositely signed values of real parts of permittivity and permeability. Various structures exhibiting MTM characteristics have been proposed by various researchers. We have constructed NRI MTM unit cell using multiple SRRs (MSRRs) arrangement.

2. Epsilon negative unit cell design using MSRR

The presence of cross-polarization effects in the EC-SRR was experimentally checked in [8] by measuring the transmission coefficient through a waveguide loaded with an EC-SRR placed at different orientations inside the waveguide in Fig. 1. Fig. 1 shows the various types of the edge-coupled SRRs with different electromagnetic orientations. Type 1 exhibits an electric and magnetic excitation and type 2 exhibits a magnetic excitation only. Type 3 and type 4 exhibits an electric excitation only and no excitation, respectively. The geometry of the proposed absorber unit cell based on the edge-coupled SRR is shown in Fig. 2. A MSRR structure was placed on FR-4 dielectric substrate (relative permittivity = 4.4, thickness = 0.8 mm). The simulations were carried out using the frequency domain solver, implemented by CST MWS [9]. The frequency characteristics of unit cell structure were simulated by using a periodic boundary condition (PBC) method, as shown in Fig. 2. The proposed unit cell was placed inside a waveguide with PBC walls and a vertically polarized TEM wave impinged upon this structure from port 1. The dimension of cubic cell was 13 mm × 13mm × 13 mm. The perfect electric conductor (PEC) boundary condition was applied to the top and bottom walls of the waveguide whereas perfect magnetic conductor (PMC) boundary condition was applied to the both side-walls of the waveguide. The other two opposite sides of the waveguide were assigned as waveguide ports. The simulated scattering parameters for the proposed unit cell were plotted in Fig. 2. As a next step, the effective permittivity and permeability of this structure were retrieved in order to confirm the double negative characteristics. In order to express the effective permittivity and permeability of an artificial material in terms of the scattering parameters, they are conventionally retrieved from scattering parameters of a unit cell under plane wave excitation [10]. The impedance parameters and ABCD parameters can be calculated from scattering parameters. Then the Bloch-Floquet theorem was used to calculate the Bloch impedance Z_B, and complex propagation constant Υ and period p.



(a) Type 1. (b) Type 2. (c) Type 3. (d) Type 4.

Figure 1: The cross-polarization effects for the various types of the edge-coupled SRRs.

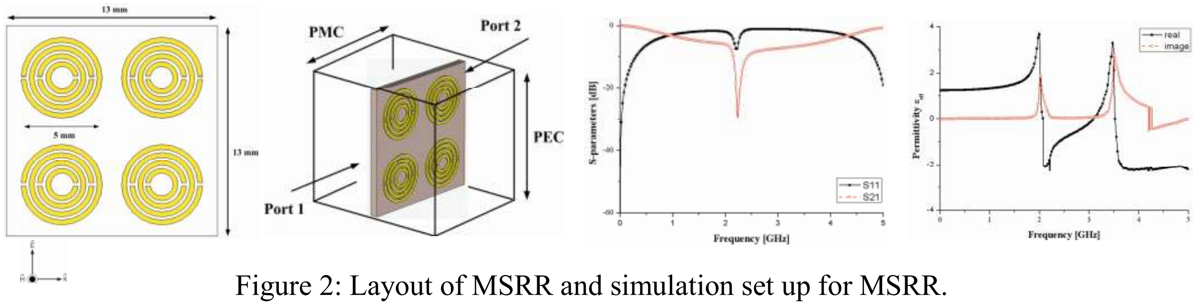


Figure 2: Layout of MSRR and simulation set up for MSRR.

$$\gamma = \frac{\cos^{-1}\left(\frac{Z_{11}+Z_{22}}{2Z_{21}}\right)}{p}. \tag{1}$$

$$Z_B = \frac{B}{\exp(j\gamma p) - A}. \tag{2}$$

$$A = \frac{Z_{11}}{Z_{21}}, \quad B = \frac{Z_{11}Z_{22} - Z_{21}^2}{Z_{21}}. \tag{3}$$

The effective permittivity ε_{eff} and permeability μ_{eff} can be easily calculated from Bloch impedance and propagation constant with free space wave number k_0, and wave impedance Z_0 of the empty waveguide.

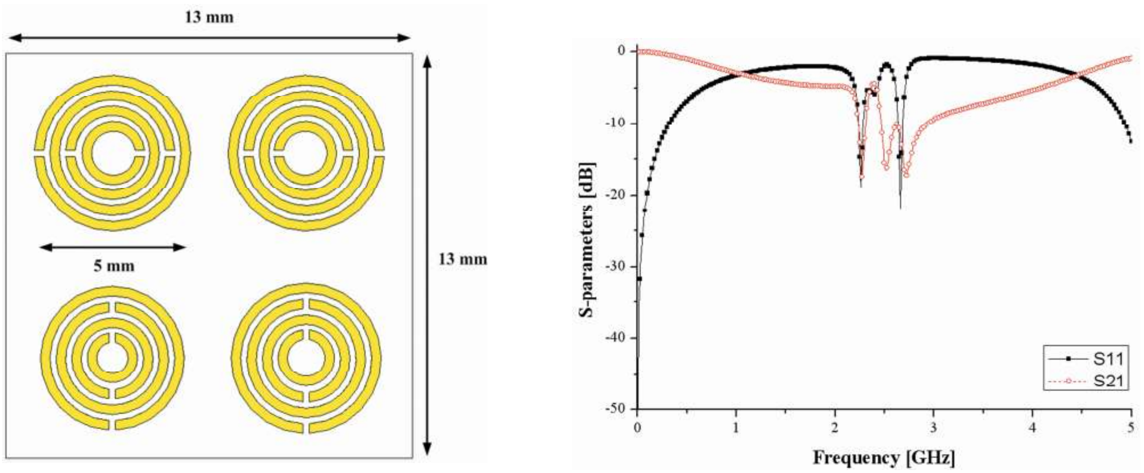
$$\mu_{eff} = \frac{\gamma Z_B}{k_0 Z_0} \tag{4}$$

$$\varepsilon_{eff} = \frac{\gamma Z_0}{k_0 Z_B} \tag{5}$$

The extracted effective permittivity and permeability of one unit cell were shown in Fig. 2, respectively. The unit cell exhibited a negative permittivity and permeability near its resonance frequency of 2.2 GHz.

3. Double negative cell using MSRR

A modified MSRR absorber structure unit cell is constructed by changing the gap direction of the MSRR shown in Fig. 2. The geometry of the modified MTM absorber structure with four MSRRs is shown in Fig. 3 (a). In this case, the lower two MSRR unit cells were turned 90^0 in order to get a magnetic excitation only. The double negative MTM parameters are extracted from the simulated scattering parameters and the retrieved material parameter also calculated as explained method. The simulated scattering parameters of this double negative MTM unit cell are plotted in Fig. 3 (b). The retrieved effective permittivity and permeability for the proposed MTM structure are shown in Fig. 4. It shows a region of negative permittivity and permeability over the range of 2.2 to 2.5 GHz. The calculated corresponding absorptivity A $(=1-|S_{11}|^2-|S_{21}|^2)$ is also plotted in Fig. 4. These results demonstrate that the proposed double negative MTM unit cell exhibit strong resonance at around 2.2 and 2.5 GHz and a maximum absorptivity of 95%.



(a) (b)

Figure 3: (a) Geometry of a modified MSRR absorber structure and (b) simulated scattering parameters.

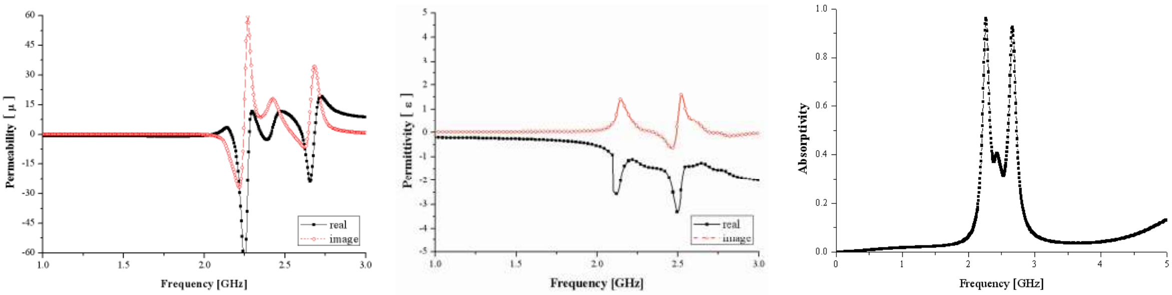


Figure 4: Extracted effective permittivity, permeability, and absorptivity of the proposed unit cell.

4. Conclusion

A new type of a thin MTM unit cell absorber structure was proposed. The four MSRR structures which are put on top of FR-4 substrate have shown to effectively absorb most of the impinging power. The total size of the miniaturized MTM absorber unit cell for 2 GHz frequency band was 13 mm x 13 mm x 0.8 mm. The proposed absorber structure can be used for microwave absorber applications.

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