Miniaturized narrowband microwave absorber based on double-negative metamaterial

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Abstract

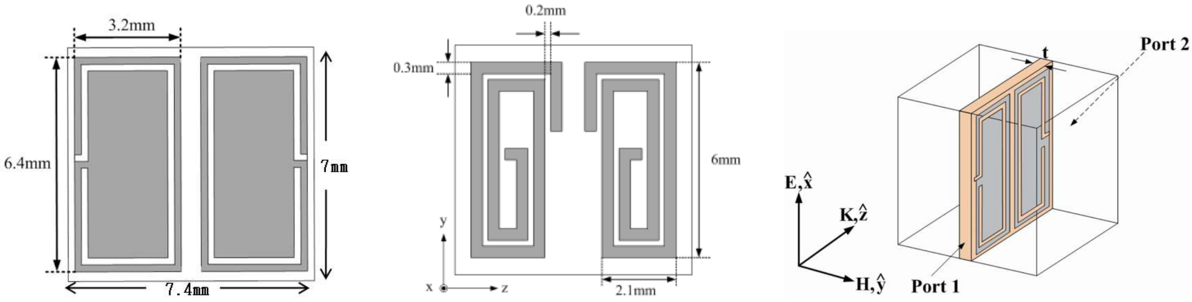
This paper presents a miniaturized microwave absorber for 2 GHz frequency band that utilizes properly arrayed double-negative metamaterial (MTM) unit cells. A MTM unit cell is constructed by two open complementary split-ring resonators (OCSRRs) and dual spiral resonators arrangement. At the aimed design frequency, the OCSRRs and dual spiral exhibit a negative permittivity and a negative permeability, respectively. Each unit cell is printed on the two sides of a FR-4 substrate to make a miniaturized thin MTM absorber unit cell. The total size of the miniaturized MTM absorber unit cell was 7.4 mm x 7 mm x 2 mm. A spatial array of absorber unit cells (13 $\times$ 3 $\times$ 2) exhibits a maximum absorbance of 93 % at 2.43 GHz.

1. Introduction

The double-negative metamaterial (MTM) structure can be manipulated to create a high-performance absorber for the microwave and terahertz frequency regime [1]-[3]. 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 resonances 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 complementary pairs, we use two open complementary split ring resonators (OCSRRs) and dual spiral resonators arrangement. The OCSRR [4] has been derived from two former planar resonant structures: the open split ring resonator (OSRR) [5] and the complementary split ring resonator (CSRR) [6]. As compared to SRR and CSRR, the resonance frequency of the OCSRR is one-half the resonance frequency of a CSRR with identical dimensions. The OCSRR is modified CSRR structure exhibiting negative permittivity and the spiral structure exhibits negative permeability. We use a single-layered structure with two spirals and two OCSRRs which are put on top of each other to make a miniaturized MTM absorber unit cell for 2 GHz frequency band.

2. Absorber design

The proposed structure of the OCSRR is shown in Fig. 1. Two symmetrically placed OCSRRs are printed one side of a FR-4 dielectric substrate with a relative permittivity of 4.4 and a thickness 2 mm. This structure was placed inside a waveguide environment. The simulations are carried out using the frequency domain solver, implemented by CST. The program simulated a single unit cell with appropriate boundary conditions, as shown in Fig. 1(c). The perfect electric conductor (PEC) boundary conditions are applied to the top and bottom walls of the waveguide, where as perfect magnetic conductor (PMC) boundary conditions are applied to the side walls of the waveguide.

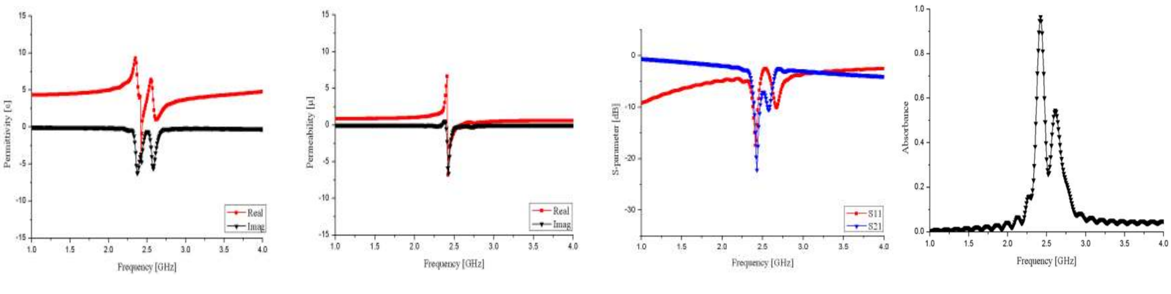


(a) Layout of OCSRRs (b) Layout of dual spiral (c) Simulation setup

Fig. 1: Schematics of optimum single-cell absorber and simulation setup.

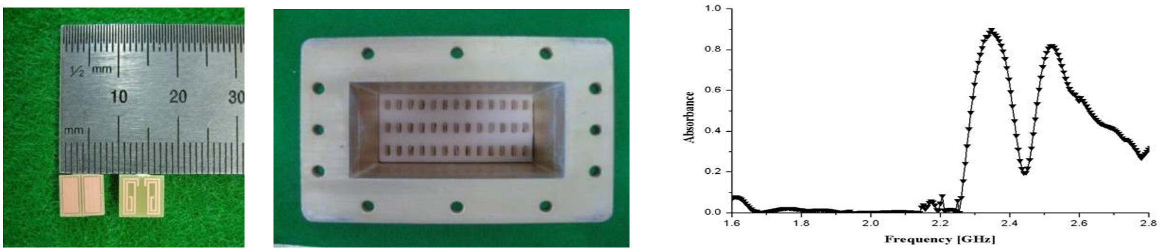
The other two opposite sides of the waveguide is assigned as waveguide ports. Total size of the MTM unit cell is 7.4 mm x 7 mm x 2 mm. The scattering parameters of this MTM unit cell were then simulated, and the absorbance was calculated using the equation $A = 1- |S_{21}|^2 - |S_{11}|^2$. As a next step, the effective permittivity and permeability were retrieved to confirm the double negative nature of this structure. The simulated and extracted parameter results for the proposed MTM unit cell shown in Fig. 1 are plotted in Fig. 2. By careful design, the negative electric response of OCSRRs and the negative magnetic response of two spirals occur near 2.43 GHz as plotted in Fig. 2(a) and Fig. 2(b), respectively. The maximum absorbance peak is 96 %, and the minimum return loss of – 23 dB occurs at 2.43 GHz, respectively, as plotted in Fig. 2(c) and Fig. 2(d), respectively. This indicates that the input impedance of the proposed MTM unit cell approximately matched that of free space.

The photographs of the fabricated two-layer metallization MTM absorber sample are shown in Fig. 3(a). It was etched on a FR-4 substrate with a relative permittivity of 4.4 and a thickness of 2 mm. In order to confirm the effectiveness of double-negative MTM absorbers, a spatial array of absorber unit cells (13 × 3 × 2) was mounted on a polystyrene foam substrate with a relative permittivity of 1.02, as shown in Fig. 3(b). This structure was placed inside a rectangular waveguide (WR430) and measurements were taken with the waveguide at the range of frequencies from 1.6 - 2.8 GHz. At these frequencies, propagation was confined to the TE_{10} mode. By using the measured S_{11} and S_{22} parameters, the calculated corresponding absorbance was plotted in Fig. 3(c). It exhibits a maximum absorbance of 93 % at 2.43 GHz. Due to a mutual coupling effect between the arrayed cells the resonant frequency of the proposed MTM was lowered than that of a single-layer unit cell, and another peak absorbance of 83 % at 2.51 GHz was observed.



(a) relative permittivity (b) relative permeability (c) scattering parameters (d) extracted absorbance

Fig. 2: Simulated and extracted parameter results for the proposed single-cell MTM absorber.



(a) unit cell (b) unit cell array in WR 430 waveguide (c) measured absorbance

Fig. 3: Photographs of the fabricated absorbers and experimental results of unit cell array.

4. Conclusion

A compact absorber at lower microwave frequencies (f_0 = 2.43 GHz) made by properly arrayed double negative MTM unit cells has been presented. A single unit cell with two spirals and two OCSRRs has shown to effectively absorb most of the impinging power. The total size of the miniaturized MTM absorber unit cell was 7.4 mm x 7 mm x 2 mm. With the help of numerical simulation, the effective parameters of the proposed double negative MTM unit cell are extracted. Absorbers based on a MTM are shown to reach the thickness of the order of $0.06\lambda_0$ in the propagation direction and are not backed by any metallic plate. The performance of the proposed absorber was verified with the experimental TE_{10} mode wave and it shows a maximum absorbance of 93 %.

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