An Array of Robust Multi-band Metamaterial Absorbers Using Octagonal Split Rings

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The purpose of this paper is to present a set of efficient and robust metamaterial absorbers based on octagonal split ring resonant (O-SRR) periodic structures that can offer multi band absorption to practical applications for electromagnetic compatibility (EMC) engineers. The models of ultra-thin, compact O-SRR absorbers for operation at microwave frequencies are exhibiting very high absorptive regions. The idea is extended to broadband performance, where different setups are demonstrated and analyzed.

***Index Terms* — Absorbers, metamaterials, microwave, multi-band**

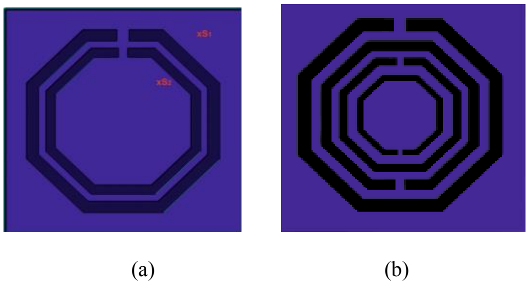
I. INTRODUCTION

METAMATERIALS are attractive not only for their exotic electromagnetic properties, but also their promise for applications. Recently, metamaterials have attracted much attention due to their designable and controllable material parameters originating from artificial inclusions of EM resonant structures. The main reason for choosing this field for research is that a particular branch, the metamaterial perfect absorber, has garnered interest due to the fact that it can achieve unity absorptivity of electromagnetic waves. Several ideas have been introduced to build resonant absorbers with metamaterials. The absorption is defined as $A(\omega) = 1 - T(\omega) - R(\omega)$, where $A(\omega), R(\omega),$ and $T(\omega)$ are the absorption, the reflection, and the transmission as functions of frequency. To maximize the absorption rate, we can minimize the reflection and transmission simultaneously at the same frequency range. The reflection can be minimized by tuning the parameters of the metamaterial impedance of the metamaterial z is equal to one and matched to the free space. Although it is difficult to get the transmission eliminated by one single layer of the metamaterial, there are ways to achieve unity absorption. As a first approach, we can use multiple layers of metamaterial films to eliminate the transmission while in the second we utilize a ground plane to reflect the transmitted wave back. The first approach can obtain effectively perfect absorption at the resonance peak, with the disadvantage of an increase in thickness. The second approach can provide a very an ultra-thin absorber, but the absorption may not be perfect.

So far the majority of the proposed metamaterial absorbers are composed of conducting electric resonators on two sides of a dielectric substrate [1,2]. In this paper, we present a set of efficient and robust metamaterial absorbers based on octagonal split ring resonant (O-SRR) periodic structures that can offer practical applications for electromagnetic compatibility (EMC) engineers in the area of absorbing materials. By utilizing the scalability feature of the O-SRR elements, we have achieved multiple absorption peaks at the desired frequencies, thus extending our idea to multi-band and broadband structures. In the proposed setups, we have managed to incorporate the “nested” technique [3] to achieve multiple high absorptive regions. These setups have been proven to exhibit several attractive characteristics by remaining electrically thin at the resonance frequency implementing a low-cost FR-4 dielectric substrate. Using this feature, these absorbers could be designed to work at other EM frequency range with nearly perfect absorption.

II. DESIGN AND ANALYSIS

To construct the proposed absorbers, an octagonal split ring resonator (O-SRR) is imprinted on the front face of a 1 mm-thick FR-4, 10 x 10 mm rectangular dielectric substrate whose relative permittivity and loss tangent are ε_r = 4.4 and $tan\delta$ = 0.025, respectively (the inner ring in Fig. 1a). The metallic parts are made of copper with σ = 5.8 x107 S/m and thickness = 17 μm, which behaves as a perfect electric conductor (PEC) at the microwave regime. The opposite side of the dielectric is covered by a full copper plane to guarantee zero transmission. Moreover, periodic boundary conditions are applied along the x and y directions, to account for an infinite array of unit cells, while a plane wave propagating along the z-axis is considered as the incident radiation. All simulations are carried out using the conventional 3D finite difference method in time domain (3D-FDTD). The technique for the design of multi-band metamaterial absorbers exploits the scalability feature of metamaterials. Specifically, by multiplying the dimensions of the original O-SRR along the x- and y-axis using a scaling factor s_x, the center absorption frequency can be down-shifted ($s_x > 1$) or up-shifted ($s_x < 1$), without changing the absorption curve’s original shape and fractional bandwidth.



(a) (b)

Figure 1. Dual-band absorber with two nested O-SR (a), Tetra-band absorber with four nested O-SRRs (b).

This property can also be used to offer broad-band absorbers by very slightly changing the scaling. Therefore the design of broadband metamaterial absorbers is considered as the borderline case of multi-band designs. However, it is important to highlight that no scaling is applied along the z-direction, since the metal thickness has no effect on the overall behavior of the absorbers.

For the two nested octagons, the first absorptive peak is 93% and is located at the frequency of 6.6 GHz, while the second occurs at 8.8 GHz and is reaching the value of 94%. It is important to examine the factors that affect the absorption and their significance. To begin with, we examine the case where the distance between the rings changes. In order to do that, the scaling changes. From the results that are presented in fig.2 we can conclude that the greater the distance between the rings the less the coupling effect.

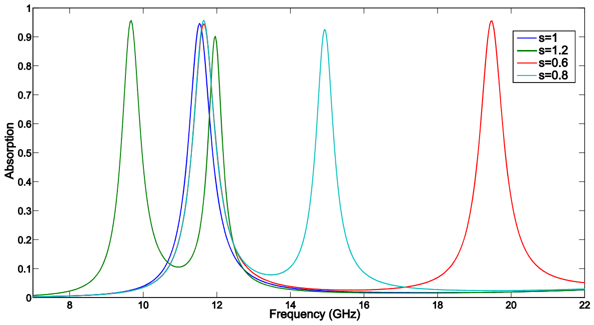


Figure 2. Comparison of the maximum absorption for different scaling.

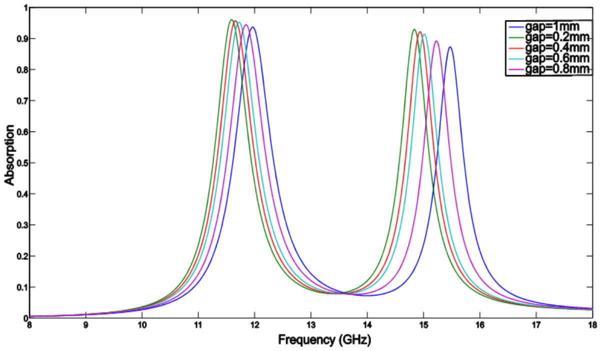


Figure 3. Comparison of the maximum absorption for gap size changes between the two nested octagonal rings.

Moreover, we investigate the effect of the OSRRs' gap size on the device's overall performance. The results are presented in fig. 3, from which, as it appears, increasing the size of the gap, the resonant frequency is shifted upwards while the absorption decreases. This can be explained if we consider the behaviour of the gap as a capacitance which is reduced as we increase the distance.

Utilizing the setup of the nested rings, a tetra band absorber can be designed and is presented using four different scales of the original O-SRR, with the values of s1 = 1.30, s2 = 1.04, s3 = 0.80 and s4 = 0.70. Four absorption peaks are occurring as expected. Table 1 shows the values of the absorption for each resonant frequency. In this case, two octagons were rotated by 180^0 along the x-axis without affecting the absorption curve, since the gap remains at the same direction.

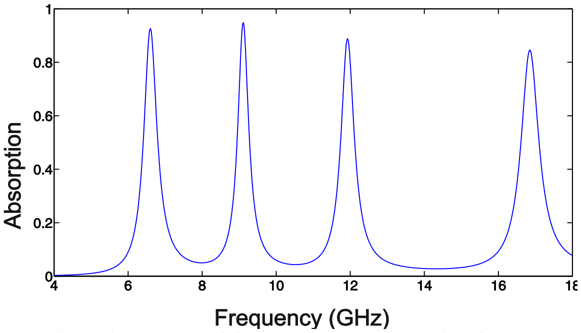


Figure 4. Absorptive spectra of the nested O-SRRs tetra-band structure

TABLE I
TETRA BAND ABSORPTION VALUES

Frequency GHz	Absorption %
6.6	92%
9.1	95%
11.9	89%
16.8	84%

By using the nesting setup it is easy to accomplish more compact and electrically small designs of multiple bands that offer good absorbing results. This setup can be extended to produce a mushroom metamaterial structure as in fig.5 with the same scaled OSRRs from fig. 1b, to produce bandwidth enhanced absorbers.

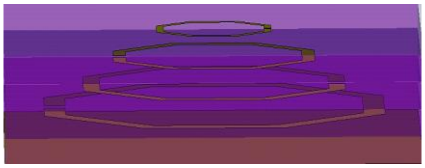


Figure 5. Mushroom structure of OSRRs.

III. CONCLUSION

The proposed setups have been proven to exhibit several attractive characteristics by remaining electrically thin at the resonance frequency implementing a low-cost FR-4 dielectric substrate. By utilising the scalability feature of the O-SRR elements, we have achieved multiple absorption peaks at the desired frequencies. This idea can be extended to mushroom structures of OSRRs to produce bandwidth enhanced absorbers. Using this feature, these absorbers could be designed to work at other EM frequency range with nearly perfect absorption.

IV. REFERENCES

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