

Electromagnetic characterization of a new metamaterial resonator for microwave applications

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Abstract— A characterization of a new metamaterial resonator is presented in this work. The studied structure is a symmetrical split rings resonator (SSRR) for square shape and magnetic activity. Two different configurations of (SSRR) are proposed to show the influence of the geometric shape on the electromagnetic qualities of the chosen metamaterial. The two resonators for the two proposed configurations (SSRR1) and (SSRR2) are formed by two square rings; inner and outer which are etched on the upper face of a dielectric substrate of FR4_Epoxy. The obtained results by simulations based on the HFSS simulator show the influence of the geometric shape on the reflection, transmission, refractive index and the absorption of the studied metamaterial resonator.

Keywords—absorption, metamaterial, reflection, resonator, transmission.

I. INTRODUCTION

For most of the current technology systems, the performance of the used devices represents the main objective for achieving the desired development. A certain compatibility between the design and the realization of a device can contribute to the improvement of these systems. The major problem which can impedes this compatibility is the chosen material for the realization, in particular for the techniques of miniaturization of the devices [1]. Several choices in terms of materials have been made in order to have suitable solutions. Currently, a new class of materials has shown its effectiveness in solving the majority of the problems imposed during realization, this class is called « metamaterials ».

Metamaterials are artificial structures or composites pseudo-homogeneous with electromagnetic properties not available in nature. In 1968, an analysis of this kind of materials was originally made by the Russian physicist Victor Veselago [2]. The effective properties of metamaterials can take unusual values compared to homogeneous (conventional) materials. The particular property that made the name "metamaterials" is the possibility of simultaneously negative permittivity and permeability [3, 4], which leads to the most

unexpected properties such as a negative refractive index [5]. Another geometrical property that characterizes metamaterials is the possibility of having resonator dimensions that are too small in front of the wavelength inside the structures [6].

The great importance of metamaterials is represented in the remarkable solutions that they can offer. In [7], M. Abdalla et al proved the efficiency of metamaterial resonators in the procedure of miniaturization of antennas. The same objective of miniaturization of microwave filters by the same class of materials is represented in [8]. In [9], Rammah et al presented a microwave sensor for solids and liquids based on metamaterials. This sensor, which has a high quality factor, can detect other types of materials with remarkable precision.

In this work, a characterization of a new metamaterial resonator is presented. Our characterization steps are based on obtaining the electromagnetic qualities of a new proposed metamaterial resonator, this resonator has two symmetrical square rings which are split in opposite (SSRR). For our study we have chosen two different configurations to show the influence of the geometric shape on the electromagnetic qualities of both (SRR1) and (SSRR2).

II. CHARACTERIZATION METHODOLOGY

The classic split ring metamaterial resonator (SRR) is a structure proposed for the first time by J. Pendry and his research team [10]. Geometrically, the (SRR) is formed by two split rings (of defined geometric shape). Physically, the (SRR) can withstand wavelengths too small; see lengths of the order of a few mm or even μm [11]. The (SRR) functions correctly when the magnetic field \vec{H} is perpendicular to the plane of the two rings. The metamaterial resonator proposed for characterization is a symmetrical split ring resonator (SSRR), the chosen shape for the two inner and outer rings is the square shape. The two proposed configurations which make it possible to define the two metamaterial resonators

(SSRR1) and (SSRR2) have the same dimensions and the same periods.

A. Configuration for (SSRR1)

The first configuration proposed for (SSRR1) has two square rings each; the interruption gaps for the two rings are crossed. The (SSRR1) of period P_1 is shown in Fig. 1.

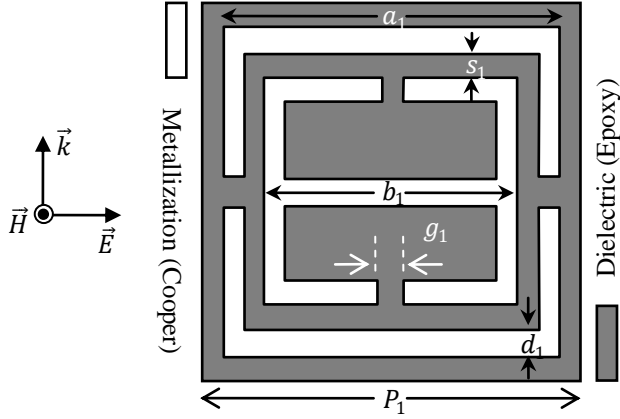


Fig. 1. Representation in rings for the (SSRR1).

B. Configuration for (SSRR2)

The second configuration proposed for (SSRR2) also has two square rings each; the interruption gaps for the two rings are aligned. The (SSRR2) of period P_2 is shown in Fig. 2.

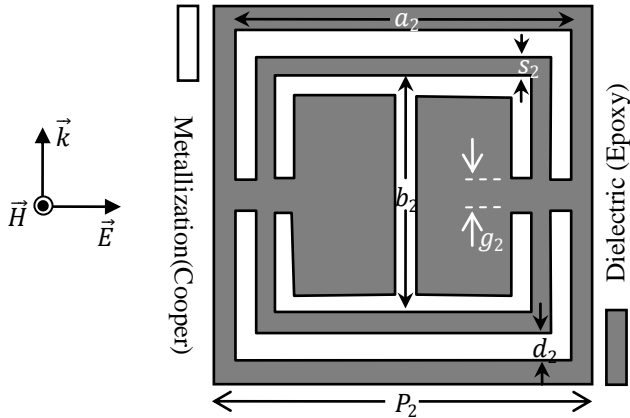


Fig. 2. Representation in rings for the (SSRR2).

The dimensions chosen (which are the same and for $g_1 = d_1 = s_1$) for the two configurations are summarized in Table 1.

TABLE I. DIMENSIONS OF BOTH (SSRR).

Parameter	g_1	a_1	b_1	P_1
Value (mm)	0.25	5.2	4.2	5.7

III. RESULTS AND DISCUSSION

A. Electromagnetic characteristics of (SSRR1)

On the FR4_Epoxy substrate with physical characteristics ($\epsilon_r = 4.4$, $tg\delta = 0.02$) and thickness ($h = 1.2$ mm), the two rings (of dimensions represented in Table 1) constituting the (SSRR1) are engraved for a thickness ($t = 15$ μm). The (SSRR1) is represented on the 3-D Modeler of the HFSS simulator by Fig. 3.

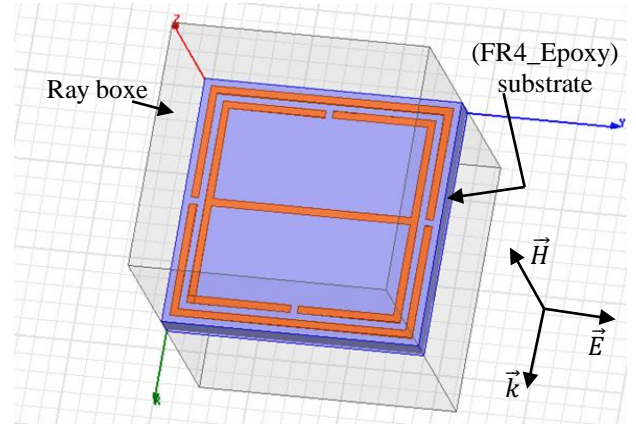


Fig. 3. Square (SSRR1) polarized according to \vec{OY} .

On the structure thus represented in Fig. 3, we will define the boundary conditions (electrical and magnetic wall) in the simulator; we can extract all the electromagnetic characteristics. The reflection and the transmission coefficient (amplitude and phase) are shown in Fig. 4.

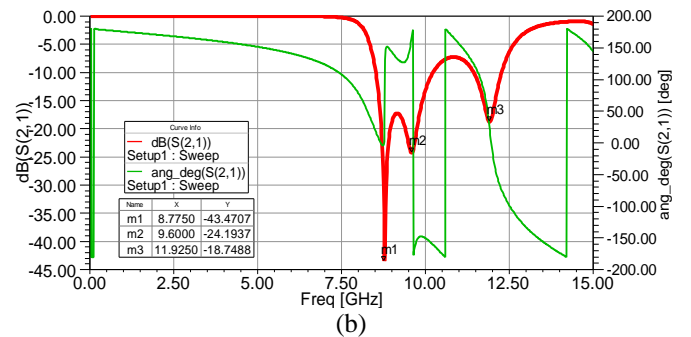
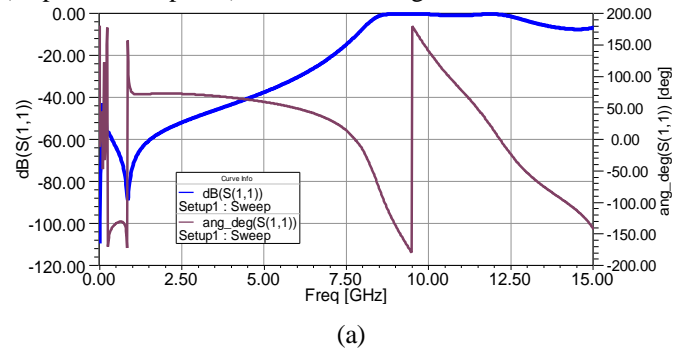


Fig. 4. (SSRR1) behavior (a) Reflection (b) Transmission.

In Fig. 4, we observe the behavior of our (SSRR1) on the frequency range [0 - 15] GHz. We notice that the resonator (SSRR1) has a stop-band behavior for three resonances; ($f_{r1} = 8.77$ GHz, $f_{r2} = 9.6$ GHz and $f_{r3} = 11.92$ GHz). The first two resonances for the two gains respectively 43.47 dB and 24.19 dB due to the two rings constituting the (SSRR1) and the third for the gain of around -18.74 dB due to the cross track of the inner ring. For the phase of the two reflection and transmission coefficients, we note that the two values min and max are contained in the interval $[-\pi, +\pi]$.

For the absorption of our (SSRR1), we will inject the expression (as a function of frequency) in the simulator, it expresses by [12].

$$A_b = 1 - R - T = 1 - |S_{11}(f)|^2 - |S_{21}(f)|^2 \quad (1)$$

Where $R = |S_{11}(\omega)|^2$ and $T = |S_{21}(\omega)|^2 = 0$. So,

$$A_b = 1 - |S_{11}(\omega)|^2 \quad (2)$$

The absorption of (SSRR1) is shown in Fig. 5.

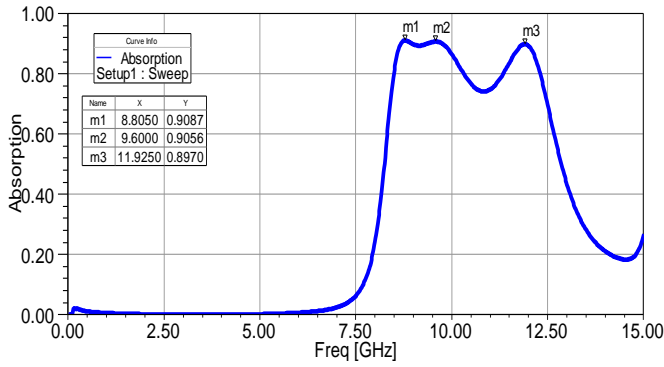


Fig. 5. Absorption of the (SSRR1).

Fig. 5 represents in the same frequency range the absorption of our (SSRR1), these are three absorption peaks associated with the three resonances; 90.87% around 8.8 GHz, 90.56% at 9.6 GHz resonance and 89.7% at 11.92 GHz resonance. We also note that the absorption band is around 3.12 GHz which is a wide band.

For the effective refractive index of (SSRR1), we use the expression [13].

$$n^2(f) = \mu(f) \varepsilon(f) \quad (3)$$

With,

$$\mu(f) = \frac{1 - |S_{21}(f)|^2 + |S_{11}(f)|^2}{j(1 - |S_{21}(f)|^2 - |S_{11}(f)|^2)} \quad (4)$$

and

$$\varepsilon(f) = \frac{1 - |S_{21}(f)|^2 - |S_{11}(f)|^2}{j(1 + |S_{21}(f)|^2 + |S_{11}(f)|^2)} \quad (5)$$

The real part of the refractive index of (SSRR1) is shown in Figure 6.

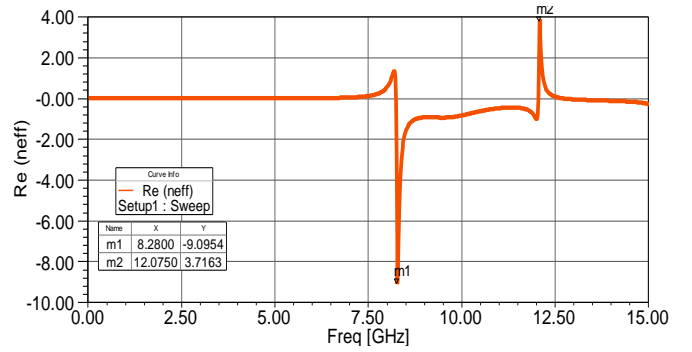
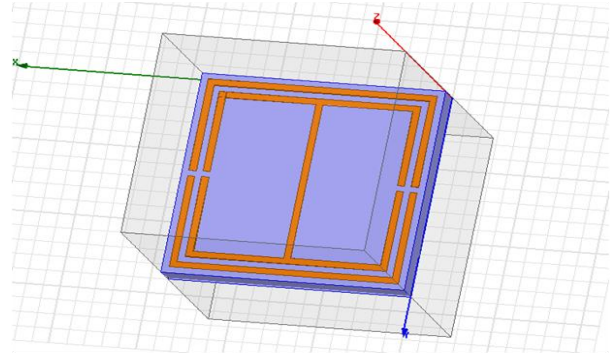


Fig. 6. Real part of the refractive index for the (SSRR1).

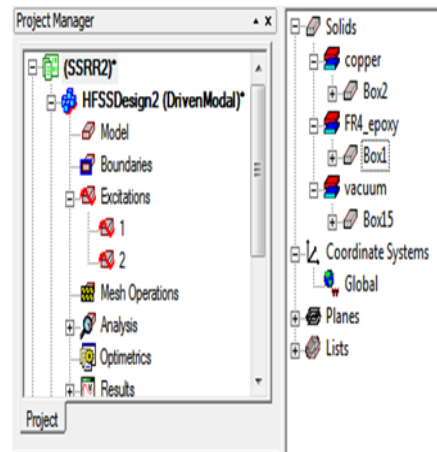
In Fig. 6 we notice that the real part of the refraction index of the first configuration for (SSRR1) changes their sign. In the [8.28 - 12.07] GHz range, i.e. the range comprising the three resonances, the real part of the effective refractive index is negative and it changes the value from -9.09 à $+3.71$. This means that the electromagnetic characteristics in the indicated range are unusual.

B. Electromagnetic characteristics of (SSRR2)

Under the same simulation conditions, the (SSRR2) and its project manager are shown in Fig. 7.



(a)



(b)

Fig. 7. Square (SSRR2) (a) polarization according to \vec{OX} (b) Project Manager.

The electromagnetic characteristics of the second configuration of the resonator can be found for the (SSRR2). The reflection and transmission coefficient (amplitude and phase) are shown in Fig. 8.

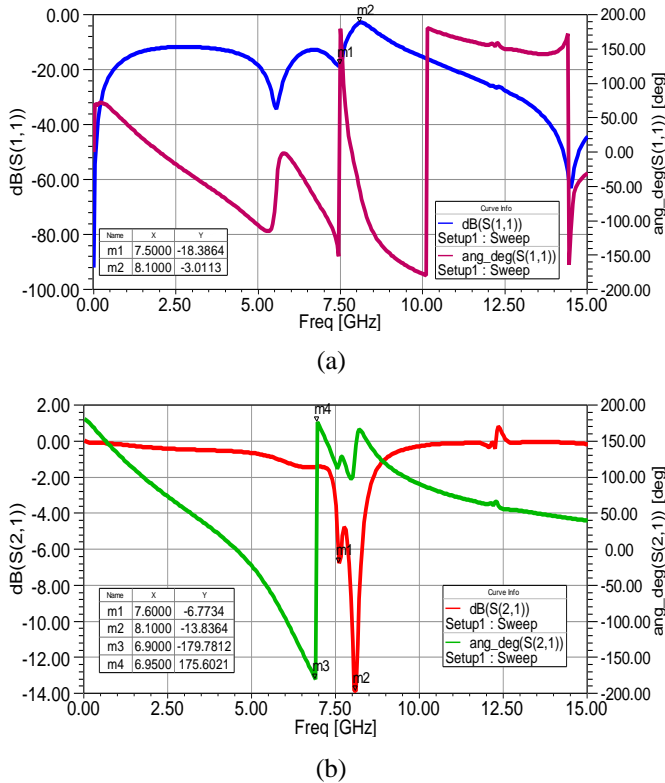


Fig.8. (SSRR2) behavior (a) Reflection (b) Transmission.

In Fig. 8, we observe the same behavior of (SSRR2) which is stop-band for two resonances; ($f_{r1} = 7.6$ GHz, $f_{r2} = 8.1$ GHz). We notice that the two resonances are close to each other which justify the capacitive effect of the second configuration. The absorption of (SSRR2) is shown in Fig. 9.

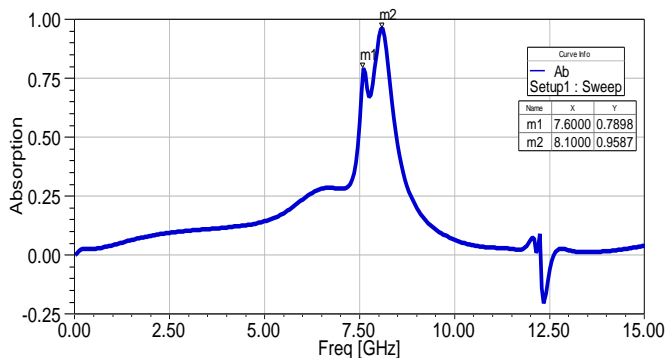


Fig. 9. (SSRR2) absorption.

Fig. 9 represents the absorption of (SSRR2), we note that there are two absorption peaks associated with the two resonances 78.98% at 7.6 GHz resonance and 95.87% at 8.1 GHz resonance. It is a narrow band in the order of 500 MHz.

The real part of the refractive index of (SSRR2) is shown in Fig. 10.

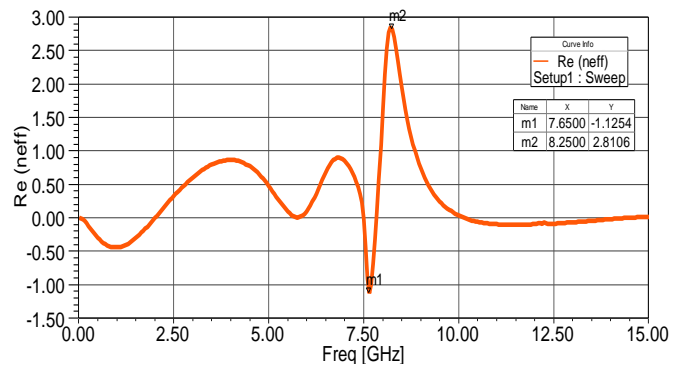


Fig.10. Real part of the refractive index for the (SSRR2).

For the (SSRR2), the real part of the refractive index changes the sign in the range containing the two resonances for the two values -1.12 and 2.81 respectively.

IV. CONCLUSION

A characterization of the electromagnetic qualities of a new metamaterial resonator is represented in this work. The geometric shape of the rings forming the studied (SSRR) is square for two different configurations. Obtaining the different characteristics for the two configurations showed us the influence of the geometric shape on the electromagnetic qualities of the resonator. The results obtained in particular for the refractive indices show that metamaterials can offer us several applications with success for microwave systems.

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