Evolution of transmission of a Split Ring Resonator with the substrate's permittivity and its thickness

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Abstract: This paper study the impact of the substrate's permittivity and its thickness on the transmission spectrum of the unit cell of an SRR, the calculations are made with HFSS (high frequency simulator structures) a commercial code that uses the finite element as method of calculation, the resonance frequencies are extracted from the S parameters.
Keywords: Split Ring Resonator, magnetic resonance, S parameters

Introduction

The design of a medium with negative permeability was only possible if ferromagnetic materials have been used. In 1999, Pendry *et al* [1] broke this law and proposed artificial magnetism based on the geometry of the structure. They designed what they called Split Ring Resonator (SRR) structure having a negative magnetic response on Microwave frequency band. SRRs have received particular interest from researchers. They have studied the properties of their transmission spectrum [2-5], their effective parameters [6-8] and magnetic resonance [9,10] in the Microwave have been investigated. Recently magnetic responses of SRRs were obtained theoretically and experimentally on terahertz frequency band [11,12].

Other geometries of resonators were proposed to obtain magnetic resonance; especially the spiral [13], the "S" [14], the "Ω" shaped [15] and more recently the triangular shaped resonator [16].

In this paper, we will study the impact of the substrate's permittivity and its thickness on the transmission spectrum of the unit cell of an SRR. The calculations were made through a commercial code that uses the finite element as method of calculation. The resonance frequencies are extracted from the S parameters and two cases are distinguished for the direction of electric field; the magnetic field is always parallel to the axis of the structure.

Simulation method and discussion

Our structure is a square unit cell of SRR made with gold; it is arranged on the substrate "Duroid" with permittivity, loss tangent and thickness close to 2.2, 0.0009 and 1 mm, respectively. The shape and the size of the structure are shown in Figure 1. The structure is placed in a waveguide and the Perfect Electric Conductor (PEC) and Perfect Magnetic Conductor (PMC) conditions are applied respectively, on the faces which are orthogonal to the X and Z axes. The Magnetic field, the electric field and the propagation are along the Z, X and Y axis, respectively.

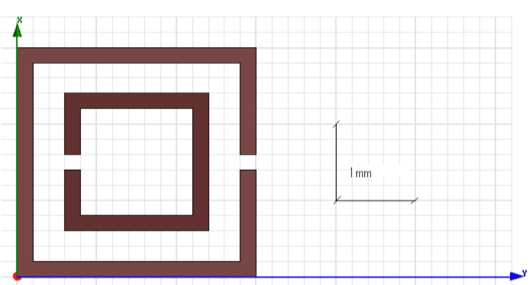

Fig.1: Shape, size and orientation of unit cell of an SRR

Firstly, the representation of the frequency evolution of S-parameters shows the existence of two resonances peaks: the first one located at 9.77 GHz with -29.80 dB is more pronounced than the second one, which is located at 19.91 GHz with -22.85 dB as shown in Figure 2. If we change the orientation of the electric field along the Y axis and the propagation direction is along X, another resonance peak appears at 8.92 GHz with -23.63 dB in addition to that which is at 7.63 GHz with -37.51 dB. The difference between the two dispositions is that the first one is such that the symmetry of the structure is not respected by the orientation of the electric field against the second one, which has the effect of creating an electric resonance over the magnetic resonance as shown in Figure 3.

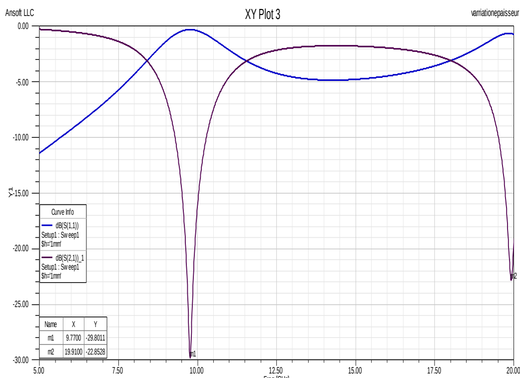

Fig.2: The reflexion-transmission coefficients show a resonance at 9.77 GHz. The electric field is along X axis.

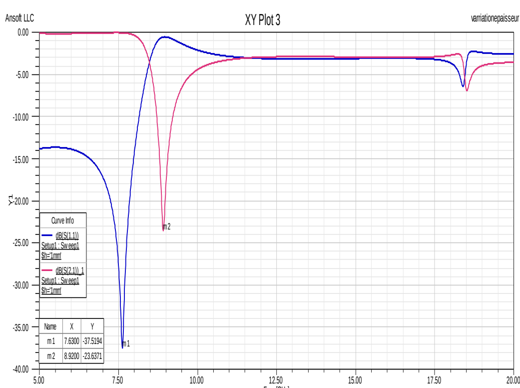

Fig.3: The reflexion-transmission coefficients show two resonances at 7.63 GHz and at 8.92 GHz. The electric field is along Y axis.

Secondly, the SRR is placed on a substrate with variable permittivity ε close to 2,3,4,5 with thickness around 1 mm. We apply boundary conditions PMC to the planes parallel to the structure and PEC conditions to the plans parallel to the Y axis. Figure 4 shows the frequency evolution of the transmission with permittivity. For a given permittivity, we note that the structure has two resonances peak in the studied frequency range. For example, for the substrate permittivity ε = 2, the first resonance peak which is located at - 9.43 GHz with 33.06 dB is more pronounced than the second one which is located at 18.43 GHz with -25.16 dB, so a reduction of nearly 24% is obtained. Now, when we vary the index of refraction of the substrate increasingly, the resonance frequency varies decreasingly, it is what is expected if we take into account the dispersion equation $k = n\frac{\omega}{c}$ or $\varepsilon = \left(\frac{kc}{\omega}\right)^2$, where c is the velocity of light in vacuum, k is the wave number, and n is the refractive index. Similarly, if we change the orientation of the electric field, we have the same phenomenon, but the attenuation of the second frequency is more acute. For example, for the substrate with dielectric permittivity close to 2, we have a regression of the transmission's from -26.10 dB to -5.95 dB and an attenuation greater than 65%.

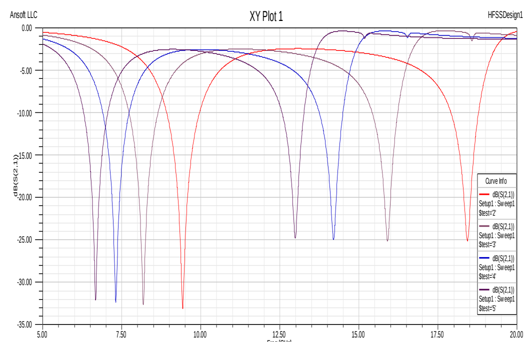

Fig.4: The evolution of transmission with the substrate's permittivity. The electric field is along X axis.

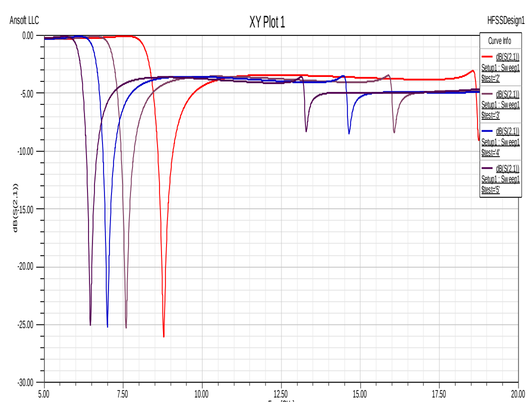

Fig.5: The evolution of transmission with the substrate's permittivity. The electric field is along Y axis, the second resonances are more attenuated.

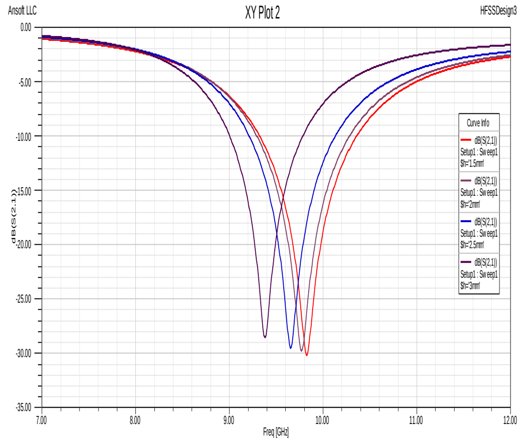

Fig.6: The evolution of transmission of the substrate's thickness.

Finally, for a fixed substrate permittivity, we consider different values of thickness. For this purpose, we place the SRR on the dielectric "Duroïd" with permittivity close to 2.2, loss tangent coefficient close to 0.0009 and the thickness values from 1 to 3 mm with an increment of 0.5mm. The obtained results are shown in Figure 6. From the diagram of transmission and as expected, we note that the resonance peak downshifts to lower frequencies gradually when the thickness of the substrate is increased. These calculations suggest that, this structure geometry can be responsible for creating this type of resonance sub-wavelength, by applying a magnetic field with parallel direction to the axis of revolution of the SRR (parallel to the Z axis). There is a creation of an induced current that will flow along the structure and an accumulation of the charges on the gaps. This structure can be modeled by a simple LC circuit with a resonant frequency $\omega = 1 / \sqrt{LC}$. To minimize the thickness is equivalent to minimize the capacitance between two adjacent unit cells, and consequently to increase the resonant frequency.

Conclusion

We have presented the results of simulation for a unit cell structure SRR inserted into a waveguide. We have shown the evolution of the reflection-transmission coefficients versus frequency. We have obtained that the studied structure is characterized by two types of resonance, magnetic and electrical properties that are due to the geometry structure and the excitation nature. Finally, it has been shown that the transmission can be tuned not only by the size structure variations, but also by varying the permittivity of the substrate and its thickness.

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