STUDY OF ARTIFICIAL MAGNETIC MATERIAL FOR MICROWAVE APPLICATIONS

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ABSTRACT

Various possibilities to design artificial magnetic materials for microwave frequencies are considered. Such composites can be used in microwave engineering at frequencies where no natural low-loss magnetic materials are available. In this paper, a magnetic particle formed by two rings with cross split having a negative permeability is proposed and analyzed numerically. The design tool is the HFSS software which uses the finite element method. The extraction of effective parameters by the reflection- transmission method demonstrates the meta-material behaviour of the studied structure.

KEYWORDS

Left handed material, cross split ring resonator, negative permeability.

1. INTRODUCTION

There is much interest in meta-materials for the microwave and optical applications because their electromagnetic properties are vastly different from ordinary materials. Meta-materials are defined as artificial electromagnetic structures which have the negative permittivity and the negative permeability simultaneously in a specific frequency range [1]. They are also called left-handed materials (LHMs) which mean the electric field, magnetic field, and propagation vector are related by a left-handed rule which results in the phase and group velocities of an electromagnetic wave being anti-parallel.

The first structure to prove the existence of meta-materials was a split ring resonator structure that has a magnetic response without magnetic materials and it was introduced by Pendry [2]. Magnetic properties of the SRR are considered as the substrate of the microstrip patch antenna instead of high permittivity materials because we can, not only reduce the size of the patch, but also improve the bandwidth of the antenna using high permeability materials for substrates of microstrip patch antennas [3] [4]. The SRR structure has a ring with a gap, which makes the inductance and capacitance. The transmission coefficient of the SRRs is minimum at the magnetic resonance frequency, which is made from the inductance and capacitance. It is important to design SRR structures in the substrate of the microstrip components because the shape, the orientation and the arrangement of SRR structures change the inductance and capacitance. There are several structures that have been introduced by the previous researchers starting with a symmetrical ring structure, then an omega, and finally an S structure [5]. In this paper, we proposed a Broadside-coupled SRR structure with cross split, having a negative permeability in the microwave frequency. Using the commercial software HFSS [6], and in normal incidence, the « S » parameters for a single unit cell are calculated with the mentioned boundaries along the wave propagation. And by an inversion technique of Fresnel coefficients [7], the effective material parameters are given. From the simulation results, the real part of the permeability is found to be negative at frequencies band where both real parts of the permittivity and refractive index are positive. Thus we show that it is possible to obtain high values of the effective permeability with different geometry from that of Pendry [2].

2. DESIGN AND SIMULATION

The geometry of the proposed artificial particle for X-band [8.2 GHz; 12.4 GHz] is shown in figure 1. The single unit cell consists of two major parts which are substrate, and the structure of Broadside-coupled SRR. The term broadside is used to characterize the coupling which is based on the width of the microstrip lines rather than the thicknesses of lines. The two rings have the same dimensions and are placed each one on a face of the substrate Flame Retardant 4 (FR-4) which is act as the core substrate in the single unit cell, while the Broadside-coupled SRR were constructed from copper metal inside the core substrate. The periodicity in space is 3.63 mm; the width of the two cross splits is 0.33 mm.

The properties of the FR-4 are shown in table 1.

Properties	values
Permittivity	4.9
Loss Tangent	0.025
Permeability	1
Substrate Height	0.4

Table1: FR-4 substrate properties.

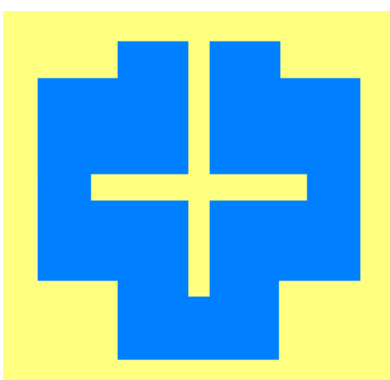


Fig.1: Geometry of the BC-SRR structure

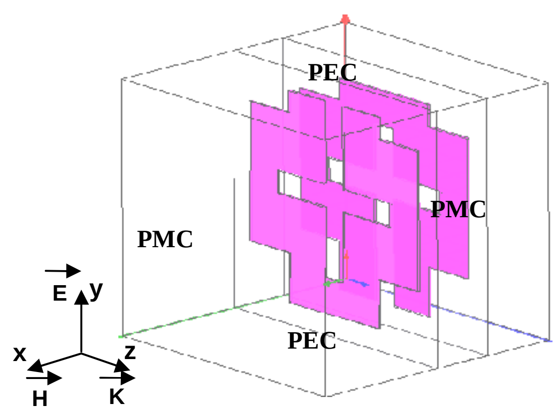


Fig.2: Simulation setup

Meta-material unit cell is designed and simulated using the HFSS software based on finite element method. Two waveguide ports were set at the top and bottom of the y-axis, the substrate with broadside structure are centered in the waveguide and it is excited by an electromagnetic wave with the propagation vector k in *y*-direction, the electric field vector E in *z*-direction, and the magnetic field H in *x*-direction. Perfect electric conductor (PEC) boundary conditions were implemented on the left and the right of the z-axis, and perfect magnetic conductor (PMC) boundary conditions were placed in front and back of the x-axis. HFSS simulations are performed with 0.1 GHz incremental steps on a frequency band between 5 GHz and 15 GHz.

To show the physical properties of the designed structures, S parameters for a single unit cell are calculated with the mentioned boundaries along the wave propagation. Next, the effective material parameters can be extracted from the S parameters as [7] [8].

$$z = \sqrt{\frac{(1+S_{11})^2 - S_{21}{}^2}{(1-S_{11})^2 - S_{21}{}^2}}. \qquad (1)$$

$$n = \frac{1}{kd}\cos^{-1}\left[\frac{1}{2S_{21}}(1 - S_{11}{}^2 + S_{21}{}^2)\right] \qquad (2)$$

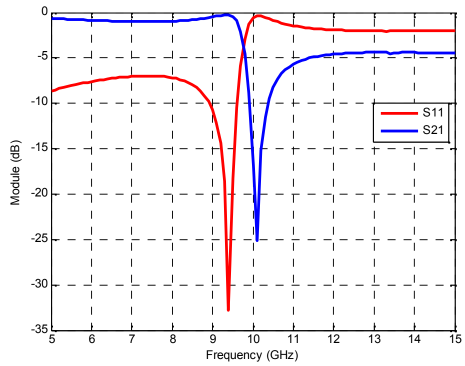
Where k and d are the wave vector and the thickness of the slab.
z and n indicate the wave impedance and refractive index, respectively. Then, the electric permittivity and magnetic permeability can be computed from the equations of $\varepsilon = n/z$ and $\mu = nz$.

3. RESULTS

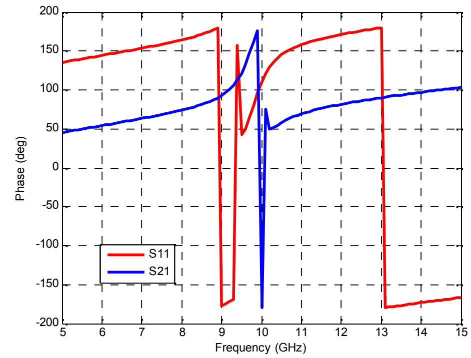
The amplitude (in dB) and the phase (in deg) of S_{11} and S_{21} parameters (coefficients of reflection-transmission) calculated by HFSS of the unit cell are presented in figure 3 (a), and 3 (b). A resonance frequency is observed at 10.1 GHz with an order transmission of -25.09 dB, which is due to the capacitive effect created by the geometry of the structure. Thus, we have a resonant LC circuit with a resonance frequency which depends only of the inductance and capacitance of the structure $\omega = \frac{1}{\sqrt{LC}}$. The phase of the reflection coefficient undergoes a peak of phase pronounced to 9.5 GHz. Let us note that this type of jump phase is always observed when we study a medium with negative permeability.

The effective parameters of the unit cell calculated by the inversion method from the coefficients S_{11} and S_{21} are shown in figure 4, a positive real part, of the impedance ensuring the passive medium is verified (figure c). The real part of the refractive index is null for the frequency range located between 10.01 GHz and 10.5GHz as shown in figure (d). The real part of the permeability shows Lorentz response behaviour; it is negative in the frequency range between 9.7 GHz and 10.7 GHz as it appears in the figure (a). The results obtained are in qualitative agreement with those obtained for square broadside coupled SRR in ref [9].

It should be noted that it is possible to control the transmission by modifying certain number of parameters with knowing the structure dimensions (height, width, and opening of the gap), nature substrate, and its thickness.

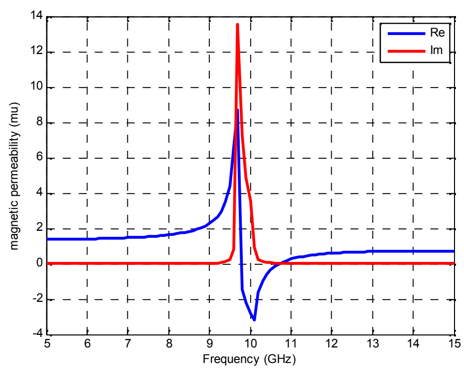


(a)

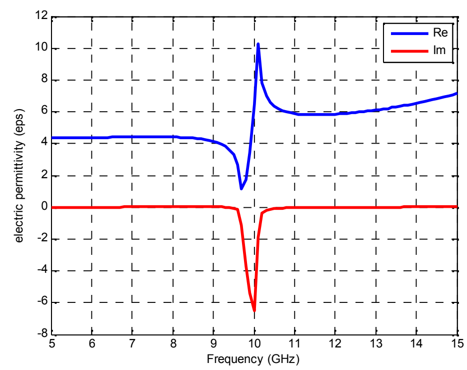


(b)

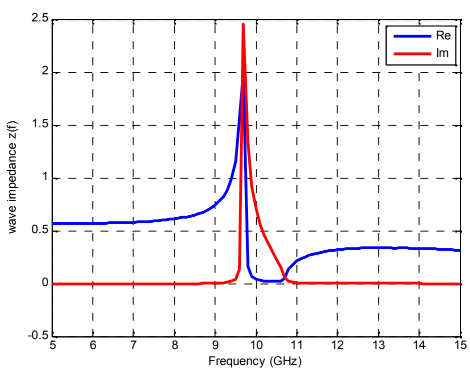
Fig.3: Magnitude and phase of S_{11} and S_{21} along the propagation direction.



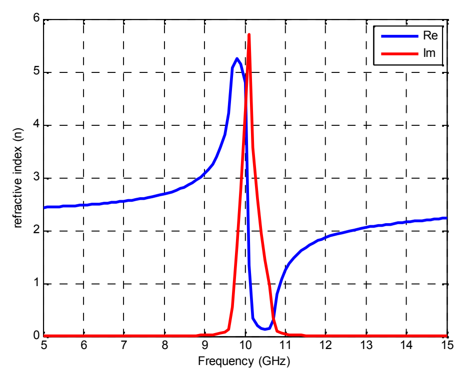
(a)



(b)



(c)



(d)

Fig.4. Effective parameters of the unit cell of BC-SRR; (a) magnetic permeability, (b) electric permittivity, (c) wave impedance, and (d) refractive index.

4. CONCLUSIONS

In this paper, BC-SRR structure for a new artificial magnetic inclusion has been introduced and validated by simulations. We can point out that the real part of the permeability is negative over a specific frequency range.

Exploitation of these results in realization of such a medium in the optical field is confronted with the problems of absorption on the one hand, and with technological difficulties which impose nanometres dimensions on the structure in the other hand.

REFERENCES

[1] Veselago, V. G., (1968) “The electrodynamics of substances with simultaneously negative values of ε and μ,” Sov. Phys. Uspekhi, Vol. 10, 509-514.

[2] Pendry, J. B., A. J. Holden, D. J. Robbins, and W. J. Stewart, (1999) “Magnetism from conductors and enhanced nonlinear phenomena," IEEE Transactions on Microwave Theory and Techniques, Vol. 47, 2075-2084.

[3] P. M. T. Ikonen, S. I. Maslovski, C. R. Simovski, S. A. retykov, (2006) “On Artificial magnetodielectric Loading for Improving the Impedance Bandwidth Properties of Microstrip Antennas”, IEEE Trans on antennas and propagation, vol. 54, no. 6, pp.1654-1662.

[4] H. Mosallaei, K. Sarabandi, (2004) “Antenna Miniaturization and Bandwidth Enhancement Using a Reactive Impedance Substrate”. IEEE Trans on AP, vol. 52, no. 6, pp.1558-1567.

[5] L. Ran; J Huangfu; H. Chen; X. Zhang; K. Cheng; T. M. Grzegorczyk, and J. A. Kong, (2005) “Experimental study on several left-handed metamaterials”. Progress in Electromagnetics Research, Vol .51, 249–279.

[6] High Frequency Structure Simulator « v11 », Ansoft Coperation, (2008).

[7] X. Chen, T. M. Grzegorczyk, B. Wu, J. Pacheco, and J. A. kong, (2004) “Robust method to retrieve the constitutive effective parameters of metamaterials,” Phys. Rev. E., 70, 016608.

[8] Smith, D. R., D. C. Vier, T. Koschny, and C. M. Soukoulis, (2005) “Electromagnetic parameter retrieval from inhomogeneous metamaterials,” Physical Review E, Vol. 71, 036617.1–036617.11.

[9] D. Seetharamdoo, R. Sauleau, K. Mahdjoubi et A-C. Tarot, (2004) “Homogenisation of negative refractive index metamaterials : comparison of effective parameters of broadside coupled and edge coupled split ring resonators”. IEEE Antennas and Propagation Society International Symposium, vol. 4, 3761–3764.