Design and Simulation of Double "S" Shaped Metamaterial

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Abstract

Metamaterials are defined as artificial electromagnetic structures based on the assembly of magnetic resonators and infinitely long metal rods at sub wavelength scale, which have the negative permittivity and the negative permeability simultaneously in a specific frequency range. However there are also some new metamaterial structures being explored which exhibit the same behavior. In this paper, we present the design, and simulation of a double S-shaped metamaterial in the microwave range. The design tool is the HFSS software which uses the finite element method. The extraction of effective parameters by the method of reflection- transmission coefficients demonstrates the metamaterial behavior of the said structure.

Keywords: *left handed metamaterial, double "S" structure, negative refraction, simulation.*

1. Introduction

In 1968, the Russian physics scientist V. Veselago suggested a new type of material which has simultaneously negative permittivity and negative permeability, and he presented general properties of electromagnetic wave propagation in such material [1]. He theoretically created a lossless meta-material and showed the extraordinary properties of this material which is not found in nature, in particular a negative refraction, a negative group speed, the reversal of Doppler Effect and Cerenkov radiation.

The Veselago's intuition remained silent for 29 years until year 1996 when Prof J.B Pendry proposed his design of Thin-Wire (TW) structure that exhibits the negative value of permittivity ε [2] and the Split Ring Resonator (SRR) with a negative value of permeability μ in 1999 [3]. Later, Smith and his colleagues demonstrated a new metamaterial that shows simultaneously negative permittivity and permeability and carried out microwave experiments to test its unusual properties in 2000 [4]. The first experiment showing negative refraction was performed using a metamaterial consisting of a two-dimensional array of repeated unit cells of copper strips and split ring resonators in 2001 by Shelby et al [5].

Most of the MMs are made of periodically arranged metallic structures much smaller than the working wavelength in size, the electromagnetic responses of MMs can be characterized as homogeneous media. As a new type of artificial materials, it can be applied to many disciplines, such as filter, waveguide, resonator and antenna [6].

Several appointments appeared since the synthesis of such a medium; left hand medium [1-5], media with negative refractive index [7], "backward-wave" which wants to say medium where the wave moves behind [8], DNG (double negative materials) [9] and meta-matérial.

The meta-material is thus an assembly of two structures, one which has a negative permeability (SRR) and the other which has a negative permittivity (TW).

Nevertheless, several work showed the possibility of synthesis of a similar medium by the means of various forms, in particular the omega form [10], the U form [11], the V form [12], and the triangular form [13].

In this paper we present a structure which has the characteristic to have at the same time a negative permeability and a negative permittivity. By the means of the commercial software HFSS which uses the finite elements as calculation method , and in normal incidence, the « S » parameters for a single unit cell is calculated with the mentioned boundaries along the wave propagation, and by inversion technique of the Fresnel coefficients [14], the effective material parameters are given. From the simulation results, the real part of the refractive index is found to be negative at frequencies where both real parts of the permittivity and permeability are negative. Thus we show that there is a frequency band where the effective refractive index of the medium is negative.

2. Retrieval procedure

To obtain the effective electromagnetic parameters of the structure, a theory of homogenization is used. The main purpose of this theory is to describe in a simple and macroscopic way the microscopic complexity of the response of objects to an incident electromagnetic radiation. Indeed, the idea was to model the metamaterial as an isotropic homogeneous slab, and to calculate the effective parameters ε, and μ of the homogenous slab from the transmission and reflection coefficients obtained by simulations under HFSS software.

For an isotropic homogeneous slab in a vacuum space, the transmission *t*, and reflection *r* have the following

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relations with the refractive index *n*, and the impedance *z*, of the slab [14]:

$$t^{-1} = \left[\cos(nkd) - \frac{i}{2}\left(z + \frac{1}{z} \right) \sin(nkd) \right]. \quad (1)$$

$$\frac{r}{t} = \left[-\frac{i}{2}\left(z - \frac{1}{z} \right) \sin(nkd) \right]. \quad (2)$$

Where k and d are the wave vector and the thickness of the slab respectively.
Equations (1) and (2) can be inverted to calculate *n* and z from t, and r. By completing this inversion, we obtain:

$$z = \pm \sqrt{\frac{(1+r)^2 - t^2}{(1-r)^2 - t^2}}. \quad (3)$$

$$\cos(nkd) = \frac{1}{2t}\left(1 + t^2 - r^2\right). \quad (4)$$

By using the S parameters, the effective material parameters can be extracted [13]:

$$z = \pm \sqrt{\frac{(1+S_{11})^2 - S_{21}{}^2}{(1-S_{11})^2 - S_{21}{}^2}}. \quad (5)$$

$$re(n) = \pm re \left[\frac{\cos^{-1}\left(\frac{1}{2S_{21}}\left(1 - S_{11}{}^2 + S_{21}{}^2\right) \right)}{kd} \right]. \quad (6)$$

$$im(n) = \pm im \left[\frac{\cos^{-1}\left(\frac{1}{2S_{21}}\left(1 - S_{11}{}^2 + S_{21}{}^2\right) \right)}{kd} \right]. \quad (7)$$

The ambiguity on the signs of the equations (5), (6) and (7) is prevented if account is held owing to the fact that the real part of the impedance is positive if it is about a passive medium, and the imaginary part of the refractive index is positive to ensure that the incident wave amplitude decreases inside the structure.
Then, the effective permittivity and permeability can be computed from the equations: $\varepsilon = n/z$ and $\mu = nz$.

3. Metamaterial design and simulation.

The structure suggested in this work is a gold in the form "S "made up of two microrubans lines laid out on the two opposite faces of a dielectric substrate (FR4) who has a permittivity ε=3.38, and a thickness of 1.6 mm, the periodicity in space is 3.63 mm. The unit cell dimensions are presented in figure1 [3].

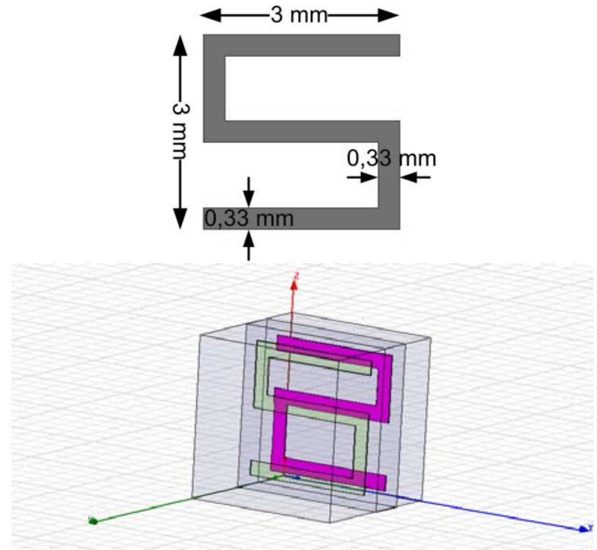

Fig.1: Geometry and dimensions of the double "S" structure.

For the simulation of the unit cell in HFSS, boundary conditions of magnetic and electric wall are applied respectively according to axes y and x. The structure is polarized so that the magnetic field is directed along x axis, the electric field is directed along y axis, the wave vector is according to the z axis. The Simulation is made on a frequency band between 10 GHz and 20 GHz with a 0.01 GHz increment.
The simulated S parameters (coefficients of reflection-transmission) for this structure are shown in figure 2.
As shown in figure 2, there is a transmission peak around 15.68 GHz, which indicates the existence of a resonance frequency which is due to the capacitive effect created by the geometry of the structure. So, we have an LC resonator who has a resonance frequency which depends only on the inductance and capacitance of the equivalent structure, where $\omega = \frac{1}{\sqrt{LC}}$. The variation of the effective impedance of the wave propagating through the structure is illustrated in figure 3. A positive real part, ensuring that the medium is passive is verified. According to the theory of metamaterials, the real parts of the permittivity and permeability must be negative, thus negative real parts for the permittivity and permeability are observed for this structure. As shown in figure 4, the real part of the permeability shows Lorentz response behavior, it is negative in the frequency range between 15.63 GHz and 17.8 GHz. In addition, the permittivity real part is negative in the frequency range located before 17.8 GHz, which is in good agreement with the Drude model as it appears on the figure 5.
The negative band for the refractive index approximately lies between 15.67 GHz and 17.43 GHz; it is the frequency range where the permittivity and the permeability are simultaneously negative as it appears on figure 6.
It should be noted that it is possible to control the transmission by modifying a certain number of

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parameters dimensions of the structure (height, width, and opening of the gap), nature substrate and its thickness. Thus it is shown that the synthesis of a medium with negative refractive index is possible with similar geometry without having recourse to the array of metallic wires as it is the case for traditional metamaterials.

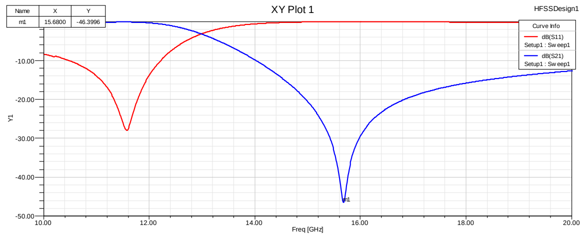

Fig.2: Amplitudes of simulated S_{11} and S_{21} of one unit cell along the propagation direction.

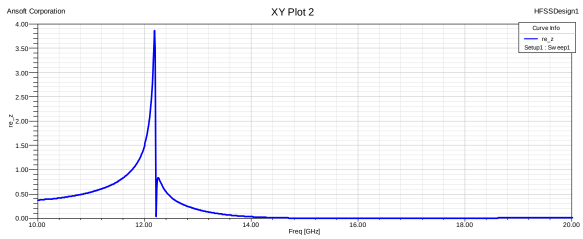

Fig.3: The real part of the impedance is positive, it is a passive medium.

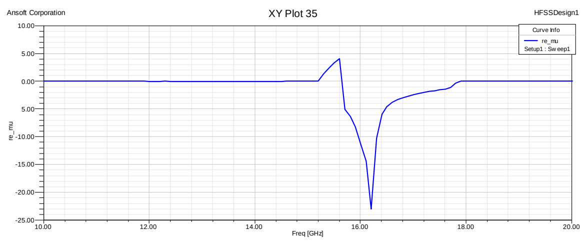

Fig.4: Evolution of the real part of the permeability according to the frequency.

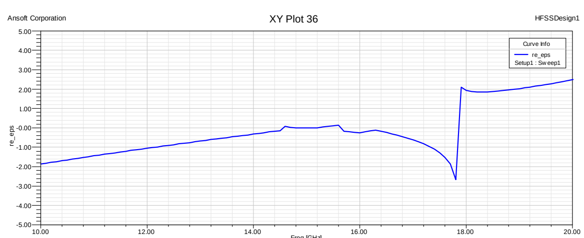

Fig.5: Evolution of the real part of the permittivity according to the frequency.

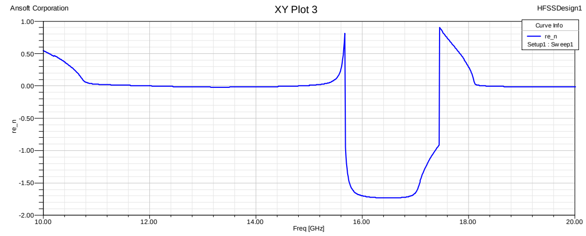

Fig.6: Evolution of the real part of the refractive index according to the frequency.

4. Conclusion

In this paper, we presented a particular meta-material structure shaped "double S". Its characteristic comes owing to the fact that it exhibits at the same time electric and magnetic activities because of its character bianisotropic. Such a geometrical configuration enabled us to highlight a frequency band where the structure behaves like a medium with negative refractive index. 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 nanometric dimensions on the structure in the other hand.

References

[1] Veselago, V. G., “The electrodynamics of substances with simultaneously negative values of ε and μ,” Sov. Phys. Uspekhi, Vol. 10, 509-514, 1968.
[2] Pendry, J. B., A. J. Holden, W. J. Stewart, and I. Youngs, “Extremely low frequency plasmons in metallic mesostructures," *Physical Review Letters*, Vol. 76, 4773-4776, 1996.
[3] Pendry, J. B., A. J. Holden, D. J. Robbins, and W. J. Stewart, “Magnetism from conductors and enhanced nonlinear phenom- ena," IEEE Transactions on Microwave Theory and Techniques, Vol. 47, 2075-2084, 1999.
[4] Smith, D. R., W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, “Composite medium with simultaneously negative permeability and permittivity,” Physical Review Letters, Vol. 84, 4184-4187, 2000.
[5] Shelby, R. A., Smith D.R., and Schultz S., “Experimental verification of a negative index of refraction,” *Science*, Vol. 292, 77-79, 2001.
[6] Kong, J. A., “Electromagnetic wave interaction with stratified negative isotropic media," Progress In Electromagnetics Research, Vol. 35, 1-52, 2002.
[7] Iyer, A. K. and Eleftheriades, G. V., “Negative refractive index metamaterials supporting 2-D waves,” IEEE MTT International Microwave Symposium (IMS) Digest, Seattle, WA, (2002) 1067.
[8] Lindell, I. V., Tretyakov, S. A., Nikoskinen, K. I. and Ilvonen, S., “BW media—Media with negative parameters, capable of supporting backward waves,” *Microwave Opt. Tech. Lett.*, 31 (2001) 129.
[9] Ziolkowski, R. W. and Heyman, E., “Wave propagation in media having negative permittivity and permeability,” *Phys. Rev. E*, 64 (2001) 056625.

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[10] Chen, H., Ran, L., Huangfu, J., Zhang, X., Chen, K., Grzegorczyk, T. M. and Kong, J. A. “left handed metamaterials composed of only S shaped resonators”, physical review E, 70 (2004) 057605.
[11] Gallas, B., Robbie, K., Abdeddaïm, M., Guida, G., Yang, J. Rivory, J. and Priou, A., “Silver square nanospirals mimic optical properties of U shaped metamaterials”, Optics express, 18 (2010) 16335.
[12] Ekmekci, E., Turhan Sayan, G., “investigation of permittivity and permeability for a novel V shaped metamaterial using simulated S parameters”, proceedings of 5th international conference on electrical ans electronics
[13] Sabah, C., "tunable metamaterial design composed of triangular Split Ring Resonator and wire strip for S and C microwave bands", Progress in Electromagnetics Research B, 22 (2010) 341.
[14] Smith, D.R. and Schultz, S., Markos, P., Soukoulis, C.M., determination of effective permittivity and permeability of metamaterials from reflexion and transmission coefficients” Phys. Rev. B, 65 (2002) 195104.