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Effect of splits in resonance permeability of ESRR metamaterial at THz

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Abstract

Left handed materials which have both negative permittivity and permeability, have been the area of potential research over a decade. This paper elucidates a Double Negative Group (DNG) Electric SRR, having 19.13THz as resonant frequency and having FR4 (εr=4.4) as substrate material . Nicolson Ross Wier (NRW) method has been used to retrieve the material parameters from transmission and reflection coefficient. Upon incorporation of splits in the structure, we find shift in resonance of permeability to a higher frequency at THz as the no. of splits increase. Also, the curve for resonance in permeability gets sharper i.e. less broadened with increase in splits (upto 3) on ESRR metamaterial.

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Keywords— Antennas; metamaterials (MTMs);negative index material;negative refraction ; RMPA ;DNG,;HFSS;THz

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1. Introduction

The past few years have been very eventful with respect to the evolution of the concept and implementation of ‘left-handed materials (LHMs)’. ‘Metamaterials’ (MTMs) are engineered to modify the bulk permeability and/or permittivity of the medium given by Ziolkowski, R.W (2003). It is realized by placing periodically, structures that alter the material parameters, with elements of size less than the wavelength of the incoming electromagnetic wave. It results in “meta” i.e. “altered” behaviour or behaviour unattainable by natural materials. Slight changes to a repeated unit cell can be used to tune the effective bulk material properties of a MTM, replacing the need to discover suitable materials for an application with the ability to design a structure for the desired effect.

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Examples of MTMs are single negative materials (SNG) like ε negative (ENG) which have effective negative permittivity and μ negative (MNG) which have effective negative permeability, and double negative materials (DNG).

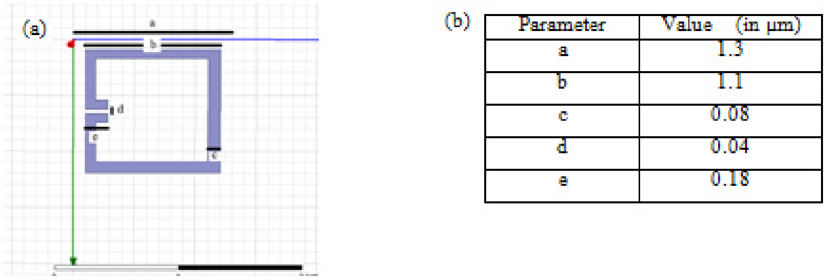
It is worth recalling that negative values of permittivity are inherently bandlimited phenomena and such a condition can hold only at a certain frequency (accompanied with imaginary part of permittivity). Frequency for which real part of permittivity hits value ‘ -2’ and infinity condition goes named as Frohlich frequency shown by A. Sihnola(2006).Particle shape has effect on the value of negative permittivity corresponding to Frohlich resonance. The geometry of negative permittivity particle has a strong effect on its surface plasmonic properties. A fresh approach to microwave and optical devices presented itself with the interesting breakthrough in the area of MTMs at high frequencies. The need of hour is to optimize the antenna parameters (gain , bandwidth , directivity) without altering its dimensions i.e. external control over antenna parameters using MTM . The software tool HFSS is used because it is a high performance full wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling. It integrates simulation, visualization, solid modeling, and automation in an easy to learn environment where solutions to 3D EM problems are quickly and accurately obtained with reference to “HFSS Online Help,” Ansoft Corporation, 2007. This paper abridges the design of proposed DNG MTM Electric SRR having negative refraction with FR4 (εr=4.4) as substrate material in section 2.Section 3 discusses the effect of insertion of splits in ESRR metamaterial. Section 4 concludes the paper.

1. Proposed ESRR MTM

In 1968, Russian scientist V. G. Veselago (1968) postulated a negative material and theoretically proved the phenomenon that a uniform plane-wave followed the left hand rule in a medium with negative permittivity (ε) and negative permeability (μ). The first work in this direction was by Pendry. He created a medium consisting of thin wires arranged in a periodic array demonstrated by J. B. Pendry, A. J. Holden, W. J. Stewart, and I. Yo (1996) These wires acted as a plasma medium, whereby ε varies with frequency, Pendry next achieved a negative μ with a periodic array of metallic loops called Split Ring Resonators explained by J. B. Pendry, A. J. Holden, D. J. Robbins and W. J. Stewart, (1999). In a medium composed of these rings the permeability, μ, varied with frequency, and could become negative. In 1999, Smith combined the rod and ring materials to finally produce a material with simultaneously negative ε and μ, a left-handed material given by D. R. Smith, Willie J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz (2000). The wire strips affect the ε and the split-ring resonators (SRRs) alter the μ of the medium thus giving a frequency dependent negative material with both the parameters negative. The wire medium and the SRRs have certain frequency dependence. The rod gives negative permittivity, ε, and ring material creates a negative permeability, μ ,this combined rod and ring material gives negative index of refraction. Electric SRR metamaterial has been proposed behaving as DNG i.e. Double Negative Group. Such materials have negative permittivity and negative permeability in the same frequency region. Thus having negative refraction in the same explained by Withawat Withayachumnankul Derek Abbott (2009) , Hayet Benosman, Nouredine Boukli Hacene (2012) . The parameter retrieval i.e. parameter extraction using S parameters shown in Daniela Ionescu, Maria Kovaci (2011) has been followed using NRW approach to observe the negative refraction region of MTM. The constructional details along with the curve showing negative refraction are as under.

2.1 Constructional Details

It is construction ally very simple, and has been designed as per figure 1 (a) with design parameters specified in figure 1 (b).It forms the LC resonant structure by having capacitance due to the dielectric gaps and inductance due to the conducting loops Li, J. N.,Withayachumnankul, Withawat,Chang, Shengjang, Abbott, Derek (2012).Each unit cell is designed on a 0.5μm thick FR4 substrate with length a=1.3μm.The thickness of the metal strip is 0.035μm and is made up of gold.



Parameter	Value (in µm)
a	1.3
b	1.1
c	0.08
d	0.04
e	0.18

Fig. 1.Electric SRR shaped MTM a)unit cell designed in HFSS b)constructional details

2.2 *Simulation Results*

Ansoft HFSS has been used to simulate the unit cell designed in figure 4(a).The boundaries and lumped ports (1 and 2) have been assigned as per figure 2(a),(b),(c).

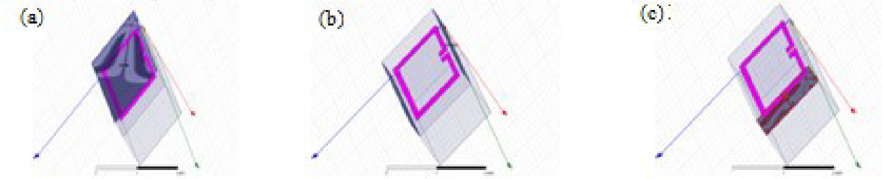


Fig. 2.a) H field b) E field specifying boundary condition c)Lumped Port

Nicolson Ross Wier method has been used to calculate the material properties from transmission and reflection coefficients. It can be observed as in figure 3 that region of negative refraction extends from 19.12THz.

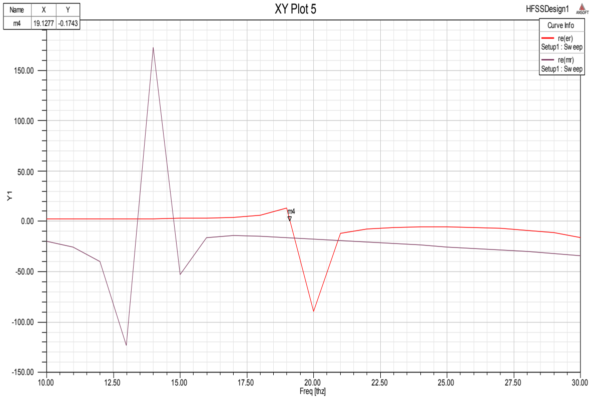


Fig. 3. Resonance at 19.12THz

2. Insertion of Splits

As we know that resonance in permeability scales reciprocally with the structural size at low frequencies explained by Minowa,Y,. Nagai, M. , Hu Tao , Kebin Fan , Strikwerda, A.C. , Xin Zhang, Averitt, R.D. ,Tanaka, K. (2011).Moving to higher frequencies i.e. THz, will not obey this linear scaling. At THz, metals become highly conductive. Thus, it effects the derived material parameters. The metal in ESRR at THz has both kinetic and magnetic energies. Thereby, adding a new term of kinetic energy of metals at THz .Also, the effective cross-section of ring becomes lesser at higher frequencies due to skin effect and the asymmetry of the current distribution between the center and the external sides of the ring in ESRR. Thus, it changes the inductance of the ESRR due to the change in the cross-section. Also, by insertion of splits , we introduce capacitance at each split. With increase in splits, total capacitance decreases, thereby, increasing the resonance frequency. As, resonance frequency is given by equation 1 below

$$\omega_m = \sqrt{\frac{1}{L.(Ceq)}} \tag{1}$$

Figure 4 (a),(b),(c) show the splits of size 1μm X 0.2μm being introduced in ESRR.

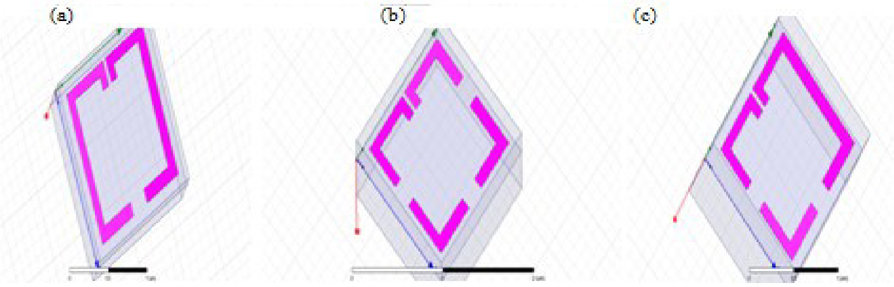


Fig. 4.Electric SRR: a)one split b) two splits c)three splits

Upon simulation in HFSS we obtained the result shown in Figure 5 ,6,7.

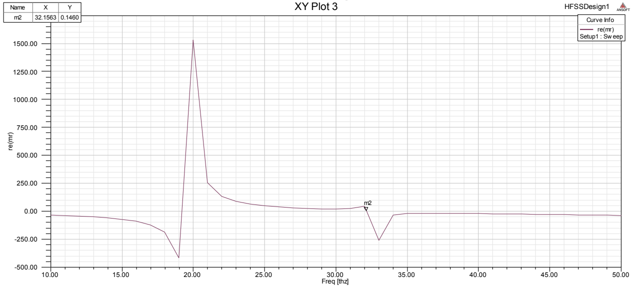


Fig. 5.Resonance in permeability for one split

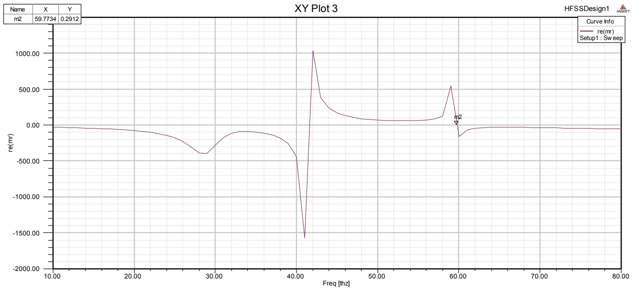


Fig. 6.Resonance in permeability for two splits

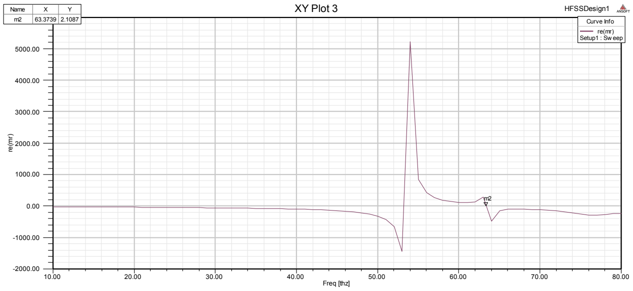


Fig. 7.Resonance in permeability for three splits

Table 1 shows the shift in resonance in permeability with the no.of splits in ESRR metamaterial.

S.No	No.of splits in ESRR	Resonance in permeability (THz)
1	0	19.12
2	1	32.16
3	2	59.77
4	3	63.37

Thus, from Table 1 it can be observed that resonance frequency in permeability increases with increase in no. of splits in ESRR and the resonance in curve gets sharper i.e. less broadened given by J. Zhou,Th. Koschny, M. Kafesaki, E. N. Economou, J. B. Pendry,and C. M. Soukoulis (2005). The curve shown in Figure 8, elucidates the shift in resonance frequency of permeability with the no. of splits in ESRR MTM.

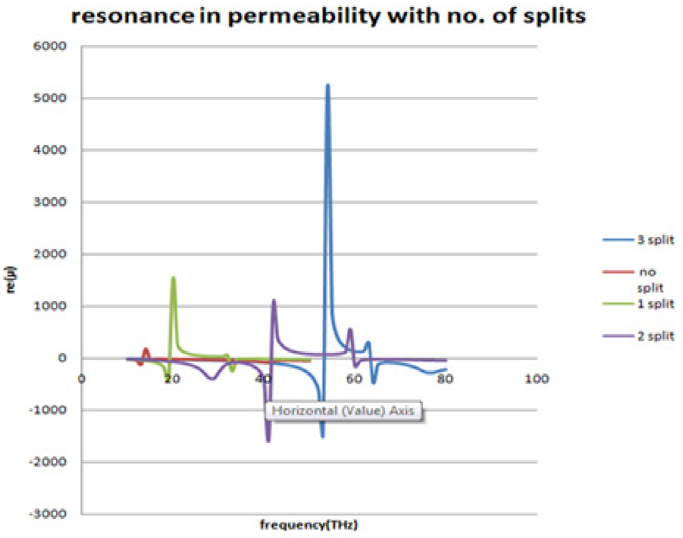


Fig. 8.Resonance in permeability Vs no. of splits in ESRR

3. Conclusion

This paper elucidates the use of metamaterial at THz frequency by increasing the no. of splits in the same. This gives us a new method of obtaining a sharper resonance in permeability for ESRR MTM which otherwise cease to exists at high frequency due to kinetic energy of electrons in metal coming into consideration.

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