Magnetic Response of Rectangular and Circular Split Ring Resonator: A Research Study

Abhishek Sarkhel
Bengal Engineering and Science University
Shibpur

Sekhar Ranjan Bhadra Chaudhuri
Bengal Engineering and Science University
Shibpur

ABSTRACT

In this paper absorption loss & negative magnetic permeability feature of split ring resonator (SRR) is demonstrated & discussed at length for rectangular as well as circular geometry in microwave frequency region. Reflection as well as transmission parameter of SRR for the afro mentioned geometry is presented. The transmission shows a dip for propagation along the direction of split ring resonator plane. From the scattered data, the nature of absorption loss for different substrate thickness is analyzed. The effective medium parameter μ and ε are also computed out of which the negative μ behavior of split ring resonator is demonstrated in the specific frequency region, thus providing us an opportunity to create artificial Mu-negative medium (MNG) having similar behavior as that of gyro-tropic or gyro-magnetic materials.

Keywords

Absorbance, Negative effective permeability, Metamaterial, Split ring resonators (SRR).

1. INTRODUCTION

In 1968 Veselago first introduced the idea of "Left Handed Medium" in his seminal work where he theoretically demonstrated the idea of negative refractive index [1]. The interest in Veselago work got a new dimension when Pendry in 1999 first proposed that SRR made of nonmagnetic material exhibits artificial negative effective magnetic permeability μ_{eff} [2]. Taking account of Pendry's suggestion and Veselago's idea Smith demonstrated in the year of 2000 first realization of artificial "Left Handed Medium" consists of split ring resonator and wire pair [3].In 2005 Smith further proposed standard retrieval procedure of effective medium parameters μ_{eff} and ε_{eff} from scattering parameter of finite thickness sample [4].In this paper we extracted the permittivity ε and permeability μ of SRR for both rectangular and circular geometry based on technique propped by Smith[4],by means of which we demonstrated negative effective permeability μ_{eff} of SRR for afro mentioned geometries. From the computed absorbance data the effect of substrate thickness on absorption loss of SRR for rectangular and circular geometry is also analyzed.

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2. GEOMETRY AND SIMULATION OF CIRCULAR AND RECTANGULAR SRR

The geometrical dimensions of rectangular SRR (RSRR) are: L1=8.5 mm, W1=6 mm, L2=5 mm, W2=2.5 mm, S=s=0.5 mm, G=g=0.5 mm as shown in Figure 1.The dimension of associated unit cell U_x=2.5 mm (U_x is the dimension of unit cell along x which is not shown in Figure 1), U_y=6.5 mm, U_z=10 mm respectively. The geometrical dimensions of circular SRR (CSRR) are: R1=4 mm, R2=3.1 mm, r1=2.9 mm, r2=2 mm, G=g=0.2 mm which is shown in Figure 2. The dimension of associated unit cell U_x=U_z =8.8 mm, U_y=2.5 mm (U_y is the dimension of unit cell along y which is not shown in Figure 2). For both rectangular and circular split ring resonator we use copper as metal with conductivity 5.8 X 10^7 mho as well as having thickness of 0.017 mm. The effective permittivity and permeability of rectangular and circular SRR is extracted for FR 4 substrate with 0.25 mm thickness having dielectric loss tangent 0.02 because for above mentioned substrate thickness both SRR possess minimum absorption loss but in order to analyse effect of substrate thickness on absorption loss we varied the substrate thickness in the sequence of 0.25 mm, 0.8 mm, 1.6 mm respectively for same substrate property. The numerical simulations are performed using commercial finite element solver. A hollow waveguide with two excitation ports are used in front and behind of unit cell for excitation and detection of linearly polarized electromagnetic plane wave. Perfect electric and magnetic boundary conditions are set at four walls of waveguide structure.

3. RESULTS AND DISCUSSIONS

Incident EM wave excites magnetic resonance of SRR through its magnetic field; hence magnetic resonance occurs if incident magnetic field H is perpendicular to the plane of SRR which implies direction of propagation is along the plane of SRR [3],[5]. Numerical computation performed in HFSS, confirms that propagation parallel to the SRR plane causes a dip in transmission close to the magnetic resonance whenever applied magnetic field is perpendicular to the SRR plane. The surface current density at the top of rectangular SRR (RSRR) is shown in Figure 3, when magnetic field is perpendicular to the plane of RSRR which is shown in Figure 1. This surface current plus displacement current at gap through substrate forms an equivalent current loop. This current loop may be conceived as magnetic dipole which exhibits magnetic resonance under the influence of incoming EM wave for specific frequency region.

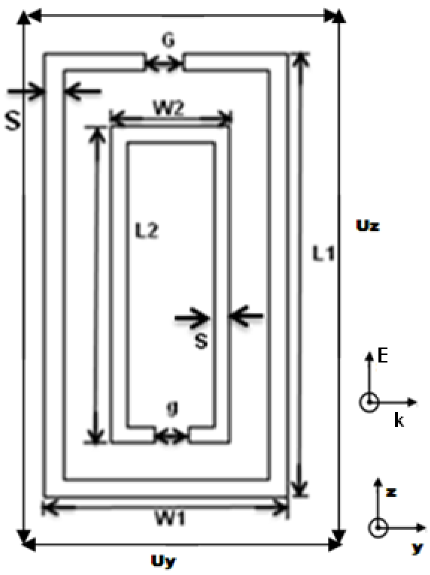

Figure 1: Rectangular SRR Dimension

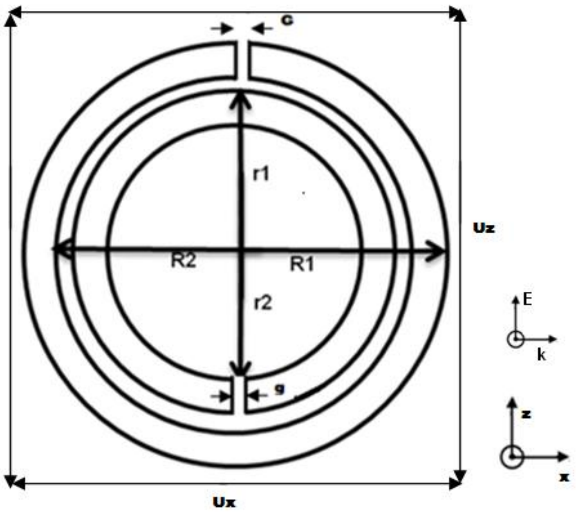

Figure 2: Circular SRR Dimension

For circular SRR (CSRR) when magnetic field is perpendicular to the plane as shown in Figure 2, the corresponding surface current density is shown in Figure 4. This surface current plus displacement current at the gap through substrate forms an equivalent current loop for CSRR which is same as rectangular SRR discussed previously. This current loop can be considered as magnetic dipole which exhibits magnetic resonance under the influence of incoming EM wave for a certain frequency region.

The permittivity and permeability of both rectangular and circular SRR are extracted from simulated scattered parameter data S_{11} and S_{21}.The equations for determining effective permittivity and permeability are as follows[4]:

$$n = \pm \frac{1}{kd} \frac{\cos^{-1}(1 - S_{11}^{2} + S_{21}^{2})}{2S_{21}} \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

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

$$\varepsilon_{eff} = \frac{n}{z} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iii)$$

$$\mu_{eff} = nz \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (iv)$$

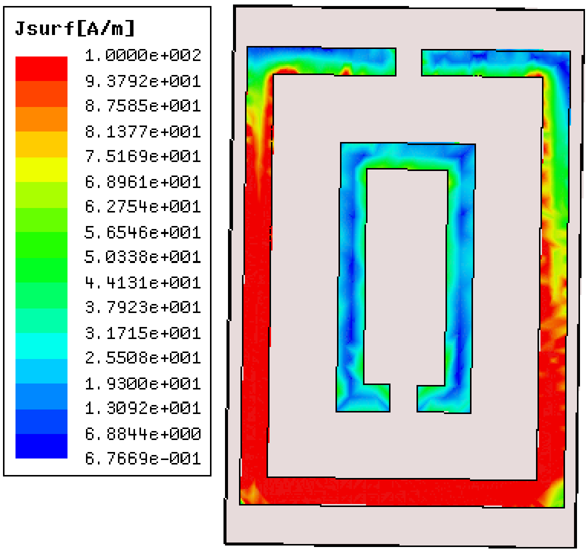

Figure 3: Surface Current density of Rectangular SRR

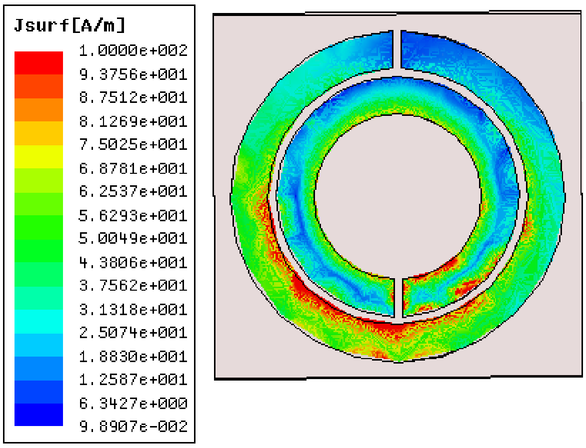

Figure 4: Surface Current density of Circular SRR

Where n is the index of refraction, z stands for relative impedance, k is the wave number, d belongs to dimension of unit cell.

FR-4 with substrate thickness of 0.25 mm is chosen as substrate because it is having minimum absorption loss which is discussed in details in later stages. For RSRR, dip in transmission phase can be observed at 2.71 GHz which is shown in Figure 5. Figure 6-11 show the magnitude and phase of S_{11} and S_{21} parameter, refractive index, relative impedance, the retrieved permittivity and permeability for both RSRR and CSRR respectively. The effect of increasing substrate thickness on absorption loss for both RSRR and CSRR is shown in Figure 12. For RSRR, the relative impedance plot of Figure 9 suggests that the impedance does not match well enough to the impedance of free space for most part of frequency range from 2.6 GHz to 3.6 GHz over which the rectangular SRR gives negative magnetic permeability as shown in Figure 11 where 2.6 GHz and 3.6 GHz are resonance and magnetic plasma frequency respectively. The positive value of imaginary part of complex permittivity being accountable for absorption loss, the negative value of the same contributes to enhancement of signal energy in the frequency range of 2.45 GHz to 2.9 GHz.

Similarly, for CSRR, dip in transmission phase is observed at 2.44 GHz which is shown in Figure 5. The relative impedance plot of Figure 9 suggests the impedance does not match well enough to the impedance of free space for most part of frequency range from 2.4 GHz to 3 GHz over which CSRR gives negative magnetic permeability as shown in Figure 11 [6] where 2.4 GHz and 3 GHz corresponds to .resonance frequency and magnetic plasma frequency respectively. For the frequency range of 2.21 GHz to 2.7 GHz where imaginary part of permittivity is negative, suggests negative imaginary permittivity boost energy gain for the mentioned frequency range for circular SRR.

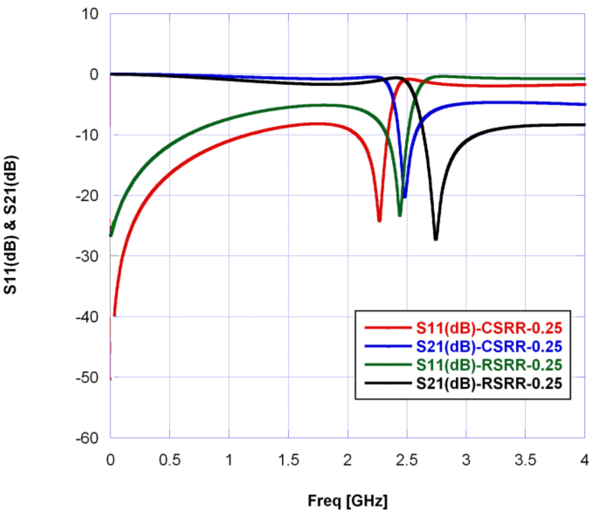

Figure 5: S Parameter in dB of Rectangular and Circular SRR

Transfer matrix method is used in numerical calculation to calculate absorption loss which is given by [7]

$$A = 1 - (S_{11}^{\ 2} + S_{21}^{\ 2})..........(V)$$

Using the above equation, absorption loss can be computed from numerically computed scattering parameter. For both rectangular and circular SRR, we used FR4 with permittivity 4.4 as substrate and dielectric loss tangent of 0.02 but having different substrate thickness. From Figure 12, the absorption plot suggests that the Circular SRR is lossier than the rectangular SRR for same substrate thickness. The absorption loss gradually increases for both circular and rectangular SRR with increasing substrate thickness. The absorption loss makes the practical use of SRR much more restricted in microwave frequency region. So, analysis of absorption loss is an important performance parameter of split ring resonator. Thus thickness of substrate influences the lossy nature of SRR for same substrate properties which is shown in tabular form in Table 1

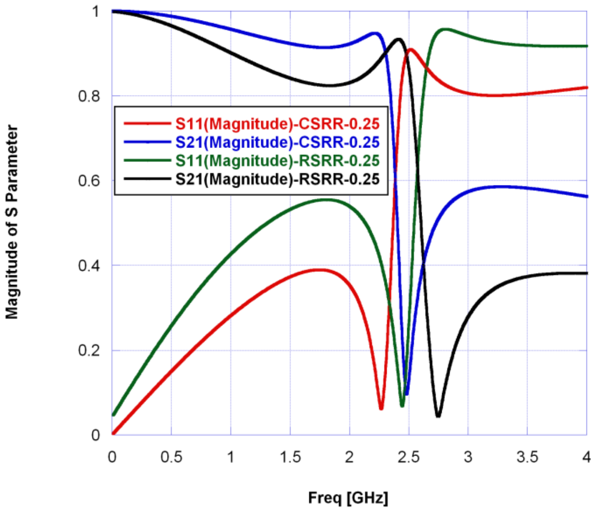

Figure 6: Magnitude of S Parameter for Rectangular and Circular SRR

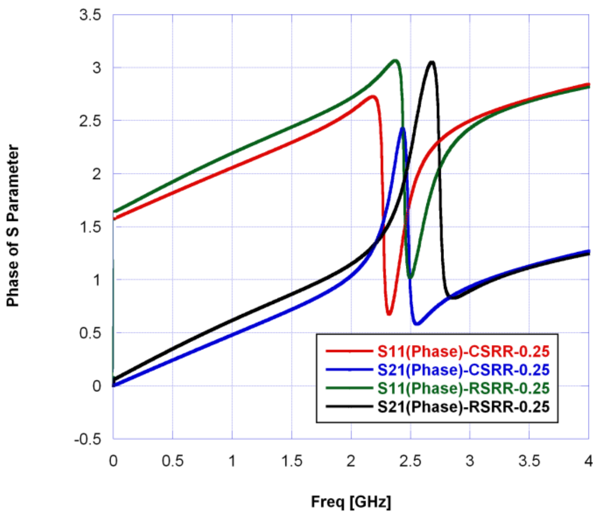

Figure 7: Phase of S Parameter for Rectangular and Circular SRR

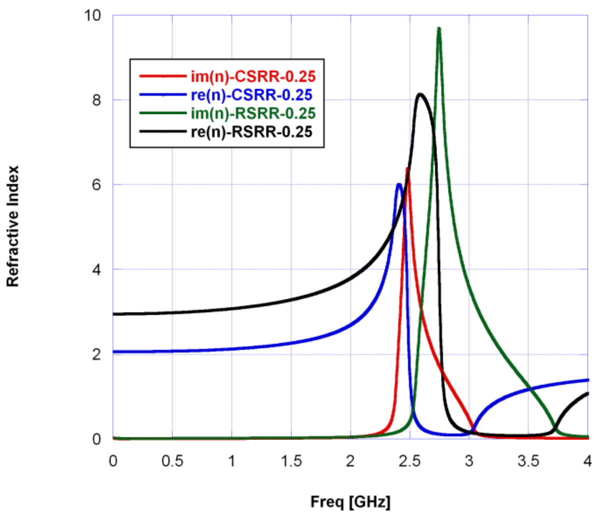

Figure 8: Refractive Index for Rectangular and Circular SRR

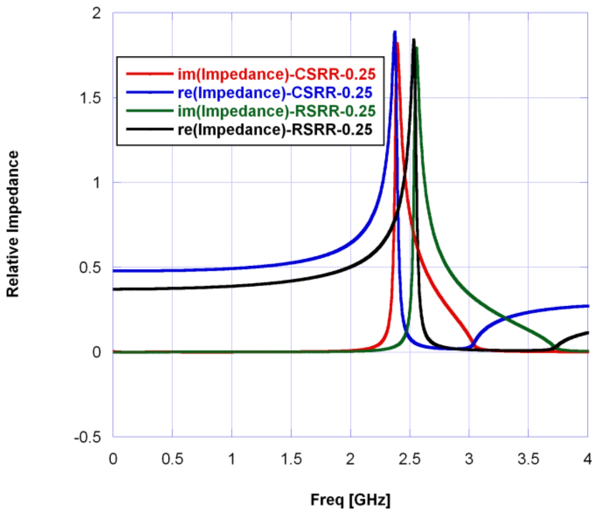

Figure 9: Relative Impedance for Rectangular and Circular SRR

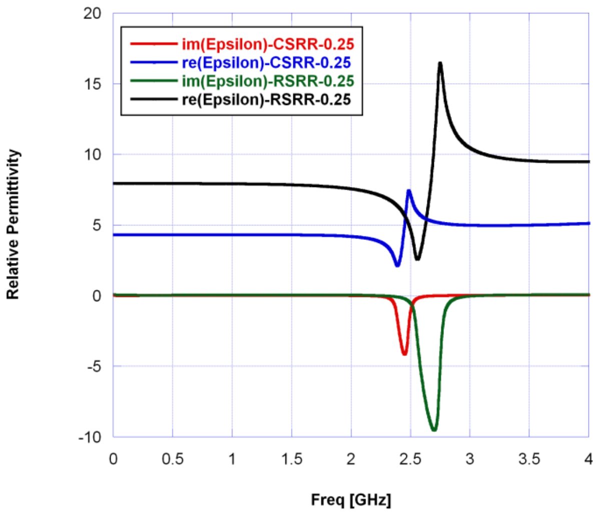

Figure 10: Permittivity of Rectangular and Circular SRR

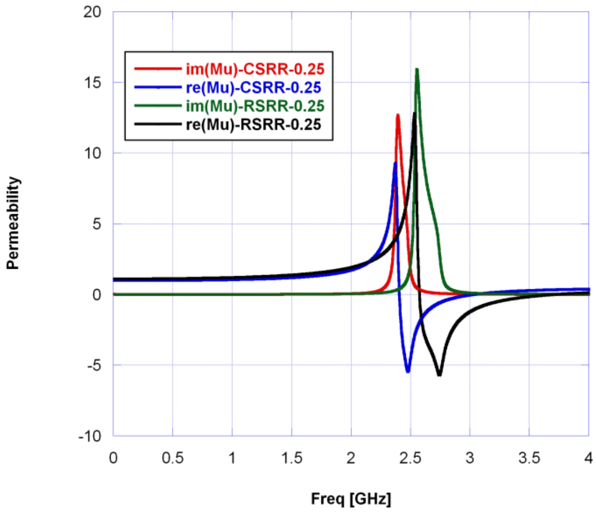

Figure 11: Permeability of Rectangular and Circular SRR

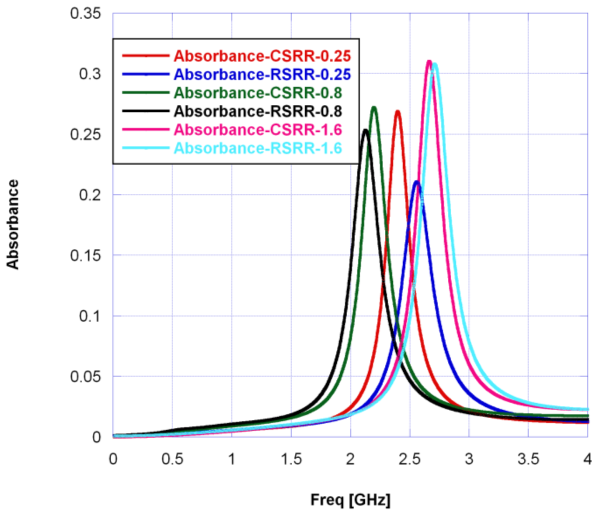

Figure 12: Absorbance loss of Rectangular and Circular SRR

Table 1.Dependancy of Absorbance on Substrate Thickness

Substrate	Thickness	Absorbance in CSRR	Absorbance in RSRR
FR-4	0.25	26.86%	21.04%
FR-4	0.8	27.19%	25.32%
FR-4	1.6	31.02%	30.72%

4. CONCLUSION

In summary, we have shown numerically computed results using FEM based Ansoft HFSS for both rectangular and circular SRR showing negative magnetic permeability for specific frequency region. This artificial MNG material has got widespread application for improvement of radiation property of antenna .Both SRR structures use same FR-4 substrate having same dielectric loss tangent of 0.02 and permittivity 4.4 .Absorbance data computed from numerically simulated scattering parameter suggests that with increasing substrate thickness absorption loss associated with SRR gradually increases for both RSRR and CSRR for same substrate permittivity and dielectric loss tangent.

5. REFERENCES

[1] V. G. Veselago, 'The Electrodynamics of Substances with Simultaneously Negative Values of ε and μ', Soviet Physics ,vol. 10,pp.517-526,February,1968

[2] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, 'Magnetism from Conductors and Enhanced Nonlinear Phenomena',IEEE Transactions on Microwave Theory and Techniques,vol.47,no.11,November 1999

[3] D. R. Smith, Willie J. Padilla, D. C. Vier, S. C. Nemat-Nasser, and S. Schultz, 'Composite Medium with Simultaneously Negative Permeability and Permittivity', Phys. Rev. Lett.,vol. 84, May. 1, 2000

[4] D. R. Smith,D. C. Vier,Th. Koschny and C. M. Soukoulis , 'Electromagnetic parameter retrieval from inhomogeneous metamaterials', Phys. Rev. ,E 71.036617,2005

[5] Lei Zhanga, G. Tuttlea, C.M. Soukoulis, 'GHz Magnetic Response of split ring resonator ', Photonics and Nanostructures-Fundamentals and Applications, vol. 2,pp-155-159,2004

[6] Jiafu Wang,Shaobo Qu,Zhuo Xu,Jieqiu Zhang,Hua Ma,Yiming Yang, Chao Gu," Broadband planar left-handed metamaterials using split-ring resonator pairs" Photonics and Nanostructures-Fundamentals and Applications, vol. 7,pp-108-113,2009

[7] C.Sabah," Tunable Metamaterial Design Composed of Triangular Split Ring Resonator And Wire Strip for S- And C- Microwave Bands" Progress In Electromagnetics Research B, vol. 22,pp-341-347,2010