Tunable Wideband Absorber with Ferrite Metamaterial

Mostafa Maleki[1], Mohammad Sadegh Abrishamian[2]
1-*Department of Electrical and Computer Engineering, K. N. Toosi University of Technology* Tehran, Iran.
Email: mostafa.smp@gmail.com (Corresponding author)
2 *Department of Electrical and Computer Engineering, K. N. Toosi University of Technology* Tehran, Iran.
Email: msabrish@eetd.kntu.ac.ir

Received: December 15, 2015 Revised: July 17, 2016 Accepted: August 2, 2016

ABSTRACT:
We proposed a new absorber based on Crescent Split Ring Resonators (CSRRs) that shows wideband absorption. This absorber is made of biased ferrite slab by embedding CSRRs. Simulation and analysis is carried out by FDTD method. The results show that the corresponding high absorption mainly originates from the CSRR's geometry. This structure can be tuned by external magnetic field.

KEYWORDS: absorption, CSRR, Ferrite, FDTD

1. INTRODUCTION

Since 2001 which Pendry and Smith constructed a composite by arranging a periodic array of small metallic wires and Split Ring Resonators (SRRs), this kind of composite that usually are called metamaterials have attracted increasing attention [1]. So far, many researches have been done such as [1-5] in order to achieve a perfect absorber according to electromagnetic resonance and Left Handed (LH) properties in metamaterials. However the majority of those schemes are narrowband which may impede their using in some applications such as electromagnetic shielding, wireless communication, satellite television systems, radar and military applications, etc. As a result, designing an absorber with wide operating bandwidth is very important in microwave engineering. The idea which is supported in this paper is to minimize the transmission and reflectivity coefficient simultaneously, then achieve to the maximum absorbance. By applying the effective medium theory, the effective permittivity and permeability, can be extracted by the design of the unit cell of the structure. Therefore, by designing of unit cell of absorber, it is possible to achieve unusual characteristics such as negative permittivity and permeability which is known as LH property. According to this theory the absorption of the structure can be tuned by the design of the unit cell of the absorber. In this paper a new absorber based on Crescent Split Ring Resonators (CSRRs) is proposed, that shows wide band absorption. This absorber is made of biased ferrite slab by embedding CSRRs. Simulation and analysis is carried out by FDTD method. The corresponding high absorption mainly originates from the CSRR's geometry. In fact, by surface current analysis, as it will be shown later, there will be an enhancement in electromagnetic resonance. This is obtained by replacing SRR with CSRR. This electromagnetic enhancement increases the bandwidth of the absorber. Moreover, by increasing in external magnetic field the bandwidth of the absorber will shift to higher frequencies, which is similar to the results in [7, 11].

2. THEORY

Fig.1 shows a single Crescent ring of CSRR with its parameters, which are:

R: Radius of the outer circle, **r:** radius of the inner circle, **d:** distance along y-axis between the centers, **g:** gap distance. The Main difference between CSRR absorber and SRR is due to its Crescent geometry. When an electromagnetic wave incident to it, as mentioned in [7,8] inductive circular currents will appear and this element can be considered as a current source. Because of unsymmetrical thickness, this surface currents density is bigger than surface currents density in an SRR and so there will be a better interaction between electric and magnetic fields.

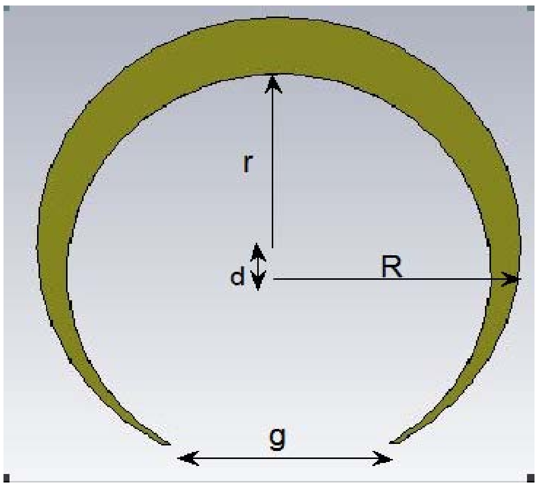

Fig .1 Crescent ring and its parameters

Resonance enhancement in this metamaterial element is mentioned in [9]. According the results in [9], crescent resonator can cause a strong resonance enhancement by an increase in interaction between electric and magnetic fields.

Let assume we have a plane wave with amplitude V_i which have normal incidence on slab with effective thickness d_e which is manifested in Fig.2. From the microwave aspect as presented in [7] and [10], S-parameters of the slab are related to reflected and transmitted coefficients as equations below:

$$S_{11} = \frac{V_r^{z=0}}{V_i^{z=0}} = \frac{\Gamma(1-\exp(-2n_r k_0 d))}{1-\Gamma^2\exp(-2n_r k_0 d)} \quad (1)$$

$$S_{21} = \frac{V_t^{z=0}}{V_i^{z=0}} = \frac{(1-\Gamma^2)\exp(-n_r k_0 d)}{1-\Gamma^2\exp(-2n_r k_0 d)} \quad (2)$$

In (1), (2) Γ is reflection coefficient for infinite slab and can be written as:

$$\Gamma = \frac{Z_e - Z_0}{Z_e + Z_0} \quad (3)$$

Where Z_e is effective wave impedance and is related to S-parameters as:

$$Z_e = \pm\sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \quad (4)$$

Then refractive index $\boldsymbol{n_r}$ has an equation as follows:

$$n_r = \frac{2m\pi - \mathrm{Im}(\mathrm{Ln}(\exp(n_r k_0 d))) + i\mathrm{Re}(\mathrm{Ln}(\exp(n_r k_0 d)))}{k_0 d} \quad (5)$$

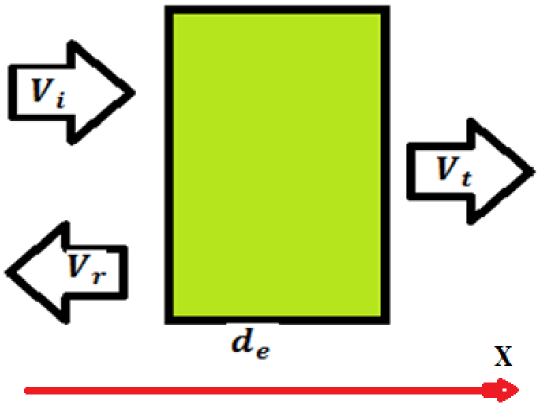

Fig.2 slab with effective thickness $d_e$which is excited with a plane wave With normal incidence, where incidence is in X direction.

In eq.(5), m is an integer number and related to branch index of real part of Re(n). There are several methods to solve these equations such as an algorithm that proposed in [6] or in [10].

Finally, with applying an algorithm which is proposed in [10], we are able to write effective permittivity and permeability as bellow:

$$\varepsilon_e = \frac{n_e}{Z_e} \qquad (6)$$

$$\mu_e = n_e Z_e \qquad (7)$$

In the next section, it is analyzed proposed structure from left handed properties aspect.

3. SIMULATION

Proposed unit cell is illustrated in Fig.3.a which includes three parts. An CSRR is etched on a ferrite slab (Fig.3.b) which this slab is sandwiched between two other slabs (Fig.3.c) and the CSRR is placed in central plane of them. Parameters of each Crescent ring are the same as in Fig.1 respectively.

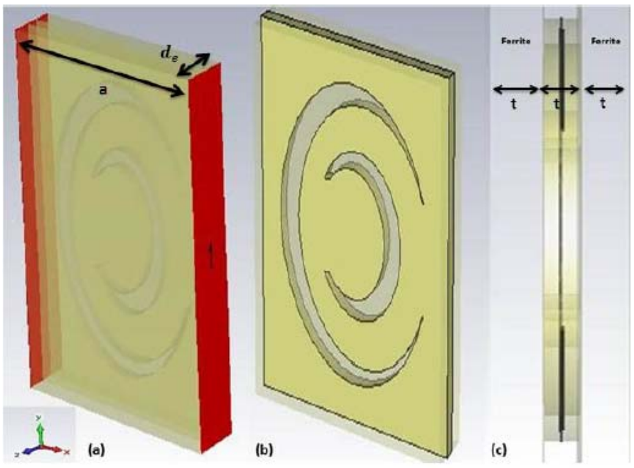

Fig.3 (a): proposed cell, **(b)**: CSRR etched on a ferrite slab, **(c):** side view of proposed cell.

The Ferrite slabs are square with the area of $\mathbf{a}^2$ and the thickness of the cell is assumed to be $\boldsymbol{d_e}$. For simulation, it is assumed that vertically polarized transverse electromagnetic (TEM) wave is incident normally in **X** direction on the right side of the cell (port 1) which is shown in Fig.3.a, and suitable boundary conditions which are: Perfect electric conductors (PE**C**) on top of waveguide, perfect magnetic conductor (PM**C**) on the sides of waveguide and two other sides in **X** direction, are defined as waveguide ports. Meanwhile magnetic bias assumed to be in Y direction. Optimized cell, which is simulated in this paper has $a = 1.9\,mm$ and $d_e = 0.6mm\ (t = 0.2mm)$, and outer CSRR ring parameters are $R = 1.6mm, r = 1.4mm$ and $d = 0.2mm$, while inner CSRR ring has $R = 0.8mm, r = 0.7mm, d = 0.1$. And CSRRs which are made from copper with thickness 0.017mm placed in the center of ferrite slabs. Ferrite slabs which are used in simulation are TT1-390 ($4\pi M_s = 2150\ \mathrm{G}$ and resonance beam width 648 0e, ε_r 12.7) [11]

4. RESULTS

With utilizing CST microwave studio suit software, proposed cell is simulated. Fig.4 shows surface currents in a period of wave at resonance frequency (f=9.86 GHz), respectively.

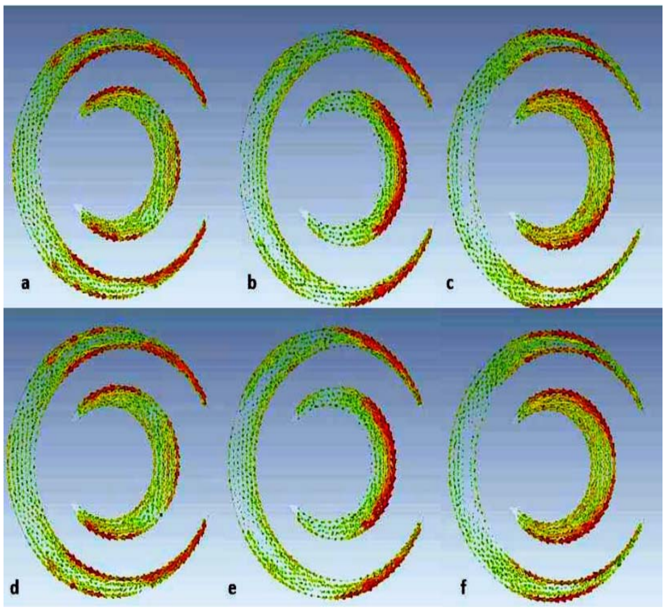

Fig.4 surface current density on CSRRs; (a):$\emptyset = \mathbf{0}°$, (b): $\emptyset = \mathbf{60}°$ (c): $\emptyset = \mathbf{120}°$, (d) : $\emptyset = \mathbf{180}°$, (e) : $\emptyset = \mathbf{240}°$, (f): $\emptyset = \mathbf{300}°$

Fig.5 shows magnetic field in a period of wave, respectively. In this figure the resonance enhancement is illustrated (f=9.86 Ghz).

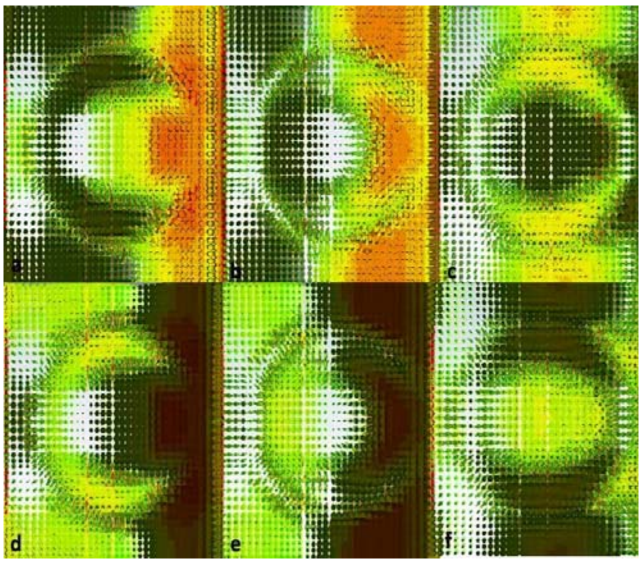

Fig.5 magnetic field in a period of wave;(a) $\emptyset = \mathbf{0}°$, (b) $\emptyset = \mathbf{60}°$(c) $\emptyset = \mathbf{120}°$, (d) $\emptyset = \mathbf{180}°$, (e) $\emptyset = \mathbf{240}°$, (f) $\emptyset = \mathbf{300}°$

From Fig.5, a strong resonance in a period of wave can be seen clearly. This is mainly originates from crescent resonators. In other words, as mentioned in [9] crescent resonators can cause a more effective resonance. Fig.4 represents that enhancement in inductive surface currents on the resonators is a good description of this phenomenon. Effective permittivity and permeability in Eq.(6), Eq.(7) is illustrated in Fig.6 and Fig.7, when magnetic bias is 3700Oe.

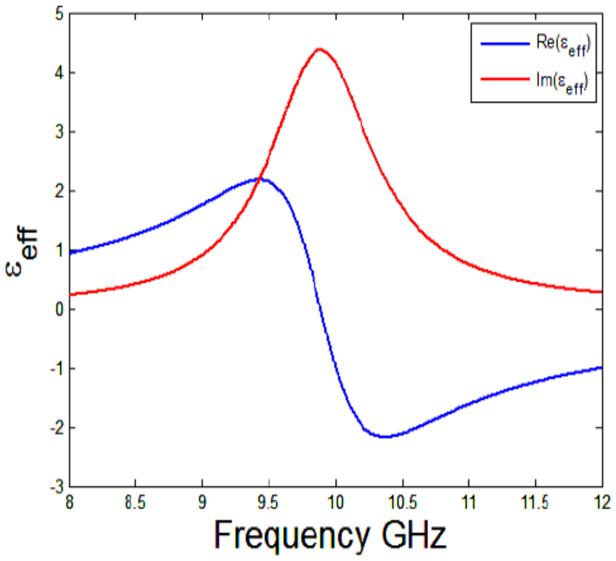

Fig.6. effective permittivity when magnetic bias is 3700Oe.

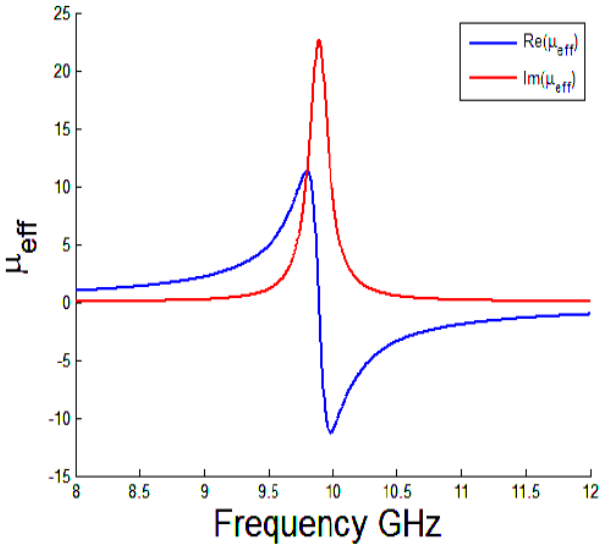

Fig.7. effective permeability when magnetic bias is 3700Oe.

From Fig.6 and Fig.7 it is inferred that proposed cell has a strong resonance at 9.86 GHz and LH properties can be concluded from Figs. [6,7]. Meanwhile, power flow and power loss of the proposed cell is plotted in Fig.8 and Fig.9. From these figures it is inferred that CSRR rings act as a filter and the part of the power of wave which arrives at port 2 is negligible. In fact, Fig.8 and Fig.9 are representing the result of increase in interaction between electric and magnetic fields.

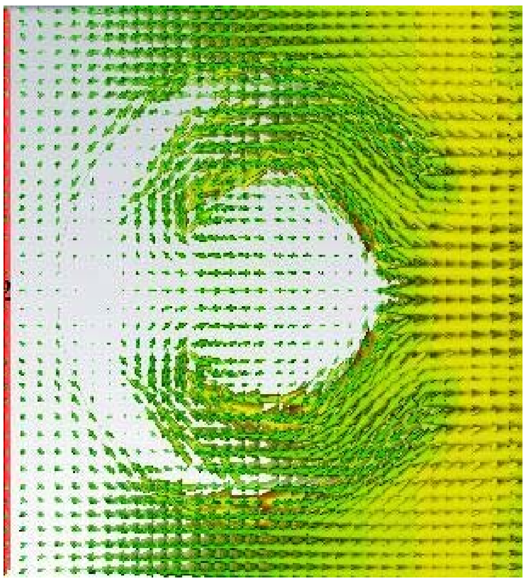

Fig.8 trajectory of power flow in proposed cell right is port 1 and left is port 2.

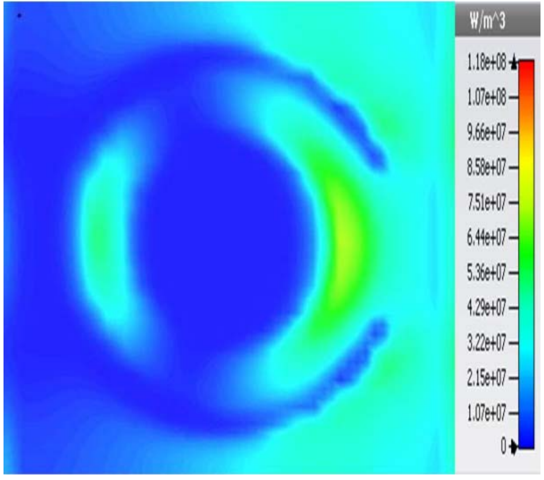

Fig.9 power loss in proposed cell, right is port 1 and left is port 2.

Finally absorption is given by:

$$A(\omega) = 1 - |S|_{11}{}^{2} - |S|_{21}{}^{2} \qquad (8)$$

And is plotted in Fig.10. The design aim which is simultaneously minimizing the transmission and reflectivity has been achieved.

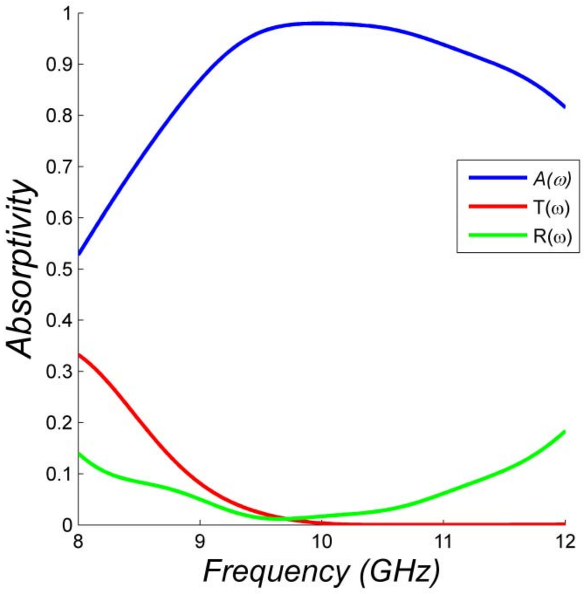

Fig.10 transmission, reflectivity and absorption of proposed cell

Fig.10 approves that proposed structure yield maximum absorption 98%. Proposed cell in comparison with other proposed schemes such as [11, 12] has more bandwidth. With this novel design bandwidth of the absorber which the absorptivity is more than 90% is about 2.5 GHz. In Fig.11 absorptivity is plotted as a function of magnetic bias, this is compatible with the results which is obtained in [11].

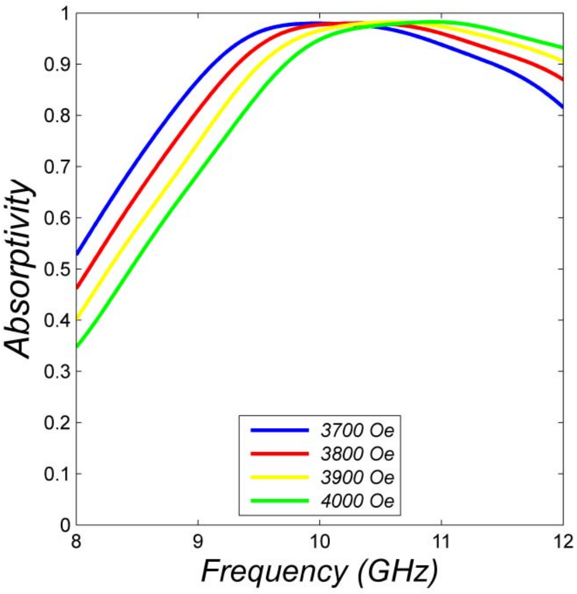

Fig.11 absorptivity as a function of magnetic bias.

5. CONCLUSION

In this paper we present a novel absorber. Proposed absorber is based on Crescent Split Ring Resonators (CSRRs) and ferrite slabs that shows wide band absorption. Simulation and analysis is carried out by FDTD method and bandwidth of proposed absorber which absorptivity is more than 90% is about 2.5 GHz. The corresponding high absorption mainly originates from the CSRR's geometry. This structure can be tuned by external magnetic field.

ACKNOWLEDGEMENT

The authors would like to thank Prof. Nader Engheta H. Nedwill Ramsey Professor at the University of Pennsylvania for helpful discussions.

6. REFERENCES

[1] Shelby B A, Smith D R, Schultz S. "**Experimental verification of a negative index of refraction**", Science. 2001;292: 77- 79.

[2] Pendry J B, Holden A J, Robbins D J, et al. "**Magnetism from conductors and enhanced nonlinear phenomena**", IEEE Trans. Microwave Theory and Techniques. 1999; 47: 2075- 2084.

[3] H. Tao, N. I. Landy, C. M. Bingham, X. Zang, R. D. Averitt, and W. J. Padilla, "**A metamaterial absorber for the terahertz regime: design, fabrication and characterization**", Opt. Express, 2008;16: 7181-7188.

[4] H. Tao, C. M. Bingham, D. Pilon, K. Fan, A. C. Strikwerda, D. Shrekenhammer, W. J. Padilla, X. Zhang, and R. D. Averitt, "**A dual band terahertz metamaterial absorber**", J. Appl. Phys. D, 2010; 43: 225102-225106.

[5] Y. Cheng, H. Yang, Z. Cheng, and Wu, "**Perfect metamaterial absorber based on a split-ring cross resonator**", J. Appl. Phys. 2012; 102: 99-103.

[6] Yanzhang Dong, WeikaiXu, Shutian Liu, "**Numerical Studies for Relative Bandwidth of Left-Handed Metamaterials with Split-Ring Resonators**", IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications" , 2009; 3: 821-825.

[7] R. Marqués, F. Martín, and M. Sorolla, "**Metamaterials With Negative Parameters**", New York: 2008, Wiley.

[8] **Microwave engineering**, David M. Pozar.4th edition, New York: 2011,Wiley.

[9] Atre, A. C., García-Etxarri, A., Alaeian, H. and Dionne. "**A Broadband Negative Index Metamaterial at Optical Frequencies**", J.Advanced Optical Materials, Wiley. 2013; 1: 327-333.

[10] Zsolt Szabó, Gi-Ho Park, Ravi Hedge, and Er-Ping Li, "**A Unique Extraction of Metamaterial Parameters Based on Kramers–Kronig Relationship**", IEEE Trans. Microwave Theory Techn , 2010; 60: 1743-1744.

[11] Yang Yong-Jun, Huang Yong-Jun, Wen Guang-Jun, Zhong Jing-Ping, Sun Hai-Bin, and Oghenemuero Gordon, "**Tunable broadband metamaterials absorber consisting of ferrite slabs and a copper wire**" Chinese Phys. B. 2012; 21.

[12] Hongmin Lee, "**Design of Metamaterial Absorber Based on Resonant Magnetic Inclusion**" Proceedings of ISAP, Nagoya, Japan, 2012.