

Artificial magnetic media and PMC with non magnetic ICSRR inclusions

F. KARADAĞ^a, M. KARAASLAN*

Telecommunication Laboratory, University of Mersin , Çiftlikköy, Mersin, Turkey

^aScience and Letter Faculty, University of Cukurova Balcali, Adana, Turkey

In this study, we investigate transmission and reflection properties of increased capacitive split ring resonator (ICSRR) at normal incidence with numerical techniques. How the dimension variations affect resonant frequency range has been observed by changing all different dimensions. Artificial Magnetic Conductor (AMC) properties of ICSRR media have been exhibited with phase angles and reflection values (S11). It has been proved that the resonant properties of ICSRRs result from magnetic effects. Permeability of ICSRR media is evaluated by extracted equations.

(Received December 20, 2008; accepted April 23, 2009)

Keywords: Artificial magnetic conductor, Metamaterials, Negative permeability

1. Introduction

Electric permittivity (ϵ) and magnetic permeability (μ) are exhibitors of electromagnetic (EM) fields' effect on bulk media. Recently, man -made EM structures for specific macroscopic properties have collected considerably interest within scientific community [1].

Artificial dielectrics include discrete obstacles or scatters, extensively studied in 1950's [2]. The applied EM wavelength are much longer than one unit cell in this artificial media means effective media and the electromagnetic properties of that media could be described in terms of bulk electromagnetic parameters permittivity (ϵ) and permeability (μ), different than Bragg diffraction and photonic crystals. Some type of diffraction could be achieved with scatters of which electrical lengths are on the order of wavelength, such as frequency selective surfaces (FSSs) and photonic crystals (PC), but bulk EM parameters (dielectric permittivity and magnetic permeability) couldn't be used to describe their properties.

Different than photonic crystals and conventional dielectric media meta-materials exhibit very different properties; left handedness (LH) [3], backward wave (BW) [4], reverse Vavilov-Cherenkov radiation [5], perfect focusing [6] and negative refraction [7]. Meta-materials include two different types of elements to achieve electrical and magnetic response, simultaneously. These elements dimensions are much less than the wavelength to create effective medium characteristics. Initially, the medium with simultaneously negative permittivity and permeability has been investigated in 1968 [6]. In this study this imagined material named as "left handed media" (LHM), since the wave components, electric field magnetic field and wave vector form a left handed triplet with respect to Maxwell equations. It was prove that, wave vector and pointing vector move opposite directions in a

LHM and this results unconventional phenomenon such as inverse refraction, reverse Doppler shift, Goos-Hanchen Phenomenon and Cherenkov radiation.

Last decade, meta-material applications have been enlarged with many different disciplines to achieve novelty properties such as, waveguide miniaturization [9, 10], sub-wavelength imaging [11], cloaking objects [12], magnetic resonance [13] and antenna gain improvement [14], etc.

Different types of split ring resonators (SRRs) have been used frequently to realize negative permeability. In these inclusions, the metal part behaves inductor and gap between metal shows capacitive response. When both these effects equate each other resonance behaviour observed. One of the disadvantages of SRR is production difficulties since it includes one split ring in one another in a unit cell.

In this study magnetic effect will be realized using periodically designed ICSRRs type inclusions. Using finite element method (FEM) S parameters and phase angle will be obtained for ICSRRs and the artificial magnetic conductor behaviour will be shown with this ICSRRs media. The extracted magnetic permeability of ICSRRs media will be evaluated.

2. Artificial magnetic media and PMC with non magnetic ICSRR inclusions

It is possible to realize diamagnetic properties with metal ring inclusions. In these periodic structures the ring dimensions are in the order of the wavelength so it couldn't be possible to mention about effective permeability. This type of inclusions can be represented with inductor as a lumped element. To maximize the current on the ring SRR type inclusions have been used which includes splits as capacitor to provide resonance

with ring metal part. So the dimensions have been reduced and effective media realized (Fig. 1).

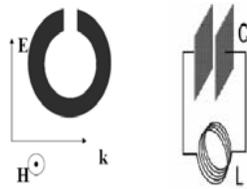


Fig. 1. SRR inclusion and lumped circuit.

ICSRRs are the other type of magnetic inclusions that have more dimensions to effect (five dimensions) and set magnetic properties of effective media. One other effect can be realized by assigning lumped capacitor in the split of ring. Artificial media with ICSRRs inclusions have been achieved with periodically arranged unit cell in one direction in FR4 dielectric media and the other two directions have been assigned as perfectly matched layer (PML). The number of ICSRRs has been determined by making optimization. The dimensions of ICSRRs are shown in Fig. 2. Although it could be possible to define the inclusions as 2D to reduce the computation time we assigned the thickness of metal plate on dielectric as $35 \mu\text{m}$ and all the metal parts of ICSRRs have been assigned equal to 0.19mm (a). These dimensions have been chosen by using optimization.

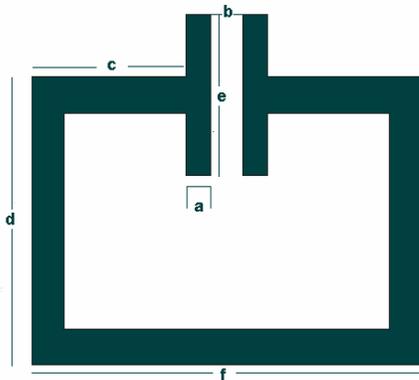
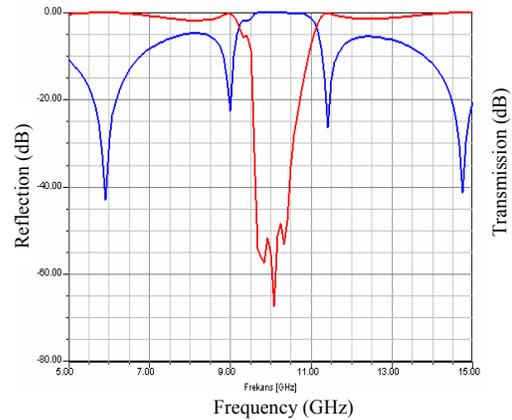


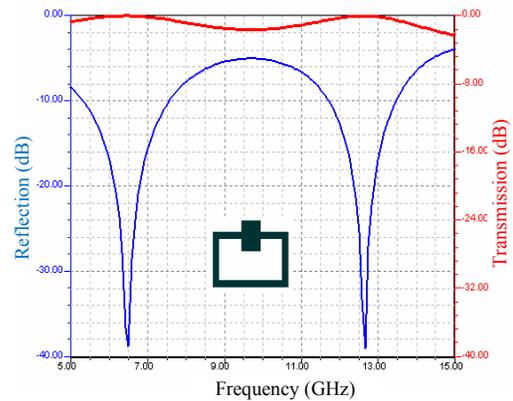
Fig. 2. ICSRRs inclusion and dimension: $a = 0.19 \text{ mm}$; $b = 0.38 \text{ mm}$; $c = 1.15 \text{ mm}$; $d = 2.03 \text{ mm}$; $e = 1.15 \text{ mm}$; $f = 3.05 \text{ mm}$.

EM fields have been applied as normally incident plane perpendicular to the centre axis of ICSRRs in the range of X frequency band. The H component of EM wave is directed to the centre axis of ICSRRs. This incident wave applied from wave ports of waveguide that includes artificial media. The wave ports have been placed far enough from closest inclusions to minimize near field effects. Full reflection is observed between 9.5GHz - 11GHz (Fig. 3) since at this frequency range S_{11} is 0 and S_{21} is reduce down to -60dB and this resonance range is quite wide with respect to SRRs. This reflection band, that

is approximately 1.5GHz , is a resonance range since it is caused from L-C resonance. At this resonance frequency range, the wavelength is $10/1$ of the maximum dimension of ICSRRs, this ratio is the proof of effective medium.



(a)



(b)

Fig. 3. Reflection and transmission characteristic of open and closed ICSRRs.

The closed ring EM response is not the same with ICSRRs since at the resonance frequency range full reflection couldn't achieved. The S_{11} is downward to approximately -10dB and good transmission (S_{21}) is observed. There is no resonance frequency in that range since these dimensions are too small than wavelength to realize reflection according to diffraction rules. As a result the resonance is stemmed from magnetic effects so magnetic permeability is negative at the resonance frequency band and it could be possible to realize a negative index metamaterial by using ICSRRs type media.

It is well known that AMC is not a natural structure. Since ICSRRs exhibits magnetic response as proved in Section 2 these artificial structures could be used as AMC. To observe this phenomenon, ICSRRs type inclusions that have same dimension as Fig. 2 used and same boundary conditions have been assigned. The reflection coefficient in dB and reflection phase in radian has been observed as shown in Fig. 4. The S_{11} parameter is equal to 1 between 9.5 GHz and 11GHz and in this frequency range there is a zero phase point at 9.75 GHz . So these means that

artificial magnetic media that include ICSRRs type inclusions could be used as AMC.

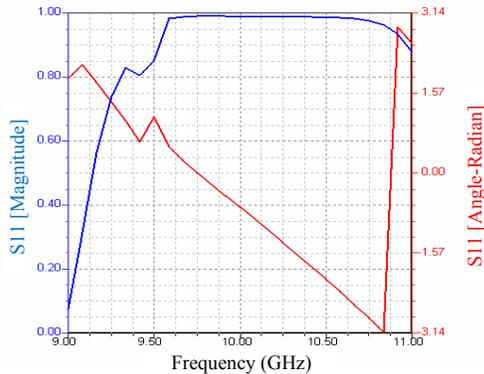


Fig. 4. AMC with artificial magnetic media that includes ICSRRs.

3. Dimension effect on magnetic resonance

One of the main tasks at the time of artificial magnetic media design is to understand the dimension variation effect on magnetic resonance response. The most time consuming event to design this type of media is to decide the dimension effect on magnetic response. To minimize this dimensions of ICSRRs have been assigned as variable and optimized for different values that are too small than waveguide dimension.

When the distance between capacitive arms increases, both resonance frequency and resonance range increase, simultaneously. This result is a well known law:

$$w_r = \frac{1}{\sqrt{LC}} \quad (1)$$

If a distance between capacitive arms increases capacity of that decrease and resonance frequency increase (table 1). As the distance between arms increase from 0.66mm to 0.81mm resonance frequency and resonance range increase approximately 100MHz and 250MHz, respectively.

Table 1. Effect of arms distance to resonance.

Arm distance(mm)	Resonance Range(GHz)
0.66	9.5-10.50
0.71	9.50-10.58
0.76	9.55-10.66
0.81	9.58-10.83

One another variable is the capacitive arms length. Since the capacitive arms area depends on the arm length they are proportional to each other. As the arms length increase both the area and capacity increase simultaneously. Since resonance is inversely proportional with square root of C, it reduces down. When the arm

length increases from 0.32mm to 0.47mm the resonance frequency reduce approximately 2 GHz (Table 2.)

Table 2. Effect of arm length to resonance.

Arm length (mm)	Resonance Range(GHz)
0.32	11-11.33
0.34	9.91-11.16
0.37	9.83-11.08
0.39	9.75-10.91
0.42	9.66-10.83
0.44	9.58-10.66
0.47	9.5-10.58

Capacitive arm thickness is the other variable that effect resonance frequency. Similar to the arm length, arm thickness is direct proportional with the capacitive area, so as the thickness increase C increase but resonance frequency decrease. When the thickness increases from 0,127mm to 0,254mm, both resonance frequency and resonance frequency band range decrease 1GHz and 330MHz, respectively (Table 3.).

Table 3. Effect of arm thickness to resonance.

Arm thickness(mm)	Resonance Range (GHz)
0.127	10.08-11.33
0.152	9.91-11.08
0.178	9.66-10.83
0.203	9.5-10.58
0.228	9.33-10.33
0.254	9.08-10.00

4. Conclusions

It has been demonstrated theoretically that ICSRRs type inclusions could be used as magnetic unit cell to achieve negative permeability. The dimension variation effect on reflection and transmission coefficients has been observed. To adjust the resonance frequency possible by changing dimensions of inclusions. The AMC has been realized by ICSRRs type unit cell.

References

- [1] J. B. Pendry, A. J. Holden, W. J. Stewart, Youngs Phys. Rev. Lett. **76**, 4773 (1996).
- [2] S. B. Cohn, J. Appl. Phys. **20**, 257 (1949).
- [3] J. B. Pendry, A. J. Holden, D. J. Robbins, W. J. Stewart, IEEE Trans. Microwave Theory Tech. **47**, 2075 (1999).
- [4] D. R. Smith, W. J. Padilla, D. C. Vier, S. C. Nemat-Nasser, S. Schultz, Phys. Rev. Lett. **84**, 4184 (2000).
- [5] R. A. Shelby, D. R. Smith, S. Schultz, Science **292**, 77 (2001).
- [6] J. B. Pendry, Phys. Rev. Lett. **85**, 3966 (2000).
- [7] V. G. Veselago, Sov. Phys.—Usp. **10**, 509 (1968).

- [8] M. Antoniadis, G. V. Eleftheriades, IEEE Antennas Wireless Propagat. Lett. **2**, 103 (2003).
- [9] R. Marques, J. Martel, F. Mesa, F. Medina, Phys. Rev. Lett. **183**, 901 (2002).
- [10] S. Hrabar, J. Bartolic, Z. Sipus, IEEE Transactions On Antennas and Propagation **53**(1), 110 (2005).
- [11] P. Belov, C. Simovski, P. Ikonen, Phys. Rev. B **71**, 193105 (2005).
- [12] P. Alitalo, O. Luukkonen, L. Jylhä, J. Venermo, S. A. Tretyakov, IEEE Trans. Antennas Propag. **56**(2), 416 (2007).
- [13] Z. Dong, M. Xu, S. Lei, H. Liu, T. Li, F. Wang, S. Zhu, Appl. Phys. Lett. **92**, 064101 (2008).
- [14] F. Zhu, Q. Lin, J. Hu, IEEE. APMC2005 Proceedings (2005).

*Corresponding author: mkaraaslan@mersin.edu.tr