 CMC, Vol.53, No.3, pp.132-140, 2016

Analysis of Metamaterial Cloaks Using Circular Split Ring Resonator Structures

Susan Thomas[1] and Dr. Balamati Choudhury[2]

Abstract A novel microwave cloak using circular split ring resonator (SRR) based metamaterial structure has been proposed in this paper. The cloak which operates at a frequency of 10.6 GHz is composed of cylindrical dielectric sheets printed with circular split ring resonators of spatially varying and anisotropic material properties. The article also focuses on the phenomenon of resonant splitting in circular SRR microwave cloak. A detailed analysis of various linear metamaterial arrays and their response has also been elucidated.

Keywords: Cloaking, metamaterial, circular split ring resonator.

1 Introduction

The theory of electromagnetic cloaking has been elevated from a fiction to a reality with the advent of metamaterials. Cloaking is an electromagnetic phenomenon which can bend the electromagnetic waves in an unusual way around the object. A cloak ensures scattering cancellation for any finite size physical object which enables it to be hidden from electromagnetic radiations. The constitutive parameters of the layered cloaking shells are spatially varied based on the principle of coordinate transformation in the realization of first experimentally proven invisibility cloak at microwave frequencies by [Schurig *et al*., (2006)]. The cloaked object and cloaking shell scatter very strongly and independently but both backward and forward scattering from the object is cancelled by the scattering from cloaking layers.

Though the dielectric permittivity tensor remains positive for the various cloaking layers, permeability tensor should range between zero and unity which is impossible with natural dielectrics [Naqui *et al*., (2014)]. Therefore, artificial periodic structures termed as metamaterials which exhibit unusual electromagnetic properties that can be tailored by changing the geometrical parameters of the unit cells are introduced into the design of invisibility cloaks [Choudhury *et al.*, (2013)]. Refractive index of a metamaterial cloak is observed to be purely imaginary due to which the penetration of electromagnetic radiations into the layers is made impossible as stated by [Yuan *et al.*, (2008)]

The first microwave cloak consisted of 10 layers of anisotropic cloaking shells printed with resonant metamaterial structures. The extensive research on cloaking reduced the thickness of the cloaking layers with cross embedded SRRs to realize an ultrathin cylindrical cloak [Zhang *et al.*, (2011)]. Further, though transmission line approach using non resonant structures has been introduced in the design of cloaks, it limits the

[1] REVA University, Bengaluru.

[2] NAL, Bengaluru.

size of object which can be concealed [Liu *et al.*, (2009)]. Electromagnetic cloaks based on LC network can be implemented using multiple resonant tanks to realize dual frequency cloaks [Shao *et al*., (2011)] which in turn increase the complexity of the cloak design. Another approach utilizes ceramic dielectric resonators which ensure cloaking effect at specific frequencies within the resonance band [Wang *et al.* (2011)]. Superthin square cloaks proposed using interconnected patches are also able to conceal only small objects [Wang *et al.*, (2015)]. Cloaks are used to minimize the scattering from receiver antennas and sensors improving their absorption efficiency [Soric *et al.*, (2014)]. This paper investigates the effectiveness of circular SRR unit cells in the realization of invisibility cloaks at microwave frequencies. The design of the circular SRR unit cell and its transmission parameters are discussed in the Section 2 and 3. The material properties for the proposed cell is extracted and analyzed in the Section 4. Further, Section 5 presents the phenomenon of existence of resonant modes in a circular SRR array.

2 Metamaterial Cloaks Using Resonant Structures

For the first practically realized electromagnetic cloak using metamaterial unit cells, a slight modification has been made in the geometrical structure of square SRR. The split in the square shaped ring is elongated towards the interior of the square shaped ring and the corners of the square SRR are kept curved. The radius of the corners as well as the length of the split determines the spatial variation of constitutive parameters of each layer. In this paper, an attempt is made to employ circular SRRs instead of square SRRs in the realization of a microwave cloak. Effective permeability being the spatially varying tensor, the metamaterial structure chosen for cloaking application should have a property to tailor the magnetic response depending on the structural parameters of the unit cell. Unlike the cloak implemented by Schurig, an attempt is made in this paper to ensure more flexibility in the design using a circular SRR. The radius of the circular SRR is invariably constant for the various cloak layers and therefore shift in resonant frequency as well as the permeability tensor values is dependent only on the length of the split.

Field excitation considerations for this novel design are same as that of the square SRR based cloak realized by Schurig. By compromising for a zero reflected power, the transformed material properties are simplified in the same way to ensure design flexibility. The variation of permeability and permittivity tensors depending on the frequency has been depicted in this paper which has not been analysed in the literature so far. Also an investigation on the resonant mode splitting (Chen *et al*., 2012) in a linear array of circular ring resonators is done to analyse the nature of cloak. The response of two different linear metamaterial arrays are discussed, one with unit cells in the direction of electric field and the other in the direction of propagation of wave.

3 Design and simulation of Circular SRR Based Metamaterial Cloak

The Figure 1 shows the design of circular SRR unit cell fabricated on Duroid 5870 substrate with dielectric constant of 2.33 and loss tangent of 0.0012 at 10GHz. The thickness of the substrate is 0.381mm and the split ring resonators are patterned with a thickness of 0.017mm.

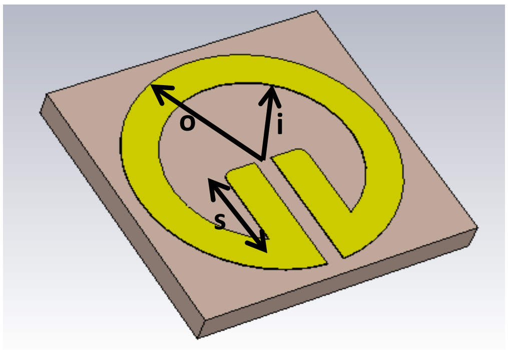

Figure 1: The design of circular SRR unit cell

Table 1: Dimensions of SRR unit cell (in millimeters)

Inner radius, i	1.1
Outer radius, o	1.5
Length of the split, s	1.4

An FEM based EM design package has been used for the design and simulation of metamaterial unit cell. Here the cloaked object is a cylinder having radius equal to 23.1mm. The cloak is formed of 5 concentric layers of cylindrical dielectric sheets printed with circular split ring resonators on them. The radius of the outermost cloaking layer is set at 58.9mm. The frequency range selected for simulation is 9GHz to 13GHz. The Figure 2 shows the magnitude of transmission characteristics of the circular SRR unit cell which resonates at 10.6 GHz. The first layer of cylindrical cloak has been designed using unit cells of dimensions mentioned in Table 1.

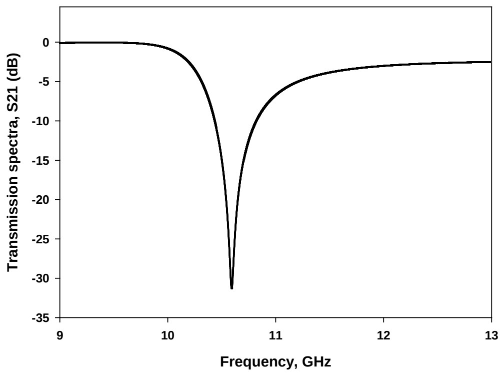

Figure 2: Magnitude of transmission spectra (S21) for single circular SRR unit cell

The length of the split determines the magnetic response and thereby the permeability tensor for each layer of the cloak. Appropriate boundary conditions are applied to a single three dimensional unit cell to analyse the nature of cloak designed using a periodic array of the same metamaterial unit cells. The unit cell is excited with a plane wave with electric field in a direction parallel to the circular SRR plane and magnetic field normal to the surface of unit cell.

References

Schurig, D.; Mock, J. J.; Justice, B. J.; Cummer, S. A.; Pendry, J. B.; Starr, A. F.; Smith, D. R. (2006): Metamaterial electromagnetic cloak at microwave frequencies, *Science Express*, vol. 314, pp. 977-979.

Naqui, J.; Martín, F. (2014): Some Applications of Metamaterial Resonators Based on Symmetry Properties, *Computers, Materials & Continua*, vol. 39, no. 3, pp. 267-288.

Choudhury, B.; Jha R. M. (2013): A Review of Metamaterial Invisibility Cloaks, *Computers, Materials & Continua*, vol. 33, no. 3, pp. 275-308.

Yuan, B.; Wang, R.; Wang, G. (2008): Refractive index in a metamaterial cloak, *8th International Symposium on Antennas, Propagation and EM Theory*, pp. 1413-1415.

Liu, X.; Li, C.; Yao, K.; Meng, X.; Li, F. (2009): Invisibility cloaks modeled by anisotropic metamaterials based on inductor-capacitor networks, *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 1154-1157.

Shao, J.; Zhang, H.; Lin, Y.; Hao, X. (2011): Dual-frequency electromagnetic cloaks enabled by LC-based metamaterial circuits, *Progress in Electromagnetics Research,* vol. 119, pp. 225-237.

Wang, X.; Chen, F.; Hook, S.; Semouchkina, E. (2011): Microwave cloaking by all-dielectric metamaterials, *IEEE International Symposium on Antennas and Propagation (APSURSI),* pp. 2876 – 2878.

Zhang, J.; Mortensen, N. A.; (2011) Ultrathin cylindrical cloak, *Progress in Electromagnetics Research,* vol. 121, pp. 381-389.

Chen, F.; Wang, X.; Semouchkina, E. (2012): Resonance mode splitting in split-ring resonator arrays used in the microwave invisibility cloak, *IEEE Antennas and Propagation Society International Symposium (APSURSI),* pp. 1-2.

Soric, J.C.; Fleury, R.; Monti, A.,Toscano, A.; Bilotti, F.; Alu, A. (2014): Controlling scattering and absorption with metamaterial covers, *IEEE Transactions on Antennas And Propagation*, vol. 62, no. 8, pp. 4220-4229.

Wang, J.; Qu, S.; Zhang, J.; Chen, H.; Ma, H.; Xu, Z. (2015): Design of super-thin cloaks with arbitrary shapes using interconnected patches, *IEEE Transactions on Antennas And Propagation,* vol. 63, no. 1, pp. 384-389.