New NRI Metamaterial for Multi-band Operation

Sikder Sunbeam Islam[1], Mohammad Rashed Iqbal Faruque[1], Mohammad Tariqul Islam[2],
Md. Moinul Islam[1], Norbahiah Misran[2]
[1]*Universiti Kebangsaan Malaysia, Space Science Centre, IPI, Research Building Complex, Bangi, Selangor 43600, Malaysia.*
[2]*Universiti Kebangsaan Malaysia, Dept. of Electrical, Electronic and System Engineering, FKAB, Bangi, Selangor 43600, Malaysia.*
sikder_islam@yahoo.co.uk

***Abstract*— A new negative refractive index (NRI) metamaterial unit cell is presented in this study. The negative refractive index property is being displayed by the unit cell of metamaterial in the four distinct microwave frequency bands. Finite integration technique was adopted to evaluate the property of the material. More than 1 GHz bandwidth region was found exhibiting NRI property for the material in the microwave spectra.**

***Index Terms*— NRI; Multi-band; Metamaterial; Finite integration.**

I. INTRODUCTION

Metamaterials are engineered electromagnetic materials where the effective permittivity and effective permeability are tailored to have some exotic properties. These properties are not naturally available in the natural materials. Tailoring negative permittivity and the negative permeability at a certain frequency, is one of the promising properties of certain class of metamaterials, which are called double negative (DNG) metamaterials. Thus, it produces negative refractive index (NRI) composite medium at that specific frequency because of these two negative properties. Smith and his collogues first reported a composite NRI material by utilizing the split ring resonator and metallic wires [1]. They showed that the negative permittivity can be obtained from the repeated wires and negative permeability can be achieved by tailoring various magnetic shapes like, π-shape, S-shape, U-shape, split-H-shape and many others interesting structures [2-5]. In NRI material, this negative property occurs due the opposite property of phase and group velocity. This unconventional behavior of these materials have attracted the researchers to apply in various electromagnetic applications like, antenna design, SAR reduction, filter design, Cloak design and so on [6-8]. Usually, the effective medium properties (like, permittivity, permeability) of such medium can be obtained from the Maxwell's equations that directly relate the current distribution and charge property of the medium. The effective medium can be formed by repeating the scattering inclusions of much smaller than the operating wavelength. Then the incident wave will see a continuous media. Usually, a number of scattering atoms (unit cells) are adopted to form a bulk metamaterial. The electromagnetic property of that bulk metamaterial is completely influenced by its scattering atoms. The characteristics of the individual unit cell are identical and therefore the characteristics of the metamaterial can be optimized from the unit cells. Similarly, it gives freedom to the designer of metamaterial to form a desired material by changing the various parameters of the unit cell.

This paper proposes a new metamaterial having negative refractive index property in the S-band, C-band, X-band and Ku-band of microwave region. The proposed design displays more than 1.5 GHz maximum bandwidth as well. Commercially available CST Microwave Studio software was used for design and S-parameters extraction of the unit cell.

II. THE DESIGN OF A PROPOSED UNIT CELL AND METHODOLOGY

Figure 1 portrays the geometry of the proposed square-shaped metamaterial unit cell. The proposed unit cell is a square structure. A horizontal copper strip was placed in the middle of the square structure in such a way that it maintains 0.5mm gap at its two ends with the inner boundary of the structure. The outer length of the structure is a= b=10 mm. The boundary of the structure was kept 1mm wide at all directions. The length and width of the metal stripe (in the middle) was 7mm and 1mm correspondingly. The distance from the central metal stripe to the square border was denoted by, c=d=3.5mm. The structure was projected on a 20×20-mm2 square shaped substrate material FR-4. It has dielectric constant of 4.3 with tangent loss of 0.025. The thickness of the substrate was 1.6 mm. The thicknesses of all other parameters were kept 0.035mm.

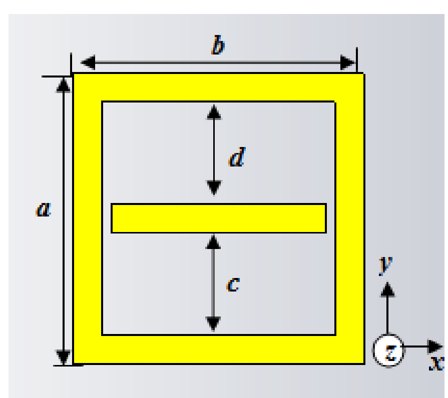

Figure 1: The proposed unit cell

For the performance investigations and S-parameters calculations, of the proposed unit cell the commercially available finite-difference time-domain based 'CST microwave studio' simulation software was utilized. The unit cell was placed between two-waveguide port facing its z-axis to the ports and the unit cell was excited by the transverse electromagnetic (TEM) waves. The whole simulation geometry is showed in Figure 2. For the simulation frequency domain solver was used and S-parameters were calculated. The Nicolson-Ross-Weir method was adopted to retrieve the effective medium parameters form the S-parameters [9].

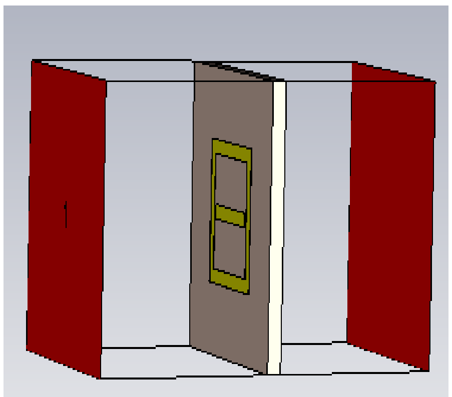

Figure 2: Simulation geometry

III. Result and Discussion

The Figure 3, shows the magnitude of transmission coefficient (S21) and reflection coefficient (S11) for the unit cell. The three resonances are clearly visible in the transmission coefficient graph those are at the frequency of 6.34 GHz, 10.56GHz and 13.90 GHz those are in the range of C-band, X-band and Ku-band respectively. Similarly, the reflection parameters exhibit resonances in the same frequency bands at 7.12 GHz, 11.78 GHz and 14.46 GHz.

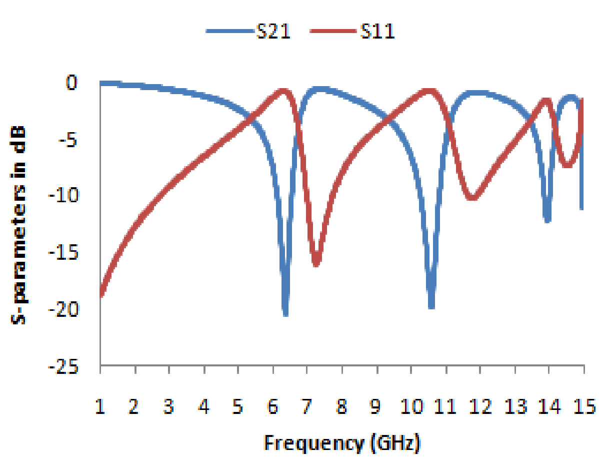

Figure 3: Magnitude of S-parameters

Figure 4 and 5 reveal the real magnitude of permittivity and permeability against the frequency for the unit cell. From Figure 4, it is evident that the permittivity curve exhibit three resonances at the frequency of 2.94 GHz, 6.50 GHz and 9.19 GHz. Moreover, the negative magnitude in permittivity curve is visible from 3.92 GHz to 5.46 GHz, 6.55 GHz to 7.28 GHz, 9.28 GHz to 10.74 GHz and 11.54 GHz to 13.19 GHz. However, two bandwidths of 1.54 GHz and 1.65 GHz for the relative frequency of 3.92 GHz to 5.46 GHz and 11.54 GHz to 13.19 GHz are found mentionable in the permittivity curve as well. Similarly, in the Fig. 5, permeability curve displays two resonances that are at the frequency of 3.75 GHz and 11.38GHz. It reveals negative magnitude from the frequency of 3.74GHz to 7.28 GHz, which contains more than 3 GHz bandwidth. Another negative area in this curve starts from 11.26 GHz to 14.70GHz that also covers more than 2 GHz bandwidth. Usually, the properties of permittivity and permeability are most likely affected by the polarization due to internal architecture of the material. When electromagnetic waves enter in anisotropic materials, which have unequal lattice axes, it is affected by the polarization inside the material. As a result, the value of permittivity and permeability changes due to changes in the design. In the same way, the refractive index curve is also affected by the polarization.

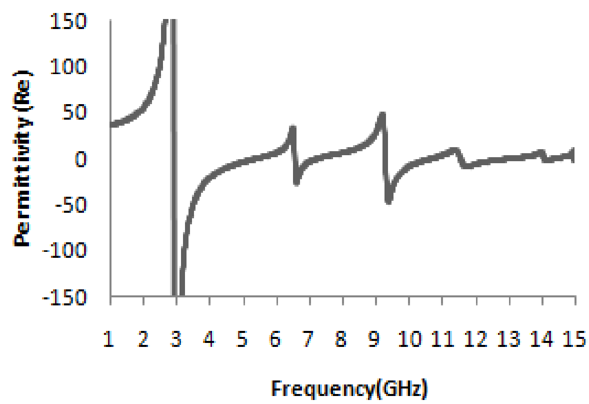

Figure 4: Real magnitude of permittivity (ε) against frequency

In the Figure 6, the refractive index graph for the unit cell is depicted. It is apparent from the Figure 4(b) that, the material shows negative real peak from the frequency of 3.74 GHz to 5.46 GHz, 6.55 GHz to 7.29 GHz, 11.54GHz to 13.19GHz and 14.09 GHz to 14.46 GHz that respectively cover 1.71 GHz, 0.74GHz, 1.69 GHz and 0.37 GHz bandwidths in the microwave regime. It is notable here that, two bandwidths here those cover more than 1 GHz bandwidth. However, the existence of any negative region in the refractive index curve is also supported by the corresponding permittivity and permeability curve as well. Moreover, these NRI- region fells in the range of S-, C-, X and Ku-band of microwave spectra. Therefore, the unit cell can be applied for double negative or negative refractive index applications in these frequency ranges effectively.

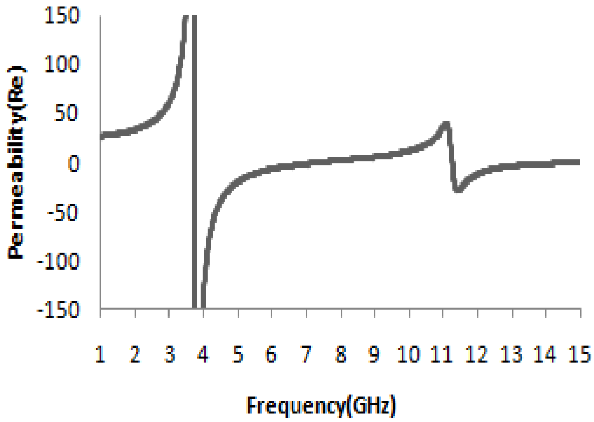

Figure 5: Real magnitude of permeability (μ)

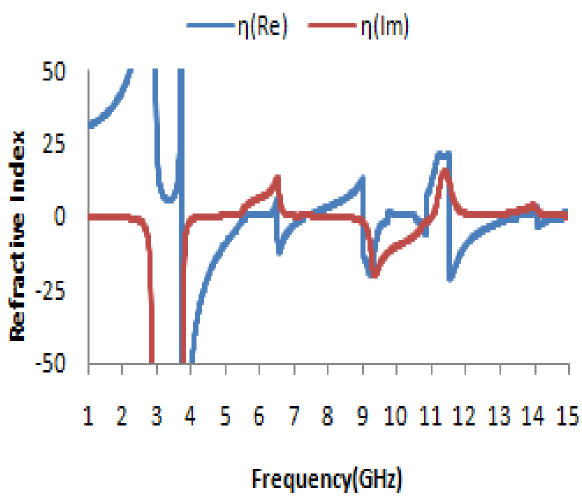

Figure 6: Magnitude of refractive index (η)

IV. CONCLUSION

A unit cell of new metamaterial was introduced in the study that exhibits negative peak in refractive index curve in four consecutive bands (S-, C-, X- and Ku-band) of microwave region. S-band, C-band, X-band and Ku-band are popular for satellite communications. Today, in satellite antenna metamaterial is being used to enhance the gain and other performance of the antenna. Beside this metamaterial can be used in WLAN, WiMax antenna applications in the S-band as well. Therefore, the simple design, NRI properties and multi-band applications have made the design novel in the electromagnetic paradigm.

REFERENCES

[1] K Smith, D. R. , Padilla, W. J. , Vier, D. C. , Nemat-Nasser, S. C. , Schultz, S., "Composite medium with simultaneously negative permeability and permittivity," *Phys. Rev. Lett*., vol. 84, pp. 4184–4187, 2000.

[2] Chang-Chun, Y. , Yi-Ping, C. , Qiong , W. , Shing-Chuang, Z., "Negative Refraction of a Symmetrical π-shaped Metamaterial," *CHIN.PHYS.LETT.,* vol. 25, pp. 482-484, 2008.

[3] Baena, J. D., R. Marques, F. Medina, and J. Martel, "Artificial magnetic metamaterial design by using spiral resonators," *Phys. Rev. B*, vol. 69, , pp. 0144021:1-5, 2004.

[4] Gallas, B., Robbie, K., Abdeddaïm, M., Guida, G., Yang, J. Rivory, J. and Priou, A., "Silver square nano spirals mimic optical properties of U shaped metamaterials," *Optics express*, vol. 18, pp. 16335, 2010.

[5] Islam, S. S., Faruque, M. R.I., Islam, M. T. , "A new double negative metamaterial for multi-band microwave applications," *Applied Physics A*, vol. 116, pp. 723-733, 2014.

[6] Alici, K. B. , Bilotti, F. , Vegni, L. , Ozbay, E., "Experimental verification of metamaterial based subwavelength microwave absorbers," *Jour. Appl. Phys*., vol. 108, pp. 083113:1-6, 2010.

[7] Islam, S. S., Alam, T.,Faruque, M. R.I., Islam, M. T., "Design and Analysis of a Complementary Split Ring Resonator (CSRR) Metamaterial Based Antenna for Wideband Application;," *Sci. Eng. Compos. Mater. , Article in press*, 2015**.** DOI: 10.1515/secm-2015-0274

[8] Islam, S. S., Faruque, M. R.I., Islam, M. T., "A two-component NZRI metamaterial based rectangular cloak," *AIP Advances*, vol. 5, pp. 107116:1-9, 2015.

[9] Islam, S. S., Faruque, M. R.I., Islam, M. T., "A New Direct Retrieval Method of Refractive Index for Metamaterials ," *Current Science*, vol. 109, pp. 337-342, 2015.