VNU Journal of Science: Mathematics – Physics, Vol. 32, No. 4 (2016) 63-67

Research and Fabrication of an Antenna Based on Meta-materials with Negative Refractive Index

Dang Thi Thanh Thuy*

Faculty of Physics, VNU University of Science, 334 Nguyen Trai, Thanh Xuan, Hanoi, Vietnam

Received 18 October 2016
Revised 20 November 2016; Accepted 24 December 2016

Abstract: For fast developing materials science, the communication technology also introduces new applications especially in the field of application of new materials and devices. Meta-materials with repeating structures that exhibit the negative refractive index, negative dielectric constant, and negative magnetic permeability promise many benefits in the wireless communication using a new class of microwave antennas. These novel antennas overcome disadvantages of traditional microwave antennas while having smaller physical size, wider band-width and higher efficiency. In this paper we present the results of fabrication and test of meta-structured antennas.

Keywords: Meta-material, antenna, meta-antenna, negative refractive index…

1. Introduction

Recent advances in the field of micro and nano materials processing allow us to create a new class of artificial materials whose characteristics fall beyond the limits of conventional traditional materials. The meta-materials are one class of the artificial materials that can be created from the traditional materials by arranging the ordered structures of different shape and size [1]. Recent interest is focused on the meta-materials having negative refractive index as these materials exhibit many important characteristics not available in the traditional materials. Negative refractive index materials were successfully fabricated for the first time in 2000 by Smith, while its properties were predicted theoretically in 1968 by Veselago [2]. These materials themselves are a perfect combination of electrical and magnetic components that simultaneously have the negative magnetic permeability (μ <0) and electrical dielectric constant (ε <0) in the same frequency range. Thereby leading to the electromagnetic properties and optical irregularities, including the inversion of Snell's law, the inverse of the Doppler shift, and the inverse of Cherenkov emission.... By adjustment of the effective μ and ε suitably the path of light rays can be bent when passing through the meta-materials while not being reflected or scattered. Besides, a series of other critical applications which has also been suggested by scientists is the application as frequency filters, resonators, sensors, absorbers, etc...

* Tel.: 84-1685292237
Email: dangthuy@vnu.edu.vn

2. Negative refractive meta-material

As commonly known when a light ray arrives at the boundary separating two different environments it will be refracted along a path 1-4 as given in Figure 1.

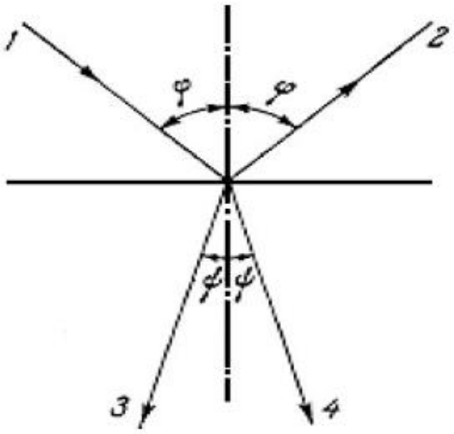


Figure 1. The light rays passing through the separator shore [2, 8, 9].

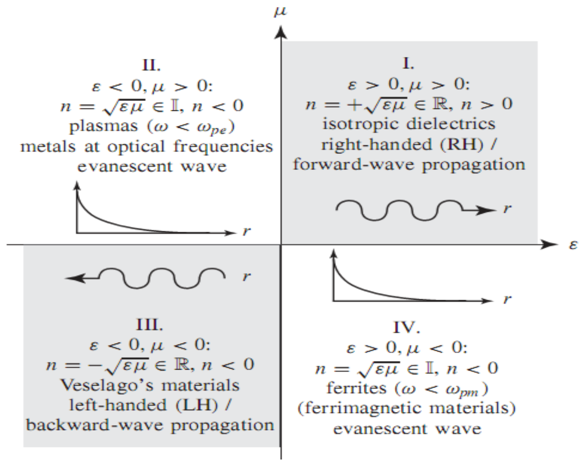


Figure 2. The coordinate system of ε, μ [2, 8, 9]

However when the phase velocity and the group velocity are not in the same direction, the strange thing happens that the beam will be deflected in the direction path 1-3. Therefore, if one wants to keep the correct formula of refraction (i.e. the Snell law) $\sin\varphi/\sin\Phi = n$, then $n < 0$ because $\sin\Phi < 0$. We have $n = \sqrt{\varepsilon\mu}$ so that: $n = \pm\sqrt{\varepsilon\mu}$. The case with the plus sign "+" applies when the material is normal, it has $\varepsilon > 0$ and $\mu > 0$; the case with minus sign "-" applies when the material has both $\varepsilon < 0$ and $\mu < 0$. From here we have the pairs of positive and negative values of (ε, μ) making up four regions in the coordinate system of ε, μ.

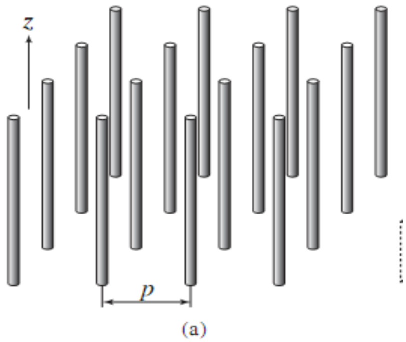


Figure 3a. A electric material model [2, 8, 10]

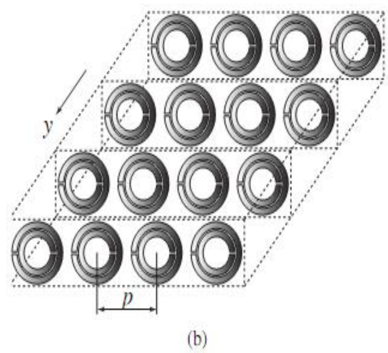


Figure 3b. A plasma magnetic material model [2, 8, 10]

Negative refractive index materials are usually formed from the basic structures, which act as the "atoms" in the materials. These "atoms" are grouped together repeatedly or not. They consist of two main components which are electrical components and magnetic components. The electrical components (electric metamaterial) generate the negative value of dielectric constant ($\varepsilon < 0$). The magnetic components generate the negative magnetic permeability ($\mu < 0$). One of the interesting properties of materials with negative refractive index is 3 vectors of electromagnetic (***E***, ***H***, ***k***) waves obey the left-handed rule. Thus, the materials with a negative refractive index are also known as the left-handed metamaterials (LHMs). LHMs can be designed and built to operate on the desired frequency band ranging from the microwave region to the far infrared, even closer to the visible light region [3-5]

3. Fabrication of antenna on the basic of meta-material

We now focus on a simulation of meta-materials with a simple structure as given in Figure 4 [6-7]. While taking into account the number of unit cells, the change in the unit cell distance can be monitored. From the original pad antenna we altered the structure of the active surface to the one of the meta-structured materials.

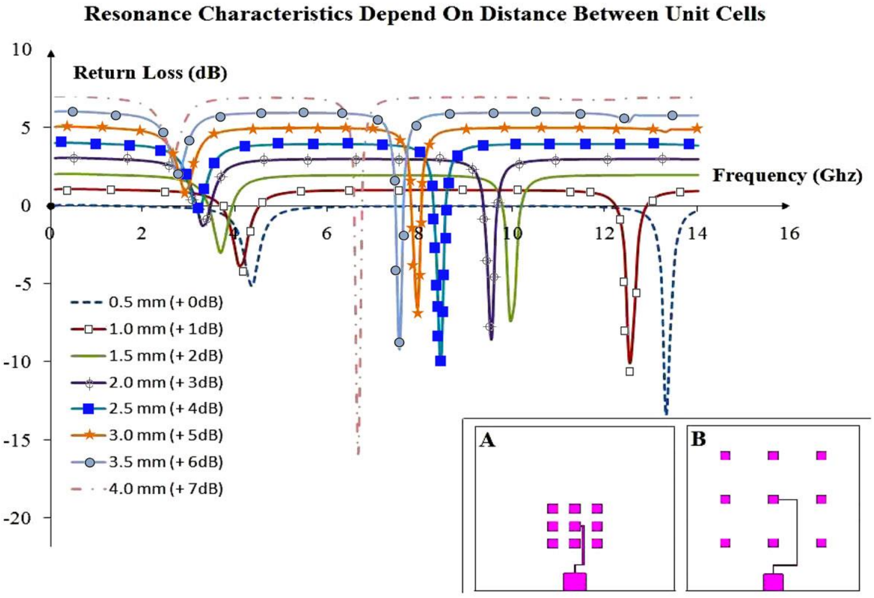
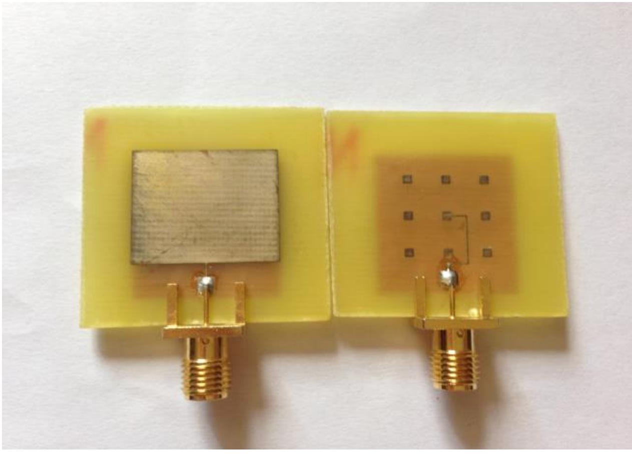


Figure 4. Resonance characteristics depends on distance between unit cells

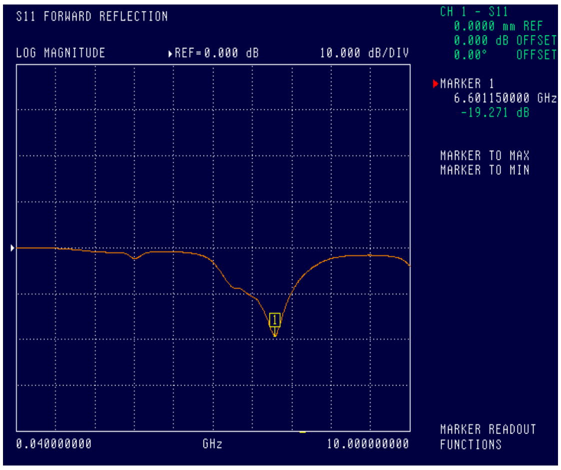
Each unit cell contains a pillar of copper of 3.5 µm in height and 1mm in size. To observe the effect of changing distance between the unit cells we modeled 9 unit cells. Here we simulated 8 antennas with the unit cell distances equal to 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4 mm respectively while keeping all other parameters of the sample antenna unchanged.

In Figure 4, a sample A has a distance d = 0.5 mm, B has d = 4 mm. These antennas are designed on a glass substrate of size 20×20 mm, and thickness 100 µm. Two copper faces have a thickness equal 3.5 µm. The lower surface size is 18×19 mm. The higher surface includes 9 unit cells of 1mm in size and 3.5 µm in height. The distance between unit cells change from 0.5 to 4 mm. The voltage supply line cross section is 100 µm and the area of the voltage supply contacting point is 2×2 mm.

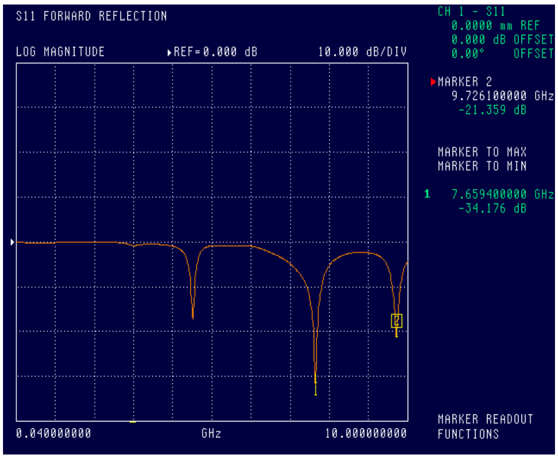
Accordingly we fabricated two antennas on glass material utilizing the Cu surfaces and examined the characteristics of these antenna responses.



a) A microtrip antenna and a meta-antenna.



b) Resonance characteristic of the microtrip antenna.



c) Resonance characteristic of the optimized meta-material antenna.

Figure 5. Resonance characteristic of the microtrip antenna and meta-material antenna.

The results showed that for a resonance seen at 6.6 GHz the feedback coefficient is -19.27 dB. We obtained 3 resonance peaks with a performance at 7.66 GHz with feedback coefficient of -34.2 dB. In comparison with a modeled antenna with 9 unit cells the best resonance peak occurred at 6.8 GHz with return loss -12.2 dB.

4. Conclusion

The fabrication and modeling simulation of a meta-materials based antenna, working in the microwave region, has been discussed. The good agreements between the theoretical and experimental results were achieved for the model antennas composed of finit number of separated square units in the active surface. The results showed that the occurence of the meta-structure led to the improvement of both band-width and gain for the antenna modelled. Therefore, the application of artificial materials in the fabrication of microwave antenna overcome the disadvantages of the old strip-technology and showed that the bandwidth could be improved as well as the performance of the antenna. This study also suggested that a simple structured meta-materials based antenna can be easily fabricated by the current technology available in Viet Nam. These results promised the application of new type of antenna in manufacturing of novel communications devices.

Acknowledgement

This research is funded by the Vietnam National University, Hanoi (VNU) under project number QG.15.12.

References

[1] N. W. Ashcroft, N. D. Mermin, "Solid State Physics", Holt, Rinehart and Winston, (1976).
[2] S. N. Khanna, P. Jena, "Assembling crystals from clusters", Phys. Rev. Lett.69, 1664–1667 (1992).
[3] Colburn J. S., and Rahmat-Samii Y. (1999), "Patch antennas on externally perforated high dielectric constant substrates", IEEE Trans. Antennas Propagat, pp. 1785–94.
[4] GA Deschamps,"Microstrip microwave antennas" presented at the 3rd USAF Symp. on Antennas, 1953; "Microstrip and Printed Antennas: New Trends, Techniques and Applications" Ed. Debatosh Guha,Yahia M.M. Antar. J. Wiley and Sons, 2011.
[5] Balanis CA. Antenna theory: Analysis and design, 3rd Ed., Wiley-Interscience; 2012.
[6] Christophe Caloz (2006), "Electromagnetic Metamaterials: Transmission line theory and microwave applications", John Wiley & Sons, Inc., Hoboken, New Jersey, Canada.
[7] Ansoft, LLC. An Introduction to HFSS: Fundamental Principles, Concepts and Use. An-soft, 2009.
[8] Shelby, R. A.; Smith, D. R.; Schultz, S. (2001). Experimental Verification of a Negative Index of Refraction. Science 292 (5514): 77–79. 2001.
[9] Hsu, Yi-Jang; Huang, Yen-Chun; Lih, Jiann-Shing; Chern, Jyh-Long (2004). "Electromagnetic resonance in deformed split ring resonators of left-handed meta-materials". Journal of Applied Physics 96 (4): 1979 (2004).
[10] WU, Q.; Pan, P.; Meng, F.-Y.; Li, L.-W.; Wu, J. (2007-01-31). "A novel flat lens horn antenna designed based on zero refraction principle of metamaterials". Appl. Phys. A 87 (2): 151–156 (2007).