# Theoretical Study of fractal shape material of negative refractive index

**The 5th International scientific Conference on Nanotechnology& Advanced Materials Their Applications (ICNAMA 2015) 3-4 Nov, 2015**

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**Abstract**

Advanced materials are artificial structure materials that exhibit properties not found in nature. Material that has a negative refractive index (left-handed materials) is found to get a lot of interest in the literatures. Controlling the geometry of classical material may lead to have a negative refractive index in a certain frequency range. In this paper, we utilized from fractal geometry in our design. A Sierpinski Carpet fractal model is proposed. Calculations show that this model has a negative refractive index in the frequency range 7.5 GHz – 16.5 GHz. Wide band behavior of this model refers to its fractal shape.

**Keywords:** advanced materials, metamaterials, left-handed materials, negative refractive index, fractal.

## دراسة نظرية لمادة ذات معامل انكسار سالب كسورية الشكل

**الخلاصة**

المواد المتقدمة هي مواد صناعية تمتلك خصائص غير موجودة في الطبيعة. المواد التي تمتلك معامل الانكسار السالب ذات اهتمام كبير في مجال البحث العلمي. التحكم بشكل المادة الاعتيادية قد يؤدي الى ان تمتلك هذه المادة معامل انكسار سالب في نطاق ترددي معين. في هذا البحث تمت الاستفادة من الهندسة الكسورية في التصميم. تم اعتماد نموذج سربنسكي الكسوري. اظهرت الحسابات ان هذا النموذج يمتلك معامل انكسار سالب في النطاق الترددي 7.5 GHz – 16.5 GHz ان النطاق العريض في تصرف هذا النموذج يعود الى شكله الكسوري.

**الكلمات المرشدة** : مواد متقدمة , معامل الانكسار السالب, الهندسة الكسورية.

## INTRODUCTION

Advanced materials or Metamaterial concept is came from the word (meta) which means beyond [1]. The term was coined in 1999 [1]. It also called Left-Handed Material (LHM). Veselago in1968, examined and studied the



https://doi.org/10.30684/etj.33.5B.6
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plane wave propagation in medium who has negative permeability and permittivity [2, 3]. In 1996, Pendry introduced the first fabricated medium (composed of wire), which has a negative value of permittivity [3, 4]. In 1999, Pendry proposed the magnetically responded artificial medium, called, Split Ring Resonator (SRR), which has a negative permeability [3,5]. The first left handed medium ($\varepsilon<0$, $\mu<0$) was achieved by Smith et al. in 2001 by using the combination of wires and Split Ring [3,6]. Metamaterials occupy new topics in several branches from science to engineering. It has attracted big attention for both theoretical and experimental study [3,7]. Advanced materials are placed at an intermediate position between science and engineering, for this reason they are of interest both physicists and engineers [3,8]. It is artificial structures that build by human to get simultaneously negative permittivity and permeability which leads to negative refractive index (NRI) at a specific frequency band. Due to having the negative refractive index it supports backward waves and does not obey some optical properties of nature [3].

In this paper, we introduce new design of advanced material (metamaterial). The design is based on controlling the geometry of the material instead of its inclusions to get its unusual behavior (metamaterial).

**Unit cell Design**

Unit cell design is utilized from fractal geometry to get its shape. Fractal model of this unit cell is called Sierpinski Carpet. The generation of this fractal shape is discussed in Ref. [9]. The fractal dimension of this model is 1.89. The configuration of this model is shown in figure 1.

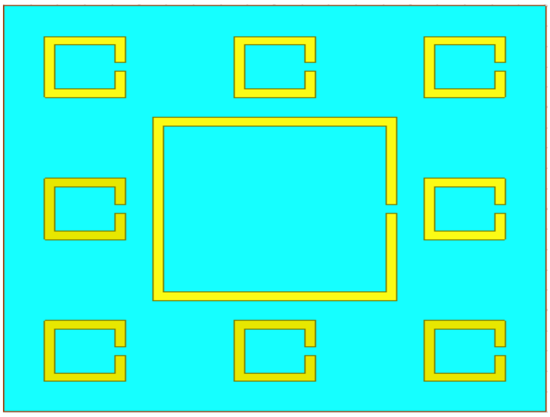


**Figure (1) Sierpinski Carpet configuration.**

The fractal metamaterial cell has side length equal to 6mm for the middle square and 2mm for the others. The gaps in the model are equals to 0.4 mm. The dielectric substrate thickness is 1.6mm its type FR4 ($\varepsilon_r$=4.4).The rings are made of copper. This model is placed in a waveguide and set the boundary conditions to simulate its parameters. The boundary conditions are shown in figure (2) . The conditions are forced the emerged wave to polarized in specific manner. The electric field component is tangential with gap of the ring to get negative permittivity and permeability.

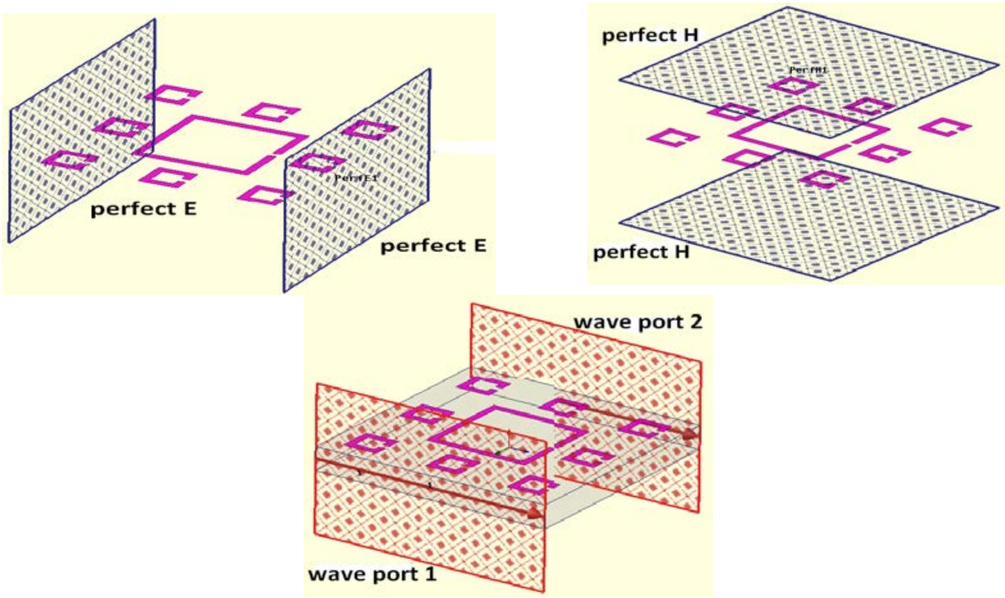



**Figure ( 2) Boundary conditions**

**Results**

The simulated parameters are shown in the following figures.

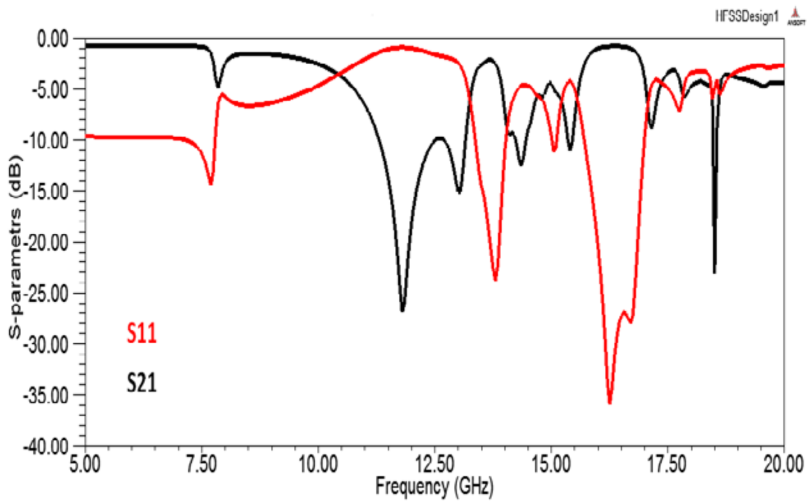



**Figure (3) S-parameters.**

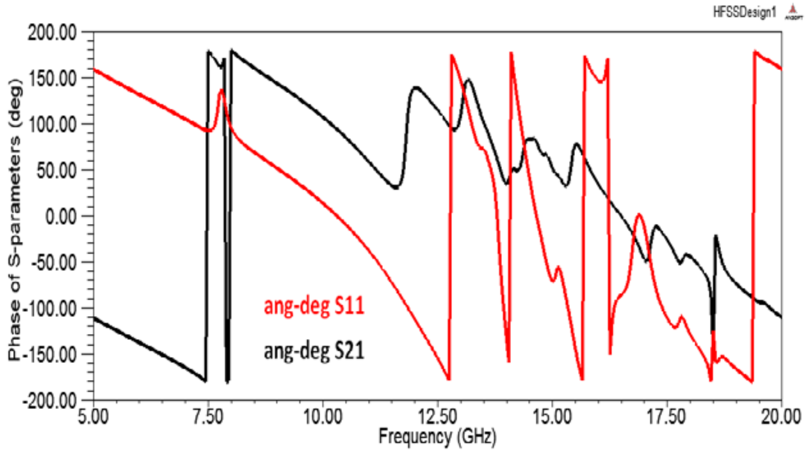



**Figure (4) Phase of S-parameters.**

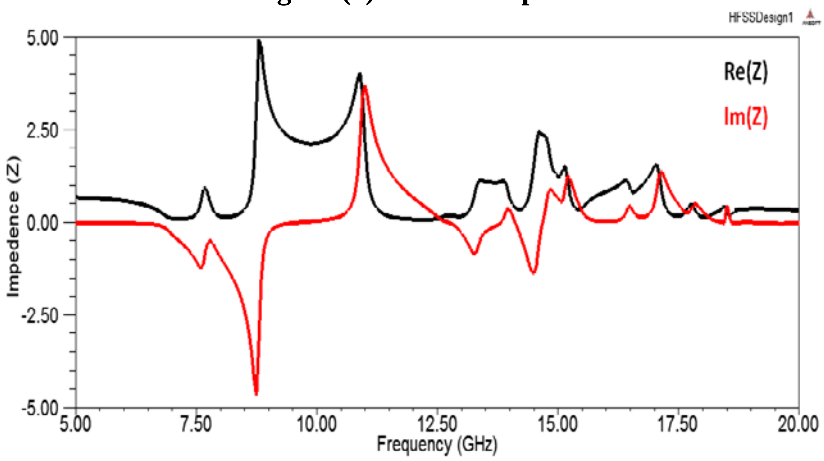
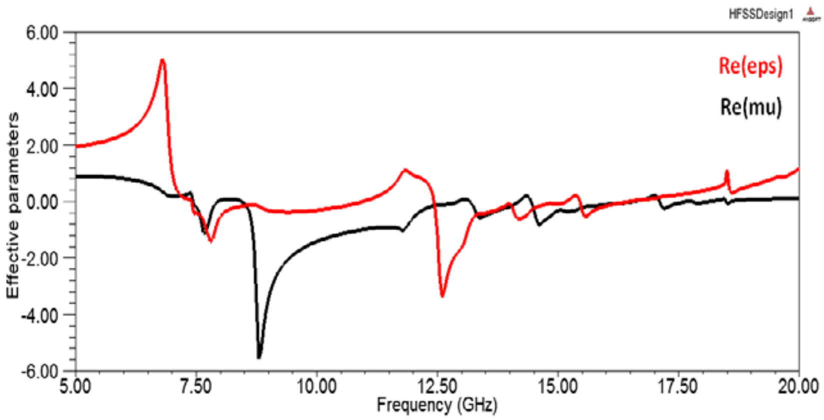
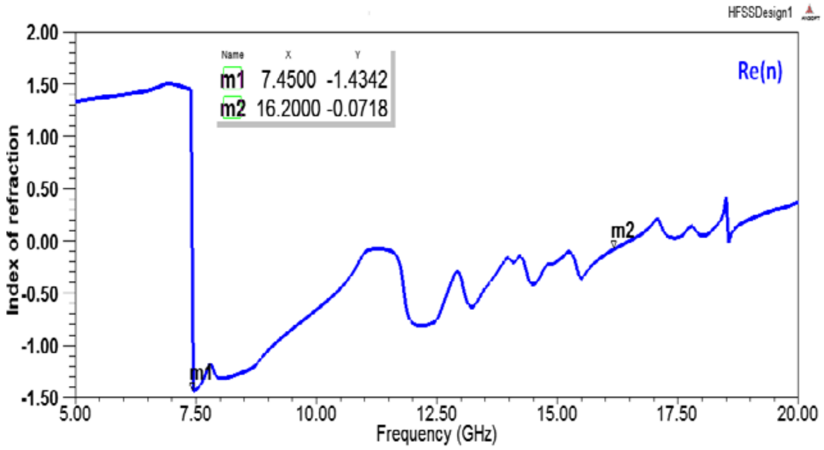



**Figure ( 5) Input impedance (real & imaginary).**




**Figure( 6) permittivity and permeability.**




**Figure( 7) Refractive Index.**

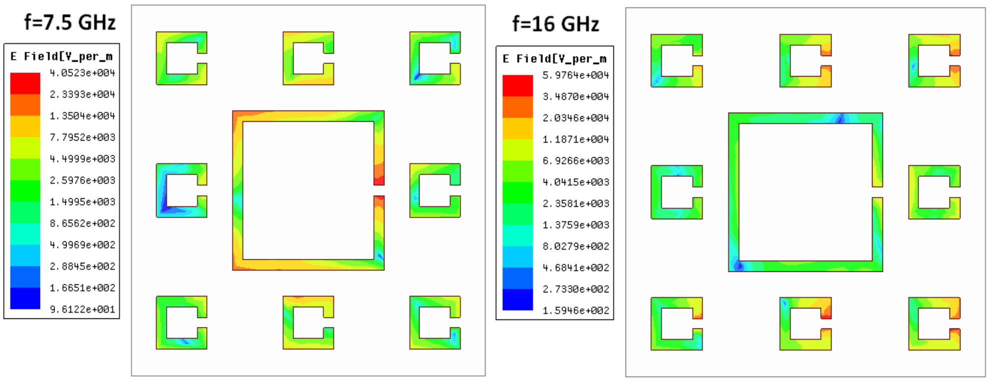



**Figure ( 8) Electric filed distribution at two frequencies.**

From figures (3,6,7) above, the fractal Sierpinski unit cell is resonate over wide band. Resonance frequencies are obvious in figures (3-5). Less than zero refractive index is obtained from permeability and permittivity magnitudes [3]. This lies in the frequency range from 7.45 GHz to 16.2 GHz. Near to zero value of refractive index lies above 16 GHz to 20 GHz. That is mean we get wide range of backward radiation. The current distribution shows in figure (8) explain the multiband behavior of this model. We can see that the middle ring is active at low frequency. While at high frequencies, the small rings became active.

## Conclusion

Fractal shape of advanced material (metamaterial) is proposed. Sierpinski Carpet fractal shape has fractal dimension 1.89. the fractal dimension is related to the properties of the shape. Different fractal shapes with different fractal dimension does not have the same properties. This shape enable the cell to behave as metamaterial over wide range of frequencies (7.45 GHz – 16.2 GHz) as in Fig. 7. It is more easy to get metamaterial behavior by controlling the geometry of the material instead of controlling its inclusions. It is characterized by low coast of fabrication does not required high technology. It is very useful in communication systems like antennas and filters.

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