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Study and Analysis the Effect of Fractal Dimension on Reflection Coefficient in 2d Metamaterial Structure

Mohammad Asaad [1], Al Samoual Saleh [2], Ali Zaid [3]
PhD Student, Faculty. Of Mechanical and Electronic Engineering, Tishreen University
Professor, Faculty. Of Mechanical and Electronic Engineering, Tishreen University
Professor, Faculty. Of Electrical and Electronic Engineering, Aleppo University
Syria

ABSTRACT

In this research, We studied the effect of fractal dimension parameter on transmission coefficient in 2D structure containing 'left-handed' metamaterials. Metamaterials are artificial structures that have simultaneously negative effective permittivity and permeability. We noticed that changing the fractal dimension leads to a difference in the positions of transmission peaks in frequency bands.

Keywords :— **Meta-materials , ,Cantorbar ,Split Ring Resonator(SRR)**

I. INTRODUCTION

Metamaterial (MTMs) is a wide research area driven both by the researcher and by scientific applications [1-2].meta consists of artificial composites with simultaneously negative effective permittivity and permeability [1-2]. The majority of the known homogenization methods for MTMs rely on the periodicity of the structure .Although the spatial period in such MTMs is typically much smaller than the wavelength, it is always finite, and thus a finite-size MTMs sample always contains a finite number of unit cells[3-4].

Based on the great diversity offered by fractal geometry and the degree of freedom it offers, it has formed with the theory of electromagnetic waves in recent years a new concept in the design of circuits and antennas. Currently, the integration of the concept of fractal with the MTMs has attracted the attention researchers, with the increasing need to take advantage of the properties of these materials in modern telecommunications devices[6-7-8]. Therefore, the objective of our research is to study the effect of fractal dimension parameter (D) on the on transmission coefficient of MTMs 2d structures and to obtain several pass bands using cantor set which is one of the known fractals that has a periodic structure, which is an important requirement when designing structures MTMs.

II. METAMATERIAL

Metamaterial, also known Left-handed materials are a structuring metallic-periodic.Those materials have an artificial electromagnetic properties not present common in nature: a permittivity and a permeability both negative [9-10]

Those structures are constructed by periodically arranging unit cells, such as split-ring resonators (SRRs) and thin wires. Due to the resonant nature of the cells, electromagnetic properties of the host medium, i.e., permittivity, permeability, or both, can effectively become negative for some frequencies. Although metamaterial were theoretically studied more than 40 years ago their actual realizations were achieved recently. Besides, many studies are based in how to enhance the electromagnetic property of the metamaterial and to improve the use of those structures. Since then, the Metamaterial have continued to attract the interest of researchers because they allow considering new applications in the field of microwave. Due to these efforts, metamaterial have been utilized in various applications such as subwavelength focusing, cloaking, and designed improved antennas. Recently, antenna and its feed system in wireless communications require to be multifunctional for enhancing flexibility and feasibility, such as easy of integrate, low profile, inexpensive and ease of fabrication, and wideband or multiband operating[9-10-11].

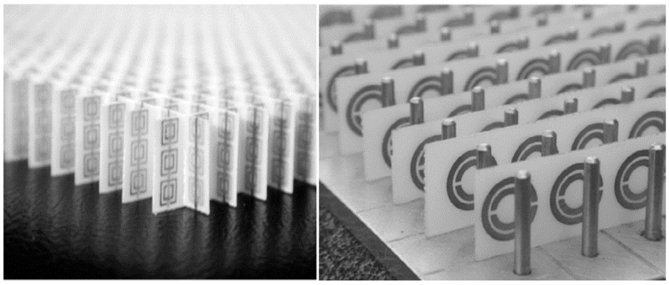

Fig. 1 example of Metamaterial

III. METAMATERIAL CLASSIFICATION

The response of a system to the presence of Electromagnetic field is determined by the properties of the materials involved. These properties are described by defining the macroscopic parameters permittivity ε and permeability μ of these materials. By using permittivity ε and permeability μ. The medium classification can be graphically illustrated as shown in Fig(2) A medium with both permittivity & permeability greater than zero ($\varepsilon > 0$, $\mu > 0$) are called as double positive (DPS) medium, Most occurring media (e.g. dielectrics) fall under this designation. A medium with permittivity less than zero & permeability greater than zero ($\varepsilon < 0$, $\mu > 0$) are called as Epsilon negative (ENG) medium. In certain frequency regimes many plasmas exhibit this characteristics. A medium with both permittivity greater than zero & permeability less than zero ($\varepsilon > 0$, $\mu < 0$) are called as Mu negative (MNG) medium. In certain frequency regimes some gyro tropic material exhibits this characteristic. A medium with both permittivity & permeability less than zero ($\varepsilon < 0$, $\mu < 0$) are called as Double negative (DNG) medium. This class of materials has only been demonstrated with artificial constructs[9-10-11-12.]

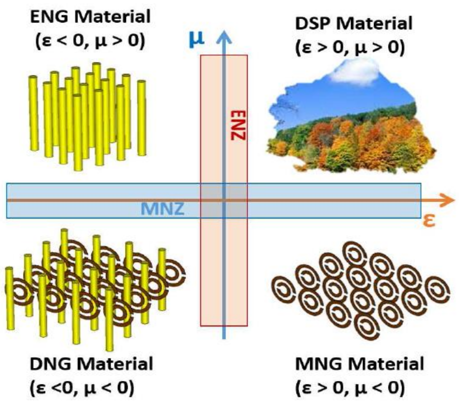

Fig. 2 Material classification in the ε ,μ domain

IV. THE SPLIT RING RESONATOR

The split ring resonator (SRR) is a common structure to obtain negative effective permeability and is used in designing metamaterials. They have been extensively studied in [13-14] and another variant of the SRR is the Square SRR (S-SRR) which has more degrees of freedom from the design aspect.
The SRRs possess large magnetic polarizability and exhibit negative effective permeability for frequencies close to their resonance frequency [2]. They also show a large magnetic dipole moment when excited by a magnetic field directed along its axis. This was shown by measurements performed by using SRR. Fig.3 shows a schematic view of a S-SRR having strip width c and spacing between the rings d. Where (g1- g2) are gaps within the inner ring and outer ring, respectively. The thickness h. SRR is printed on a dielectric substrate with dielectric constant .When a magnetic field is applied, an electromotive force will appear around the SRR and will induce currents which would pass from one ring to the other through the gaps and g1- g2 . The structure behaves as an LC circuit having resonance frequency given in Eq (1)[13-14-15]

$$f_0 = \frac{1}{2\pi\sqrt{L_m C_{eq}}} = \frac{1}{2\pi\sqrt{L_m(C_m + C_g)}} \approx \frac{1}{2\pi\sqrt{L_m C_m}} \quad (1)$$

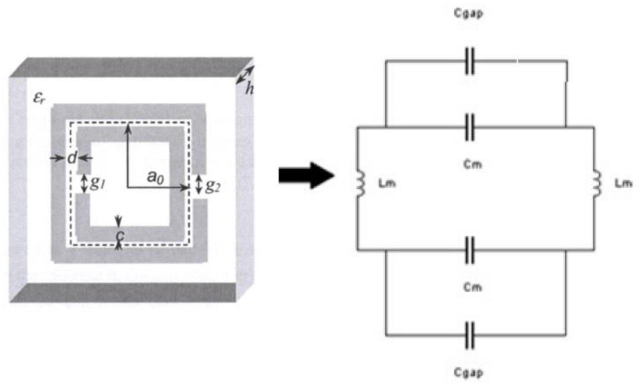

Fig.3 schematic view of a S-SRR

V. THE CANTOR SET

The Cantor set was first published in 1883 by German mathematician Georg Cantor [16-17].
The Cantor set plays a very important role in many branches of mathematics as in set theory, chaotic dynamical systems and fractal theory.

A. The Cantor ternary set

The cantor ternary[16-17] set is subset of [0,1]. To define cantor ternary set we begin with the closed real interval S0 = [0,1] and divide it into three equal subintervals. Remove the central open interval (1 /3, 2/ 3) such that S1 = [0,1]−(1/ 3, 2/ 3) = [0, 1 /3]∪[2 /3, 3 /3]. Next subdivide each of these two remaining intervals into three equal subintervals , and from each remove the central third, and continue in the previous manner. As illustrated in Eq (2)

S2 = ([0, 1 /3]−[1 /9, 2/ 9])∪([2 /3, 3/ 3]−[7 /9, 8/ 9]) = [0, 1/ 9]∪[2 /9, 3/ 9]∪[6 /9, 7 /9]∪[8 /9, 9 /9] (2)

Fig (4) shows ternary cantor set with s={1,2,3,4}

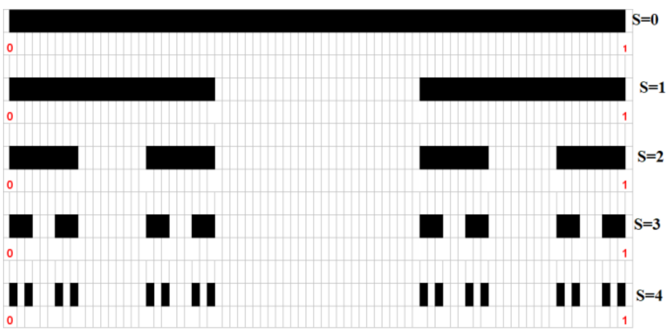

Fig.4 Cantor ternary set

B. The Cantor quintuple set

Motivated by the ternary Cantor set, we construct the Cantor quintuple set[16-17]. We begin with the closed real interval S0 = [0,1] and divide it into five equal subintervals. Remove the open intervals (1 /5, 2/ 5) and (3 /5, 4/ 5) , such that S1 = [0,1]−((1/ 5, 2/ 5) ∪(3/ 5, 4/ 5)) = [0, 1 /5]∪[2 /5, 3 /5] ∪ [4 /5, 5 /5]. We subdivide each of these three remaining intervals into five equal subintervals, and from each remove the second, and fourth open subinterval, and continue in the previous manner. In this way we obtain a sequence of closed intervals, one in the zero step, three in the first step, nine in the second step, etc. Fig (5) shows Cantor quintuple set with s={1,2}

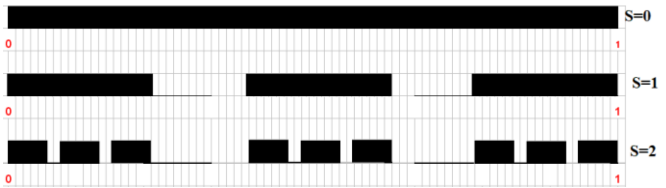

Fig.5 Cantor quintuple set with s= {1, 2}

C. The Cantor septuple set

We begin with the closed real interval S0 = [0,1] again and divide it into seven equal subintervals. Remove the open intervals , (1 /7, 2/ 7) and (3 /7, 4/ 7) and (5 /7, 6/ 7) , such that S1 = [0,1]−((1/ 7, 2/ 7) ∪(3/ 7, 4/ 7) ∪(5/ 7, 6/ 7)) = [0, 1 /7]∪[2 /7, 3 /7] ∪ [4 /7, 5 /7] ∪ [6 /7, 7 /7]. Fig (6) shows The Cantor septuple set [16-17]

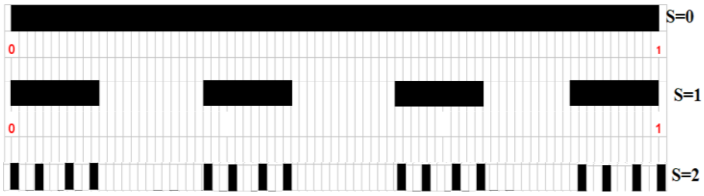

Fig.6 Cantor septuple set with s={1,2}

VI. CANTOR SETS AS FRACTALS

The Cantor set is the prototype of a fractal. A fractal is an object, which appears self-similar under varying degrees of magnification. One of the typical features of fractals is their fractal dimension. The fractal dimension is essentially a measure of self-similarity (it is sometimes referred to as the similarity dimension). The fractal dimension is greater than the topological dimension [17]. There are many specific definitions OF fractal dimension that is given by the Eq (3)

$$D = \frac{\log(N)}{\log(1/\rho)} \qquad (3)$$

where N is the number of self-similar pieces and ρ is the contraction factor .

VII. RESULTS AND DISCUSSION

In this research we will use the (square resonance on or face of the structure and Metal wire on the other that is show in Fig 7. Physical dimensions are shown in Table (1

Propagation towards the Y axis , and the operation frequency band is between 6 and 13Ghz .The Permittivity of substrate layer εr = 2.33

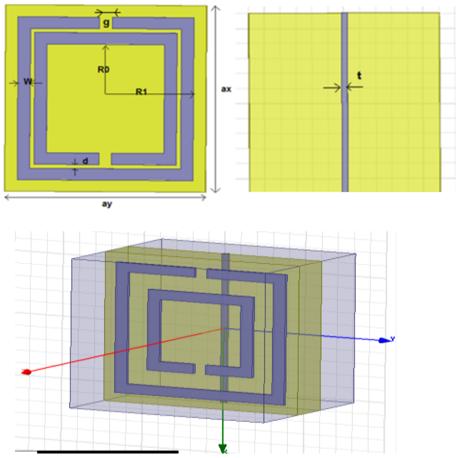

Fig.7 Metamaterial Structure

TABLE (1) Physical Dimensions for SSRR and Wire

(mm)	Dimension
0.7	(R0)
1.05	(R1)
0.15	(w)
0.05	(d)
0.15	(g)
0.5	(h) thickness dielectric
2.4	Ax
2.4	Ay
2	Az
0.075	(t)

We obtained the following result for the transmission, reflection, permittivity and permeability coefficients

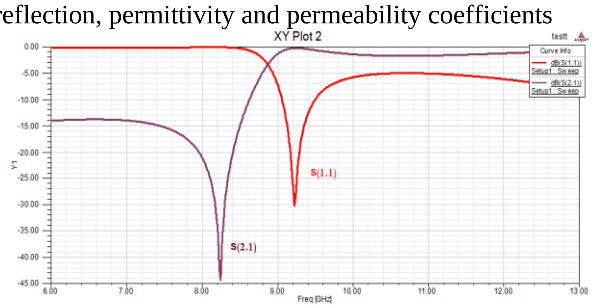

Fig.9 Transmission and Reflection Coefficients

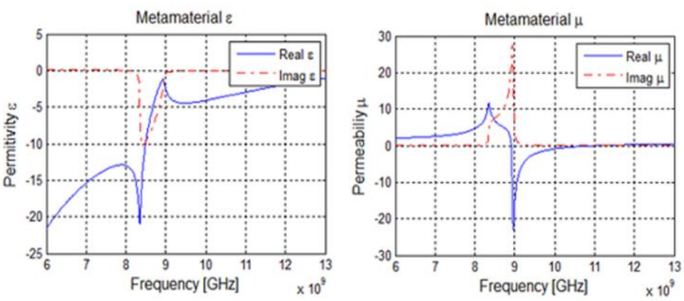

Fig 10 permittivity and permeability

Analysing the reflection and transmission coefficients shown in Fig(9) , we see that transmission peak is at frequency (9.2) Ghz with amplitude (-30) db. Fig 10 shows negative value for permittivity and permeability.

We studied 2D fractal metamaterial structures (cantor set) and found the effect of changing the fractal dimensions on the reflection coefficient.

❖ fractal dimension $D = \log 2/3$

The structure consists of SRRS and metal wire that is distributed in fractal manner. Where D= log 2/3 Fig. 11-a

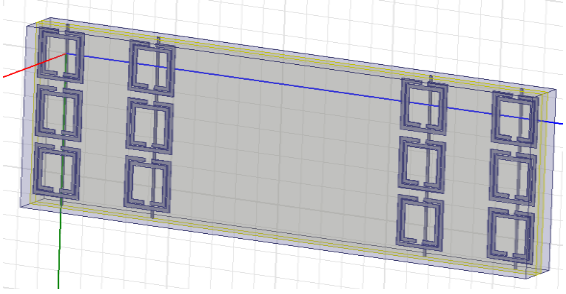

Fig. 11-a

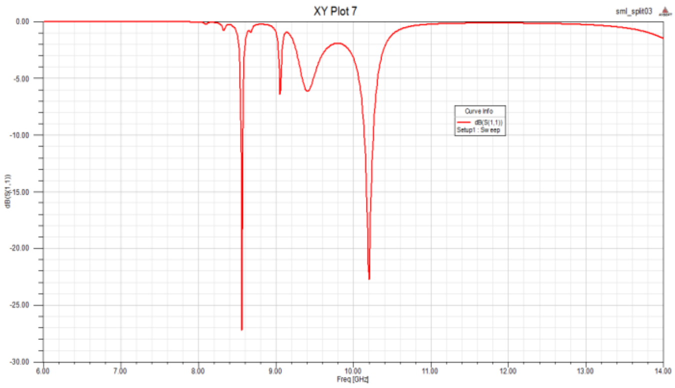

Fig.11-b

Fig(11-a) structure consists of SRRS and metal wire distributed in fractal .Fig(11-b) reflection coefficient of SRRS and metal wire distributed in fractal Where D= log 2/3

Analysing the reflection coefficient shown in Fig (11-b), we see that transmission peak is at frequency (8.8-10.2) Ghz with amplitude (-27.1, -22.2) db.

❖ fractal dimension $D = \log 3/5$

The structure consists of SRRS and metal wire that is distributed in fractal manner. where D= log 3/5 Fig. 12-a

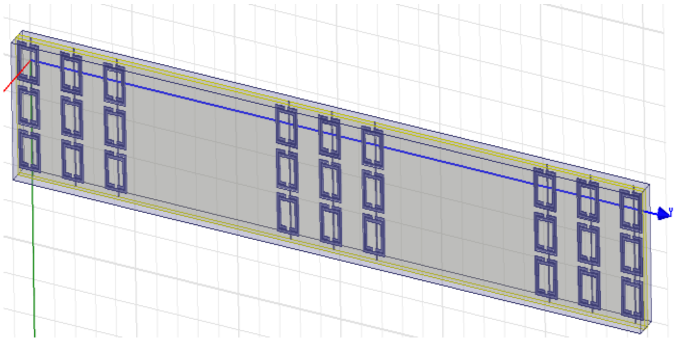

Fig. 12-a

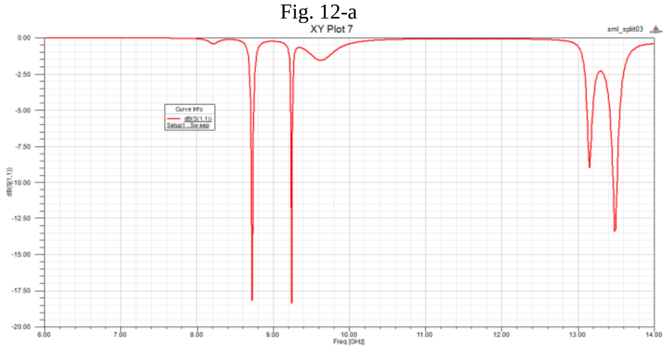

Fig. 12-b

Fig. (12-a) structure consists of SRRS and metal wire distributed in Fractal. Fig (.12-b) reflection coefficient of SRRS and metal wire distributed in fractal Where D= log 3/5

Analysing the reflection coefficient shown in Fig(12-b) we see that transmission peak appears at frequency (8.7-9.22-13.5)Ghz at amplitude (-18, -18.2 ,-13.25)db.

❖ fractal dimension $D = \log 4/7$

The structure consists of SRRS and metal wire that is distributed in fractal manner. where D= log 4/7 Fig.13

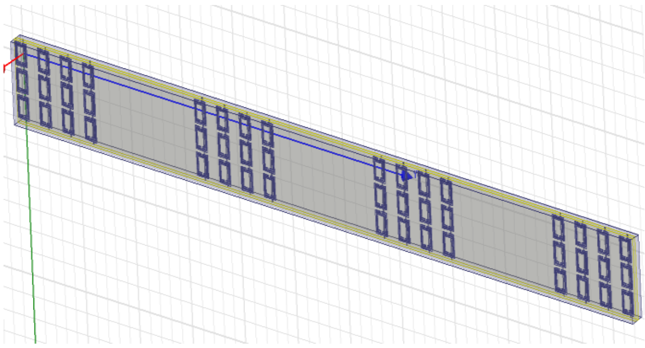

Fig 13 structure consists of SRRS and metal wire distributed in fractal Where D= log 4/7

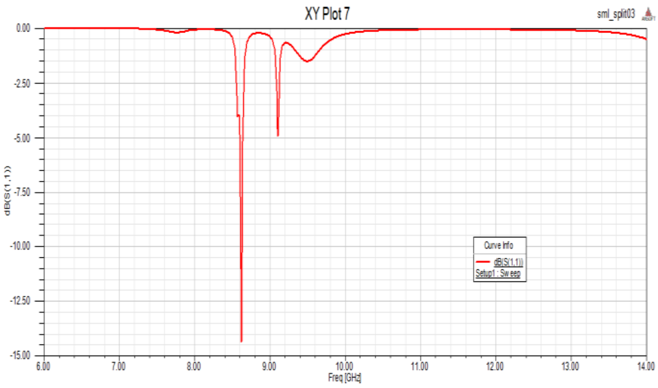

Fig.14 reflection coefficient of SRRS and metal wire distributed in fractal Where D= log 4/7

Analysing reflection coefficient shown in Fig (14) we see that transmission peaks appear at frequency (8.6) Ghz at amplitude (-14.5)db. We notice that Changing the fractal dimension leads to a difference in the positions of transmission peaks in frequency bands

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VIII. CONCLUSION

In this research, Cantor Set was used to design 2D structures consisting of negative electric permittivity (Ɛ) and magnetic permeability (µ). This structure is simulated using HFSS. We noticed that, the effect of changing the fractal dimension led to a difference in the positions of transmission peaks in frequency bands.

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