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Study And Design SRR And Complementary SRR For Novel Printed Microwave Elements

A project

Submitted to the Department of Communication University of Diyala-College of Engineering in Partial Fulfillment of the Requirement for Degree Bachelor in Communication Engineering

BY

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بِسْمِ اللهِ الرَّحْمَنِ الرَّحِيمِ

﴿ اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ (١) خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ (٢) اقْرَأْ وَرَبُّكَ الْأَكْرَمُ

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صدق الله العلي العظيم

سورة العلق : الايات :١– ٥

SUPERVISORS CERTIFICATION

We certify that the preparation of this project entitled "***Study And Design SRR And Complementary SRR For Novel Printed Microwave Elements*** ", was made under our supervision at Communication Engineering Department/College of Engineering in Diyala university by (**Saja Fead Allah & Saja Mohammed**) as a partial fulfillment of the requirements for the degree of B.Sc. in Communication Engineering.

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Date: / / 2016

<u>CERTIFICATION OF THE EXAMINATION COMMITTEE</u>

We certify that we have read this project entitled "***Study And Design SRR And Complementary SRR For Novel Printed Microwave Elements*** " and as examining committee examined the students (**Saja Fead Allah & Saja Mohammed**) in its contents and that in our opinion it meets the standards of a project for the degree of B. Sc. in Communication Engineering.

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Approved for Communication Engineering Department.

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Date: / / 2016

Dedication

TO

MY "FAMILY" WITH LOVE

Acknowledgement

We wish to thank our family for their understanding and support including our parents , siblings , our big family and our friends inside and outside university.

We would like to express our deep gratitude for Dr. Saib. Th. alwan and Asst .Lect. Israa .H .Ali

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ABSTRACT

The electromagnetic properties of complex media called" Left-Hand Metamaterials (LHMs)" in which both permittivity and permeability attain negative real parts over a given band of frequency have become the subject of research interest in recent years. These new materials have a wide range of potential applications including lightweight concave lenses for radar, increasing density with which DVDs can be written and the density of electronic circuitry created via optical lithography, based on sub-wavelength imaging .

In this project , we propose a theoretical model to estimate the resonance frequency and the magnetic permeability of the square split ring resonators (S-SRR) having varying gap width within the rings. The model also predicts the quantitative change in permeability depending on the geometrical orientation of the S-SRR. The computed results are verified with results obtained using the Math Lab simulator.

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LIST OF ABBREVIATIONS

SRR	–	split ring resonator
TW	–	thin wires
FSS	–	Frequency Selective Service
EBG	–	Electromagnetic Band Gap
EM	–	electromagnetic
GA	–	genetic algorithm
ANN	–	Artificial Neural networks
BGA	–	Binary genetic algorithm
ECA	–	Equivalent Circuit Analysis
S-SRR	–	Square split ring resonator
WLAN	–	Wireless Local Area Network
RMPA	–	*Rectangular Microstrip Patch Antenna*
DNG	–	*Double-Negative*
NRW	–	*Nicolson-Ross-Weir*
SRRs	–	Split Ring Resonators
MWS	–	Microwave Studio
RHM	–	Right-Handed Material
LHM	–	Left-Handed Material
EAC	–	equivalent circuit analysis
PBG	–	Photonic Band Gap

LIST OF SYMBOLS

ε_{eff}	_	the Permittivity effective
μ_{eff}	_	the permeability effective
$n(w)$	_	the index of refraction
f_0	_	the resonant frequency
C_s	_	the equivalent capacitance
L	_	the effective inductance due to both of the rings
a	_	denotes the length of the side of the square
w	_	denotes the width of the conductor
d	_	denotes the dielectric width between the inner and the outer square
r	_	denotes the gab present in the rings
F	_	the fiiling factor of the inductance
C_{pul}	_	per unit length capacitance between the rings
ω_p	_	the plasma frequency
ω	_	angular frequency
Γ	_	damping factor
fr	_	Operating frequency
Ɛr	_	Dielectric constant of the substrate
σ	_	Copper conductivity

Chapter One
Introduction And Literature Survey

1.1 Introduction

This chapter consists of an introduction of metamaterial. The literature survey of metamaterial, and finally the problems statement and aims of the project are also included.

1.2Metamaterials

Metamaterials are artificially constructed materials that have electromagnetic properties not found in nature [1]. Meta-" means "altered, changed" or "higher, beyond". The concept of metamaterials with simultaneously negative permittivity and permeability, more commonly referred to as left-handed metamaterials, was first theorized by the Russian physicist Veselago in 1968 [2]. The electric and magnetic properties of materials are determined by two important material parameters, dielectric permittivity ε and magnetic permeability μ. Together the permeability and the permittivity, determine the response of the material to the electromagnetic radiation. Generally, ε and μ are both positive in ordinary materials. While ε could be negative in some materials for instance, ε possesses negative values below the plasma frequency of metals (plasma frequency is the total number of electrons per unit volume), no natural materials with negative μ are known. However, for certain structures, which are called left-handed materials (LHM), both the effective permittivity ($\mathcal{E}_{eff}$) and permeability(μ_{eff}) possess negative values. In such materials, the index of refraction (n), is less than zero, and therefore, phase and group velocity of an electromagnetic wave can propagate in opposite directions such that the direction of propagation is reversed with respect to the direction of energy flow. The negative permittivity is easily obtained by an array of metallic wires and was theorized in 1996. It was shown that, the structure has a plasma frequency in the microwave regime. Because of its low plasma frequency, this structure can produce an effective negative permittivity at microwave frequencies while suffering relatively small losses. JB Pendry also theorized the structure of negative permeability which is established in 1999 with split ring resonator (SRR) structure. The first negative index medium was developed when both of these structures were combined and it was shown that, the negative index of refraction exists in the region where both the real parts of the electric permittivity and magnetic permeability are simultaneously negative typically, in a structure composed of SRRs and strip wires [3]. The history of LHM started by Veselago when he made a theoretical speculation of this artificial material that exhibits negative permittivity and permeability. Thirty four years later, in 2001, Smith made the first prototype structures of LHM. The LHM is a combination of SRR and thin wires (TW). New structures have been proposed such as Omega shape, spiral multi-split, fishnet and S-shape, and they exhibit the properties of a LHM. Since then, many researchers have been interested in investigating this artificial material, and several of them used the LHM to improve the properties of the microwave devices such as antennas and filters . Many papers have been published regarding the LHM integrated with antennas, and their properties have been analyzed . Although other metamaterials such as Frequency Selective Service (FSS) and Electromagnetic Band Gap(EBG) have been used to enhance the gain of an antenna ,the focusing effect of a LHM can be exploited in order to improve the directivity and gain of antenna[4].

1.3 Literature Survey

Volkan Oznazli and Vakur B. Ertuk in 2007 [5]**,** presented studying both theoretically and experimentally the transmission properties of a lattice of split ring resonators (SRRs) for different electromagnetic (EM) field polarizations and propagation directions. Founded unexpectedly that, the incident electric field E couples to the magnetic resonance of the SRR when the EM waves propagate perpendicular to the SRR plane and the incident E is parallel to the gap bearing sides of the SRR. This is manifested by a dip in the transmission spectrum.

ricardo marques ,ferran martin and mario sorolla in 2007[6] , Continuous media with negative parameters, that is, media with negative dielectric constant, 1, or magnetic permeability, m, have long been known in electromagnetic theory. In fact, the Drude–Lorentz model (which is applicable to most materials) predicts regions of negative 1 or m just above each resonance, provided losses are small enough

Vidyalakshmi.M.R and Dr.S.Raghavan in 2010[7], In this paper, three optimization techniques namely genetic algorithm (GA), Artificial Neural networks (ANN) and hybrid GA-ANN is applied to the case of square split ring resonator. The obtained results are compared. In all the cases, the size of the split ring resonator is optimized in order to obtain minimum error in resonant frequency. There are many types of GA and ANN. Here, Binary genetic algorithm and feed forward backpropagation ANN is chosen. A new method of hybridization is presented here which gives effective results. Index Terms- Artificial neural network (ANN), Binary genetic algorithm (BGA), Equivalent Circuit Analysis (ECA), Hybrid GA-ANN and Square split ring resonator (S-SRR).

***Chinmoy Saha*1, *Jawad Y. Siddiqui2 and Yahia M. M. Antar2* in 2011[8] ,** In this paper, we present a design of a coplanar waveguide loaded with square split ring resonators for filter applications. A theoretical formulation to estimate the resonant frequency of the square split ring resonator is also proposed. Experimental verification of the proposed theory is reported and the computed data are also compared with simulation results revealing good agreement

H. Nornikman , Badrul Hisham Ahmad , Mohamad Zoinol Abidin Abd Aziz and A.R. Othman in 2012[9] , This paper had been comparing the performance of the normal patch antenna with single complimentary SRR patch antenna. Four different shapes of single complimentary split ring resonator structure had been incorporated into the microstrip patch antenna - square, circular, triangular, and rhombic. This simulation works had been done in CST Microwave Studio simulation software. The operating frequency of this antenna is 2.40 GHz for Wireless Local Area Network (WLAN) application. The parameters that considered in these works are return loss, resonant frequency, input impedance, gain, radiation pattern and bandwidth. The focusing parameter is to achieve the best gain performance that obtained from the single complimentary split ring resonator patch antenna. The addition of square SRR onto patch antenna will improve the gain from 6.334 dB to 6.508 dB.

McGregor and K. M. Hock in 2013[10] , In this paper, we present theoretical and simulation-based analyses of a novel, normal-conducting, multiple-cell, traveling wave accelerating structure. Instead of the conventional circular apertures, we utilize asymmetric complementary split-ring resonators to couple pillbox cavities and bring the phase velocity below that of the speed of light in vacuo. We show that this architecture exhibits a low, negative,

group velocity and that the 0 through modes decrease in order of frequency—in contrast to conventional electrically coupled structures in which the 0 mode has the lowest frequency and the mode the highest. We illustrate the efficacy of the proposed design via electromagnetic and particle simulation results for a four-cell structure operating around 1.9 GHz. Results are given for operation in the , 2=3, and =3 modes. Our design achieves accelerating gradients of around 3:3 MV=m and a cavity voltage of 0.594 MV for an applied rf power of 82 kW (mode). The accelerating gradients achieved are up to 3.3 times that of a conventional circular aperture-coupled design with the same phase velocity, rf excitation power, operating frequency, mode type, and number of cells.

Pedro J. Castro, Joaquim J. Barroso and Joaquim P. Leite Neto in 2013 [11], Metamaterial one-dimensional periodic structures are composed of split-ring resonators, which can display electric per- mittivity and magnetic permeability simultaneously negative, are studied experimentally. In the present study, each resonator is made up of two concentric circular copper rings patterned on a substrate of kapton, with slits diametrically opposite each other and with the line of the splits along the longitudinal direction of the periodic array containing seven split rings evenly spaced. The experiments consist in inserting the metamaterial slab into a square waveguide of side length 6 mm, corresponding to a cutoff frequency of 25 GHz. Transmission bands due to magnetic and electrical re- sponses are identified for slits with aperture widths of 1 mm and 2 mm, centered at 5.67 and 6.12 GHz frequencies, re- spectively, values well below the 25 GHz frequency cutoff, so characterizing a medium with negative permeability and permittivity.

Anuradha Singh and Sanjay Kumar Sharma in 2014[12], In this paper, an artificial neural network model is proposed to find out the resonant frequency of a metamaterial based Hexagonal Split Ring Resonator (SRR). The main advantage of Hexagonal SRR is small electrical size at resonance (electrically small) in the microwave regime. The method can be used for a wide range of different depending parameters (effective radius of the Hexagonal ring, split gap in the rings, width of the rings, spacing between the rings, depth of the substrate). The calculated resonant frequency is in very good agreement with the experimental results.

Ankita Tomar in 2014 [13] , In this work, Rectangular Microstrip Patch Antenna (RMPA) along with metamaterial which has Square Split Ring Resonator (S-SRR) with Horizontal Rectangular Strip (HRS) structure is proposed. Which has been superimposed on RMPA atheight of 3.2mm from its ground plane.The RMPA with proposed metamaterial structureis designed to resonate at 2.097 GHz frequency. This work is mainly focused on increasing the potential parameters of microstrip patch antenna. The simulation results showed that the impedance bandwith of RMPA with Proposed metamaterial structure is improved by 17 MHz to 36.2 MHz significantly the return loss reduced by -10.425 db to -28.15 db and increased the bandwidth and directivity of the antenna . These improvements are due to the Double-Negative (DNG) properties of metamaterial structure that acts as a lens when placed in front of the RMPA. All the simulation work is done by using CST-MWS Software. Nicolson-Ross-Weir (NRW) method is also used for verifying DNG properties of proposed metamaterial structure.

Najuka Hadkar and Santosh Jagtap in 2015[14] , Microwaves are constantly experiencing changes for many years. Microwave circuits use microstrip lines because it allows easy integration of active and passive surface mount components and it is less costly. In addition to a large number of benefits, microstrip lines have some disadvantages such as narrow-band loss, interference and low efficiency. To overcome the disadvantages, metamaterials are introduced. The proposed work shows various concentric U-shaped multi-split ring resonators(SRRs) metamaterial structures with & without broadside coupling. As compared to the conventional split ring resonators , broadside coupled resonators shows decrease in the LC resonance frequency and provide an electrically small and easy-to-fabricate alternative to the present multi-band metamaterial structures. The multi-band magnetic resonator topologies are simulated using CST Microwave Studio (MWS) to compute and compare their electrical sizes. Different types of U-shaped structures with inner and outer rings of SRR are used to realize transmission spectra, resonant frequencies and electrical sizes. This topology has the flexibility of adjusting the resonance frequencies by changing the design parameters such as the gap width, metal width and inter-ring distances. The broadside-coupled multiple U-Shaped magnetic resonator topology is considered to be a useful contribution to multi-band metamaterial research applications.

1.4 problem statement

The project gives how to achieve Square Split Ring Resonator in a band frequency (1-10)GHz .Hence the problem that be noted in this research is we cannot achieve practical.

1.5 Aim of the Thesis

Design Square Split Ring Resonator in a band frequency (1-10) GHz and a achieve negative permeability.

1.6 Thesis Organization

This thesis is organized, as follows:

Chapter 1:

Presents an introduction for metamaterials, literature survey followed by aim and outline of the thesis.

Chapter 2:

The theory of metamaterial and its types.

Chapter 3:

Implementation to the design of the Square Split Ring Resonator (S-SRR).

Chapter 4:

The Math Lab software is used to obtain the permeability and permittivity of the S-SRR, and the results discussion.

Chapter 5:

Provides the conclusion remarks and presents some ideas for the future works.

Chapter Two

Theory Of Metamaterial

2.1 Introduction

This chapter is divided into three main sections. The 1st section is a brief theory of metematerial which includes the properties of metamaterial in electromagnetic field, the behavior of negative index of reflection, and the other prominent properties of metamaterial such as refraction and the Snell's Law is also presented. The 2nd section explains the SRR structure and how it affects the left-handed properties of metamaterial is observed where the emphasis is focused on the single-ring SRR versus double-ring SRR as well as different structures of the SRRs. Next, the 3rd section presents the types of SRR.

2.2 Brief Theory of The Metamaterials

Metamaterial exhibits negative electrical permittivity and/ or negative permeability. These two properties determine how a material will interact with electromagnetic radiation including microwave, radio wave, x-rays and all other electromagnetic wavelengths. When both permittivity and permeability are negative, it is then they have a negative refractive index or left-handed material [3].
This relationship is shown by the following Maxwell's equation for refractive index:

$$n = \pm\sqrt{\mu\,\varepsilon} \tag{2.1}$$

Electromagnetic waves are governed by Maxwell's equations, which show that these waves contain both electric and magnetic fields, as shown in Figure (2.1). Electromagnetic waves consist of in-phase, oscillating electric and magnetic fields. Plane waves, as shown here, have electric and magnetic fields that are polarized at right angles to each other. The field directions in a plane wave also form right angles with respect to their direction of travel (the propagation direction). When an electromagnetic wave enters in a material, the fields of the wave interact with the electrons and other charges of the atoms and molecules that compose the material, causing them to move about. For example, this interaction alters the motion of the wave-changing its speed or wavelength [3].

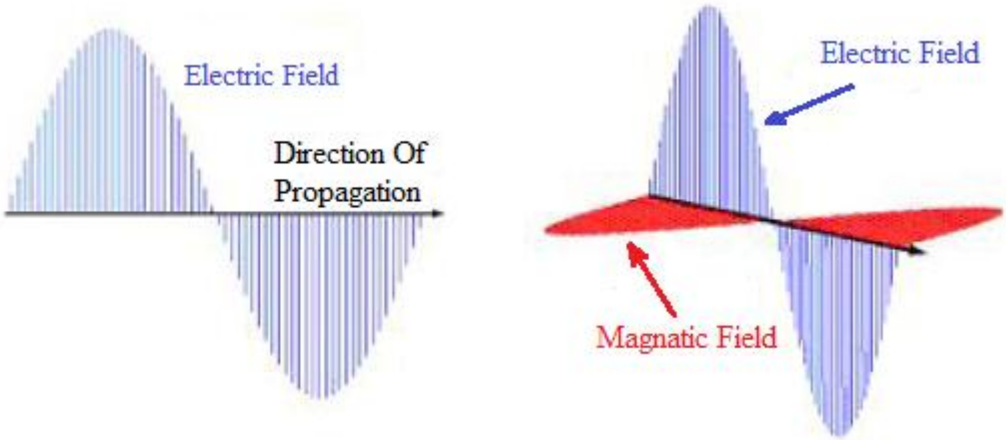


Figure 2.1: Electromagnetic waves [3]

Knowing that the permittivity and permeability are the only relevant material parameters for electromagnetic waves, a 'material parameter space' can be imagined into which all materials can be placed. This is illustrated in Figure (2.2).

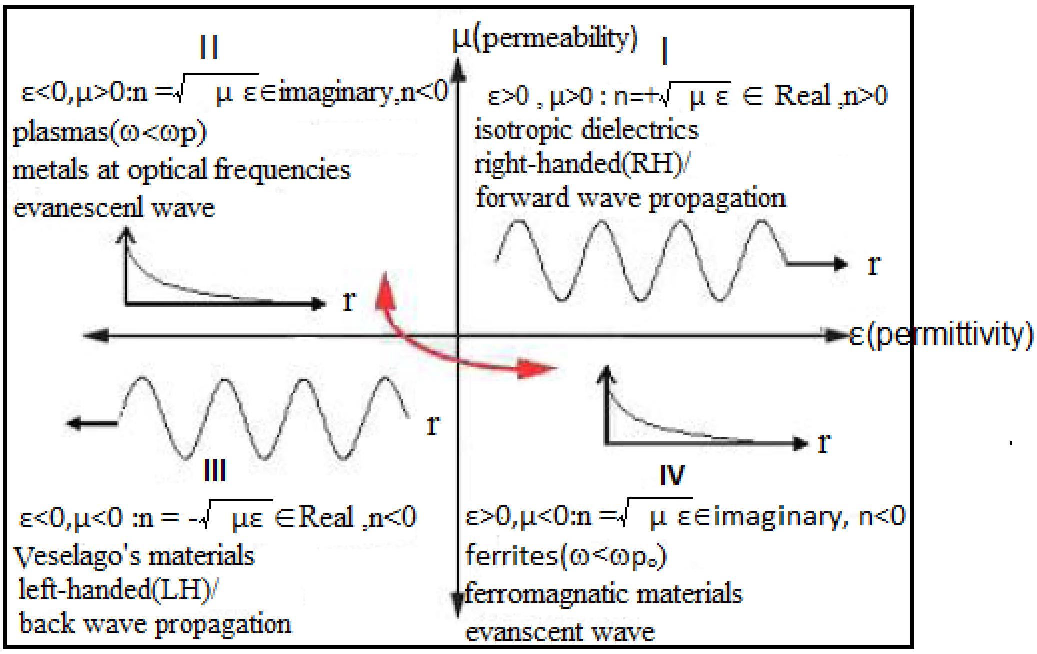


Figure 2.2: Permittivity(ε),permeability(μ)and refractive index (n) diagram [3]

Region I is where the permittivity and permeability are both positive. Since most known materials have this property, this region of material parameter space has been the most explored. However, the larger part of the map-three quarters, in fact has been much less explored. This is because materials are just not so easily available in these regions. In fact, materials that lie in the region III, where the permittivity and permeability are both less than zero, do not appear in nature at all, while nature appears to have limitations in terms of the material properties that are found. The hope, then, is that the most of the material parameter space can be made accessible with metamaterials. An important step towards this goal was made in 2000, when a metamaterial was demonstrated to have a permittivity and permeability both less than zero [3].

2.3 Negative Index Refraction

All transparent or translucent materials that are known of possess positive refractive index or a refractive index that is greater than zero, in nature. However, as proposed by Veselago and realized by Pendry, a negative refractive index is made possible. Maxwell's equations relate the permittivity and the permeability to the refractive index as follows in Equation (2.1): The sign of the index is usually taken as positive [15]. However, Veselago showed that, if a medium has both negative permittivity and negative permeability, this convention must be reversed, thus the negative sign of the square root is chosen to indicate the negative refractive index [2]. This negative value can be explained as follows; as an example, it is often said that, the velocity of a wave in a material is given by *c/n*, where c is the speed of light in vacuum. The implication of a negative index, then, is that the wave travels backwards, as shown in Figure (2.3). An electromagnetic wave can be depicted as a sinusoidally varying function that travels to the right or to the left, as a function of time. Figure (2.3) shows that a wave is incident on a positive index material (the reflected wave has been ignored). The greater index of the second medium implies that, the wavelength decreases (by a factor of *1/n*); however, to maintain the same phase at the interface as a function of time, the speed of the wave must also be reduced, again by a factor of *1/n*.

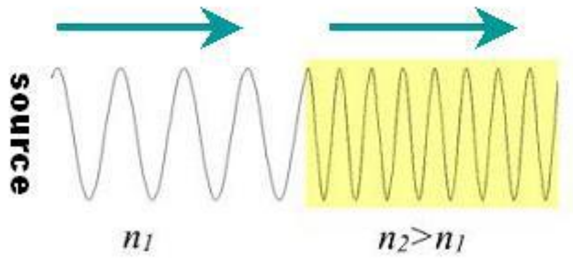


Figure 2.3: Wave incident on a positive index material [3]

When the refractive index is negative, the speed of the wave, given by *c/n* is negative and the wave travels backwards toward the source, as shown in Figure (2.4). Yet, it is reasonably expected that since energy is incident on the material from the left, the energy in the material should likewise travel to the right, which is away from the interface. To resolve this, Veselago showed that, there are more ways to define the velocity of a wave. The definition *c/n* is well known as the phase velocity and determines the rate at which the peaks (or zeros) of a wave pass a given point in time. But this is not most relevant definition of a wave's velocity as the group, energy, signal and front velocities can be defined, and these generally differ from the phase velocity. Therefore, in left-handed metamaterial, wave propagates in the opposite direction to the energy flows [3].

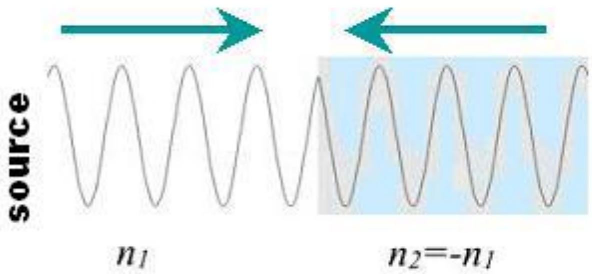


Figure 2.4: Wave incident on a negative index material [3]

The startling properties of negative refractive index metamaterials are [15]:

- Snell's Law ($n_1 \sin \varphi = n_2 \sin \theta$) still applies but rays are refracted away from the normal on entering the material.

- The Doppler Shift is reversed that is a light source moving toward an observer appears to reduce its frequency.
- Cherenkov radiation points the other way. Cherenkov radiation is the light emitted when a charged particle passes through a medium under certain conditions, in normal material the emitted light is in a forward direction; whereas, in LHM, light is emitted in the reverse direction.
- The group velocity is anti-parallel to phase velocity.

2.4 Left-Handed Metamaterials

Almost all natural materials follow the so called "Right-hand Rule" because their permeability and permittivity both have positive signs, then the electric field ($\vec{E}$), magnetic field ($\vec{H}$) and wave vector ($\vec{k}$) in such materials form a right handed set of vectors, as shown in Figure (2.5). Wherein the electric field $\vec{E}$ is along the positive *x* direction, the magnetic field $\vec{H}$ is along the positive *y* direction and the wave propagates along the positive *z* direction, thus $\vec{E}$, $\vec{H}$ and $\vec{k}$ build a right-handed triplet. All materials encountered so far in a natural form are right handed.

In Left-handed Metamaterial (LHM), the wave vector $\vec{k}$ is reversed in comparison with what should have been for a RHM. The electric field $\vec{E}$ and the magnetic field $\vec{H}$ make a left-handed triplet with the wave vector $\overrightarrow{k}$.That means if the electric field $\vec{E}$ is along the positive *x* direction and the magnetic field $\vec{H}$ is along the positive *y* direction, the wave will propagate along the negative *z* direction in LHM, as shown in Figure (2.6) [15].

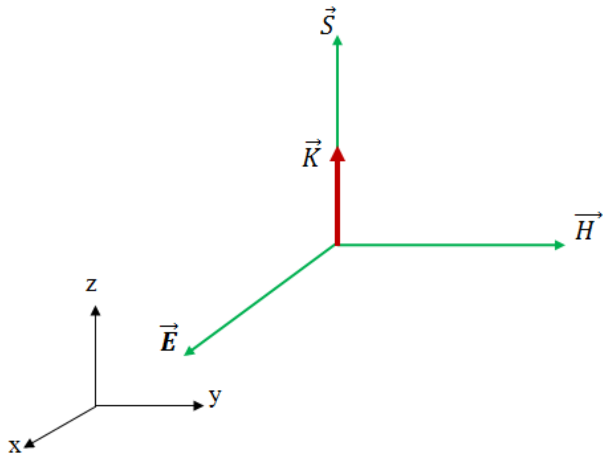


Figure 2.5: In Right-Handed Material (RHM), the electric field $\vec{E}$, magnetic field $\vec{H}$ and wave vector $\vec{k}$ build a right-handed triplet and the Poynting vector $\vec{S}$ has the same direction as the wave vector $\vec{k}$ [15]

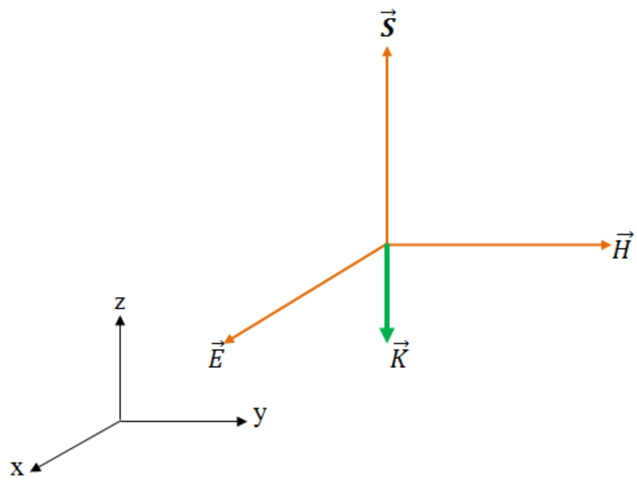


Figure 2.6: In Left-Handed Material(LHM), the electric field $\vec{E}$, magnetic field $\vec{H}$ and wave vector $\vec{k}$ build a left-handed triplet and the Poynting vector $\vec{S}$ is in the opposite direction of the wave

vector $\vec{k}$ [15]

Now, examine the direction of the energy flow in LHM, which is characterized by the Poynting Vector, as follows:

$$\vec{S} = \frac{c}{4\pi} \vec{E} \times \vec{H} \qquad \textbf{(2.2)}$$

the Poynting vector power density can be written as:

$$\vec{E} \times \vec{H} = \frac{1}{\omega^2 \varepsilon \mu} (\vec{k} \times \vec{E}) \times (\vec{k} \times \vec{H})$$

$$= \begin{cases} \frac{-1}{\omega\mu} (\vec{k} \times \vec{E}) \times \vec{E} = \frac{\vec{k}}{\omega\mu} |\vec{E}|^2 \\ \\ \frac{-1}{\omega\varepsilon} \vec{H} \times (\vec{k} \times \vec{H}) = \frac{\vec{k}}{\omega\varepsilon} |\vec{H}|^2 \end{cases} \quad \textbf{(2.3)}$$

2.4.1 Unique Properties of Left-Handed Metamaterials

- Negative Refractive Index: For conventional material with $\mathcal{E}_r>0$ and $\mu_r > 0$, the refractive index is given by $n = \sqrt{\varepsilon_r \mu_r}$, so that the conventional material possesses a positive refractive index.

  Yet, Left-handed Meta-material has both negative permittivity ($\mathcal{E}_r$ (ω) < 0) and negative permeability (μ_r (ω) < 0), the refractive index n has negative value [3].
- Inverse Snell's law: An incident light that enters left-handed meta-materials from a right-handed medium will undergo refraction, but opposite to that usually observed for two right-handed media [16].

The Snell's law is described as:

$$\frac{\sin \varphi}{\sin \theta} = \frac{n_2}{n_1} \quad \textbf{(2.4)}$$

where φ is the incident angle and θ is the refraction angle. Supposing medium I and medium II are conventional materials with n1 > 0 and n2 > 0 respectively, the refracted light will be bent with positive θ with the normal line OO', as indicated by the 4th light ray in Figure (2.7). If medium II is a left-handed metamaterial with $n_2 < 0$, the refracted light will be bent in odd way with a negative angle with OO', as indicated by the 3rd light ray in Figure (2.7).

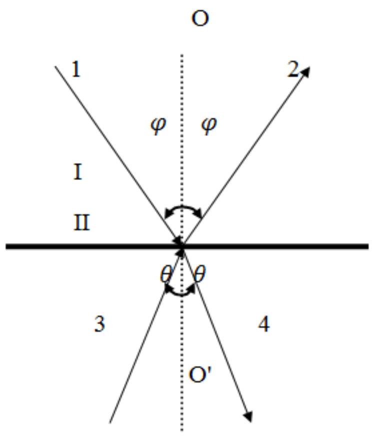


Figure 2.7: Passage of a light ray through the boundary between medium I with positive refractive index $n_1 > 0$ and medium II with refractive index n_2. 1 - incident light ray; 2 - reflected light ray; 3 - refracted light ray if $n_2 < 0$; 4 - refracted light ray if $n_2 > 0$[16].

- Negative Phase Velocity: the phase velocity expression $v_p = c/n(\omega)$ shows that the phase velocity v_p is related to the index of refraction $n(\omega)$, here c denotes the speed of light in a vacuum. For LHM has negative refractive index ($n(\omega) < 0$), the phase velocity has negative value. In LHM, the phase velocity is in the opposite direction of the energy flow in the sense that the energy flow leaves the source in waves with a phase velocity pointing backward, as shown in Figure (2.8) [17] .

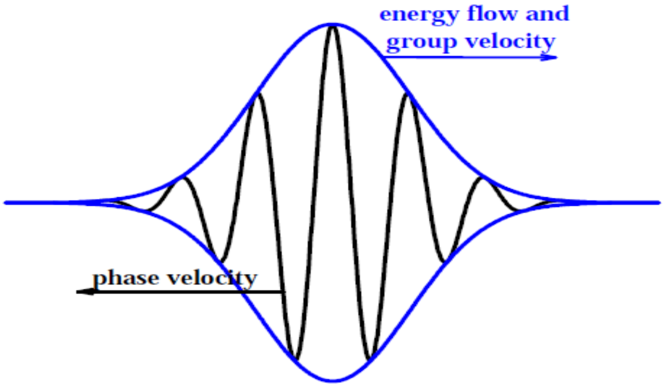
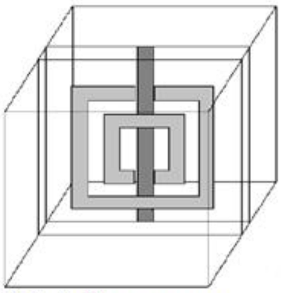


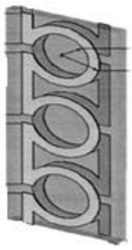
Figure 2.8: The energy flow and group velocity propagate forward in LHMs but the phase velocity is backward[17]

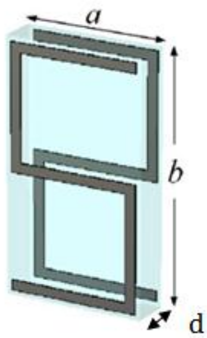
Veselago also predicted that the Doppler and Cerenkov effects will be reversed in LHM [2]: an approaching source will appear to radiate at a lower frequency and charged particles moving faster than the speed of light in the medium will radiate in a backward cone, not a forward cone.

2.5 Different Metamaterial Structures

There are different metamaterial structures as antenna substrate, which includes 1-D Split Ring structure, Symmetrical –Ring structure, Omega structure and S structure. These structures are all left-handed materials where there will be a region where *n* is negative and the index of refraction is zero would occur at the frequencies where either permittivity or permeability is zero. These structures are illustrated in Figure (2.9) [3].


(a) Split Ring structure


(b) Omega structure



(c) S structure

Figure 2.9: Different metamaterial structure [3]

2.5.1 Split Ring Resonator(SRR)

A single cell SRR has a pair of enclosed loops with splits in them at opposite ends. The loops are made of nonmagnetic metal like copper and have a small gap between them. The loops can be concentric, or square, and gapped, as needed [18].

The SRR in its simplest form consists of a highly conductive metallic ring which is broken in one (or several) location(s) by a non-conductive gap of air or other dielectric materials. If this ring is placed in a temporally varying magnetic field an electric circular current is induced in the metallic ring which in turn leads to charge accumulating across the gaps. The electric field which builds due to the charge at the gap counteracts the circular current leading to energy stored (predominantly) in vicinity of the gaps and magnetic field energy concentrated in the region enclosed by the ring. The SRR is thus a resonator which couples a perpendicular magnetic field and can be characterized by the effective capacitance of the gaps and effective inductance of the loop defined by the ring. It can be understood in terms of a resonant LC circuit with a resonance frequency $\omega_m^2 = 1/LC$, where L is the inductance and C is the capacitance of the SRR. The resonant response of the circular current in the SRR to an external magnetic field leads to a resonant magnetic moment which may reach large negative values for array of SRRs such that the size of the SRR is much smaller than the wavelength of an incident electromagnetic wave around the resonance frequency behaves as a homogeneous effective medium with at negative (resonant) permittivity $\mu_{eff}(\omega)$ [19].

The structure of the square split double ring resonator is as shown in Figure (2.10).

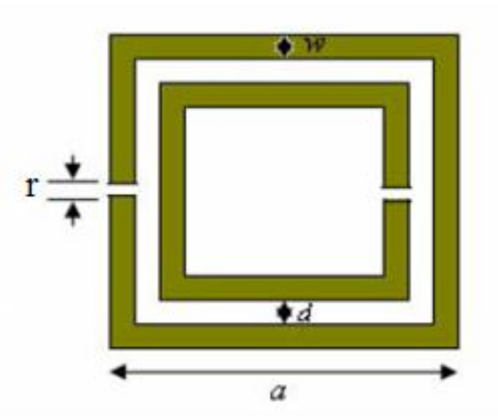


Figure (2.10) structure of the square split ring resonator

It consists of two square shaped rings with gaps in between them on the opposite side of both the rings. One method of obtaining the resonant frequency is by using the equivalent circuit analysis (EAC) method [20]. The given distributed network is converted into lumped network and analyzed.

When a magnetic field is applied perpendicular to the plane of the ring. The ring begins to conduct and gives rise to current flowing through the rings will enable it to act as an inductor and the dielectric gab(d) between the rings will lead to mutual capacitance. Hence the equivalent circuit of the S-SRR will be a parallel LC tank circuit as shown in Figure (2.11).

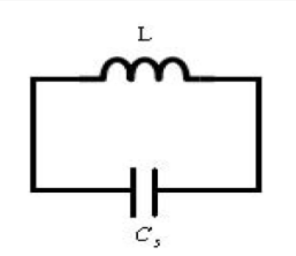


Figure (2.11) lumped equivalent circuit of S-SRR

From this, we can calculate the resonant frequency:

$$f_0 = \frac{1}{2\pi\sqrt{LC_s}} \quad \textbf{(2.5)}$$

Where

C_s is the equivalent capacitance and

L is the effective inductance due to both of the rings.

The expressions for effective inductance and capacitance can be obtained as :

$$L = \frac{4.86\mu_0}{2}(a - w - d)\left[\ln\left(\frac{0.98}{\mathrm{F}}\right) + 1.84\,\mathrm{F}\right] \quad \textbf{(2.6)}$$

Where,

'a' denotes the length of the side of the square,

'w' denotes the width of the conductor,

'd' denotes the dielectric width between the inner and the outer square and 'r' denotes the gab present in the rings.

F is the fiiling factor of the inductance and is given by:

$$F = \frac{\pi\, r^2}{d^2} \tag{2.7}$$

the effective capacitance is given by:

$$C_S = \left(a - \frac{3}{2}(w+d)\right) C_{pul} \tag{2.8}$$

where,

C_{pul} is per unit length capacitance between the rings.

According to Equations (2.6) and (2.8), the angular resonant frequency (ω_0) is given by:

$$\omega_0 = \sqrt{\frac{3\, d\, c_0{}^2}{\pi^2\, r^3}} \tag{2.9}$$

To calculate the effective permittivity of free space (ϵ_{reff}) :

$$\epsilon_{\text{reff}} = 1 - \frac{\omega_p{}^2}{\omega^2 + j\Gamma\omega} \tag{2.10}$$

Where

(ω_p) is the plasma frequency ,

(ω) angular frequency and

(Γ) damping factor

To calculate the plasma frequency (ω_p) and damping factor (Γ) are given by:

$$\omega_p = \frac{\sqrt{2\pi}}{d^2\ c_0{}^4\ \mu_0{}^2\ a^2\ \ln(\frac{a}{r})} \qquad \textbf{(2.11)}$$

$$\Gamma = \frac{2}{r\ \sigma\ \mu_0} \qquad \textbf{(2.12)}$$

To calculate the effective permeability (μ_{eff}) is given:

$$\mu_{eff} = 1 - \frac{F\ \omega^2}{\omega^2 - \omega_0{}^2 + j\Gamma\omega}$$

(2.13)

The refraction index n(w) is given by :

$$n(\omega) = \sqrt{\varepsilon(\omega) + \mu(\omega)} \qquad \textbf{(2.14)}$$

2.5.2 The Omega Structure

The Omega structure, as the nomenclature describes, has an Ω-shaped ring structure. The omega structure resembles the Greek letter omega, and consists of a C-shaped ring resonator with two wires connected to both ends, as shown in Figure (2.9 b). These metamaterials have bi an isotropic characteristics and also named as pseudochiral media . Electric and magnetic polarizations are induced by both electric and magnetic fields in bi an isotropic media. There are two of these, standing vertical, side by side, instead of lay flat, in the unit cell. In 2005 these were considered to be a new type of metamaterial [21].

2.5.3 S Shape Split Ring Resonator(S-SRR)

The first split-ring resonators (SRR) exhibits a negative permeability at a given frequency range. A common characteristic of all the SRR used in the realization of metamaterials so far is that they need to be combined with a periodic arrangement of rods in order to exhibit left-handed properties. As a matter of fact, although it is known that the SRR itself does respond to the electric field, the frequencies associated with this response usually does not overlap with the frequency response due to the magnetic field. In [22], Chen et al., proposed an S-shaped SRR structure (S-SRR) which, without the need of additional rods as shown in Figure (2.9 c), produces an electric and magnetic response within the same frequency range [23].

Chapter Three

Methodology

3.1 Introduction

This chapter presents the methodology will explain the steps of work operation, the requirement to design Square Split Ring Resonator.

3. 2 Design Procedure

In order to clarify the processes of designing the (Square Split Ring Resonator), the flow chart, as in Figure (3.1), explains the process.

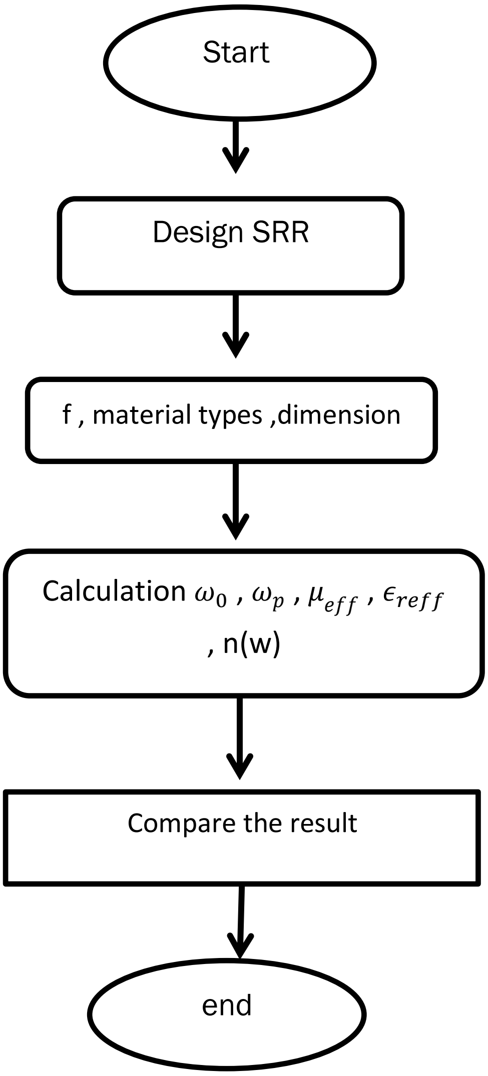


Figure 3-1: Flowchart for the Design S-SRR

3.3 Design Specifications

There are four essential parameters for the designs of square SRR

- Operating frequency (fr): The resonant frequency

must be selected appropriately. The resonant frequency selected

for this design is (8.2 - 12.4) GHz in X- band.

- Dielectric constant of the substrate (Ɛr): The dielectric material

selected for this design is (Ɛr = 2.2) for Epoxy material.

- permeability effective of free space (μ_{eff}) :
- permittivity effective of free space (ϵ_{reff}) :

Table(3.1): Laminates specifications of S-SRR

Parameters	Dimensions (mm)
Spacing between ring edges (d)	0.8
side (a)	7.5
inner ring radius (r)	0.7
Copper conductivity (σ)	5.96 * 10^7
frequency (GHz)	8.2-12.4

According to the dimensions of the S-SRR in the Figure (3.1), these parameters can be obtained.

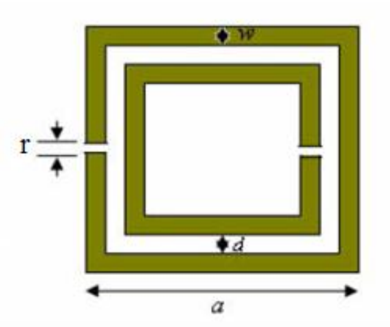


Figure (3.2) structure of S-SRR

- According to Equation (2. 10), the effective permittivity of free space (ϵ_{reff}) is calculated after substituting plasma frequency(ω_p) , angular frequency(ω) , damping factor(Γ)

  $$\epsilon_{\mathrm{reff}} = 1 - \frac{\omega_p{}^2}{\omega^2 + j\Gamma\omega}$$

To calculate plasma frequency (ω_p), angular frequency(ω) and damping factor(Γ) Equations (2.11), (2.9) and (2.12) are given that.

$$\omega_p = \frac{\sqrt{2\pi}}{d^2\ c_0{}^4\ \mu_0{}^2\ a^2\ \ln(\frac{a}{r})}$$

$$\omega_0 = \sqrt{\frac{3\ d\ c_0{}^2}{\pi^2\ r^3}}$$

$$\Gamma = \frac{2}{r\ \sigma\ \mu_0}$$

Substituting

d= 0.8mm , c =3x10^8m/s , μ_0=4π*10^{-7} , a= 7.5mm , r =0.7mm

Substituting π =3.14 , Operating frequency (f) = (8.2 - 12.4)
σ =5.96 * 10^7

- According to Equation (2.13) effective permeability (μ_{eff})is calculated after substituting filling factor of SRR(F) , (ω) angular frequency , (ω_0) angular resonant frequency , (Γ) damping factor.

  $$\mu_{eff} = 1 - \frac{F\ \omega^2}{\omega^2 - \omega_0{}^2 + j\Gamma\omega}$$

To calculation filling factor of SRR (F), the Equation (2.7) is given that.

$$F = \frac{\pi\ r^2}{d^2}$$

- Calculation n(w) given by Equation (2.14).

  $$n(\omega) = \sqrt{\varepsilon(\omega) + \mu(\omega)}$$

Chapter Four

Results and Discussion

4.1 Introduction

This chapter consists of the simulation of the designed Square Split Ring Resonator S-SRR using Math Lab software and discussion of these results .

4.2 S-SRR metamaterial

The aim of this project is to obtain negative permeability to achieve S-SRR. Therefore, vary dimension of S-SRR to vary band frequency to achieve negative permeability are selected.

Table (4.1) dimensions of the S-SRR obtained as a result

Resonant frequency (GHz)	a (mm)	r (mm)	d (mm)
1.0	6.2913	0.6323	0.6894
1.5	4.7410	0.3041	0.7167
2.0	4.4614	0.4114	0.9604
3.0	3.4066	0.4211	0.8575
4.0	3.2414	0.6182	0.9525
5.0	3.1144	0.7589	0.9375
6.0	3.1652	0.9085	0.9648

Table (4.1) shown vary frequency band from (1-7) GHz, and the dimensions of S-SRR also varied ,' a' decrease with increased frequency, while 'r' and 'd' increase with increased frequency .

According to calculation of dimensions in the section (3.3) and according to Equations in the section (2.5.1), the results with varying dimensions are:

4.2.1 When the dimensions (f = 1.0 , a = 6.2913 , r = 0.6323 , d =0.6894)

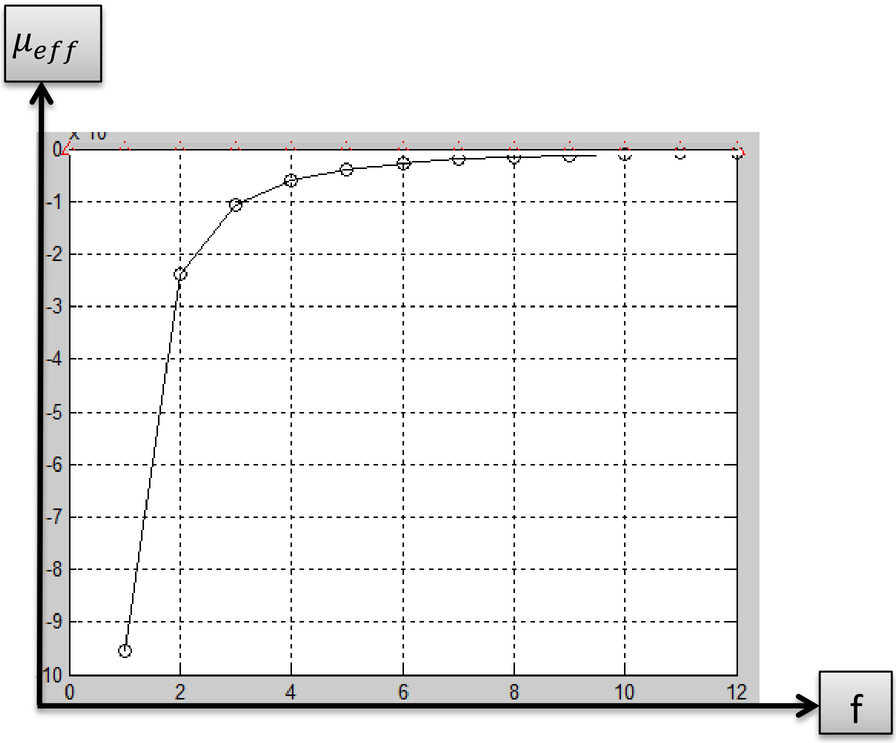


Fig (4.1) effective permeability for S-SRR in section 4.2.1

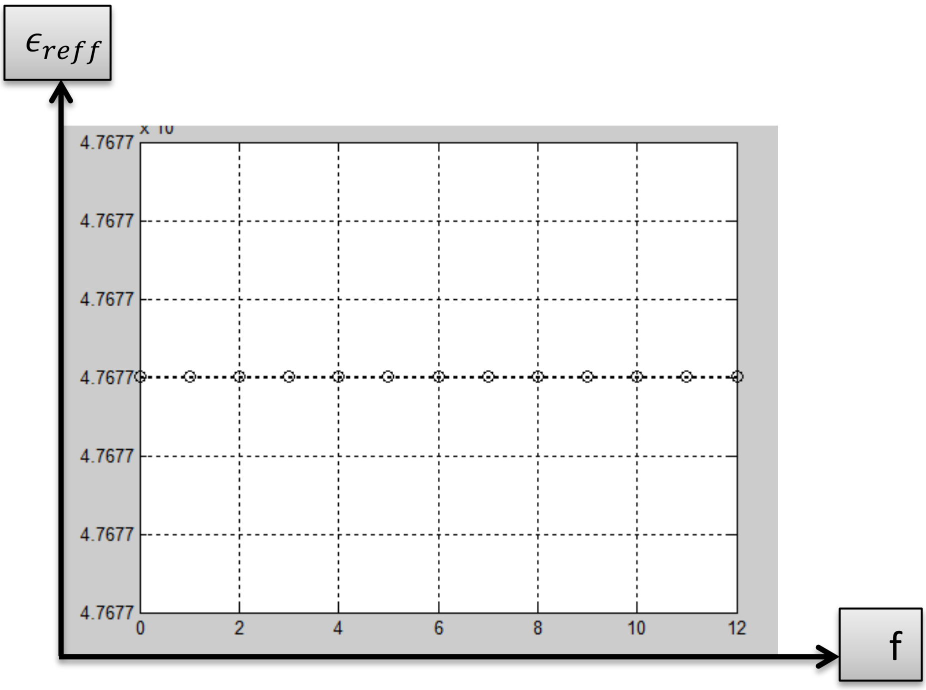


Fig (4.2) effective permittivity for S-SRR in section 4

.2.1

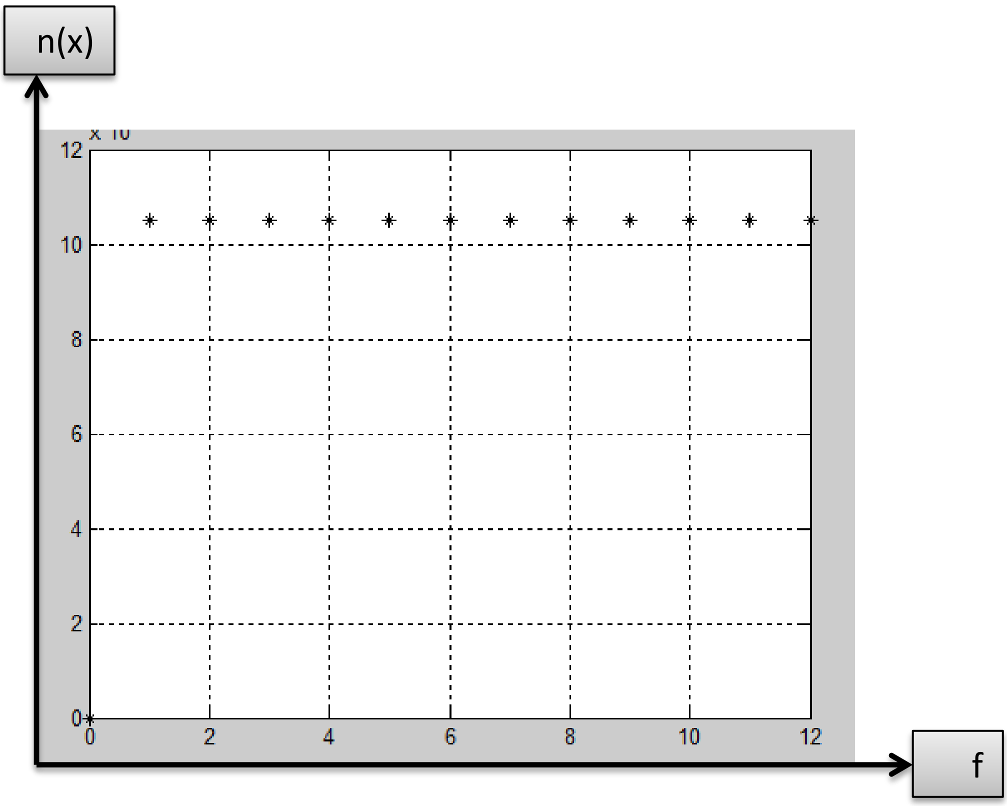


Fig (4.3) refraction index for S-SRR in section 4.2.1

4.2.2 When the dimensions (f = 1.5 , a = 4.7410 , r = 0.3041 , d =0.7167)

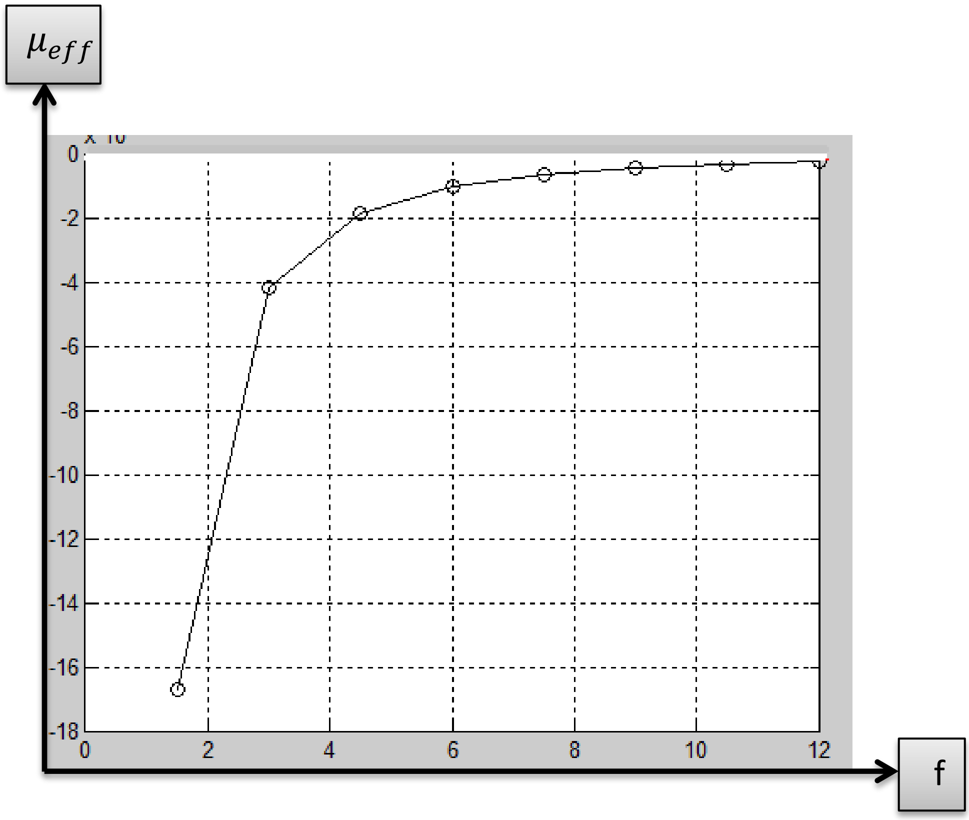


Fig (4.4) effective permeability for S-SRR in section 4.2.2

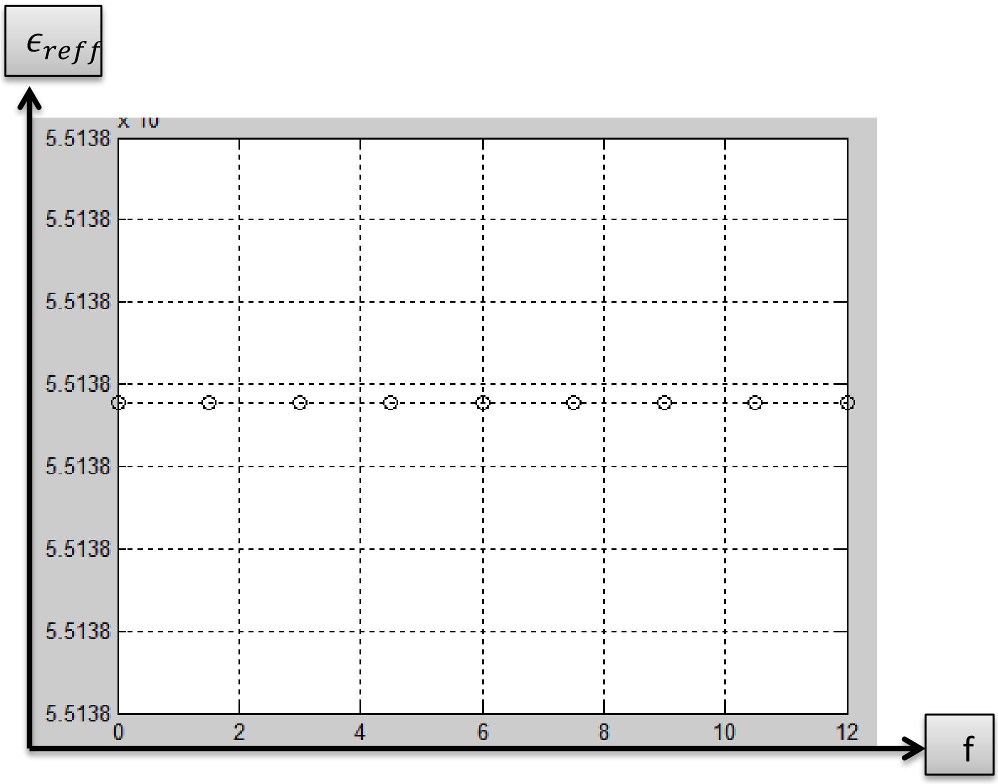


Fig (4.5) effective permittivity for S-SRR in section 4.2.2

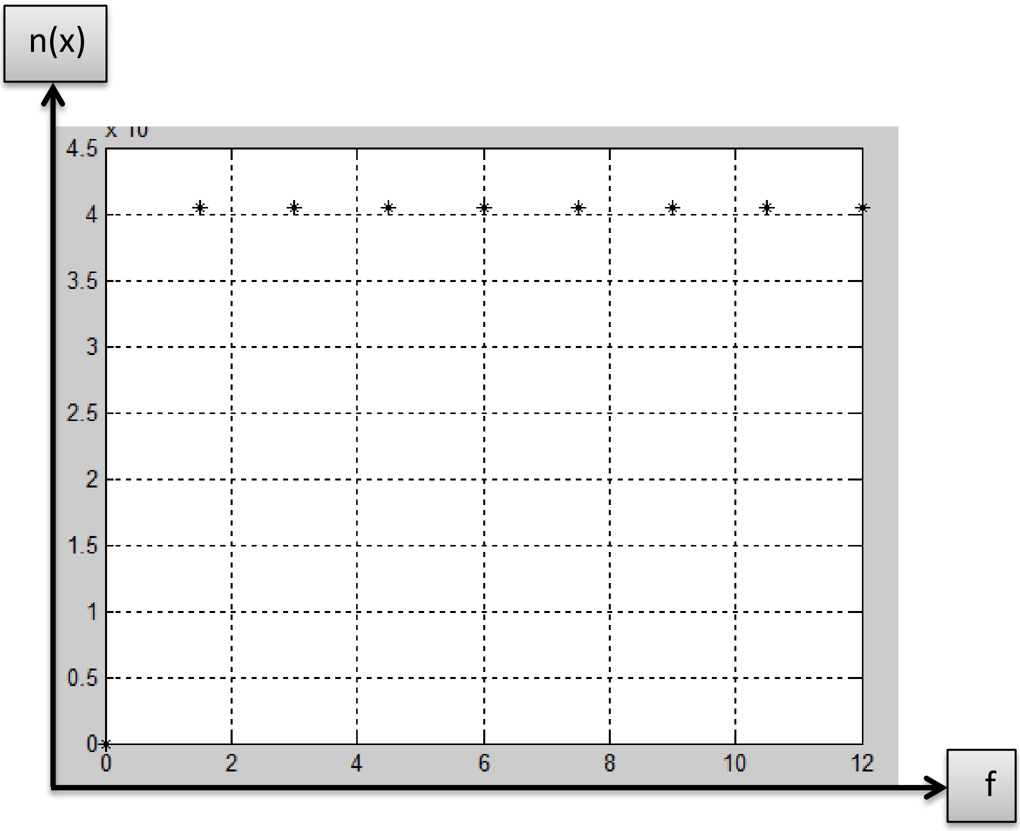


Fig (4.6) refraction index for S-SRR in section 4.2.2

4.2.3 When the dimensions (f = 2.0 , a = 4.4614 , r = 0.4114 , d =0.9604)

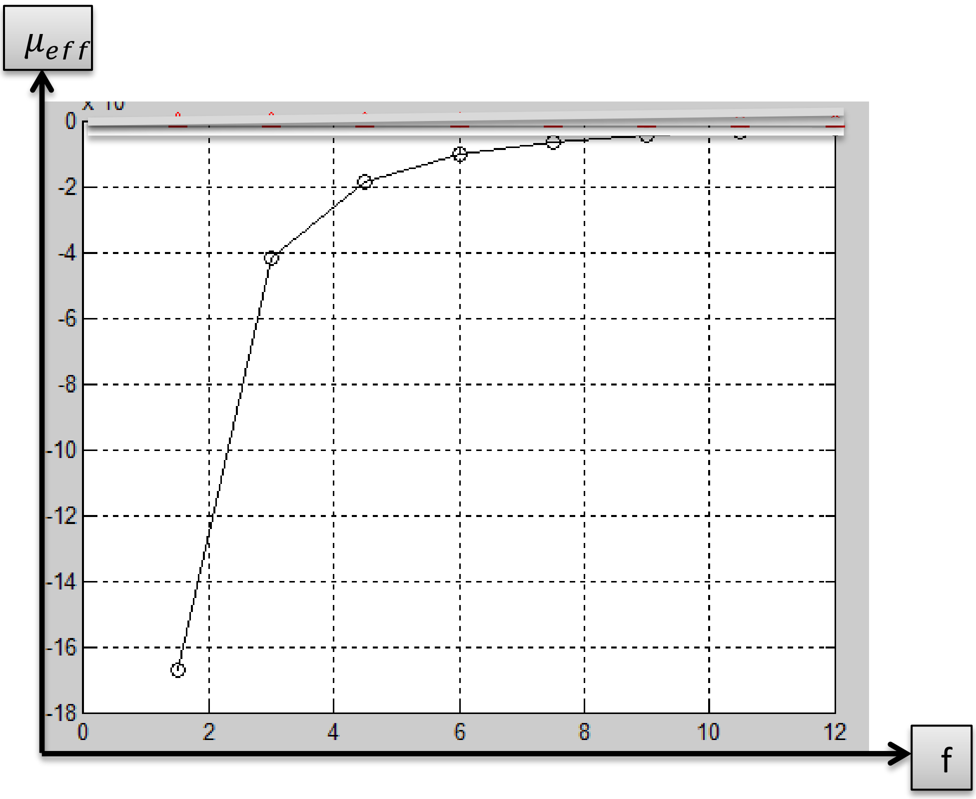


Fig (4.7) effective permeability for S-SRR in section 4.2.3

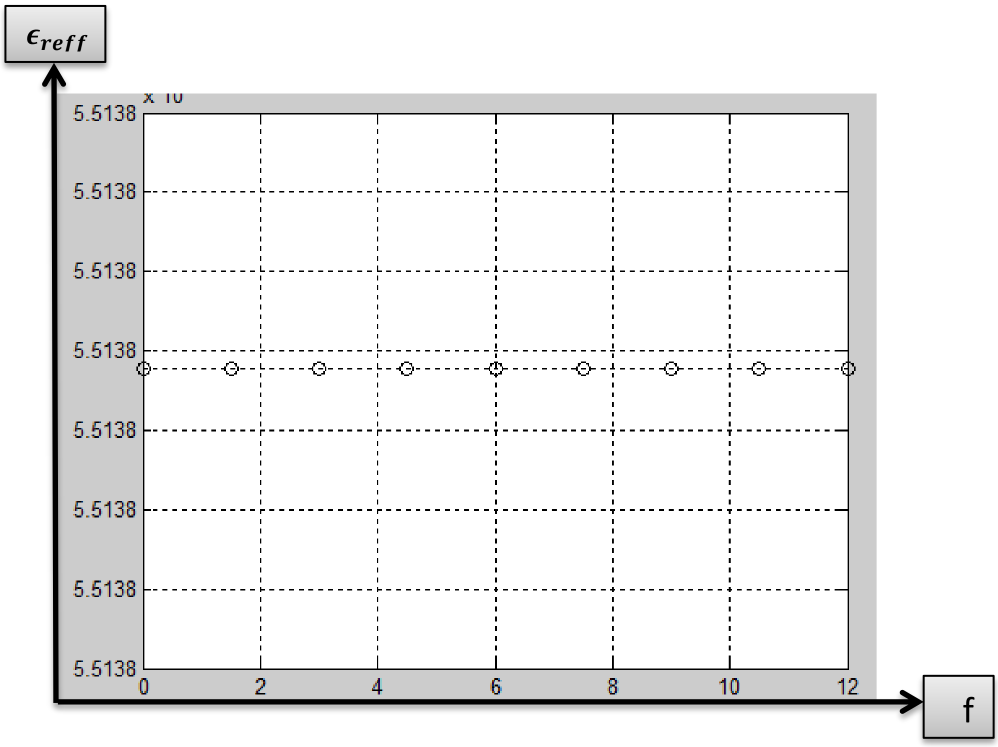


Fig (4.8) effective permittivity for S-SRR in section 4.2.3

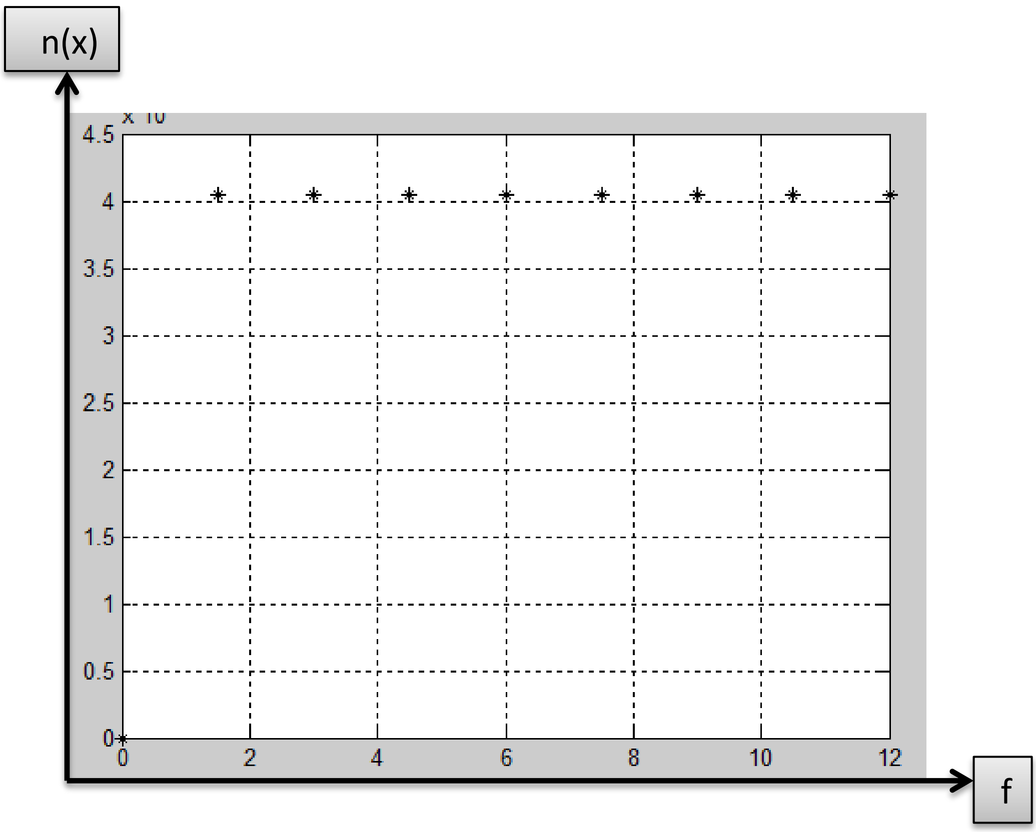


Fig (4.9) refraction index for S-SRR in section 4.2.3

4.2.4 When the dimensions (f = 3.0 , a = 3.4066 , r = 0.4211 , d =0.8575)

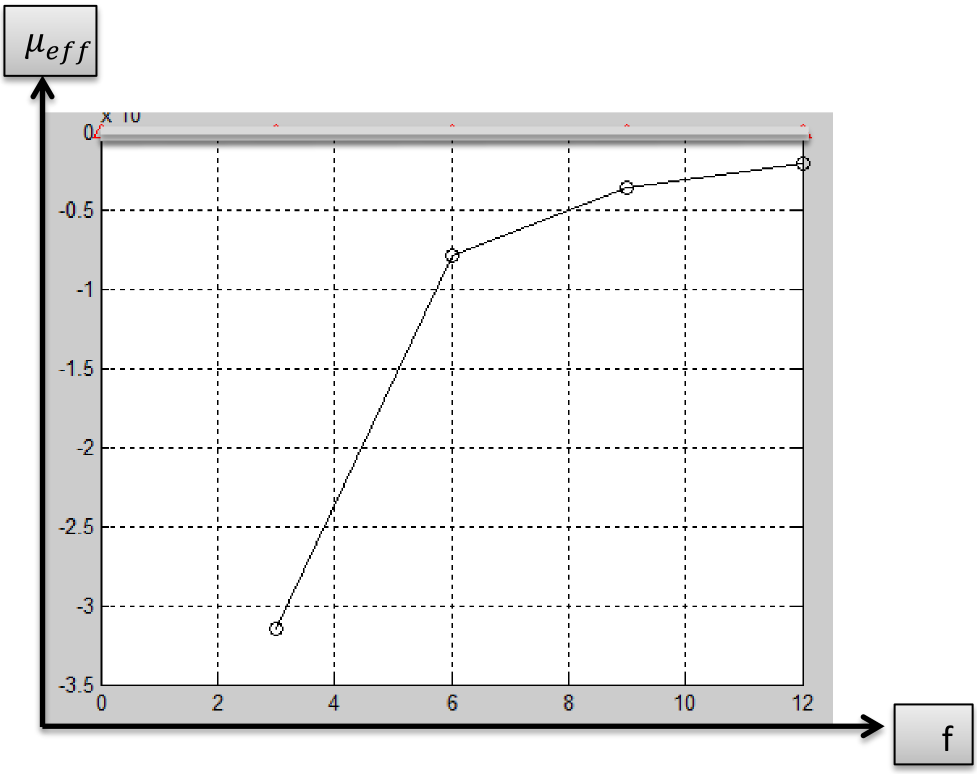


Fig (4.10) effective permeability for S-SRR in section 4.2.4

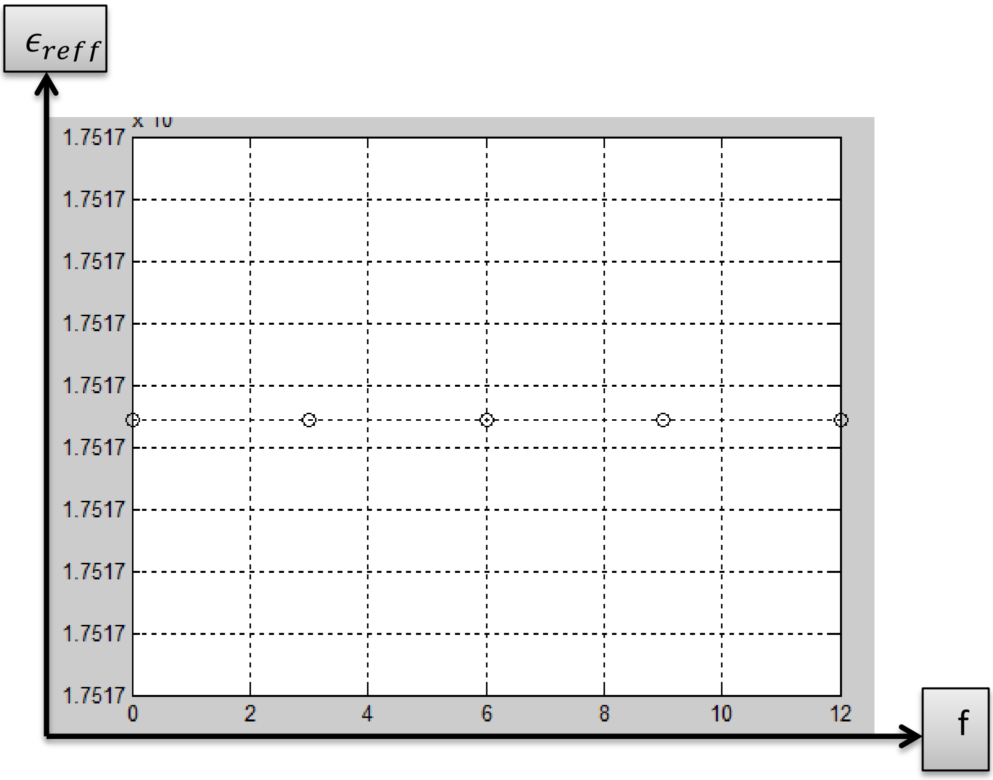


Fig (4.11) effective permittivity for S-SRR in section 4.2.4

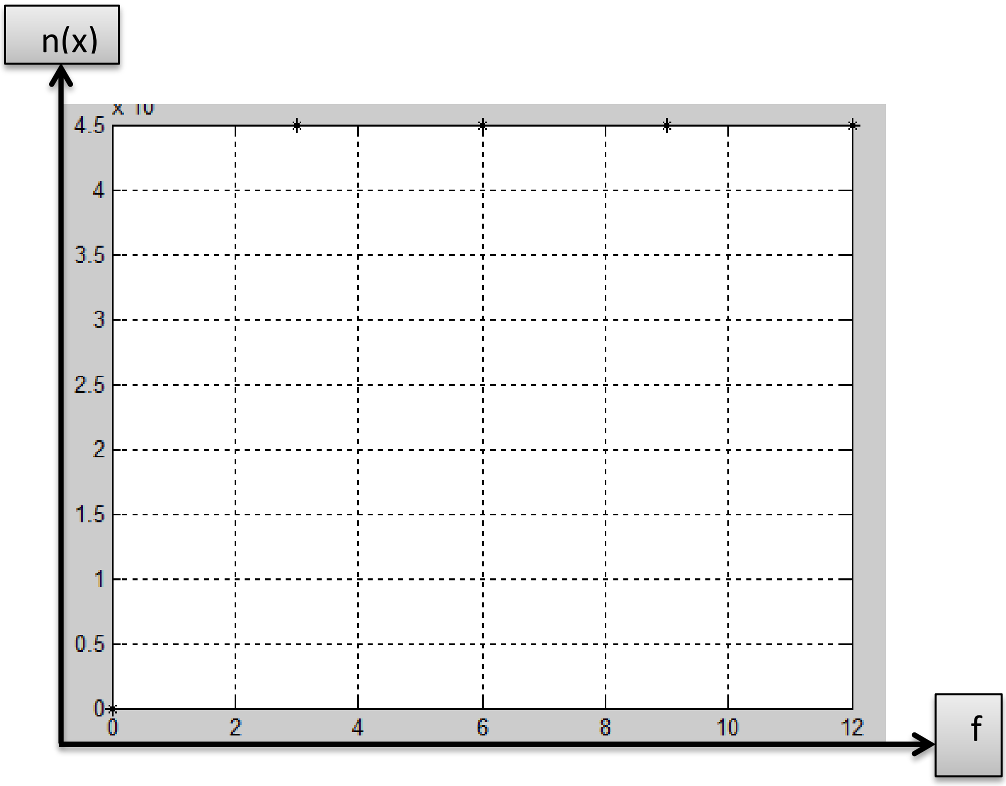


Fig (4.12) refraction index for S-SRR in section 4.2.4

4.2.5 When the dimensions (f = 4.0 , a = 3.2414 , r = 0.6182 , d =0.9525)

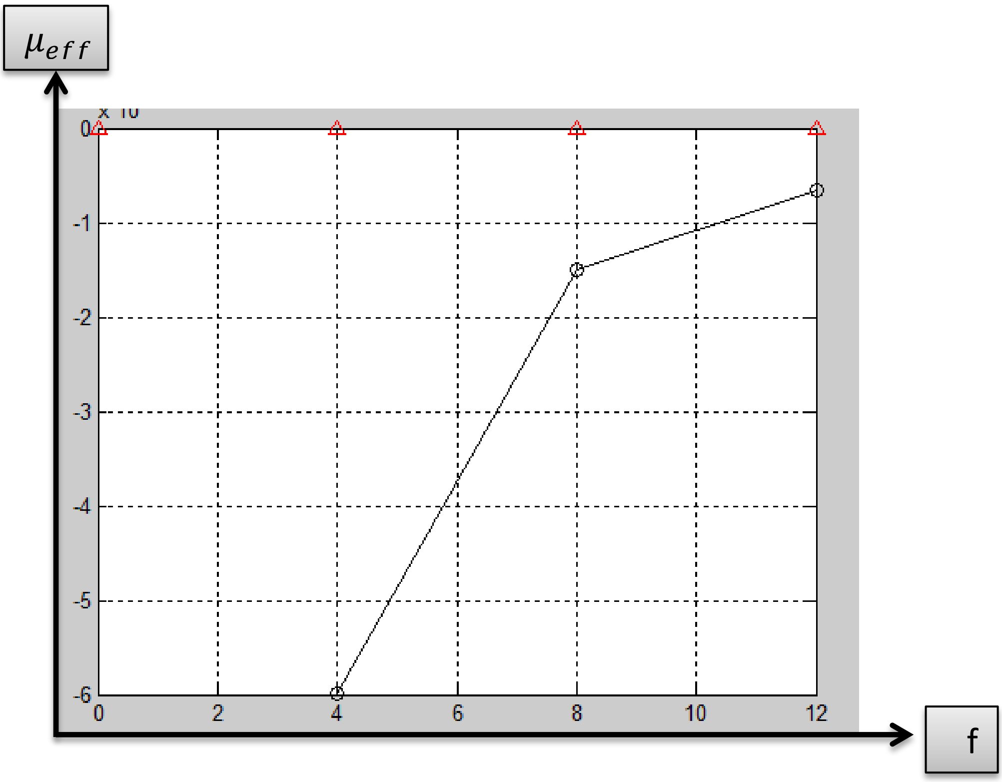


Fig (4.13) effective permeability for S-SRR in section 4.2.5

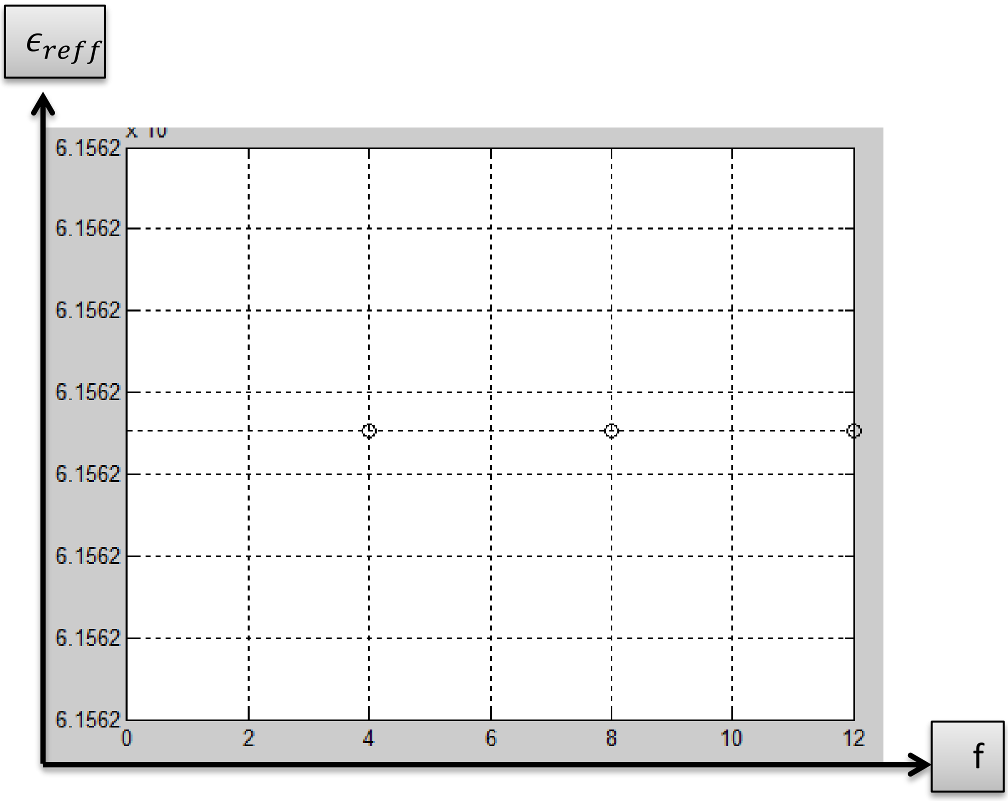


Fig (4.14) effective permittivity for S-SRR in section 4.2.5

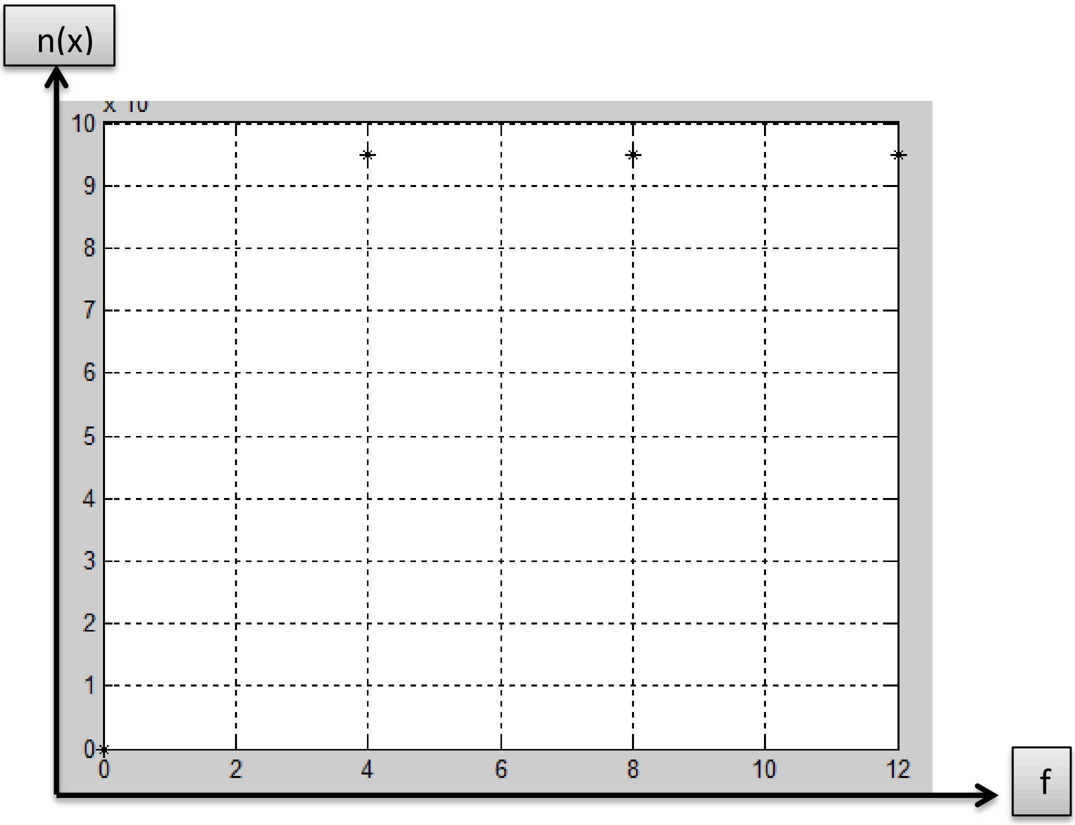


Fig (4.15) refraction index for S-SRR in section 4.2.5

4.2.6 When the dimensions (f = 5.0 , a = 3.1144 , r = 0.7589 , d =0.975)

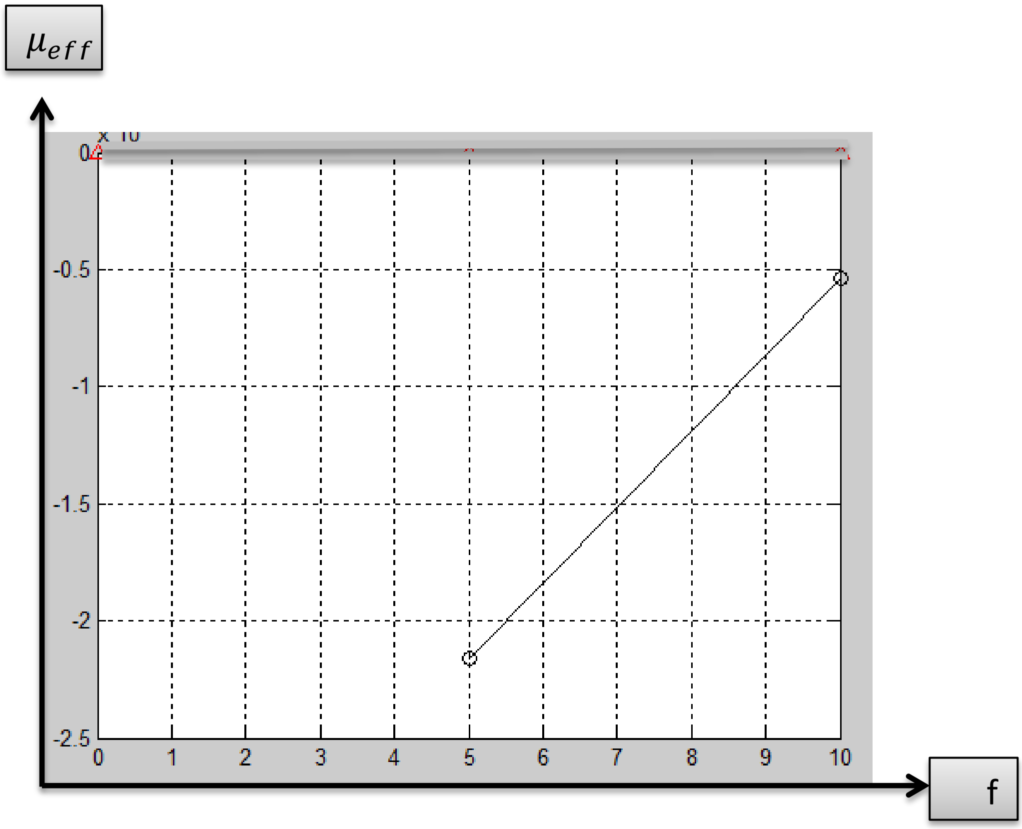


Fig (4.16) effective permeability for S-SRR in section 4.2.6

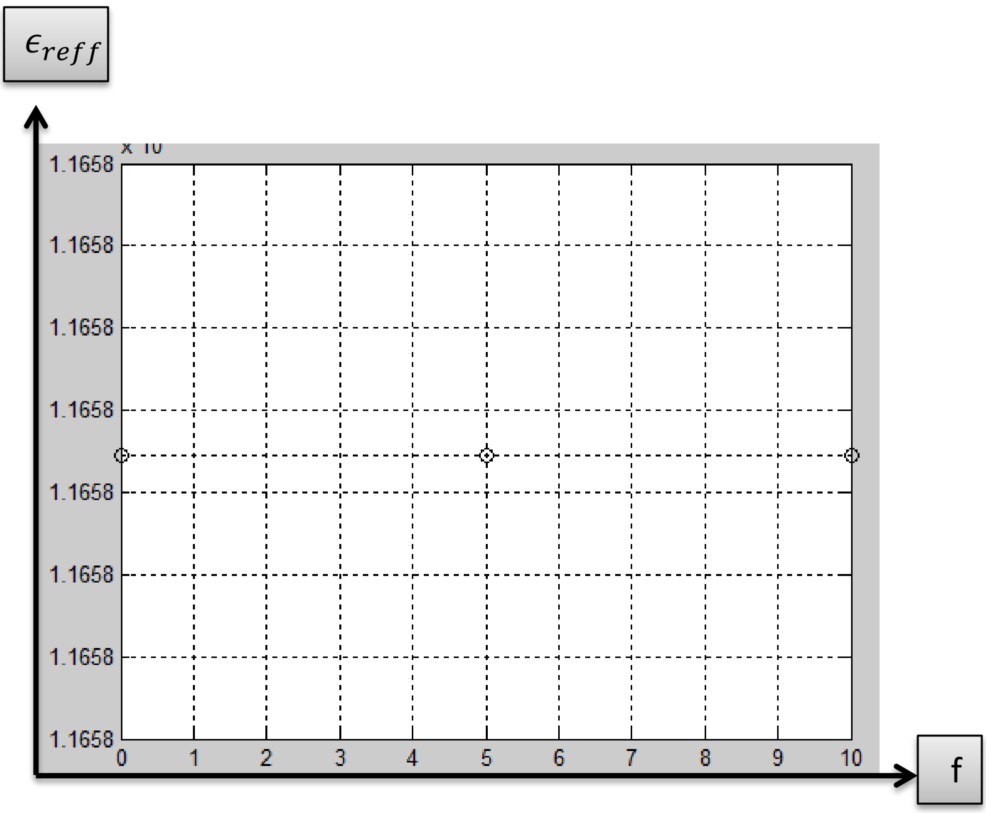


Fig (4.17) effective permittivity for S-SRR in section 4.2.6

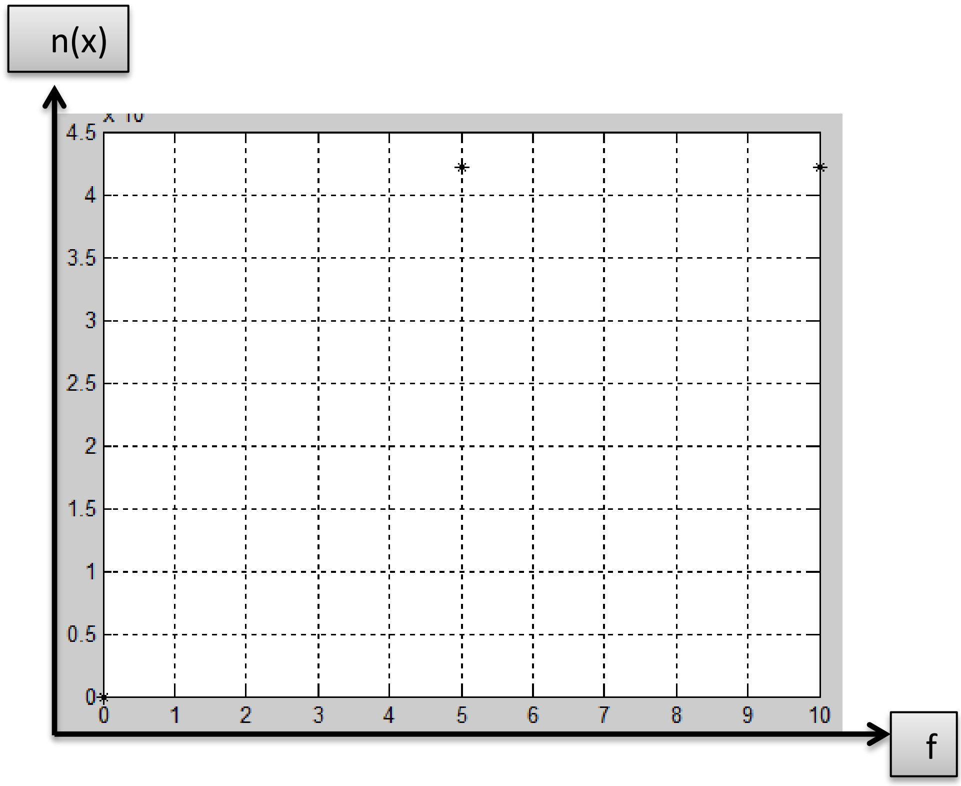


Fig (4.18) refraction index for S-SRR in section 4.2.6

4.2.7 When the dimensions (f = 6.0 , a = 3.1652 , r = 0.9085 , d =0.9648)

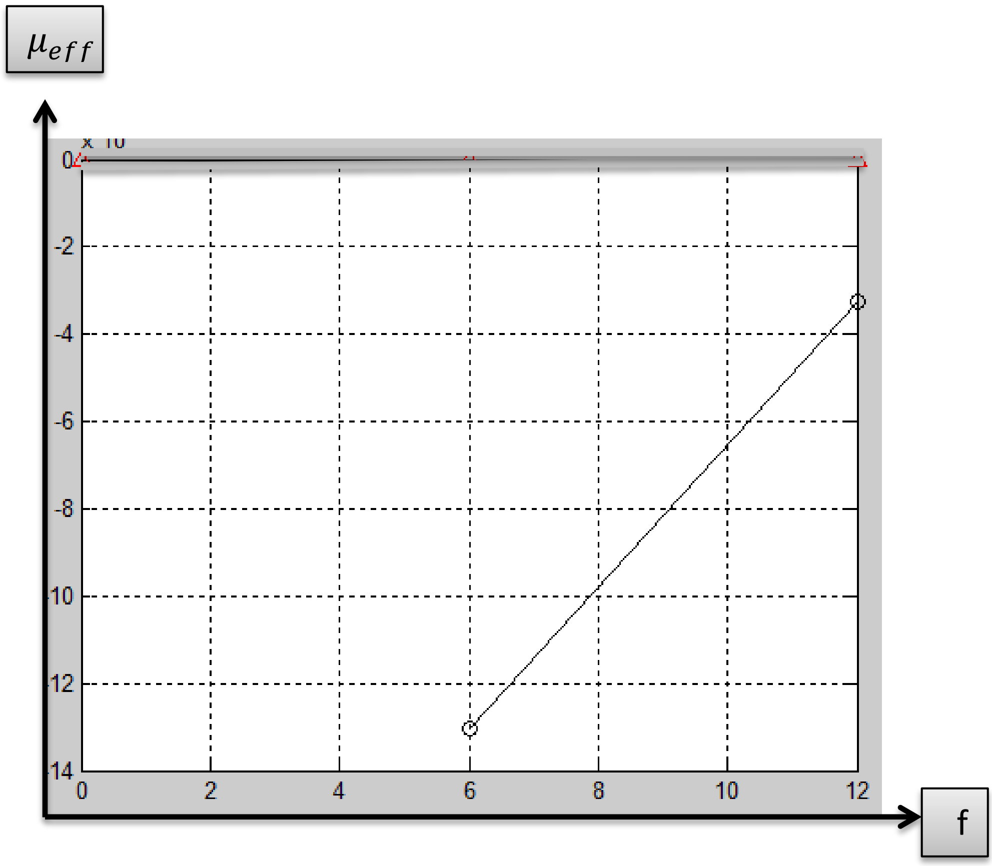


Fig (4.19) effective permeability for S-SRR in section 4.2.7

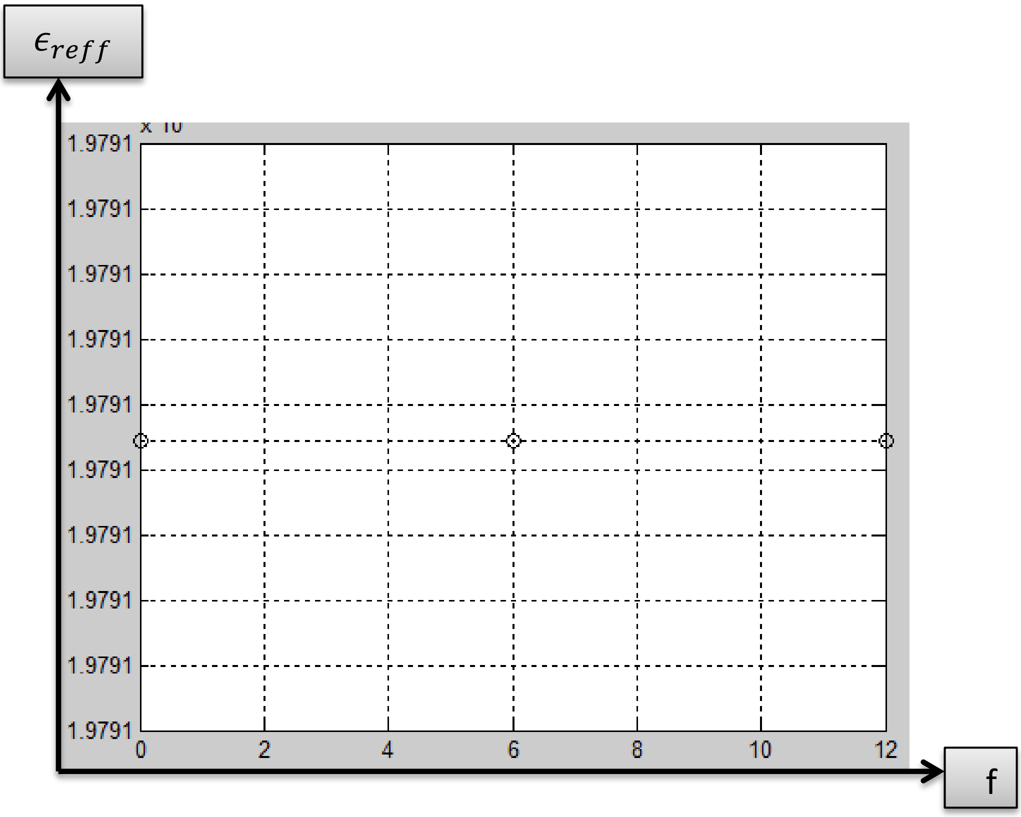


Fig (4.20) effective permittivity for S-SRR in section 4.2.7

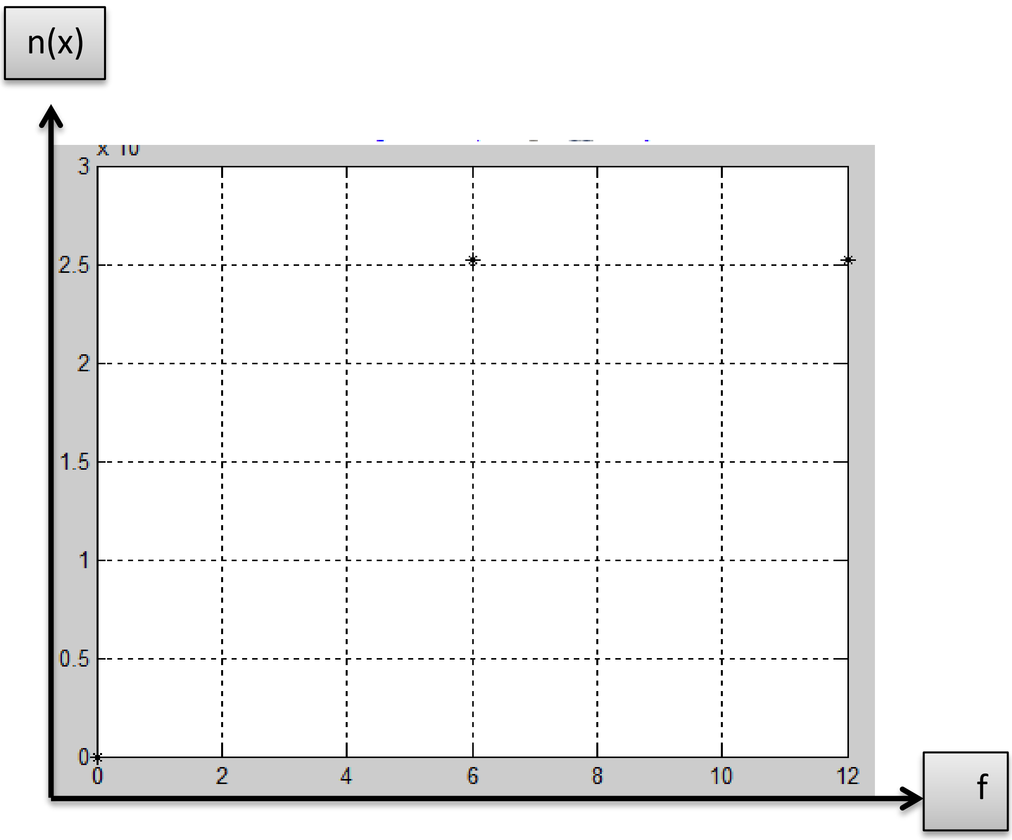


Fig (4.21) refraction index for S-SRR in section 4.2.7

4.2.8 When the dimensions (f = 7.0 , a = 7.5 , r = 0.7 , d =0.8)

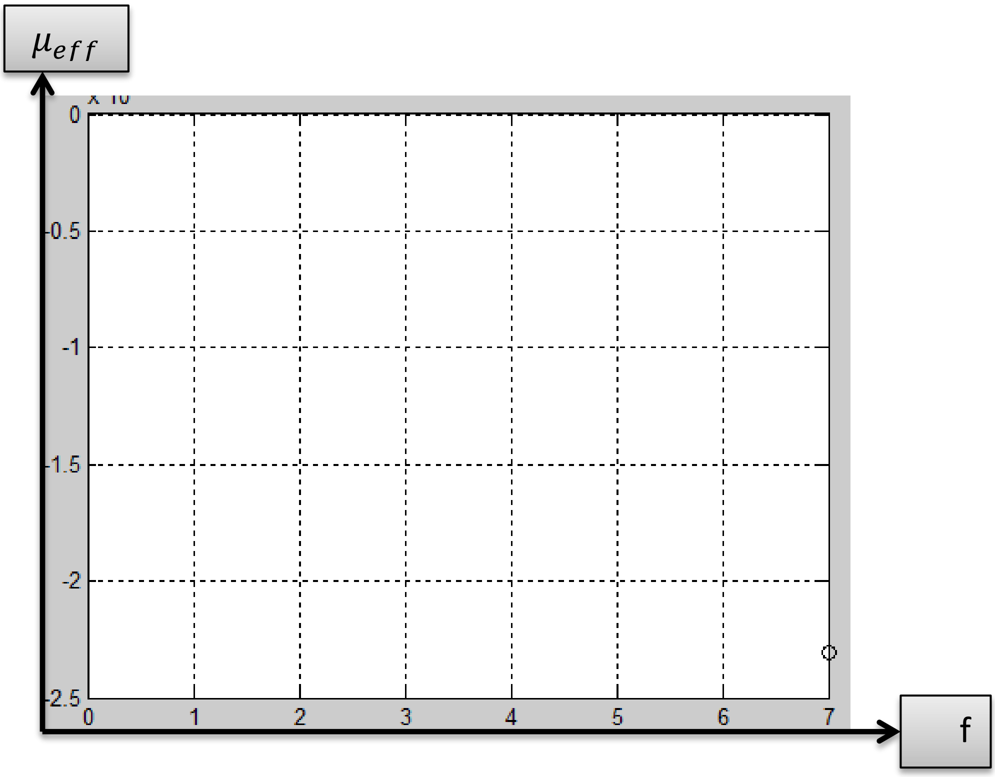


Fig (4.22) effective permeability for S-SRR in section 4.2.8

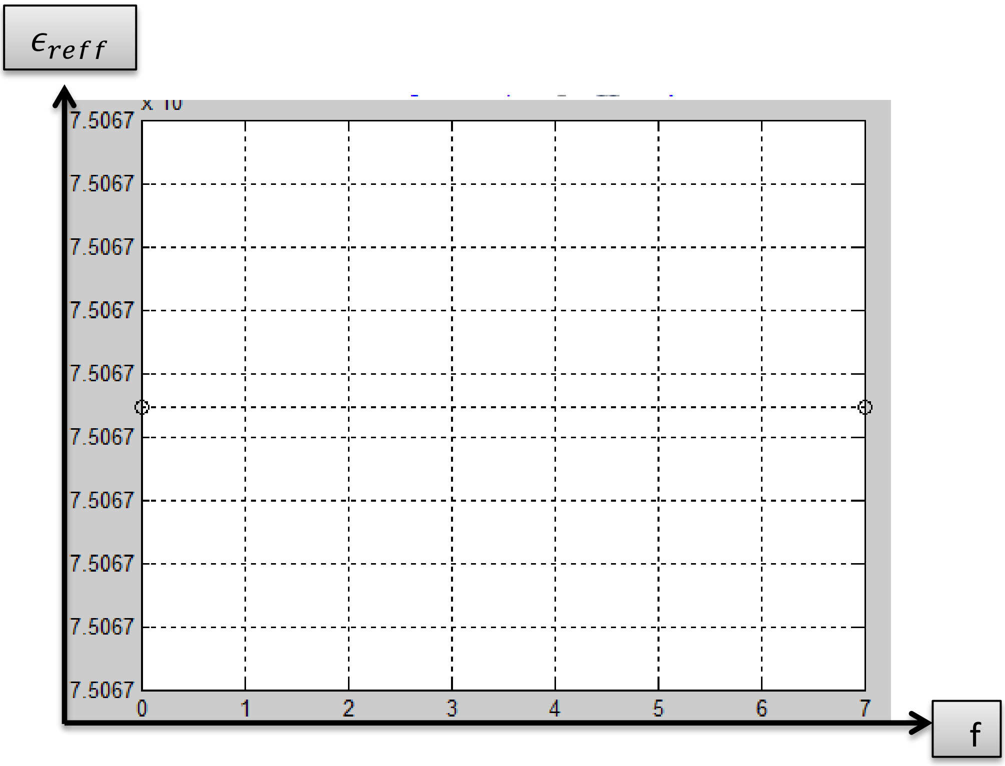


Fig (4.23) effective permittivity for S-SRR in section 4.2.8

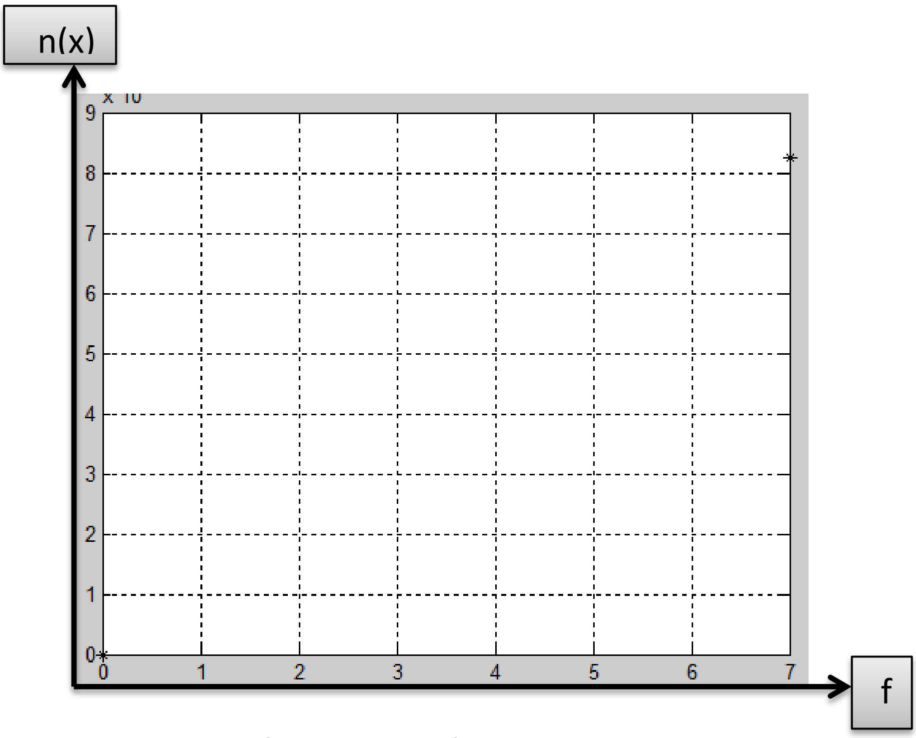


Fig (4.24) refraction index for S-SRR in section 4.2.8

According to Figures (4.1), (4.4), (4.7), (4.10), (4.13), (4.16), (4.19) and (4.22), its show the simulated results of negative permeability; the range of the negative permeability starts from 1GHz to 7.25 GHz .

While the Figures (4.2), (4.5), (4.8), (4.11), (4.14), (4.17), (4.20) and (4.23),show the simulated results of positive permitivity. So the single Left Hand-Metamaterial(LHM) can appear as the Figurs (4.3), (4.6), (4.9), (4.12), (4.15), (4.18), (4.21) and (4.24) are shown.

Chapter Five

Conclusion And Feature Work

5.1 conclusion

The design of Square Split Ring Resonator S-SRR has been presented. The work includes design, simulation and measurement of the permeability, permittivity and refraction index.

From this project, the following points can be concluded:

1. The permeability is obtained in negative value at the band 1GHz to 7GHz, that means the LHM is achieved.
2. Positive permittivity is appeared in the same band.
3. Single Left-Hand Metamaterial LHM is achieved in the frequency band 1GHz to 7GHz.

5.2 Feature work

This project can be expanded to use other types of :

1. Metamaterial as Photonic Band Gap (PBG) which can be implemented on the design
2. Double Left-Hand Metamaterial can be implementation with negative permittivity and permeability.

REFERENCES:

[1] Philip Felber: "Fractal Antennas ", progress in Illinois Institute of Technology, USA, 2001.

[2] V. G. Vesalago, "The Electrodynamics of Substances with Simultaneously Negative Values of ε and □□", P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R., Vol.10, No. 4, February 1968.

[3] SURIA BINTI HALIM, "Antenna with Metamaterial Design", Myster theses, University Technology Malaysia, May 2007.

[4] H. A. Majid, M. K. A. Rahim, and T. Masri ," Microstrip Antenna's Gain Enhancement Using Left-Handed Metamaterial Structure " Progress In Electromagnetics Research M, Vol. 8, 235-247, 2009. IVSL

[5] J.B. Pendry, A.J. Holden, D.J. Robbins, and W.J. Stewart, Magnetism from Conductors and EnhancedNonlinear Phenomena, IEEE Trans Microwave Theory Tech 47 (1999), 2075-2084

[6] R. F. Harrington Time-Harmonic Electromagnetic Fields. McGraw-Hill, New York, 1961.

[7] Christophe Caloz and Tatsuo Itoh, “Electromagnetic Metamaterials: Transmission line theory and microwave applications”, 2006, John Wiley and Sons, Inc., Publications.

[8]J.B. Pendry, A.J. Holden, D.J. Ribbins, and W.J. Stewart, “Magnetism from conductors and enhanced nonlinear phenomenon,” IEEE Trans. Microwave Theory Tech., 47, 1999, pp. 2075-2084.

[9] M. Z. M. Zani, M. H. Jusoh, A. A. Sulaiman, N. H. Baba, R. A. Awang, M. F. Ain, “Circular Patch Antenna on Metamaterial, Electronic Devices,” 2010 International Conference on Systems and Applications (ICEDSA), pp. 313-316, 2010.

[10] E. J. N. Wilson, Introduction to Particle Accelerators (Oxford University Press, New York, 2001), Chap. 10.

[11] J. J. Barroso, P. J. Castro and J. P. Leite Neto, “Experi- ments on Wave Propagation at 6.0 GHz in a Left-Handed Waveguide,” Microwave and Optical Technology Letters, Vol. 52, No. 10, 2010, pp. 2175-2178.

[12]. V. G. Veselago, “The Electrodynamics of Substances with Simultaneously Negative Values of ε and μ”, Soviet Physics Uspekhi, Vol. 10, No.4, 1968.

[13]. V.G. Veselago “The electrodynamics of substances with simultaneously negative value ε and μ” Sov. Phys. Uspekekhy.10 (4), 509-514,1968

[14]. "A New Design of a Band pass Filter at 2.45 GHz Based on Microstrip Line Using the Property of the Double Negative Metamaterials", HananeNASRAOUI1, Ahmed MOUHSEN2, Jamal EL AOUFI3 1,2,3LaboratoryIMMII FST Settat University Hassan1 Settat, Morocco

[15] G. Konstantos, C. Soras, G. Tsachtsiris, M. Karaboikis and V. Makios," Finite Element Modeling of Minkowski Monopole Antennas
Printed on Wireless Devices ", Taylor & Francis Inc. , 2004. IVSL

[16] Qing Liu ," Antennas Using Left-Handed Transmission Lines ",
PHD thesis, University of Birmingham, December 2009.

[17] Ling Lu ," Characterization and Application of Left-Handed Metamaterials Using the Dispersive Finite-Difference Time-Domain
Method ", PHD thesis, University of London, May 2006.

[18] Jiangfeng Zhou, Thomas Koschny and Costas M. Soukoulis ,"
Magnetic and Electric Excitations in Split Ring Resonators ", Optical
Society of America, Vol. 15, No. 26, 24 December 2007. IVSL

[19] Koray Aydin and Ekmel Özbay ," Experimental and Numerical
Analyses of the Resonances of Split Ring Resonators ", WILEY-VCH

Verlag GmbH & Co. KGaA, Weinheim, 22 March 2007. IVSL

[20] J.D. Baena, J.Bonache, F.Martín, R.M.Sillero, F.Falcone, T.Lopetegi, M.A.G.Laso, J.García- García, I.Gil, M.F.Portillo and M.sorolla, “Equivalent-Circuit models for Split ring resonators and complementary split ring resonators coupled to planar transmission lines”, IEEE Microwave Theory and Techniques, Vol.53,No.4,April 2005.

[21] L. Ran, J. Huangfu, H. Chen, X. Zhang, and K. Cheng ," Experimental Study On Several Left-Handed Metamaterials ", Progress In Electromagnetics Research, PIER 51, 249–279, 2005. IVSL

[22] Hongsheng Chen, Lixin Ran, Jiangtao Huangfu, Xianmin Zhang, and Kangsheng Chen ," Left-Handed Materials Composed of Only SShaped Resonators ", Physical Review E 70, 057605, 2004. IVSL

[23] H. S. Chen, L. X. Ran, J. T. Huangfu, X. M. Zhang, and K. S. Chen," Magnetic Properties of S-Shaped Split Ring Resonator ", Progress In Electromagnetics Research, PIER 51, 231–247, 2005. IVSL

APPENDIX A

```
function h = surf(varargin)
%SURF   3-D colored surface.
%   SURF(X,Y,Z,C) plots the colored parametric surface defined by
%   four matrix arguments.  The view point is specified by VIEW.
%   The axis labels are determined by the range of X, Y and Z,
%   or by the current setting of AXIS.  The color scaling is
determined
%   by the range of C, or by the current setting of CAXIS.  The
scaled
%   color values are used as indices into the current COLORMAP.
%   The shading model is set by SHADING.
%
%   SURF(X,Y,Z) uses C = Z, so color is proportional to surface
height.
%
%   SURF(x,y,Z) and SURF(x,y,Z,C), with two vector arguments
replacing
%   the first two matrix arguments, must have length(x) = n and
%   length(y) = m where [m,n] = size(Z).  In this case, the vertices
%   of the surface patches are the triples (x(j), y(i), Z(i,j)).
%   Note that x corresponds to the columns of Z and y corresponds to
%   the rows.
%
%   SURF(Z) and SURF(Z,C) use x = 1:n and y = 1:m.  In this case,
%   the height, Z, is a single-valued function, defined over a
%   geometrically rectangular grid.
%
%   SURF(...,'PropertyName',PropertyValue,...) sets the value of the
%   specified surface property.  Multiple property values can be set
%   with a single statement.
%
%   SURF(AX,...) plots into AX instead of GCA.
%
%   SURF returns a handle to a surface plot object.
%
%   AXIS, CAXIS, COLORMAP, HOLD, SHADING and VIEW set figure, axes,
and
%   surface properties which affect the display of the surface.
%
```

```
%   See also SURFC, SURFL, MESH, SHADING.

%-------------------------------
%   Additional details:
%
%   If the NextPlot axis property is REPLACE (HOLD is off), SURF
resets
%   all axis properties, except Position, to their default values
%   and deletes all axis children (line, patch, surf, image, and
%   text objects).

%   Copyright 1984-2008 The MathWorks, Inc.
%   $Revision: 5.14.4.15 $  $Date: 2008/09/18 15:56:55 $

%   J.N. Little 1-5-92

error(nargchk(1,inf,nargin,'struct'))

% First we check whether Handle Graphics uses MATLAB classes
isHGUsingMATLABClasses = feature('HGUsingMATLABClasses');

% Next we check whether to use the V6 Plot API
[v6,args] = usev6plotapi(varargin{:},'-mfilename',mfilename);

if isHGUsingMATLABClasses
    hh = surfHGUsingMATLABClasses(args{:});
else
    [cax,args,nargs] = axescheck(args{:});

    hadParentAsPVPair = false;
    if nargs > 1
        % try to fetch axes handle from input args,
        % and allow it to override the possible input "cax"
        for i = 1:length(args)
            if ischar(args{i}) && strncmpi(args{i}, 'parent',
length(args{i})) && nargs > i
                cax = args{i+1};
                hadParentAsPVPair = true;
                break;
```

```
            end
        end
    end

    % do input checking
    dataargs = parseparams(args);
    error(surfchk(dataargs{:}));

    % use nextplot unless user specified an axes handle in pv pairs
    % required for backwards compatibility
    if isempty(cax) || ~hadParentAsPVPair
        if ~isempty(cax) && ~isa(handle(cax),'hg.axes')
            parax = cax;
            cax = ancestor(cax,'Axes');
            hold_state = true;
        else
            cax = newplot(cax);
            parax = cax;
            hold_state = ishold(cax);
        end
    else
        cax = newplot(cax);
        parax = cax;
        hold_state = ishold(cax);
    end

    if v6
        hh = surface(args{:},'parent',cax);
    else
        hh = double(graph3d.surfaceplot(args{:},'parent',parax));
    end

    if ~hold_state
        view(cax,3);
        grid(cax,'on');
    end
end

if nargout == 1
    h = hh;
```

```
end

% function out=id(str)
% out = ['MATLAB:surf:' str];
```

الخلاصة:

الخصائص الكهرومغناطيسية من وسائل الإعلام معقد يسمى "الأيسر يتعلق بما وارء (LHMs)" والذي على حد سواء السماحية والنفاذية بلوغ أجزاء الحقيقية السلبية على نطاق معين من الترددات أصبحت موضع اهتمام الأبحاث في السنوات الأخيرة. هذه المواد الجديدة لديها مجموعة واسعة من التطبيقات المحتملة بما في ذلك عدسات مقعرة خفيفة الوزن لأجهزة الرادار، وزيادة الكثافة التي أقراص الفيديو الرقمية يمكن أن تكون مكتوبةوكثافة الدوائر الإلكترونية التي تم إنشاؤها عن طريق الطباعة الحجرية الضوئية، استنادا إلى التصوير الطول الموجي من الباطن. في هذا المشروع، فإننا نقترح نموذج نظري لتقدير تردد صدى والنفاذية المغناطيسية للالمرنانات حلقة الانقسام مربع (S-SRR) وجود تفاوت عرض الفجوة داخل الحلقات. كما يتنبأ نموذج التغيير الكمي في نفاذية اعتمادا على التوجه الهندسي للS-SRR. والتحقق من النتائج المحسوبة مع النتائج التي تم الحصول عليها باستخدام جهاز محاكاة الرياضيات مختبر.

وزارة التعليم العالي والبحث العلمي

جامعة ديالى

كلية الهندسة

قسم هندسة الأتصالات

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مشروع

مقدم الى قسم هندسة الأتصالات

في جامعة ديالى – كلية الهندسة كجزء من متطلبات نيل درجة البكلوريوس

في هندسة الأتصالات

من قبل

سجى فيض الله سلطان

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م.م أسراء حازم علي

May/2016 رجب/١٤٣٧