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Analysis of magnetic resonance in Metamaterial structure

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Abstract: 'Metamaterials' is one of the most recent topics in several areas of science and technology due to its vast potential in various applications. These are artificially fabricated materials which exhibit negative permittivity and/or negative permeability. The unusual electromagnetic properties of metamaterial have opened more opportunities for better antenna design to surmount the limitations of conventional antennas. Metamaterials have created many designs in a broad frequency spectrum from microwave to millimeter wave to optical structures. The edifice building blocks of metamaterials are synthetically fabricated periodic structures of having lattice constants smaller than the wavelength of the incident radiation. Thus metamaterial properties can be controlled by the design of their building blocks. The basic building blocks of metamaterials can be of many different shapes. Most common building blocks of metamaterials are Split Ring Resonators (SRR). This paper emphasizes on simulation of a SRR metamaterial structure of Copper on a substrate of Silica glass with 'COMSOL Multiphysics' to have negative permeability in a specific band of frequency. A magnetic response is attained with this resonator and negative magnetic permeability values can be achieved which is generally unity for naturally occurring materials. In this paper, the magnetic resonance of split-ring resonators (SRR) has been investigated numerically with GMRES solver and variation of the geometrical parameters on the magnetic resonance frequency of SRR is studied. The main aim of this study is to approximate the behaviour of SRR structures with COMSOL Multiphysics.

Keywords: **Split ring resonator (SRR), Magnetic resonance frequency (ωm) Left-Handed Metamaterials (LHM).**

1. Introduction

Metamaterials are artificial materials synthesized by embedding specific inclusions like periodic structures in host media. These materials have the unique property of negative permittivity and/or negative permeability not encountered in the nature. If materials have both parameters negative at the same time, then they exhibit an effective negative index of refraction and are referred to as Left-Handed Metamaterials (LHM). This name is given to these materials because the electric field, magnetic field and the wave vector form a left-handed system. These materials offer a new dimension to the antenna applications. The phase velocity and group velocity in these materials are anti-parallel to each other i.e. the direction of propagation is reversed with respect to the direction of energy flow[1-3]. This concept was first theoretically analyzed by Veselago in 1968, who had also investigated various optical properties of the negative refractive index structures [1]. Although LHMs have been theoretically predicted and studied a few decades ago, it was only recently that such materials were realized experimentally when Sir J. B. Pendry proposed an array of split ring resonators (SRRs) design and Periodically arranged thin metallic wires. An array of split-ring resonators (SRRs) is shown to exhibit a negative μeff for frequencies close to the magnetic resonance frequency (ωm) of the SRR structures[4]. Periodically arranged thin metallic wires are used as negative εeff media, since dielectric permittivity is less than zero below the plasma frequency [5]. Experimental investigation of LHMs is done by constructing a composite metamaterial consisting of two components $\varepsilon(\omega)<0$ and $\mu(\omega)<0$ simultaneously over a certain frequency range [6]

Different geometrical dimensions of SRRs affect the frequency response. Although much effort in metamaterials research is focused on higher optical frequencies[, less work has concentrated on THz frequencies. However, the potential uses of metamaterials in this frequency range offer a great promise that overcome the limitations of natural materials. In this paper, FEM based COMSOL Multiphysics has been used to approximate the behaviour of SRR structures with variation in geometrical parameters. Then the simulation also being performed on the antenna with metamaterial structure and the effect is observed and analyzed where we can see a frequency shift occurred.

2.Theory of SRR

SRRs are metallic rings made of metal with a split introduced in its structure. When a current circulates a coil it creates a magnetic dipole moment. The generated dipole moment vector is at right angles to the plane of the coil. The coil with a plate capacitor together gives us an LC circuit and therefore an increased dipole moment at its resonance. The SRRs behave similar to the LC circuit mentioned above. The metallic ring does function of a coil (inductance L) and the split in the ring generates a parallel plate capacitor (capacitance C).

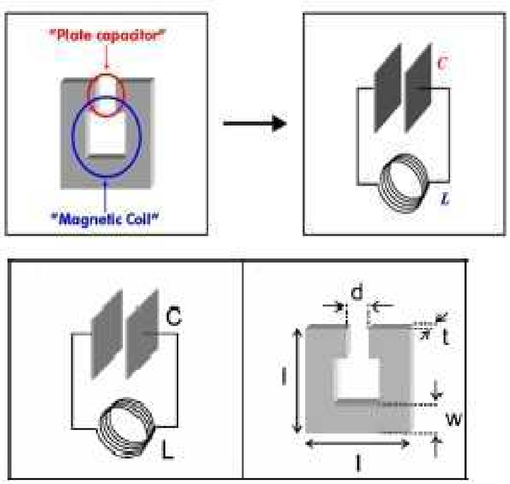

Figure 1. Equivalent circuit of SRR with LC circuit

Thus we can realize LC resonance frequency in SRR whose position can be evaluated using basic formulae of capacitance and inductance and substituting the geometrical parameters of SRR as shown in Fig 1.

The resonance frequency of SRR with geometrical parameters shown in the fig 1 can be derived as follows :

Magnetic resonance frequency $\omega m = 1/sqrt(LC)$ …………(i)

Capacitance, $C = (\varepsilon o \varepsilon r\ A)/d = (\varepsilon o \varepsilon r\ wt/d)$ …………(ii)

A is area and

d the distance between the plates

ε r is relative permitivity of dielectric present between the plates.

and Inductance, L= μo coil area / length ……………(iii) with a single turn in the coil.

Equation(i) shows that the presence of a dielectric also influences the value of resonance wavelength of SRR and the resonance frequency is inversely proportional to the size of SRR. If there is no split in SRR, then the capacitance will become infinity as d=0 and there will not be a resonance. So it is vital to introduce the split in the ring to have a capacitive effect which can lead to the negative value of magnetic permeability, μ.

3. Use of Comsol for modeling and simulation of SRR

In the geometry, four subdomains, ring,substrate, box surrounding ring and boundary are taken. SRR are considered to be made of gold. The scattering boundary conditions for all the external boundaries of the computational domain, are used. The scattering boundary condition is perfectly absorbing for a plane wave and is used to treat open boundaries. The boundary conditions for all the internal boundaries of the ring and the substrate are taken as continuity. The substrate is taken of silica glass of refraction index 1.45. Metal thickness of SRR is taken 15nm. SRR is surrounded by a box to see the radiated field in SRR. The RF module of Comsol Multiphysics 3.3 is used to carry out the simulations. Harmonic propagations is used as the analysis type and the solver is selected as parametric. The parameter is taken as the free space wavelength. The problem is solved for different free space wavelengths. The magnetic resonance of split-ring resonators (SRR) has been investigated numerically with GMRES solver and variation of the geometrical parameters on the magnetic resonance frequency of SRR is studied.

4. Results and Conclusions

In the fig 2-4 ,are simulated by changing the gap width between the two arms of SRR. Fig. 5 is simulated by changing the length of two arms of SRR. The field distribution by the simulation is shown in the figures given below. It is observed that there is high field intensity at the split.

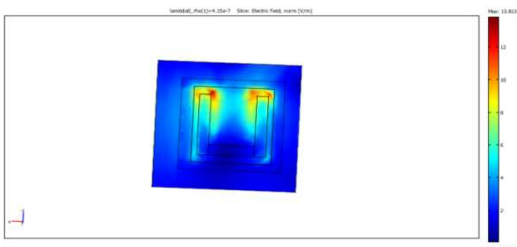

Fig2. 41µm wavelength for gap 40nm

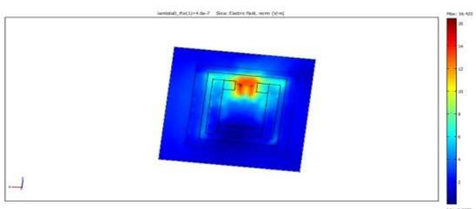

Fig.3. 46µm wavelength for gap 20nm

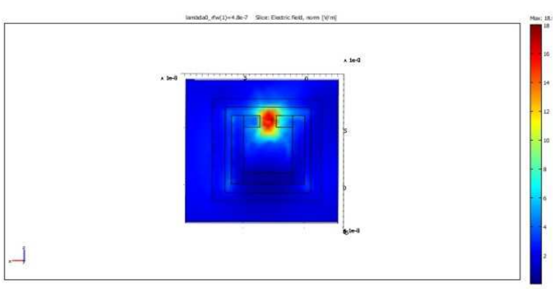

Fig.4. 48µm wavelength for gap 14nm

Introduction of the gap leads to two major changes in the spectra. The gap provides a capacitance, which defines together with the loop of the SRR an LC-circuit to which the electric field resonantly couples. For a sufficiently small gap, this resonance will appear in the low frequency domain (high wavelength) and shift to higher frequencies (lower wavelengths) with increasing gap width *g* as shown in fig1,2, and 3. This behavior is credited to a decrease in capacitance for larger gap widths, which increases the resonance frequency. We have found that opening the SRR gap shifts the LC resonance towards higher frequencies due to a reduced capacitance.

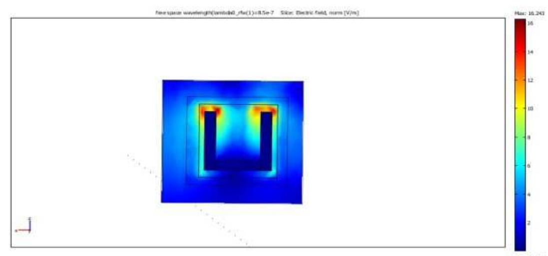

Fig.5. 85µm wavelength for gap 80nm with increase in arm length of SRR.

The frequency of the plasmonic resonance is eva by the rluated by atio of the SRR base line length to its height. The second resonance associated with the LC-circuit changes its frequency in dependence of various parameters. Increasing the SRR legs leads to an increase in both the SRR inductance and the capacitance and hence resonant frequency get decreased(i.e. wavelength increased in fig. 5)

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