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Design and Parametric Analysis of Circular Shaped Split Ring Resonator

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Abstract—*In this paper, design of circular split ring resonator(SRR) at a given resonant frequency is presented. Firstly the parameters of split ring are derived from mathematical equation and then it is simulated using HFSS software. Theoretical and simulated results are approximately same. Effect of the split ring design parameters like radius, split width, ring width and the distance between the ring edges on the resonant frequency of SRR is also presented. Simulation results shows that resonant frequency decreases with increasing the radius and ring width, whereas resonant frequency decreases with decreasing spacing between the ring edges and split width has almost negligible effect on the resonant frequency.*

1. INTRODUCTION

Metamaterial is the arrangement of periodic structures to have properties different from conventional materials. Metamaterials were firstly introduced by Veselago[1] in 1967. He showed that the propagation of wave in metamaterial was in opposite direction than the conventional material. Left handed metamaterials exhibits negative values for both permittivity and permeability. Split ring resonators(SRR) are mostly used to design metamaterials. John Pendry[2] firstly introduced the concept of SRR. He showed that the microstructures made of non-magnetic conducting materials like copper exhibits negative permeability. He considered the periodic structure of unit cells of circularly shaped split rings. Due to splits in the rings, SRR unit cell can achieve resonance at wavelength much larger than the dimensions of the ring.

In 2000, R. A. Shelby et al[3] presented that the scattering of the beam through the prism designed from metamaterial. The metamaterial was made of 2D arrray of periodic structures of copper strips and split ring resonators. SRR have wide applications in many areas. It has been used in acoustic[4] metamaterials, transmission line metamaterials[5][6], and also in patch antennas to obtain compactness[7][8][9], enhancement of gain and directivity[10][11][12], and in achieving ultra wide band[13][14].

In this paper, the design of SRR using mathematical equation and its parametric analysis has been done. In parametric analysis, effect of the parameters such as radius, ring width, split width and spacing between the ring edges has been studied.

2. DESIGN OF SRR

It consists of two homocentric circular metallic rings which are printed on the dielectric substrate.

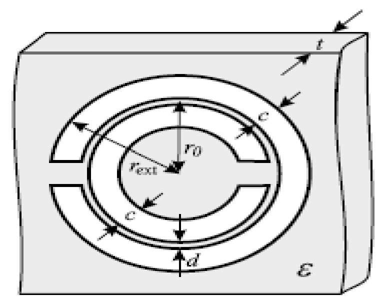

Fig. 1: Split Ring Resonator

where r_0 is the inner ring radius, r_{ext} is the external ring radius, c is the ring width, d is the spacing between the ring edges and t is the thickness of the dielectric substrate.

Frequency is calculated using the formula

$$f = \frac{c_0}{2\pi}\sqrt{\frac{2a_z}{r_{ext}^2\ \ln\left(1+\frac{2c}{d}\right) r_{av}\pi(1+\varepsilon_r)}}$$

where r_{av} is the average radius , ε_r is the dielectric constant of the substrate and a_z is the lattice constant.

Average radius and outer ring radius are given as

$$r_{av} = r + 1.5c + 0.5d$$

$$r_{ext} = r + 2c + d$$

The simulated results are a little different from the calculated results.

A substrate with dielectric constant 1, dimensions 10×10×1.6 mm^3 is taken, and split rings parameters are given below

$r_0 = 3mm,\ r_{ext} = 3.7mm,\ d = 0.1mm,\ c = 0.6mm,$ split width = 0.1mm, $a_z = 1mm$

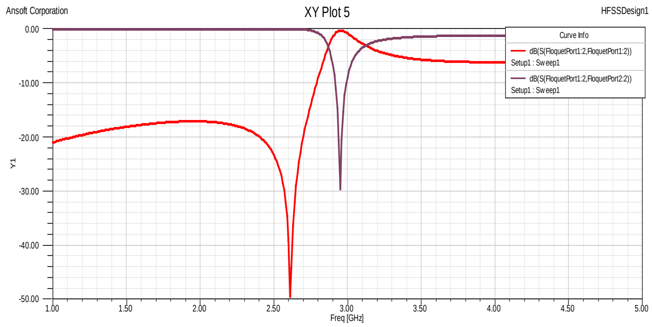

Fig. 2: Reflection Coefficient and Transmission Coefficient when $r_0 = 3mm$

The graph is plotted between Reflection Coefficient (S_{11}) and Resonant Frequency. Red Curve indicates the Reflection Coefficient (S_{11}) and violet curve indicates the Transmission Coefficient.

The simulated result gives the resonant frequency 2.6 GHz whereas its numerically calculated value is 2.48 GHz.

3. PARAMETRIC ANALYSIS

The effects of radius, ring width, split width and the spacing between the ring edges of split rings on the resonant frequency of SRR are studied.

An FR4 Epoxy substrate of dielectric constant 4.4, dimensions 10×10 mm^2 and thickness 1.6mm is taken.

The parameters of split rings are as given below

$r_0 = 1.24mm$, $r_{ext} = 1.94mm$, $d = 0.3mm$, $c = 0.4mm$, split width = 0.1mm, $a_z = 1mm$

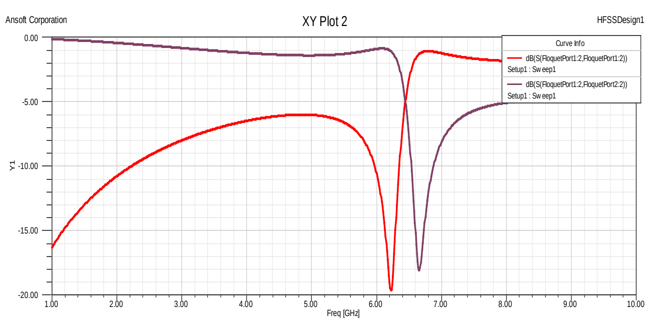

Fig. 3: Reflection Coefficient and Transmission Coefficient when $r_0 = 1.24mm$

The simulated result gives the resonant frequency 6.2 GHz whereas its numerically calculated value is 5.88 GHz.

3.1 Effect of Radius

An FR4 Epoxy substrate with the same dimensions as above and the parameters of the split ring are given below

$r_0 = 1.36mm$, $r_{ext} = 2.06mm$, $d = 0.3mm$, $c = 0.4mm$, split width = 0.1mm

Radius is increased from 1.24mm to 1.36mm.

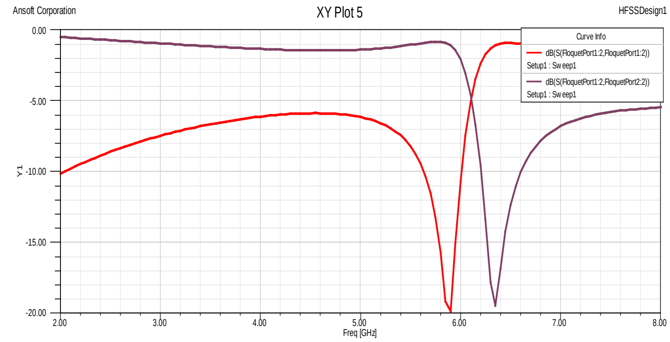

Fig. 4: Reflection Coefficient and Transmission Coefficient when $r_0 = 1.36mm$

The simulation results shows that the resonant frequency is 5.89 GHz. Thus the resonant frequency decreases on increasing the radius.

One more set of parameters for illustration of the effect of radius is given below

$r_0 = 1.44mm$, $r_{ext} = 2.14mm$, $d = 0.3mm$, $c = 0.4mm$, $a_z = 1mm$, split width = 0.1mm

Radius is increased from 1.24mm to 1.44mm.

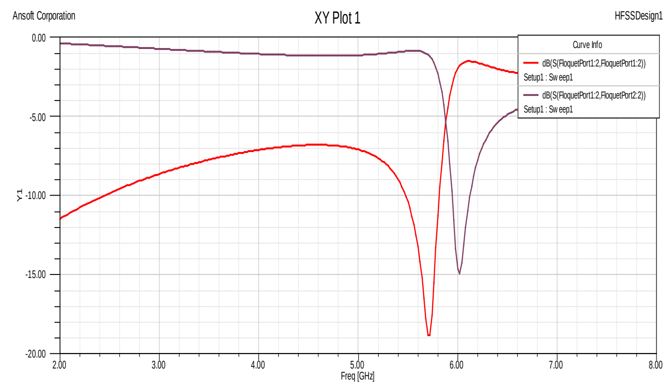

Fig. 5: Reflection Coefficient and Transmission Coefficient when $r_0 = 1.44mm$

The simulation results shows that the resultant frequency is 5.7GHz and it has been decreased. Thus, on increasing the radius, resonant frequency decreases.

3.2 Effect of Ring Width

An FR4 Epoxy substrate with dimensions 10×10×1.6mm^3 and split ring parameters are given below

$r_0 = 1.44mm$, $r_{ext} = 2.34mm$, $d = 0.3mm$, $c = 0.6mm$, split width = 0.1mm, $a_z = 1mm$.

Simulation results shows that the resonant frequency is 5.48 GHz which has been decreased. Thus the increase in ring width caused the decrease in resonant frequency.

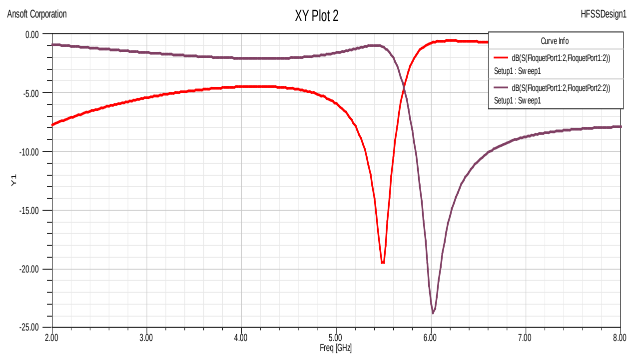

Fig. 6: Reflection Coefficient and Transmission Coefficient when $c = 0.6mm$

3.3 Effect of Split Width

An FR4 Epoxy substrate with dimensions 10×10×1.6mm^3 and split ring parameters are given below

$r_0 = 1.24mm$, $r_{ext} = 1.94mm$, $d = 0.3mm$, $c = 0.4mm$, split width = 0.2mm, $a_z = 1mm$

Split width has been increased from 0.1mm to 0.2mm.

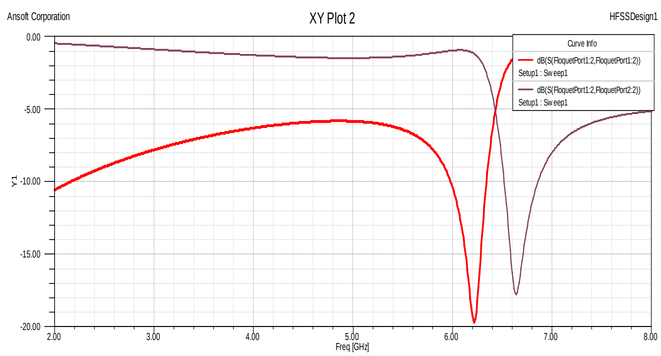

Fig. 7: Reflection Coefficient and Transmission Coefficient when split width = 0.2mm

Simulation result shows that the resonant frequency is about 6.22 GHz which is not so much changed. Thus there is negligible effect of split width on resonant frequency of SRR.

3.4 Effect of Spacing between the Ring Edges

An FR4 Epoxy substrate with dimensions 10×10×1.6mm^3 and split ring parameters are given below

$r_0 = 1.24mm$, $r_{ext} = 1.74mm$, $d = 0.1mm$, $c = 0.4mm$, split width = 0.1mm, $a_z = 1mm$

Spacing between ring edges has been decreased from 0.3mm to 0.1mm.

Simulation result shows that the resonant frequency is approximately 6.03 GHz. Therefore, the result showed that the resonant frequency decreases with decrease in spacing between the ring edges.

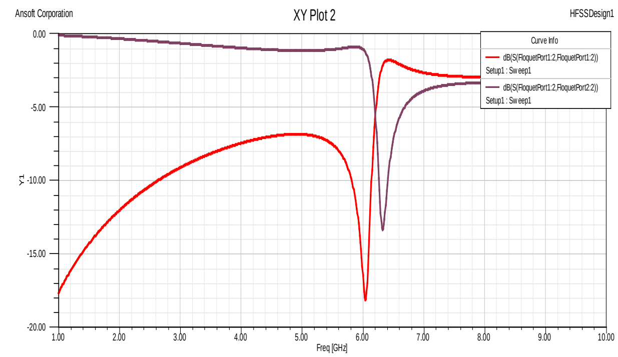

Fig. 8: Reflection Coefficient and Transmission Coefficient when $d = 0.1mm$

4. CONCLUSION

This paper described the design of SRR and the effect of the parameters of split ring resonator (SRR) on the resonant frequency using mathematical equation and HFSS simulation. The difference between the calculated value and simulated value of resonant frequency is increasing as the resonant frequency is increasing. Thus we can design the SRR resonating on any arbitrary frequency by selecting its proper parameters. The split ring resonator can be used in various fields like antennas, electromagnetics, microwave and optics.

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