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Modeling of Split Ring Resonators Loaded Microstrip Line with Different Orientations

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ABSTRACT

This paper presents the different circuit approaches of the electric and magnetic interaction of Single Split Ring Resonator (SRR) loaded microstrip line. We loaded the microstrip line with planar square split ring resonator in different configurations and orientations. The modeling behavior of metamaterials-based microstrip lines loaded with single and two-mirrored split ring resonators is analyzed numerically in two orientations (with gap of SRR parallel and perpendicular to the line). The full wave simulations are performed for the single and two-mirrored split ring resonators loaded microstrip inside a waveguide with 'High Frequency Structure Simulator' software. The equivalent circuit parameters are obtained for the single split ring resonator loaded with microstrip line with the gap parallel and near to the line from transmission line theory that make use of just the resonance frequency and minimum of the reflection coefficient. The simulation of different orientations of split ring resonator gives better reflection coefficient and wider frequency.

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1. INTRODUCTION

The development of metamaterials opened a new possibility for designers to create a novel structure with unusual properties or enhanced performance [1], [2]. Metamaterials are artificially invented materials that show properties not detected in naturally occurring materials and have negative refraction index. One of the most important contributions to this topic was made in 1968 by VG Veselago who said that materials with both negative permittivity and permeability is theoretically possible [3]. In 1999, John Pendry identified a practical way to make left-handed metamaterials (LHM) which did not follow the right hand rule [4]. Later then, Smith and his colleagues demonstrated metamaterials to show negative permittivity and permeability simultaneously and carried out microwave experiments to test its unusual properties in 2000. In 2001, Smith et al showed negative refraction experimentally, using a metamaterials with repeated unit cells of split-ring resonators (SRR) and copper strips [5]-[7]. In 2002, Marques et al investigated a modified version of SRR i.e. broadside coupled (BC-SRR) to avoid bianisotropy and showed comparative analysis of the conventional (or edge-coupled) SRR and BC-SRR with printed metallic rings of the BC-SRR on both sides of the dielectric substrate [8]. In 2005, Juan Domingo Baena et al proposed new approach for designing planar metamaterial structures with SRR and complementary split-ring resonators (CSRRs) coupled to planar transmission lines and analyzed the stop band/pass band characteristics of the SRR/CSRR loaded transmission lines [9]. Bilotti et al, in 2007 discussed multiple split ring resonators (MSRR) with multiple rings and spiral ring (SR) to increase the miniaturized rate and concluded that increase in number of turns and rings of SRs and MSRRs respectively, increases the saturation of the resonant frequency [10]. Bojanic et al, in 2011, proposed multiband delay line with broadside coupled and the single SRRs and exhibits two left-handed bands that can be shifted by twisting the split rings for certain angle or by changing their lengths [11]. In 2012, Sindreu et al suggested the use of SRR in coupled transmission line as compared to microwave components, to achieve better performance parameters [12]. Naqui et al in 2013 proposed a model with the electromagnetic properties of transmission lines loaded with SRRs and CSRRs randomly oriented and resonators are aligned in a non orthogonal direction to the line axis, cross-polarization effects arises[13]. Younesiraad et al in 2014 analysed resonator antenna for multi-band application with Finite Element Method and Finite Integral Technique [14]. In 2014, Kuldeep Kumar Parashar proposed a new patch antenna with compact size and large bandwidth by using simple inset feed technique [15]. In 2014, Bojanic et al presented an enhanced equivalent circuit approach for the magnetic/electric interaction of SRRs with printed lines and extract the different parameters of microstrip line with parallel and perpendicular gap to line [16].

The aim of present work is to design a microstrip line loaded with metamaterials and examine shifting of resonant frequency with different orientations of single and two mirrored SRRs. The outline of paper is as follows: Section 1 gives the brief literature review of the work done in the area. Section 2 describes the proposed SRRs loaded microstrip line model with different orientations. Section 3 presents results and discussion. Section 4 gives the conclusion of the paper.

2. PROPOSED SRR LOADED MICRO-STRIP LINE MODEL

In the proposed model, a conventional microstrip line is loaded with planar square SRRs with the gap parallel to the line. The square shape SRRs is coupled to microstrip line by placing it at distance‘s’, in the same plane. Figure 1 shows layout of SRR coupled to microstr/ip line in the same plane with gap parallel to the line. This coupled line is modeled on Rogers RO3010 substrate of thickness (h) 1.27 mm, dielectric permittivity εr =10.2 and loss tangent 0.035. The dimensions of SRR coupled to rectangular microstrip line are given in Table 1.

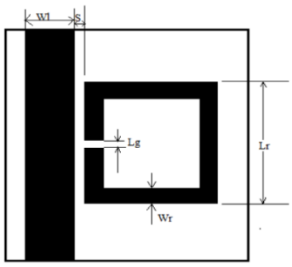


Figure 1. Layout of SRR loaded microstrip line

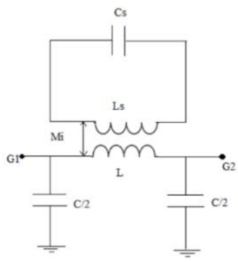


Figure 2. Equivalent circuit of SRR loaded microstrip line

Table 1. Dimensions of SRR loaded microstrip line

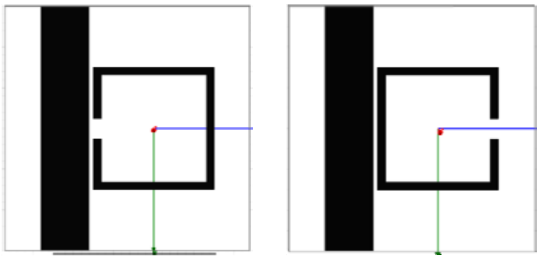
S. No	Parameters		
	Name of parameter	***Representation***	***Dimensions(mm)***
1	Width of microstrip line	Wl	1.2
2	Length of SRR	Lr	3.0
3	Width of SRR	Wr	0.2
4	Gap of split	Lg	0.5
5	Gap between microstrip line & SRR	S	0.1

Microstrip lines loaded with SRRs for different configurations are examined. It has been found that different configurations of SRR loaded microstrip line can be modeled by the same circuit topology, but with different values of the circuit parameters. For each topology, resonance frequency and the minimum reflection frequency can be obtained.

1) Single SRR loaded microstrip line with the gap parallel to the line (i) gap near orientation (ii) gap far orientation
2) Single SRR loaded microstrip line with the gap perpendicular to the line
3) Two mirrored SRRs with the gap parallel to the line (i) Both gaps near orientation (ii) Both gaps far orientation
4) Two mirrored SRRs with the gap perpendicular to the line
5) Two SRRs with the gap parallel to the line (i) one gap near and one far orientation
6) Two cascaded SRRs with the gap parallel to the line(i) gap near orientation (ii) gap far orientation
7) Two cascaded SRRs with the gap perpendicular to the line
8) Double SRR loaded microstrip line with the gap parallel to the line

2.1. SRR Loaded Microstrip Line with the Gap Parallel to the Line

Microstrip line loaded with SRRs with gaps parallel to the line is shown in Figure 3 and 4. Figure 3 depicts the microstrip line loaded with single SRR with gap parallel to the line and gap is near to the microstrip line. In Figure 4 the gap of SRR loaded microstrip line is parallel and far from the line.



(a) (b)

Figure 3. Microstrip line loaded with SRRs with gap parallel to the line. (a) One SRR with gap near the line (b) One SRR with the gap far from the line

To extract the parameters L and C of the transmission line in Figure 2, taking into account the coupling between the line and the nearest SRR arm, inductance is modeled as if there were two inductances.. One is coupled with the transmission line or second is isolated transmission line with length equal to the remaining uncoupled part of the SRR length. Figure 3 shows the equivalent circuit of microstrip line coupled to SRR where Ls and Cs is inductance and capacitance of SRR respectively and L and C is inductance and capacitance of microstrip line respectively. The G_1 and G_2 are two ports and M_i is mutual inductance. The capacitance C_s is obtained from the SRR resonance frequency f_r as follows:

$$f_r = \frac{1}{2\pi\sqrt{LsCs}} \quad (1)$$

Where resonance frequency is also calculated as:

$$f_r = \frac{w_r}{2\pi} \quad (2)$$

The coupling coefficient M_i is then obtained as a function of $f_{min.}$, the resonance frequency f_r , and the line parameters L and C as follows:

$$M_i^2 = \left(1 - \frac{w_r^2}{w_{min}^2}\right)(1 - a_1) \quad (3)$$

The term mutual inductance M_i is also affected by variation of the distance 'S' between the microstrip line and split ring resonator (SRR). Where a_1 correspond to the circuit with one cell and $f_{min} = \frac{w_{min}}{2\pi}$. These coefficients are given by:

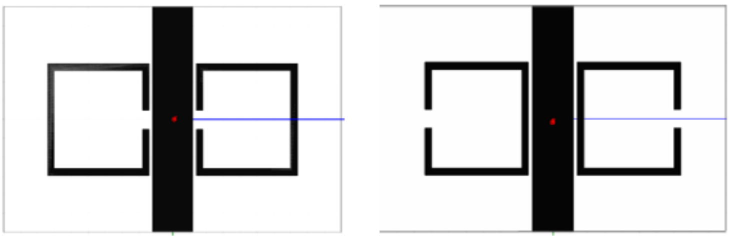
$$a_1 = \left[\frac{L}{C} Y_0^2 + 2b\right] \quad (4)$$

Where Y_0 is the characteristic admittance of the microstrip line and:

$$b = \left(\frac{w_{min}}{w_0}\right) \; ; \; w_0^2 = \frac{8}{LC} \quad (5)$$

2.2. Two Mirrored SRRs Loaded Microstrip Line with the Gap Parallel to the Line

The microstrip line loaded with two mirrored SRRs with the gap parallel to the line is shown in Figure 4. The gap of two mirrored SRRs is near and far from the microstrip line as in Figure 4(a) and 4(b) respectively.

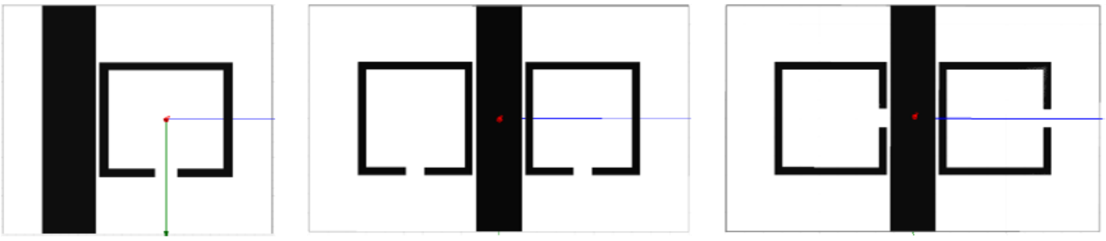


(a) (b)

Figure 4. Microstrip line loaded with SRRs with gap parallel to the line. (a) Two SRRs with gap near the line (b) Two SRRs with the gap far from the line.

2.3. SRRs Loaded Microstrip Line with the Gap Perpendicular to the Line

The microstrip line loaded with single SRR and two mirrored SRRs with the gap perpendicular to the microstrip line shown in the Figure 5.



(a) (b) (c)

Figure 5. Microstrip line loaded with SRRs (a) Single SRR with gap perpendicular to the line (b) Two SRRs mirrored with gap perpendicular to the line (c) SRRs with one gap parallel and another perpendicular to the line

2.4. SRRs Loaded Microstrip Line with the Gap Parallel to the Line

The microstrip line loaded with two SRRs with the gap parallel to the line but one SRR gap has near to the line and other has far from the line as depicted in the Figure 5(c).

2.5. Two Cascaded SRRs Loaded Microstrip Line with the Gap Parallel to the Line

The microstrip line is loaded with two cascaded SRRs with the gap parallel to the line as seen in Figure 4. The distance'd' between the two cascaded SRRs is 0.5mm. The gap of two cascaded SRRs near to the microstrip line as and far from the microstrip line is shown in the Figure 6(a) and Figure 6(b) respectively.

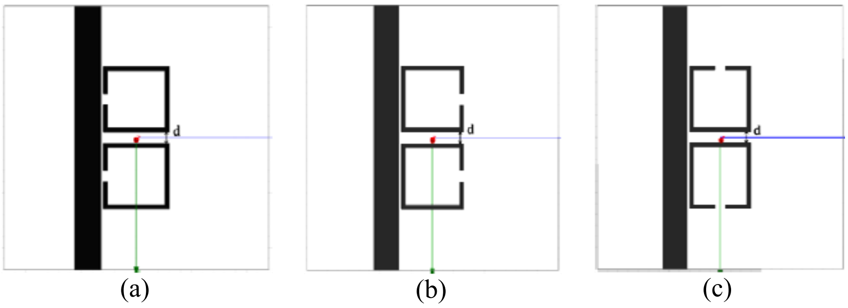


Fig. 6 Microstrip line loaded with two cascaded SRRs with. (a) Two SRRs with gap parallel and near the line (b) Two SRRs with the gap parallel and far from the line (c) gap perpendicular to the line

2.6. Two Cascaded SRRs Loaded Microstrip Line with the Gap Perpendicular to the Line

The microstrip line is loaded with two cascaded SRRs with the gap perpendicular to the line as seen in Figure 6(c).

2.7. Double SRR Loaded Microstrip Line with the Gap Parallel to the Line

Microstrip line loaded with double SRR with the gap parallel to the line is seen in Figure 7. It depicts the microstrip line loaded with double SRR with gap parallel to the line and both splits are opposite to each other.

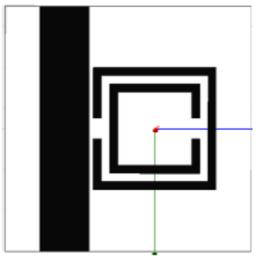


Figure 7. Microstrip line loaded Double SRR with gap parallel to the line

3. RESULTS AND DISCUSSION

The SRR loaded microstrip line is simulated inside a waveguide to attain the resonating frequency region. The Perfect Electric Conductor (PEC) boundary conditions are employed on the z-faces of the unit cell. The Perfect Magnetic Conductor (PMC) boundary conditions are used on top and bottom y-faces of the unit cell so that the negative permeability behavior of SRR would be excited. The two wave ports 1 and 2 are assigned to the both sides of microstrip line on the x-faces of waveguide. The proposed structure is simulated with Ansoft software 'High Frequency Structure Simulator (HFSS)'.

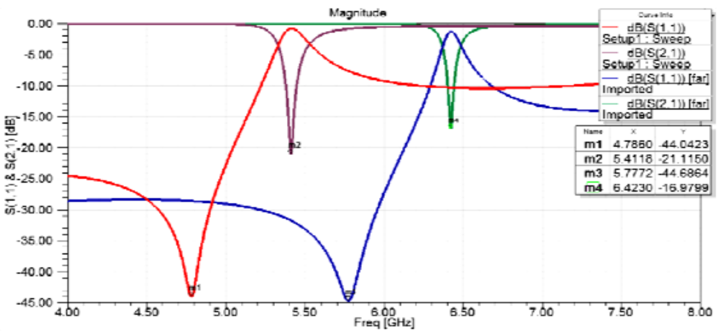


Figure 8. Reflection coefficient S_{11} and Transmission coefficient S_{21} of SRR loaded microstrip line with the gap parallel and near to the line and far from the line

Figure 8 shows the reflection and transmission coefficient of SRR loaded microstrip line with the gap parallel to the line. It shows that resonant frequency is shifted to the right as the gap of SRR is changes from near to the microstrip line and far from line.

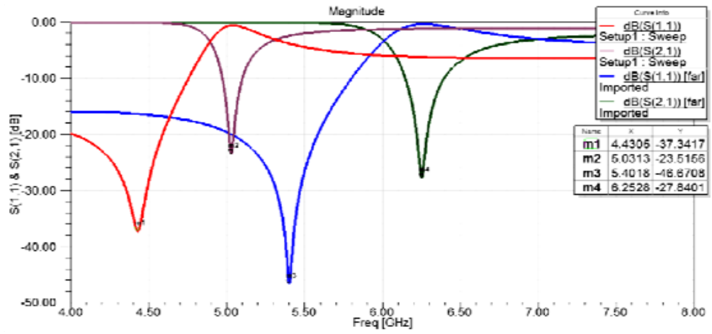


Figure 9. Reflection coefficient S_{11} and Transmission coefficient S_{21} of two mirrored SRRs loaded microstrip line with the gap parallel and near to the line and far from the line

Figure 9 shows the reflection and transmission coefficient of two mirrored SRRs loaded microstrip line with the gap parallel to the line. It shows that resonant frequency and return loss get increased as the gap of SRR is varied from near to far from the microstrip line.

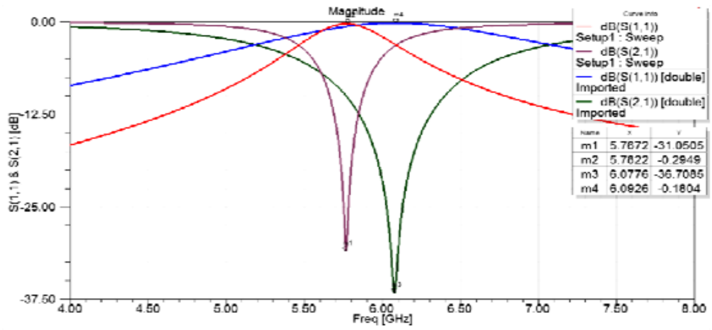


Figure 10. Reflection coefficient S_{11} and Transmission coefficient S_{21} of single and two mirrored SRRs loaded microstrip line with the gap perpendicular to the line

Figure 10 shows the reflection and transmission coefficient of single and two mirrored SRRs loaded microstrip line with the gap perpendicular to the line. It shows that the bandwidth and return loss is increased as the gap of SRR changes from near to the microstrip line and far from line. The resonant frequency is shifted right as the gap changes from near to the far from the line.

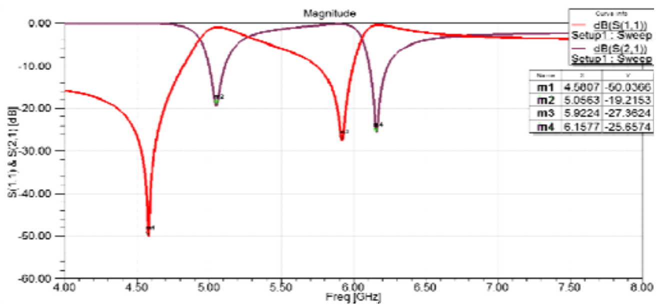


Figure 11. Reflection coefficient S_{11} and Transmission coefficient S_{21} of double SRRs loaded microstrip line with the gap parallel and one SRR is near and other is far from the line

Figure 11 shows the reflection and transmission coefficient of double SRRs loaded microstrip line with the gap parallel to the line but the gap of one SRR is near to the line and other has far from the line. It shows that the bandwidth is increased and resonant frequency is shifted from lower to higher frequency region. .

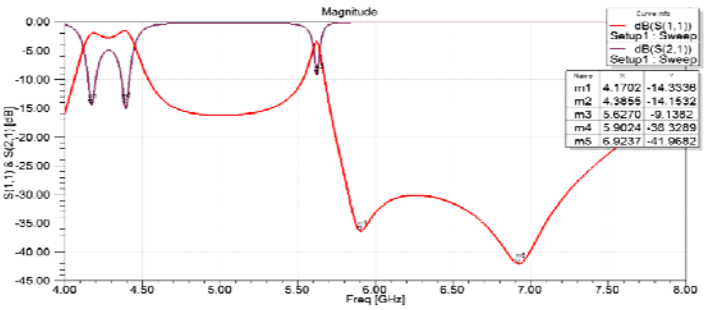


Figure 12. Reflection coefficient S_{11} and Transmission coefficient S_{21} of two cascaded SRRs loaded microstrip line with the gap parallel and near to the line

Figure 12 shows the reflection and transmission coefficient of two cascaded SRRs loaded microstrip line with the gap parallel and near to the line. It shows that the return loss is improved with a shift in the resonant frequency is from lower to higher region

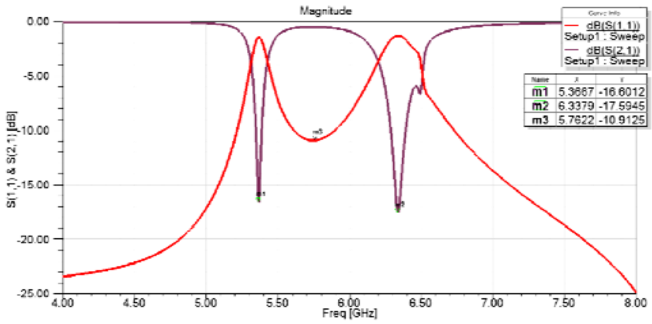


Figure 13. Reflection coefficient S_{11} and Transmission coefficient S_{21} of two cascaded SRRs loaded microstrip line with the gap parallel and far from the line

Figure 13 shows the reflection and transmission coefficient of two cascaded SRRs loaded microstrip line with the gap parallel and far from the line. It shows that the return loss and bandwidth is increased and resonant frequency shift to higher side.

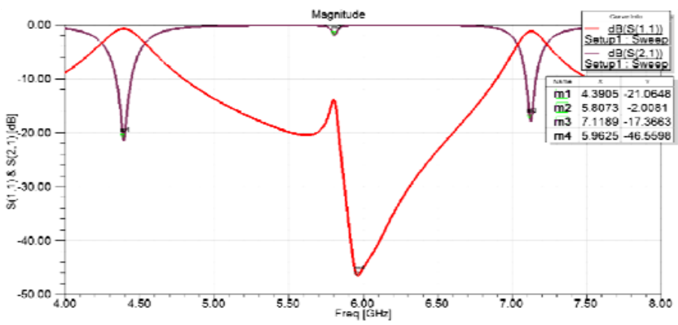


Figure 14. Reflection coefficient S_{11} and Transmission coefficient S_{21} of two cascaded SRRs loaded microstrip line with the gap perpendicular to the line

Figure 14 shows the reflection and transmission coefficient of two cascaded SRRs loaded microstrip line with the gap perpendicular to the line. It can be seen that resonant frequency is shifted to higher side.

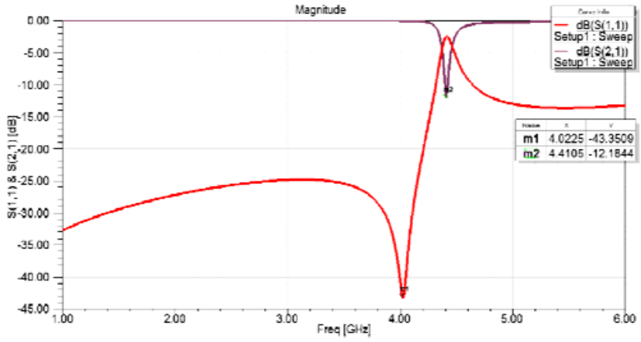


Figure 15. Reflection coefficient S_{11} and Transmission coefficient S_{21} of double SRR loaded microstrip line with the gap parallel to the line

Figure 15 shows the reflection and transmission coefficient of double SRR loaded microstrip line with the gap parallel to the line. It shows that the transmission line resonates at lower frequency as compared to all other compared to all other orientations.

4. CONCLUSION

In this paper, microstrip lines loaded with single and double split-ring resonators in different orientations have been proposed. These orientations of the SRR with respect to the line are analyzed with the parallel gap near and far from the line, with the gap perpendicular to the line. The printed line is loaded with a single SRR at one side, or with two mirrored SRRs placed with respect to the line. This type of structures demonstrates stop band response, but the proposed equivalent circuit model can easily be extended to structures with pass band response. The improved equivalent circuit of proposed SRR model moves the resonance to higher frequencies. The cause of frequency shifting is variation in capacitance of strip line due to SRRs coupled in various configurations. Therefore, the bandwidth is increased along with good matching.

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