Analysis of Split Ring Resonator for Metamaterial Antennas

[1]Manjunatha. K. H, [2]Dr. Shilpa Mehta, [3]Dr. Rohith. U. M
[1] PDIT, Hosapete,[2] Presidency University, Bengaluru, [3]PDIT, Hosapete

Abstract*—Metamaterial structures have found applications in antennas. In this paper a split ring resonator is analyzed for use in software defined radios and cognitive radios. A split ring resonator is designed and simulated in CST. The dimensions of the inner and outer ring are varied and tested in CST EM tool. It is been observed that the resonant frequency shifts to higher value with reduction in the inner ring size and total structure size. Meanwhile the SRR exhibits dual band resonance with large bandwidth. An array of two SRRs is also simulated. The results show dual bands, one at 5.66 GHz and other at 8.64 GHz. Such Metamaterial antenna finds applications in cognitive radios for free channel allocation from TV white spaces satellite microwave channel bands.

Index Terms—*Cognitive radio, CST EM tool, Metamaterial antennas, Split Ring Resonator*.

I. INTRODUCTION

Antennas are used in everyday life in sensing devices, communication systems, radar systems etc. They are used as converters between electrical signals and electromagnetic waves. Impedance matching, shape, size, radiation pattern, frequency agility, reduced out of band emission, bandwidth are an antenna design parameters.

In recent years, the left handed artificial material structures have gained analysis in antenna applications. The response of such material to electromagnetic waves is determined by the important parameters, namely, dielectric permittivity, ε, and magnetic permeability, μ. In ordinary materials these two parameters are positive. But for artificial structures, the effective permittivity, ε_{eff} and effective permeability μ_{eff} can be negative. Such materials are called as left handed metamaterials (LHMs), because the electric, magnetic and wave vector components form left handed coordinate system. The refractive index is also negative, so, the phase and group velocities are opposite in direction [1]. An artificial left hand artificial material operating in the microwave region was reported by Smith *et al* [2].

II. SPLIT RING RESONATOR STRUCTURE

A. A simple SRR structure

Split ring resonator (SRR) is one of the most important metamaterials found. SRR was designed originally by Pendry *et al*. in 1999 [3]. A SSR have two patch concentric rings having small gaps which are oppositely directed as shown in Fig. 1.

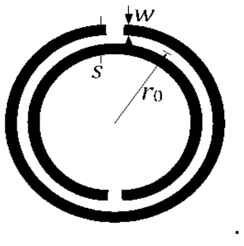


Fig. 1: A split ring resonator structure

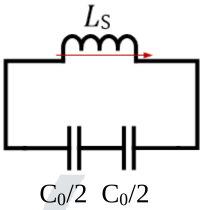


Fig. 2: SRR equivalent circuit.

Fig. 2 depicts the equivalent lumped circuit for SRR [3]. A complementary SRR structures were also proposed in many literatures. The resonant frequencies are determined by the geometrical parameters of the SRR [4-6].

B. SRR simulation experiment

SRR structures are investigated using CST EM tool. In this paper we have proposed SRR as an antenna for frequency agility with variations in the geometrical parameters. The first SRR is called as SRR1 in which the spacing between the two rings is small. The geometrical parameters for SRR1 are shown in Table 1. The second SRR called as SRR2 has been simulated with the smaller inner ring (ring2) as compared to SRR1. And the spacing between the rings is increased by an amount of 1 mm. Change in resonant frequency is observed from SRR1 to SRR2. Table 2 shows the dimensions of SRR2.

Table 1: Dimensions of SRR1

Parameter		Notation	Dimension (mm)
Substrate height		h	1.6
Substrate Length		L	14
Substrate width		W	14
Copper thickness		t	0.017
Spacing between rings		w	1
Split width		s	1
Ring1	Outer Radius	R_{01}	6
	Inner Radius	R_{i1}	5
Ring2	Outer Radius	R_{02}	5
	Inner Radius	R_{i2}	3
Ring width		d	1

Table 2: Dimensions of SRR2

Parameter	Notation	Dimension (mm)

Substrate height		*h*	1.6
Substrate Length		*L*	14
Substrate width		*W*	14
Copper thickness		*t*	0.017
Spacing between rings		*w*	2
Split width		*s*	1
Ring1	Outer Radius	R_{01}	6
	Inner Radius	R_{i1}	5
Ring2	Outer Radius	R_{02}	3
	Inner Radius	R_{i2}	2
Ring width		*d*	1

Fig. 3 shows the structure of SRR1 modeled in CST. As said above the SRR is formed by two coupled conducting rings, i.e., two concentric metal rings separated by a gap, each with a split at opposite sides. Pendry *et al.* in [7] calculated the fundamental magnetic resonant frequency of SRR using the transmission-line model method given by,

$$f_{SRR} = \frac{c}{2\pi^2}\sqrt{\frac{3w}{\varepsilon_r(R_0 - 2d - w)^3}} \tag{1}$$

$$\lambda_{gSRR} = 2\pi^2\sqrt{\frac{(R_0 - 2d - w)^3}{3w}} \tag{2}$$

Where, f_{SRR} is fundamental magnetic resonant frequency of SRR, λ_{gSRR} is the guided wavelength, ε_r is relative permittivity of dielectric substrate, *r* is the radius of the outer ring, *d* is the width of the metal lines, and *w* is the gap between the inner and outer ring. Fig. 4 shows the structure of SRR2 modeled in CST. In SRR2 the gap between inner and the outer ring is w = 2 mm while in SRR1, it is 1 mm.

Changing the distance between the outer and inner rings will change the mutual capacitance and mutual inductance between the rings. An analytical model by Sauivac *et al.* [8] proposes that increasing the gap distance, decreases both mutual capacitance and mutual inductance of the equivalent L–C circuit of SRR. By following the model given in [8], the resonant frequency is found to increase with increasing gap distances, that agrees with the results of experiments.

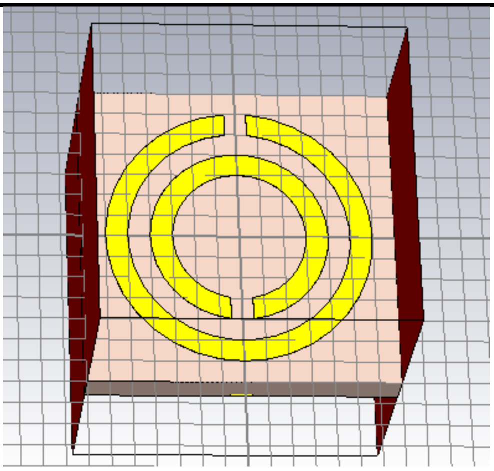


Fig. 3: SRR1 structure in CST

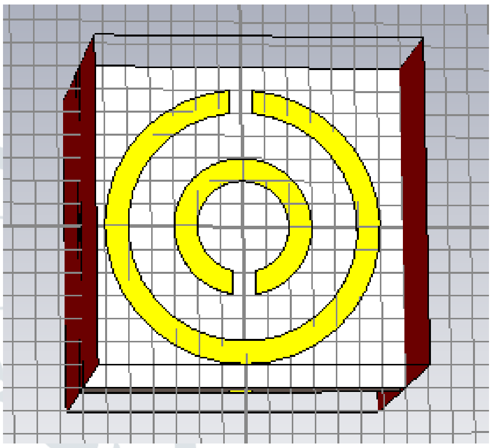
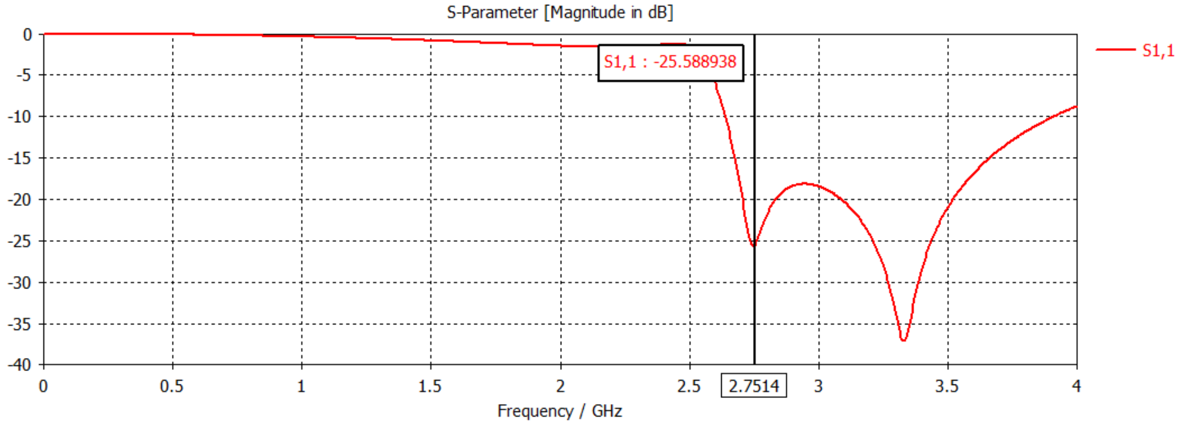


Fig. 4: SRR2 structure in CST

III. RESULTS AND DISCUSSION

The simulation results for SRR1 show the dual resonant frequencies one at 2.75 GHz with approximately 25dB down from zero and another at 3.328 GHz with approximately 37dB down. The frequency shift is about 0.5766 GHz. And these frequencies are above 2.4 GHz ISM bands. The variation of S-parameter, S_{11}, the reflection coefficient with frequency are shown in Fig. 5 and Fig. 6. It can also be observed the bandwidth supported is higher.

The simulation results for SRR2 show the dual resonant frequencies one at 2.375 GHz with approximately 19dB down and another at 3.42 GHz with approximately 34 dB down as shown in Fig. 7.



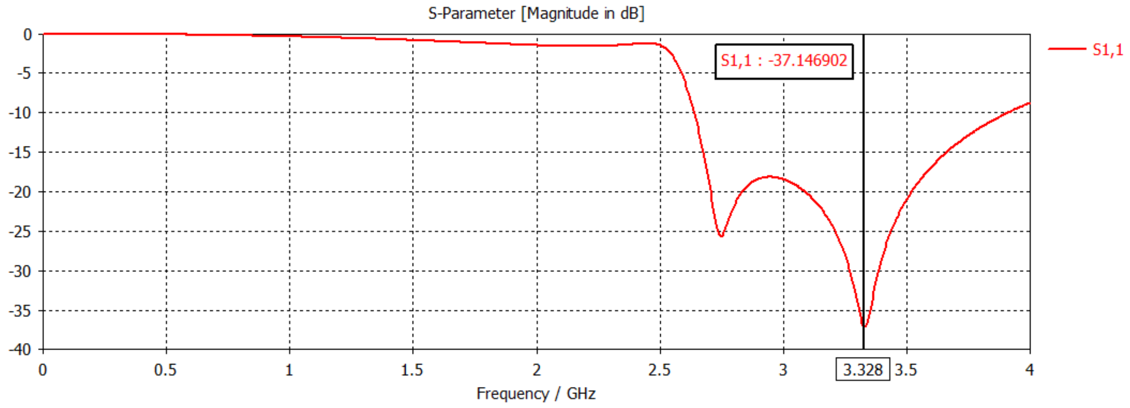


Fig. 5: S_{11} variation with frequency for first band of SRR1.

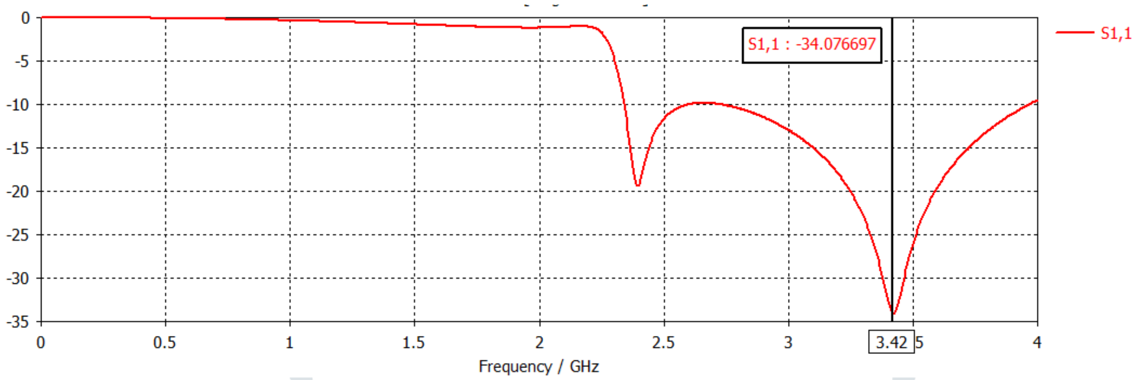


Fig. 6: S_{11} variation with frequency for second band of SRR1.

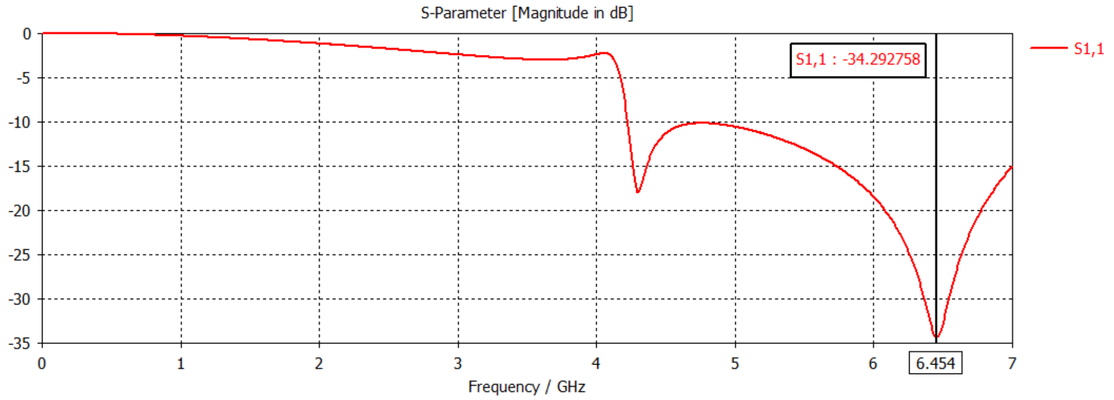


Fig. 8: S_{11} variation with frequency of SRR3.

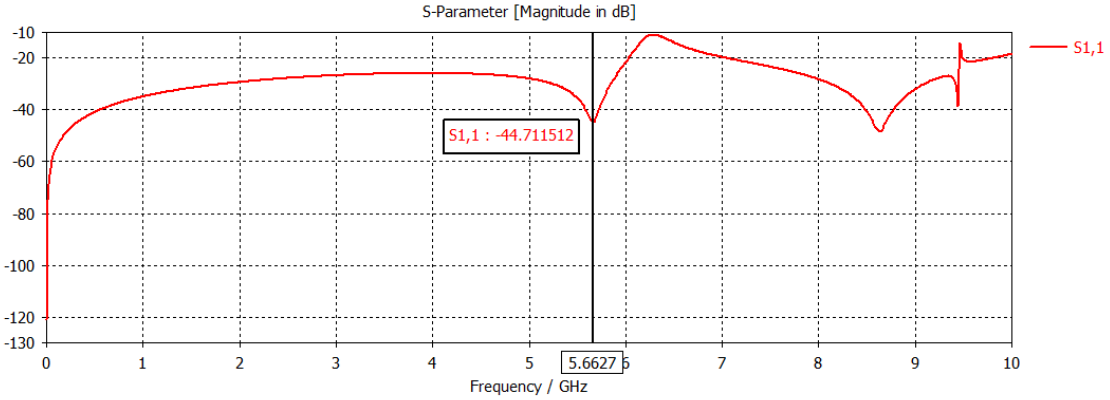


Fig. 9: S_{11} variation with frequency of array of two SRRs.

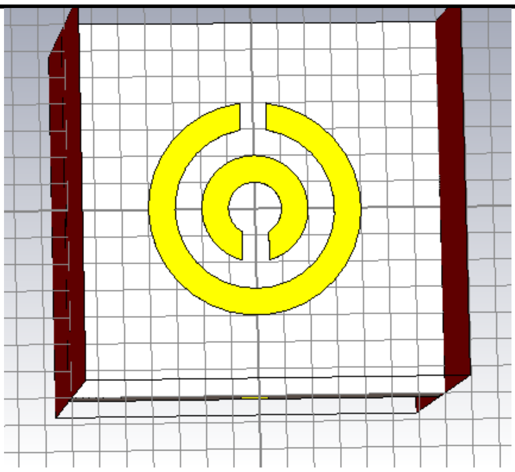


Fig. 10: SRR3, reduced ring radius.

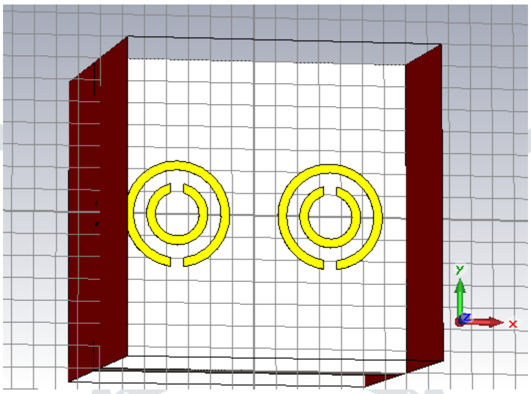


Fig. 11: Array of two SRRs.

Fig. 8 shows the variation of reflection coefficient, S11, with frequency for the SRR3 shown in Fig. 10. Here both ring radii are reduced. Ring 1, the outer one, has inner radius of 3 mm and the ring 2, the inner one, has inner radius of 1 mm. As the SRR size is reduced there is increase in resonant frequency of the antenna. The magnetic resonance is observed at 4.175 GHz and the second band at frequency 6.454 GHz.

The total capacitance of the SRR arises from the splits in each ring and the gap between the concentric rings. Inductances arise from gap between inner and outer rings and the conducting rings [9]. The values of capacitance and inductances contribute to the magnetic resonance of the SRR.

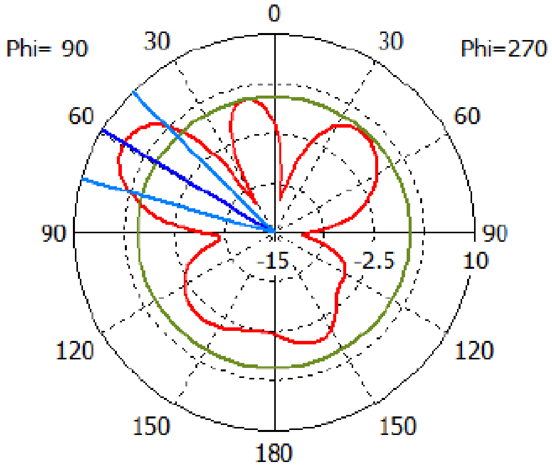


Fig. 12: Radiation pattern of array of two SRRs at 5.66GHz

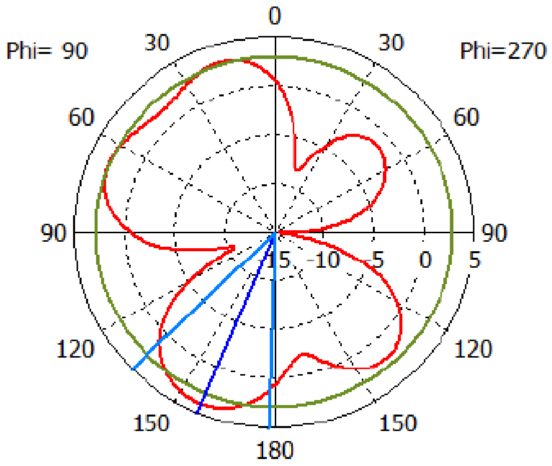


Fig. 12: Radiation pattern of array of two SRRs at 8.64GHz

Fig. 9 shows the S_{11} variation of an array of two SRRs. This has magnetic resonance at 5.66 GHz and 8.64 GHz. Such metamaterial microstrip antennas find applications in cognitive radio systems for channel allocation in TV band white spaces and satellite microwave channels. Fig. 11 shows the array of two SRRs built in CST. The width of the ring is reduced to half of that of the previous single SRR i.e., 0.5 mm. The inner radius of the inner rings is kept as 1 mm and the outer radius is 1.5 mm. The inner radius of the outer ring is 2 mm and the outer radius is 2.5 mm. The selected substrate is FR4 material. The thickness of substrate is same for all SRRs, 1.6 mm.

Fig. 11 and Fig. 12 show the radiation patterns of array of two SRRs obtained at 5.66 GHz and 8.64 GHz. The main beams are in 60^0 and 160^0 directions as evident from the figures. The patterns are near isotropic.

CONCLUSION

We have analyzed four microstrip split ring resonators of different sizes. The difference between first and second SRR is in the gap between the two rings. It's been observed that as the gap is increased, there is increase in the separation between the two bands. And as the total size is of the SRR is reduced, the magnetic resonant frequency shifts to higher value. And as the unit cell size is reduced and an array is formed with two SRR unit cells, there is a shift in frequency to higher value as well as the separation between the two bands also increased. This analysis of the SRRs satisfies the theory of metamaterial split ring resonator as antennas proposed in various publications. The reflection coefficient variation for each of the SRRs as shown in figures give the magnetic resonance and hence the radiation frequency of the metamaterial antenna. The radiation patterns are shown for the array only. Higher radiations are possible, that is above 3 dB, in a particular direction. Side lobes are also observed in other directions.

These type of split ring resonator antennas are used in software defined radios and cognitive radios specially, where frequency reconfiguration is required for transmission in different free channels. The future work relies on a novel method to change the size of SRR and the gap between the rings in SRR.

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