Resonant Characteristics of Split Ring Resonator and Unit Cell for Periodic Metamaterial Devices

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***Abstract*—The resonant characteristics of single split ring resonator-based metamaterial devices with single gap are presented using the analytical formulation developed for the lumped element equivalent circuit model. The characteristics of the metamaterial resonators have been investigated for different ring sizes, gap widths and substrate permittivity. Equivalent circuit model is developed for two ring structures. The analytical, and simulation results are compared and verified. The prototype has been then built and measured. It has been observed that all the results agree. The results presented in this paper can be used to develop devices at the THz range that can operate as sensors, antennas or tuning elements.**

***Keywords*—Gap, metamaterials, resonate, resonator, ring, sensor, split ring, THZ.**

I. INTRODUCTION

Split ring Resonator (SRR) is a conducting ring with a split printed on a dielectric substrate. This structure creates characteristics of metamaterial which can generate desired magnetic response up to 200 terahertz [1, 2]. Split ring resonator structures are also called artificial left-handed materials which was primarily discovered in the seventies [3]. In [4], researchers examined split ring structures for negative permittivity and permeability.

Split ring resonators can be modeled as LC circuit as reported in [5]. In [6], authors formulated circular split ring resonator with two rings and showed the accuracy of the formulation. In last two decades, different types of split ring resonator are being proposed. Edge-coupled SRRs (EC-SRR) are proposed in [6]. This structure is also formulated with simple closed form equations in [6]. Another type of SRR is the broadside-coupled SRR (BC-SRR) which was proposed in [7]. Difference between these two structures is that EC-SRR has two rings on the same side of the substrate whereas in BC-SRR two rings are on the opposite side. Multiple split ring resonators are formulated and designed to increase the capacitance without increasing the size [8]. Periodic structures are being studied recently because of their higher symmetric property than the unit cells [9, 10].

In this paper, characteristics of a single gap ring resonator are analyzed for different parameters such as ring radius, gap width and substrate permittivity. A unit cell (with two rings) is proposed to form a periodic structure. An equivalent circuit model is developed for the proposed design. Prototype is built and measured which gave similar results obtained in simulation. The novelty of this work is a simplified analytical model based on the physical dimension for one ring SRR and equivalent circuit model for a two-ring unit cell.

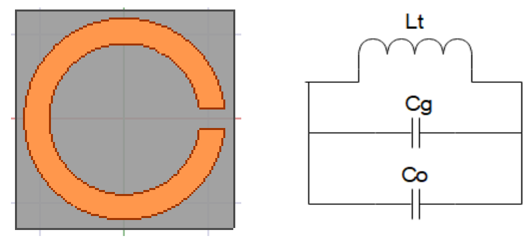

Fig. 1. SRR structure with equivalent circuit .

II. CHARACTERISTICS OF SRR RESONANCE

The dimensions of geometry of single gap split ring resonator and equivalent circuit are shown in shown in Fig. 1. Circuit parameters are calculated from,

$$L_T = 0.002\,(\ln\frac{4l}{c} - \gamma)\ \mu H, \tag{1}$$

$$C_{eq} = C_g + C_o = \varepsilon_o\frac{ct}{g} + l_{avg} \times \frac{\sqrt{\varepsilon_e}}{c_o Z_o}. \tag{2}$$

The resonant frequency of the total structure is,

$$f_o = \frac{1}{2\pi\sqrt{L_T C_{eq}}}, \tag{3}$$

where, t= ring thickness, h= substrate height, rext=ring external radius, g=gap, and ε_r = substrate permittivity.

Effect of changing ring parameters on the resonant frequency is studied. The resonant frequency decreases with the increasing the value of the external ring radius as shown in Fig. 2. It is observed that to get higher resonating frequency ring radius should be decreased.

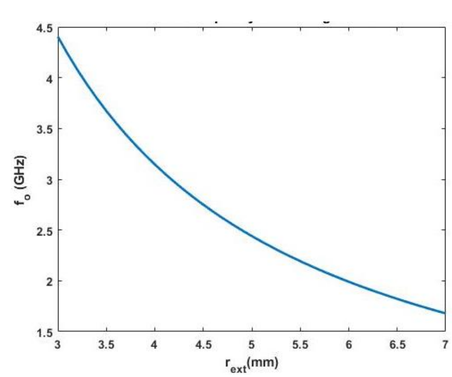

Fig. 2. Calculated resonant frequency for rext = 3mm to 7mm, c = 1.2 mm, t = 0.0175 mm, g = 0.8 mm, h = 1.27mm, εr = 4.4.

The resonant frequency is also dependent on the gap size. With increasing the gap, capacitance increases, hence the resonant frequency decreases as shown in Fig. 3. Substrate

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material permittivity also has effect on the resonant frequency. Higher substrate permittivity gives lower capacitance and so increases the resonant frequency as illustrated in Fig. 4.

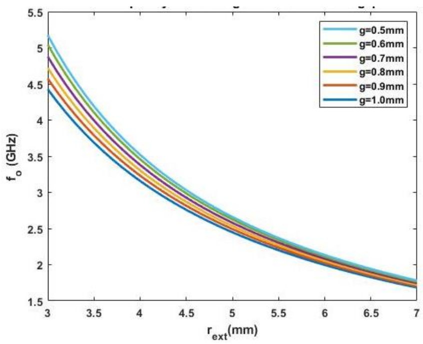


Fig. 3. Calculated resonant frequency for rext = 3mm to 7mm, c = 1.2 mm, t = 0.0175 mm, h = 1.27mm, εr = 4.4 with different gap.

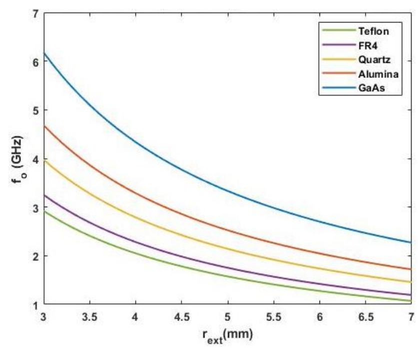


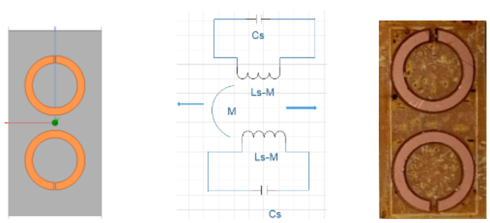
Fig. 4. Calculated resonant frequency for different substrate with rext = 3mm to 7mm, c = 1.2 mm, t = 0.0175 mm, g = 0.8mm, h = 1.27 mm.

III. Two Rings Unit Cell

We developed a unit cell with two rings for infinite periodic structures. Two magnetically coupled rings are considered as unit cell as shown in Fig. 5 (a) for the periodic structure [10]. Equivalent circuit is shown in Fig. 5 (b). Mutual inductance between two rings is considered for intra-unit cell and inter-unit cell. ABCD matrix is also developed.

ABCD parameters of the unit cell are,

$$ABCD = \begin{bmatrix} 1 & -j\frac{\omega^3(L_S-2M)C_SL_S-\omega(L_S-M)}{\omega^4(L_S-2M)C_S^2L_S-1} \\ 0 & 1 \end{bmatrix}. \qquad (4)$$



(a) (b) (c)

Fig. 5. (a) Two rings as a Unit Cell, (b) Equivalent Circuit of unit cell, and (c) Fabricated structure.

IV. Measurement

We built a prototype for two ring unit cell using PCB milling machine with FR4. Due to milling machine capability, the prototype is built at the milli meter scale. To get THz frequency, resonators must be built at the micrometer scale. To measure the prototype, rectangular waveguide is used. Measured results shown in Fig. 6 are aligned with the EM simulation and circuit simulation.

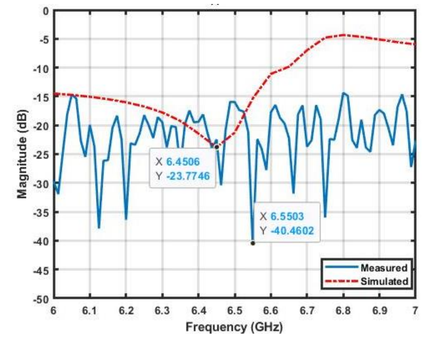


Fig. 6. Comparison of Simulation and Measured resonant frequency for two ring unit cell with rext = 5mm, c = 1.2 mm, t = 0.0175 mm, g = 0.8 mm, h = 1.27 mm , εr = 4.4.

V. Conclusion

In this paper, we analyzed resonant characteristics of SRR with varying parameters like ring radius, gap width and substrate permittivity. A two rings unit cell is developed with network parameters which can be used to build infinite periodic structure. Our measurement results agree with the EM and circuit simulation results. This unit cell can be used to build periodic structure for sensors operating at the THz range.

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