A Study on the Novel Rectangular Split Ring Notch Resonators

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Abstract— In this paper, a novel notch resonator is proposed based on Rectangular Split Ring Resonator (R-RSS) element. We represented the electrical characteristics for R-SRR elements coupled with microstrip line, and measured result is compared with electromagnetic simulation (HFSS) result. We also solved equivalent circuit for R-SRR element, and also discussed influences of change structural parameters of R-SRR. The size of R-SRR is the most important parameters for frequency tuning. Also we can make tunable resonator form the basic structure. This novel resonator can apply to design of tunable bandpass filter and voltage control oscillator.

Index Terms— metamaterials; notch resonator; Rectangular Split Ring Resonator (R-SRR); tunable filter

I. INTRODUCTION

Resonator forms the basic design elements in many circuit components including filter, oscillator, couplers and antennas. Planar resonators offer several advantages over conventional rectangular/circular waveguide resonators including size, weight and cost. The microstrip resonator was introduced by Troughton [1] in 1968. Since its introduction, the microstrip resonator has been used widely.

Recently, metamaterials attracts increasing interest in the engineering and scientific communities. The metamaterials is an artificial structure which does not exist in nature. Therefore, it provides another method and concept to develop various kinds of microwave circuits and its application. As important part of metamaterials, split ring resonators (SRRs) have attracted many interests in recent years as key constituent particles for the design of effective media with negative magnetic permeability or left-handed metamaterials (LHM). Originally proposed by Pendry [2], SRRs are sub-wavelength resonators able to inhibit signal propagation in a narrow band in the vicinity of their resonant frequency, provided the magnetic field is polarized along the axis of the ring. Recent strong experimental efforts have been directed towards the attainment of metamaterials with negative response in the Terahertz [3] and even optical [4, 5] frequency domain.

In this paper, we proposed a novel notch microstrip resonator based on Rectangular Split Ring Resonator (R-RSS) element. A 50 Ohm microstrip line is on the top with one R-SRR element. In this work, we essentially compared the measurement with electromagnetic simulations. The simulated performance was obtained using simulator HFSS (V10), and measurement is accomplished with Anritsu MS4644A network analyzer. The measured results and simulation result show the good characteristic. And we also discussed the different influence of different parameters. Numbers of R-SRR cell, the gap between microstrip line and R-SRR cell, and the size (including the width of cell) of the cell are discussed. Using HFSS, we can get the results for different parameters. The size of R-SRR (including the width of cell) is the most important parameters for frequency tuning. Resonant frequency is changed widely when the size of cell changed. This resonator we proposed can be used in oscillator and bandpass filter. Also we can make tunable resonator form the basic structure.

II. R-SRR ELEMENT

The basic cell of the structure is represented in Fig. 1. R-SRRs can be modeled as LC resonant tanks that can be externally driven by a magnetic field and are therefore able to inhibit signal propagation in a certain narrow band if they are properly oriented [6]. R-SRRs also exhibit cross-polarization effects (magneto-electric coupling). Since the equivalent capacitance is given by the edge capacitance between concentric rings, the resonant frequency can be made very small by decreasing the rings' separation(g). In recent papers [7-11], the equivalent circuit model of a basic cell of SRRs is shown in Fig. 2. As shown in Fig. 2, L_r is effective inductances; C_L is effective capacitance. The parameters affecting the characteristic of R-SRR cell include the shape, size, gap and so on.

We designed one sample structure to measure the characteristics of R-SRR element as shown in Fig. 3. The 50 ohm microstrip line is electrically coupled with one R-SRR cell. The substrate is Teflon with dielectric constant $\varepsilon_r=2.3$, thickness h=31mil). All dimensions of structure are B=50mm, s=0.2mm, D=16mm, w=2.36 mm, and g=c=d=1.5mm. The photograph of fabricated is shown in Fig. 4. The simulated characteristic was obtained using simulator HFSS (V10), and measurement is accomplished

with Anritsu MS4644A network analyzer. The simulated and measured results are shown in Fig.5. Referring to the measured results, the resonant frequency is about 2.02GHz. The insertion loss is mainly about -15dB. Good agreement between the simulation and measurement is achieved.
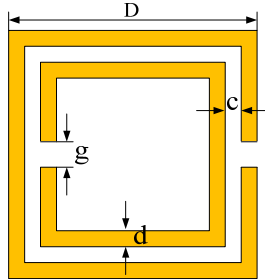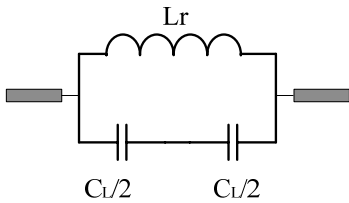

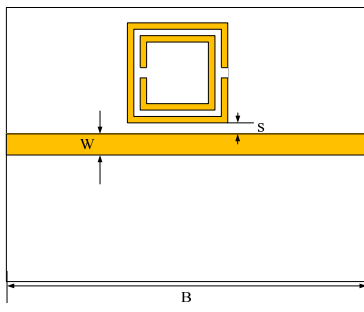Fig.1 R-SRR element

Fig. 2 Equivalent Model of R-SRR cell

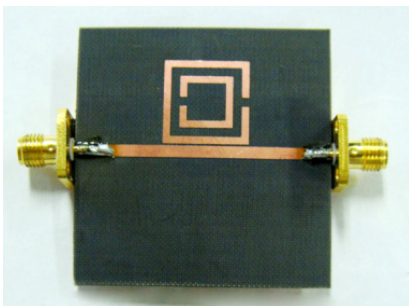Fig. 3 Test Sample for R-SRR
(B=50, s=0.2, D=16, g=c=d=1.5, w=2.36 mm)
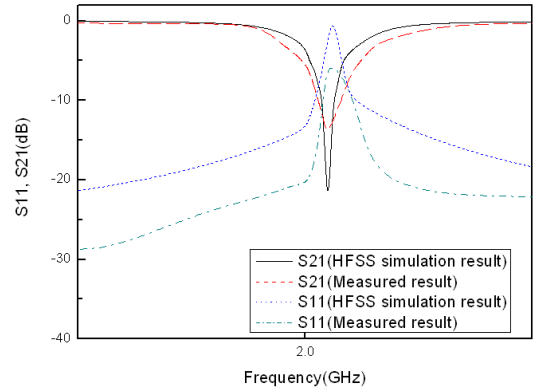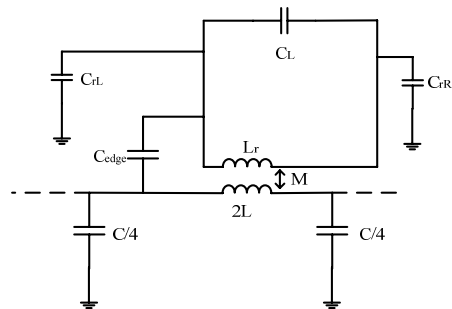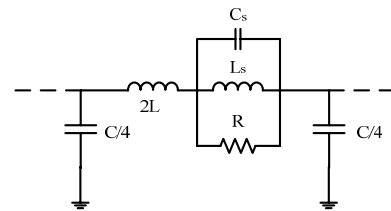

Fig. 4 Photograph of R-SRR with one cell

Fig. 5 Characteristics Results of R-SRR

III. EQUIVALENT CIRCUIT FOR R-SRR ELEMENT

The R-SRR resonator equivalent circuit model is depicted in Fig. 6. C_r and C_L are the edge capacitances corresponding to the equivalent of R-SRR cell; L_r is inductance corresponding to the equivalent of R-SRR cell. Both couplings have been properly modeled by means of a mutual inductance M (magnetic coupling) and the edge capacitance between the line and the external ring C_{edge} (electric coupling). C_{rL} and C_{rR} are small. Except for the mutual inductance M, the other element values have been estimated either through geometrical considerations or with the help of the commercial software Agilent ADS. The simplified equivalent circuit model of Fig. 6(a) can be further simplified to that shown in Fig. 6(b).

(a) Equivalent Model of R-SRR

(b)Simplified circuit

Fig. 6 Equivalent circuit of R-SRR

Using the equation (1) to (7), we can calculate the simplified equivalent circuit element values. The voltage-current equations for the transformer are first derived, i.e.,

$$V(j\omega) = j\omega 2LI_1(j\omega) + j\omega MI_2(j\omega) \qquad (1)$$

$$-I_2(j\omega)Z_a(j\omega) = j\omega 2MI_1(j\omega) + j\omega L_r I_2(j\omega) \qquad (2)$$

where Z_a is the impedance of C_L, namely,

$$Z_a(j\omega) = \frac{1}{j\omega C_L} \qquad (3)$$

By isolating I_2 in (2) and substituting it into (1), we directly obtain the series impedance of the line

$$Z_S(j\omega) = j2\omega L + \omega^2 M^2 \left\{ \frac{j\omega C_L}{1 - \omega^2 L_r C_L} \right\} \qquad (4)$$

This impedance is equivalent to the series connection of an inductor (with inductance 2L) and a parallel RLC tank, provided the following conditions are satisfied:

$$L_s = \omega_0^2 M^2 C_L \qquad (5)$$

$$C_s = L_r / \omega_0^2 M^2 \qquad (6)$$

$$R = \omega_0^2 M^2 / R_s \qquad (7)$$

We can get the element values from equations: C_L =1pF, L_r=3.81nH, C_{rL}=1pF, C_{rR}=1pF, L=1.8975nH, C_{edge}= 0.792pF, C=3.6pF. The circuit simulation result using the ADS tool of Agilent is compared with others in Figure 7. It is agreed with measured and HFSS simulation result as shown in Figure 7.
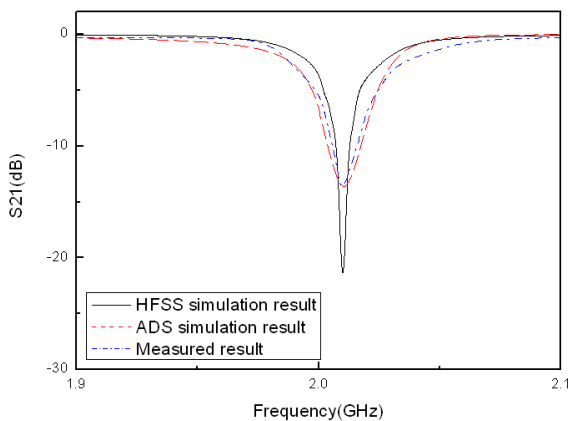

Fig. 7 Simulation Results and Measured Results

The insertion loss of a conventional bandstop resonator is given by:

$$IL = 10\log\left[1 + \frac{1 + 4R}{4R^2 + 4Q_u^2 R^2 \left[\dfrac{\omega}{\omega_0} - \dfrac{\omega_0}{\omega} \right]} \right] dB \qquad (8)$$

The 3-dB bandwidth is:

$$\Delta_{3dB} = \omega_0 \sqrt{\frac{1 + 4R - 4R^2}{4Q_u^2 R^2}} \qquad (9)$$

Now let $\dfrac{\omega_0}{\Delta_{3dB}} = \dfrac{Q_u}{2}$ equal to (9)

$$\frac{2}{Q_u} = \sqrt{\frac{1 + 4R - 4R^2}{4Q_u^2 R^2}} \qquad (10)$$
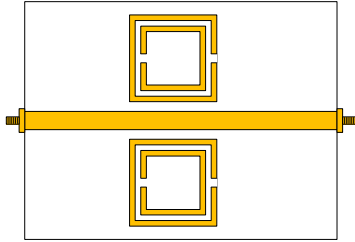
Therefore at ω_0:

$$IL = 10\log\left[1 + \frac{1 + 4R}{4R^2} \right] \qquad (11)$$
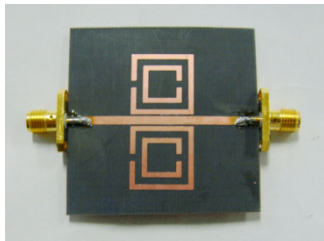
IV. DISCUSSION for R-SRR CELL PARAMETERS

In this section, we discuss some parameters of R-SRR cell to get the most important influence one for the notch resonator. First, we changed the numbers of R-SRR cell. In Fig. 8, we changed the cell number into two and four. All the dimensions are the same with previous proposed structure. We also use simulator HFSS to get the simulation results. The simulation results are shown in Fig. 9. The resonant frequencies for different cell number are nearly the same; frequency difference among them is about maximum 10MHz. One cell resonant frequency is 2.03GHz, resonant frequency for two cells is 2.023GHz, and resonant frequency for four cells is 2.012GHz. According to increase number of cell, there are coupling capacitances between cells, so the resonant frequency is move to lower a little bit. But, if the gap between cells is enough, we can ignore the influence of coupling capacitance between cells. According to the analysis of equivalent circuit, even if cell numbers are changed, capacitance C_L and inductance L_r have not changed. Due to the cell number, the S21 insertion loss has changed.

The second parameter we will discuss is the size D of cells between in Fig. 1. We choose the different size of D (12cm, 16 cm and 20 cm). In Fig. 10, the simulation results are presented (use HFSS V10). The resonance
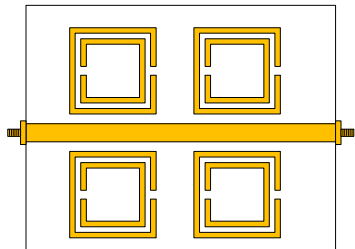
frequencies are 2.02, 1.5, 1.3GHz for D=16, 12, 20mm. The insertion loss also has different. From the frequency, there is a big different value. And according to the equivalent circuit, we can conclude that there is big influence with the size.

(a) Proposed R-SRR with two cells

(b) Photograph of R-SRR with two cells

(c) Proposed R-SRR with four cells
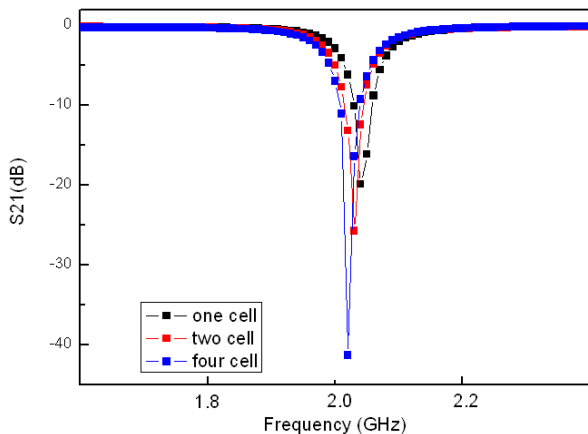
Fig. 8 R-SRR Structures

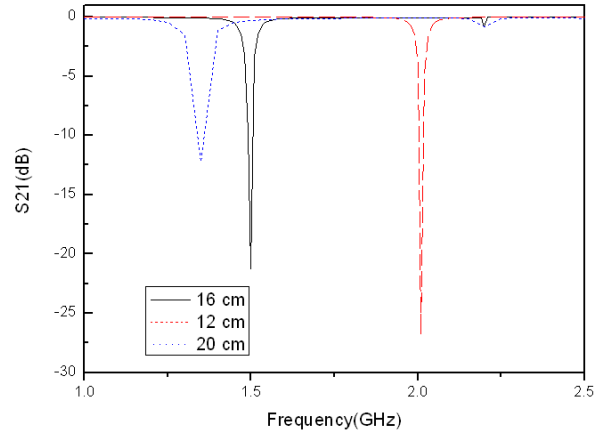Fig. 9 The simulation results with different cell numbers

Fig. 10.The simulation results with different cell size

IV. CONCLUSIONS

In summary, it has demonstrated that a compact notch filter has been presented, simulated and measured. The measured results and simulation result show the good characteristic. And we also discussed the different influence of different cell parameters. Numbers of R-SRR cell, and the size (including the width of cell) of the cell are discussed. Using HFSS V10, we can get the results for different parameters. The size of R-SRR (including the width of cell) is the most important parameters for frequency tuning. Resonant frequency is changed widely when the size of cell changed. This resonator we proposed can be used in oscillator and bandpass filter. Also we can make tunable resonator form the basic structure.

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