academicJournals

Vol. 8(37), pp. 1857-1861, 9 October, 2013
DOI: 10.5897/IJPS2013.3952
ISSN 1992 - 1950 © 2013 Academic Journals
http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Full Length Research Paper

A tuneable metamaterial design using microelectromechanical system (MEMS) based split ring resonator (SRR)

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Accepted 26 September, 2013

In this paper, we present a study of tuneable equilateral triangular shaped spilt ring resonator (ETSRR). In this ETSRR we rotate the inner and outer rings by varying the position of the splits in rings. For this we used radio frequency microelectromechanical system (RF MEMS) switches. By making MEMS switches ON/OFF, the positions of splits in the rings were varied which can be considered as rotation of rings. As we rotate the inner and outer rings (by varying the position of splits), the configuration is tuned to different frequency from its basic configuration, thus we get tunability.

Key words: Split ring resonator (SRR), metamaterials, equilateral triangle, radio frequency microelectromechanical system (RF MEMS) switch.

INTRODUCTION

Nowadays, metamaterial becomes most popular among the researchers because it shows simultaneously negative values of effective permittivity (ε_{eff}) and effective permeability (μ_{eff}) over a common frequency band. Metamaterials are also regarded as left handed materials (LHMs) or negative refractive index materials (NIMs) because these materials exhibits the properties like backward propagation, reverse Doppler effect and reverse Vavilov - Cerenkov effect which are not possessed by natural material (Ziolkowski, 2003). The negative values of effective permittivity (ε_{eff}) can be obtained by using metal rod and effective permeability (μ_{eff}) can be obtained by Split ring (Huang et al., 2010). The design of metamaterial based on shape and geometry is most popular work among the others. Various types of ring type structures like circular, square, U-shaped, S- shaped, Ω- shaped, elliptical shaped, phi-shaped (Sharma et al., 2011) have been proposed till now. The split ring resonator (SRR) structures which are most famous, circular or rectangular. The triangular shaped metamaterial resonator was first studied by Sabah and Uckun (2008) although now few studies are there in literature (Zhu et al., 2009; Jalali et al., 2009; Sabah, 2010). Metamaterials can also be used in antenna designing to enhance the gain and directivity of the antennas (Wu et al., 2005; Lee and Hao, 2008; Gil et al., 2006; Qureshi et al., 2005).

Compared to PIN diodes and FET transistors, RF MEMS switches have better performance in terms of isolation, insertion loss, power consumption and linearity (Muldavin et al., 2000a, 2000b).

Wang et al. (2008) purposed a theory about SRR with

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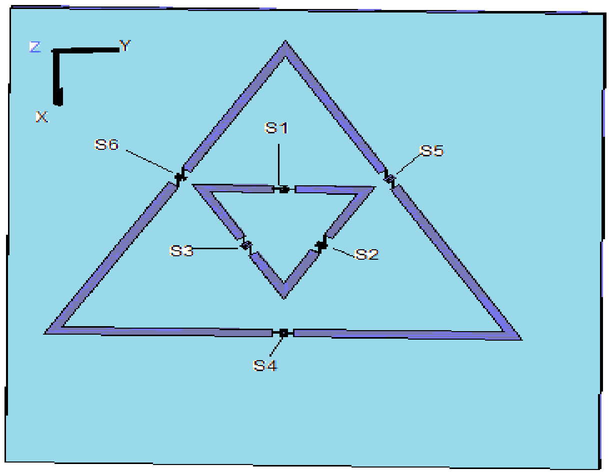

Figure 1. Equilateral triangular spilt ring resonator with splits and RF MEMS switches in each arm.

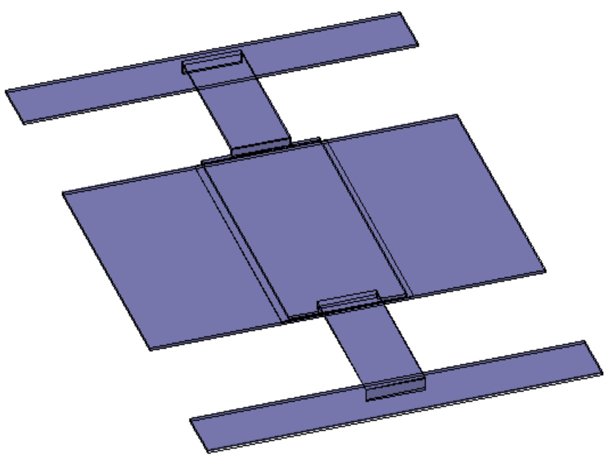

Figure 2. The structure of RF MEMS shunt switch.

rotated inner ring to analyze the controllability of its magnetic resonant frequency. The inner ring was rotated by means of control bars and by rotation of inner ring as the angle between the two splits decreases magnetic resonant frequency increases.

Sabah (2010) proposed tuneable metamaterial (MTM) structure composed of triangular spilt ring resonator and wire strip. These MTMs are formed from FR4 and RT/duriod 5880 substrates show tunability in terms of substrate thickness. The results shown are very promising.

The rotation of rings can also be achieved by putting splits in each arm of rings and then the position of splits can be made ON/OFF by using MEMS switches. By this, the magnetic resonant frequency gets shifted and thus getting tunability.

In present paper, authors have obtained frequency tuneable MTM triangular SRR (Sabah, 2010) by rotating the inner (Wang et al., 2008) and outer ring. The rotation of rings is implemented by change in position of splits in each arm by using MEMS switches. Excellent performance is achieved.

DESIGN

In this design, RogersRT /duriod5880 (relative permittivity = 2.2) is used as a substrate with a thickness of 0.8 mm .The length and width of the substrate is 28 and 30 mm, respectively. The dimensions of outer ETSRR base length is 22.52 mm and height is 19.5 mm; 8.66 and 7.52 mm for inner ETSRR.

The separation between outer and inner ETSRR is 9.5 mm from vertex of outer ETSRR to base of inner ETSRR. The width of each strip is 0.5 mm. The split gap in each ETSRR is 1.0 mm. Splits are made at each arm of inner and outer ETSRR along with RF MEMS switches placed in each split. Switches S1, S2, S3 are placed in inner ETSRR and switches S4, S5, S6 are placed in outer ETSRR. The proposed design is shown in Figure 1.

The structure of RF MEMS shunt switch (Figure 2) consist of thin metal (gold in this case) membrane bridge that is suspended over the central conductor of coplanar waveguide (CPW) and fixed on the ground conductor. The dimensions of shunt switch are: length of the bridge = 200 µm, width of the bridge = 90 µm, thickness of the bridge = 2 µm, silicon nitrate (relative permittivity = 7) is used as the dielectric having a thickness of 0.2 µm, air gap between lower conductor and upper conductor is 0.9 µm.

When a switch is in ON position in a particular arm, that means there is no split in that particular arm; whereas, when the switch is in OFF position, then it means there is presents of a split in that arm. The whole structure is designed and placed in two port waveguide formed by a pair of both perfect magnetic conductor (PMC) walls in z-direction and perfect electric conductor (PEC) walls in y-direction. The whole structure is excited by an electromagnetic wave with propagation vector in x-direction. The structure is designed and simulated by using Ansoft HFSS simulator, finite element based electro-magnetic mode solver.

To show the physical properties of the designed structure, S parameters are calculated and effective permeability is extracted by using effective parameter retrieval method (Smith et al., 2005).

ANALYSIS AND DISCUSSION

Metamaterials type structures can be considered as LC resonant circuit whose resonance frequency can be determined by $\omega = 1/\sqrt{LC}$. When the switch S4 was OFF in outer ETSRR and switch S1 was OFF in inner ETSRR, while rest of switches were ON (Figure 3a); the

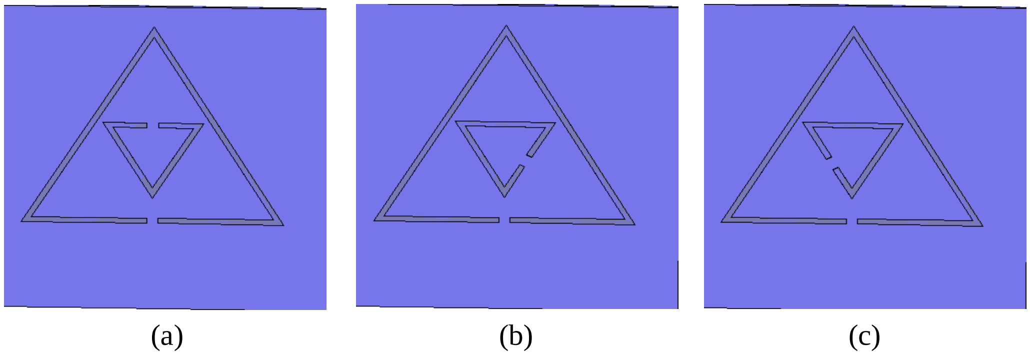

Figure 3. ETSRR Configuration: When switch S4 in outer ETSRR is OFF and (a) switch S1, (b) switch S3, (c) switch S2 in inner ETSRR are OFF; and rest of the switches are ON.

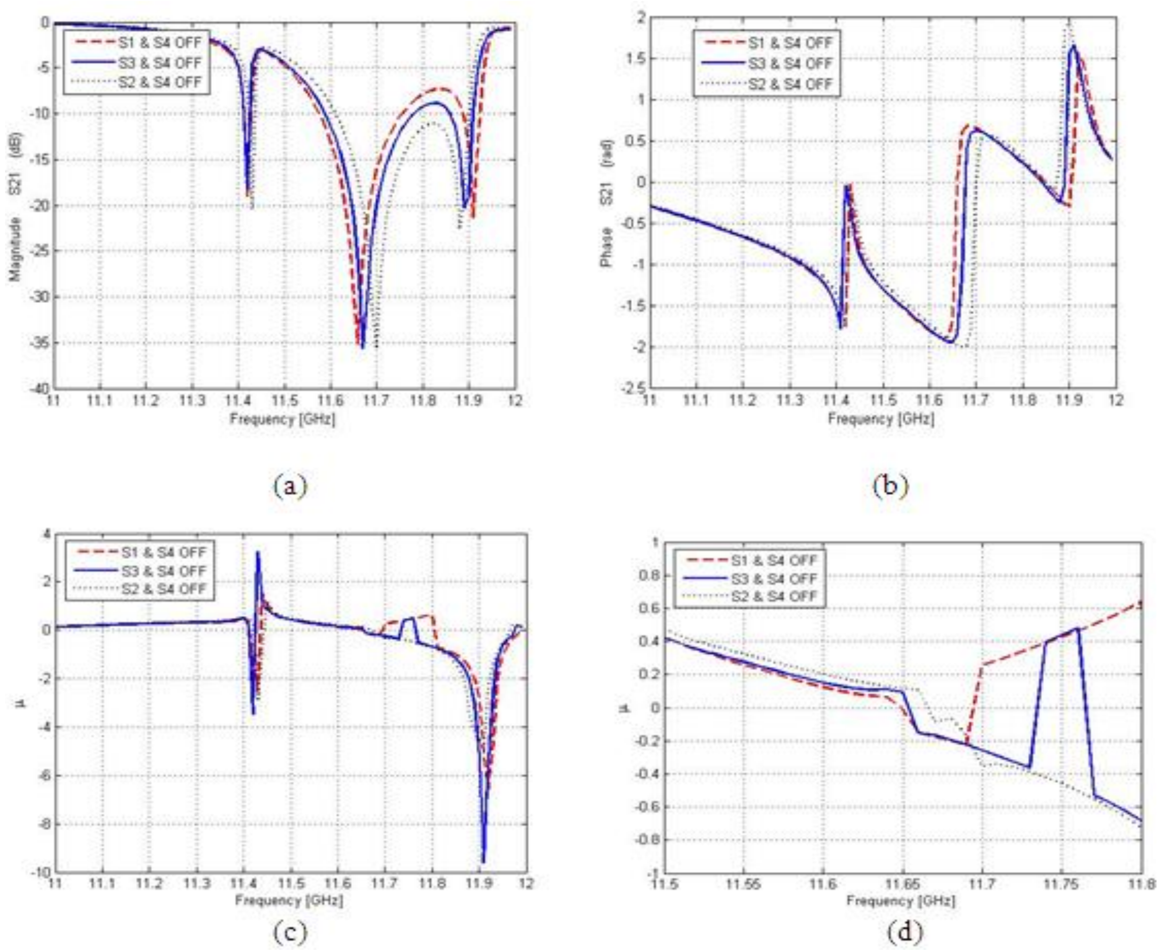

Figure 4. (a) minimum of transmission (S_{21}) in dB, (b) dip in phase of S_{21} (rad), (c) effective permeability, (d) Zoom of effective permeability.

minimum of transmission (S_{21}) was observed at 11.66 GHz (Figure 4a, red curve), the dip in phase of S_{21} was observed at 11.63 GHz, (Figure 4b), red curve), negative permeability occurred in frequency regime 11.65 GHz ~ 11.69 GHz (Figure 4c), red curve), but they overlap each other at frequency 11.66 GHz. Because of negative permeability, EM waves cannot transmit through the structure which result in dip in transmission spectrum. In the original ETSRR the angle between two splits is π.

Now, when we rotated the inner ring by making the

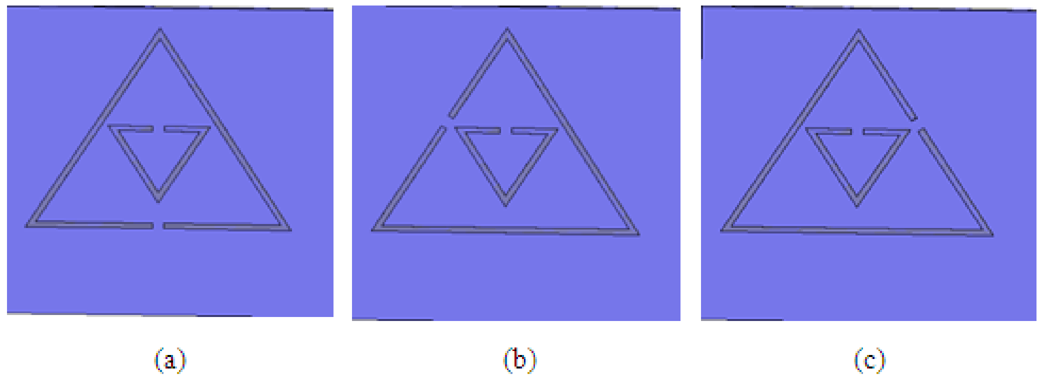

Figure 5. ETSRR Configuration: When switch S1 in inner ETSRR is OFF and (a) switch S4, (b) switch S6, (c) switch S5 in outer ETSRR are OFF; and rest of the switches are ON.

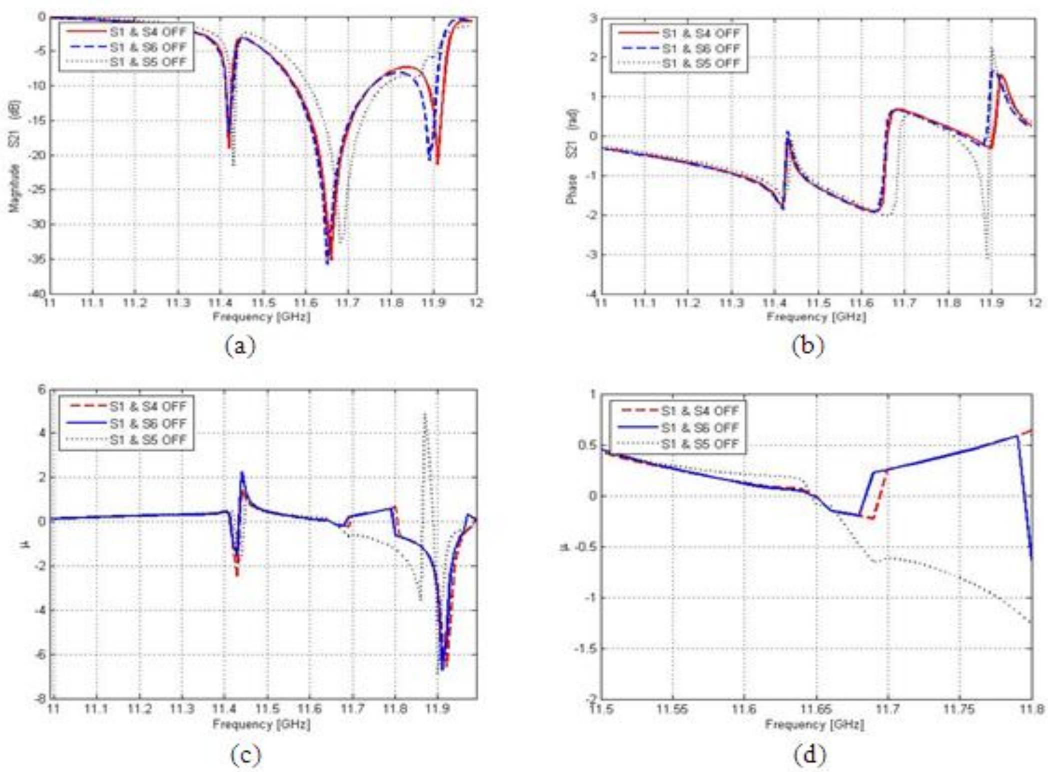

Figure 6. (a) minimum of transmission (S_{21}) in dB, (b) dip in phase of S_{21} (rad), (c) effective permeability, (d) Zoom of effective permeability.

switch S1 transit from OFF to ON position and S3 or S2 were transited from ON to OFF position in inner ETSRR (S4 in outer ETSRR remained OFF) while rest of the switches remained as they were (Figure 3b, c); the minimum of transmission (S_{21}) were shifted to higher frequency 11.67 GHz (Figure 4a) blue curve) and 11.70 GHz (Figure 4a) black curve), and the dip in phase of S_{21} were also shifted to higher frequency (Figure 4b) blue and black curve); accordingly, the negative permeability frequency regime shifted to 11.66 GHz ~ 11.73 GHz (Figure 4c, blue curve) and 11.67 GHz ~11.96 GHz (Figure 4c, black curve), respectively. Thus, by rotating the inner ring, the angle between the two splits decreases, so the resonant frequency shifted to higher side.

When we rotated the outer ring by making the switch S4 transit from OFF to ON position and S6 or S5 were transit from ON to OFF position in outer ETSRR (S1 in inner ETSRR remained OFF) while rest of the switches remained as they were (Figure 5b, c); the minimum of transmission (S_{21}) were shifted to higher frequency 11.65 GHz (Figure 6a, blue curve) and 11.68 GHz (Figure 6(a) black curve), and the dip in phase of S_{21} were also shifted to higher frequency (Figure 6b, blue and black curve); accordingly, the negative permeability frequency regime shifted to 11.65 GHz ~ 11.68 GHz (Figure 4(c) blue curve) and 11.65 GHz ~11.86 GHz (Figure 4(c) black curve), respectively. Thus, by rotating the outer ring, the angle between the two splits decreases, so the resonant frequency shifted to higher side.

Thus, we can control the magnetic resonant frequency by rotating the inner and outer ETSRR. In each case, the configuration is tuned to different frequency. If we compare this with purposed technique in Sabah (2010) in which he got tunability by varying the substrate thickness; the technique presented in this paper is easy to get tunability because in this we rotate the rings by means of MEMS switches (making then ON/OFF to make splits present or not); as well as from technique presented in Wang et al. (2008) in which they rotated the inner ring by using control bars.

Conclusion

In this paper we design an equilateral triangle shaped split ring resonator with their basic configuration. Then we varied the position of splits in inner ring by using RF MEMS switches (making them ON/OFF) that was considered as the inner ETSRR was rotated. So by rotation of inner ring, the configuration was tuned to different frequency. Similarly, when we rotated the outer ring by varied the position of splits in outer ring using MEMS switches; the configuration was again tuned to different frequency. So, by rotation of inner or outer ring, we can control the magnetic resonant frequency and thus we get tunability. This ETSRR can be used in antenna design to obtain high directivity and high gain of the antennas.

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