Split Ring Resonator Structure on Microstrip Patch Antenna and Other Microwave Application Design: A Review

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***Abstract*— Beyond 2000, the number of investigation and fabrication on metamaterial especially of split ring resonator structure has developed exponentially. Two main enhancement by split ring resonator structure in microstrip patch antenna is the miniaturized of patch size and multiband effect for many application by a single patch antenna. In this review paper, the several examples on the previous researcher on microstrip patch antenna with different structure of split ring resonator had been done. Before that, a sample of split ring resonator on others microwave range applications such microwave filter, frequency selective surface, pyramidal microwave absorber, amplifier and oscillator are discussed.**

***Index Terms*—split ring resonator, microstrip patch antenna, miniaturized antenna, multiband antenna, return loss**

I. Introduction

At current time the user are demand on the high data rate and mobility technology of telecommunication devices with the smaller antenna design and a multi-frequency capability. Beside the telecommunication area, the others critical areas that also require this enhanced technology are in automotive, oil and gas, biomedical, military, and also in agriculture sector.

One of the techniques that apply to reduce the size of antenna and multi-frequency for multi-application is using split ring resonator (SRR) structure. The history of this structure started after Second World War parallel with the development of artificial dielectrics in microwave engineering. Split ring resonator is one of the left handed materials or matematerial structure. The metamaterial (from a Greek word of beyond) is one type of material that cannot be found in nature but can be only defining by design. Veselago had predicted in 1967 that metamaterial designed structure has negative permeability and positive permittivity (dielectric constant) or both negative.

These split ring resonator structures have purposes to enhance the return loss and bandwidth performance of microstrip patch antenna. Beside antenna technology, this technique also can have been applied in many telecommunication area applications, such as microwave filter, frequency selective surface (FSS), microwave absorber, oscillator, amplifier, switch and many others. Beyond 2000, the number of investigation and fabrication on metamaterial has developed exponentially [1].

II. Basic Split ring resonator

The split ring resonator is a popular artificial magnetic material or matematerial structure. The most exciting feature of this split ring resonator structure is its capability to exhibit a quasi-static resonant frequency at wavelengths that are larger than its own size. Thus, the split ring resonator structure has the potential in to reduce the size of microwave range application design [2].

In 1999, Pendry [3] claimed that successfully develop a microstructured metamaterial structure. His design is based on two concentric circular rings that separated by a gap. Compared with closed ring resonator (CCR), the split ring resonator (SRR) has advantages of magnetic resonant effect. This closed ring resonator structure only has capability to terminate the magnetic resonance, but it still keeps the electrical resonance He said that there is magnetic resonance effect by the gap between of the inner and outer rings and also at the gap of the rings. Figure 1 shows the example of the array structure of split ring resonator by Pendry. *2r* shows the diameter of the split ring resonator structure while *a* represent the gap between two split ring resonator structures.

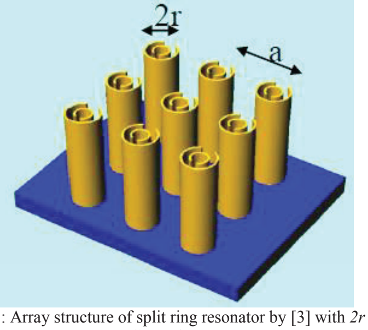


Figure 1: Array structure of split ring resonator by [3] with *2r* and *a* dimension

In Figure 2 the Padilla illustrates the structure of split ring resonator that consists of a pair of concentric ring shapes and a wire line at the center of split ring resonator structures. It also has a small gap at the rings with larger resonant wavelength than the diameter of the rings.

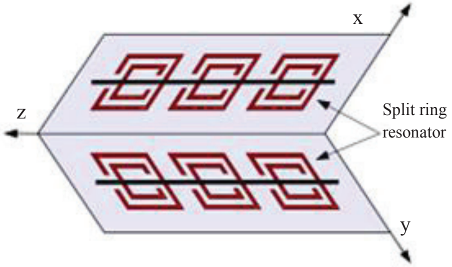
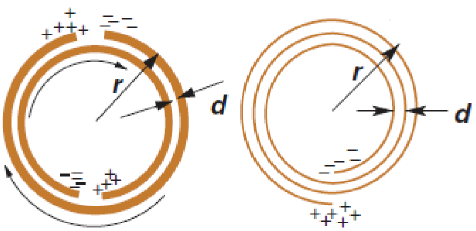


Figure 2: The structure of split ring resonator with wire lines [4].

This small gap has the capability to produce a high capacitance value, which could reduce the value the resonance frequency. A magnetic flux penetrating at the ring will effect to produce its own current flow. This matter can also give effect to oppose the incident field, and results in lower relative losses and also has high value for quality factor. At frequency points below the resonance frequency, it shows that the real part of the permittivity becomes positive. At frequencies above the resonance frequency, the permittivity becomes negative.

Besides, the SRR functions on the concept that the magnetic field of the electromagnetic radiation can drive a resonant *LC* circuit through the inductance. The induced currents flow in the directions indicated in; with charges assemble at the gaps in the rings. Figure 3 shows the different capacitance effects on split ring resonator and the Swiss roll structure. The large gap in each ring avoids the current from flowing around in a single ring, and the circuit is completed across the small capacitive gap between the two rings [2].



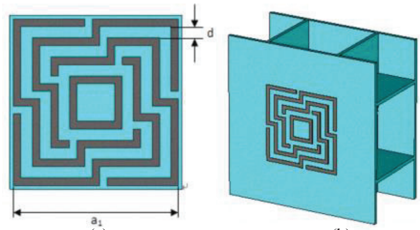
(a) (b)

Figure 3: The capacitance across the rings causes the structure to be resonant for (a) split ring resonator, and (b) Swiss roll structure [2].

III. SPLIT RING RESONATOR IN MICROWAVE RANGE APPLICATION

Beside microwave absorber and antenna, the split ring resonator structure can be applied in many applications such as frequency selective surface (FSS), microwave filter, oscillator, amplifier, and others. In its basic design, it is well known that the band-stop filtering behavior is provided based on SRRs, while band-pass filtering features are obtained from complementary SRR structures.

In addition, [5] introduced a novel split ring resonator based on frequency selective surface, as shown in Figure 4. The concept of split ring resonator in this work consists of four strips placed spirally out of a square. The advantages of this new structure are to improve the stability of the structure, it has low impedance for pass-band, and also miniaturizes at some degree of the structure. This frequency selective surface was operated at a frequency of 6.64 GHz. The dimension was 0.3 mm.



(a) (b)

Figure 4: A novel frequency selective surface with strips of split ring resonator, (a) top view of the spirally split ring resonator structure, and (b) frequency selective surface with strips of split ring resonator structure [5].

Furthermore, Figure 5 shows the designed a structure of split ring resonator for band-reject filter with a resonant frequency of 9.3 GHz [6]. This band-reject filter used a Roger RO4003C high-frequency laminate (ε_r = 3.38) substrate. A simple 50 Ω microstrip lines were loaded with split ring resonator. A very compact band-reject filter was gained after the addition of this split ring resonator structure. This filter had a dimension of one-eleventh of a wavelength at the resonant frequency.

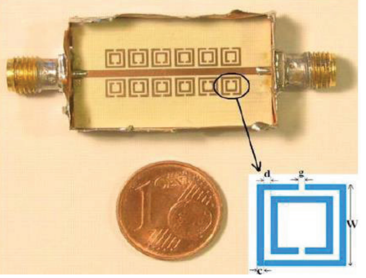
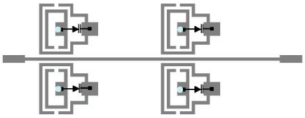
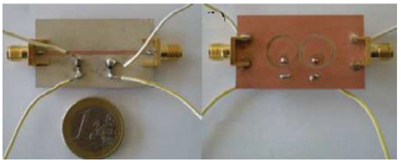


Figure 5: Split ring resonator based microstrip band-reject filter [6].

There is limited research found on oscillator technology area. Figure 6 shows the voltage-controlled oscillator (VCO) using a tunable metamaterial transmission line based on varactor-loaded split ring resonator (VLSRR). The negative effective permeability is delivered by VLSRR in a narrow band above the resonant frequency. The bias of VLSRR is controlled by the varactor diodes. The square-shaped split ring structure has large coupling coefficient value. This condition produces a high Q value and it is effective in reducing the phase noise in VCO. Compared to conventional VCO, the widened tuning range and the reduced phase noise was four times better on improvements [7].



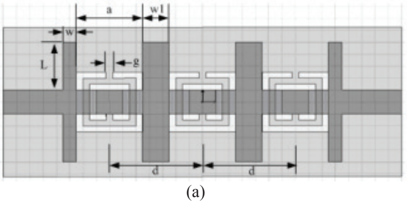
(a)



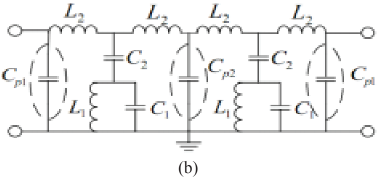
(b)

Figure 6: The VCO using a tunable metamaterial transmission line based on VLSRR by [7], (a) simulation stage, and (b) fabricated stage (front view and ground plane view.

An amplifier can also be enhanced of its performance by integrating the split ring resonator structures, but not many researches have given attention to this type of design. An example of the design of amplifier with split ring resonator structure is found in a study carried out by [8], as depicted in Figure 7. An EC-SRR with DGS was obtained by etching two concentric split-ring defected patterns in the ground plane part. An SRR-DGS cell has a flat low pass and also a narrow band-gap effect. It shows 5 % or 24 dB of enhancement rate for output power performance in the amplifier.



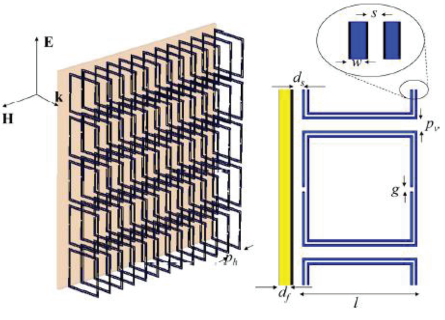
(a)



(b)

Figure 7: Band notched UWB antenna, (a) Simulation stage, and (b) fabricated antenna stage [8].

In a report by [9] the researcher presented a design of miniaturized narrowband-microwave absorbers using SRR structure. The microwave absorber is made from a resistive film of thickness, d_f, and a planar array of SRRs spaced d_s from the resistive film. The finite-planar array of split ring resonators is placed inside a hollow waveguide with inhomogeneous boundaries: top and bottom walls are described by the boundary condition of a perfect electric conductor (PEC), left and right walls by the condition of a perfect magnetic conductor (PMC). The two main advantages of the concept of absorber are presented in this paper. The first advantage is to reduce the thickness (close to λ 0 / 100 and even beyond) and the second advantage is the absence of the metallic plate on the back of the absorbing structure. Figure 8 shows the microwave absorber based on an split ring resonator.

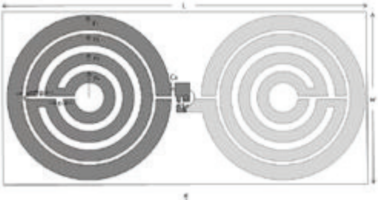


(a) (b)

Figure 8: (a) Geometrical sketch of a microwave absorber based on SRR resonant magnetic inclusions, and (b) The single unit of SRR structure [9].

IV. Examples of Split Ring Resonator in Patch Antenna

There are also many designs of antenna that apply the SRR structure previously. Zhu [10] designed a compact triple-band split ring resonator antenna at 0.43 GHz, 0.68 GHz, and 0.99 GHz of frequency, as shown in Figure 9. It is just 100 mm long, which corresponds to λ/7 at the lowest working frequency of 430 MHz. This antenna is composed of two split ring resonators, forming a dipole as the main radiating element. The inner ring of each resonator is extended to a meandered ring to interact with the main resonator to generate extra resonances.



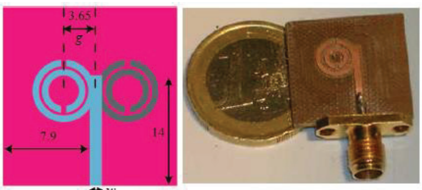
(a)

(b)

Figure 9: Plan view and side view of the triple band meandered split ring resonator antenna with L = 100 mm, and W = 48 mm [10], (a) plan view, (b) side view

The surface currents are mainly induced by the driven ring itself and the large capacitance exist between the split rings. The width of the ring and the gap between the rings are tuned to generate resonances at specified frequency bands. Besides, due to negative permeability in certain frequency ranges, the split ring resonator could generate resonance at wavelengths that are larger than its own size.

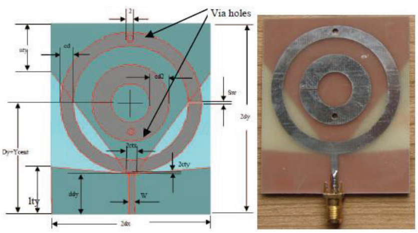
In addition, [11] designed a compact and a symmetrical antenna based on split ring resonator structure and simple feeding techniques, as shown in Figure 10. This antenna is composed of two split ring resonators that are printed symmetrically on different sides of the dielectric substrate, which is an Arlon with permittivity $\varepsilon_r = 2.43$ and the thickness of the substrate is 0.49 mm. The bottom microstrip line of split ring resonator acts as a ground plane. The position of the SRR that is close to the microstrip line increases magnetic coupling. This antenna resonates at 5.0 GHz with – 27 dB.



(a) (b)

Figure 10: A compact split ring resonator antenna for wireless communication system, (a) simulation antenna design, (b) fabricated antenna [11].

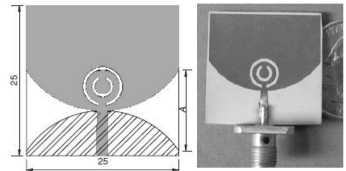
Next, [12] developed an ultra-wide band (UWB) SRR antenna with microstrip-fed parasitic, coupled with monopole and a pair of V shape notch ground plane. This antenna operates at narrow bandwidth with resonant frequency of 0.537 GHz in a UWB range from 2.07 GHz to 9.74 GHz. Figure 11 shows the UWB antenna with SRR structure.



(a) (b)

Figure 11: UWB antennas with SRR structure, (a) Simulation, and (b) Measurement [12].

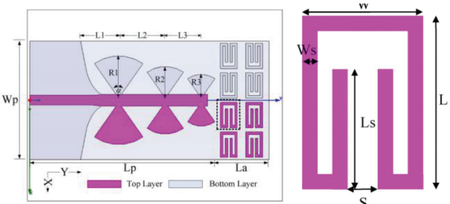
Furthermore, [13] designed a band notched UWB antenna with split ring resonator structure for the patch. The SRR structure is functioned to reject the unwanted frequency band in the UWB of the antenna, maintaining its high Q characteristic and small real estate. This antenna was operated at a frequency between 3.1 GHz and 10.6 GHz by rejecting resonant frequency at 5.2 GHz of WLAN application. Very sharp selectivity at 5.2 GHz was observed in both the return loss and the gain of the antenna. In addition, it had been expected that, in general, the smaller slot structure could affect the radiation patterns of the UWB antenna less than the existing approaches [14]. Figure 12 shows the UWB notched antenna.



(a) (b)

Figure 12: Band notched UWB antenna, (a) Simulation stage, and (b) fabricated antenna stage [13].

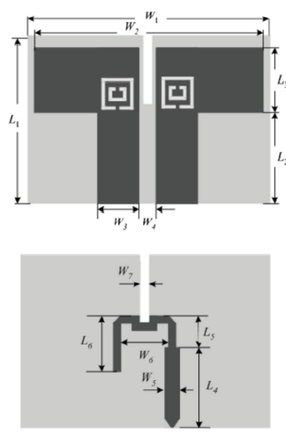
Moreover, [15] fabricated the broadband periodic endfire antenna with split ring resonator structures, as shown in Figure 13. The gain was enhanced by 1.3 dB through the integration of the split ring resonators at the antenna with 6.2 dB.



(a) (b)

Figure 13: Broadband periodic endfire antenna with split ring resonator structures [15], (a) plan view, and (b) split ring resonator structure.

On the other hand, [16] introduce a dual-polarized antenna using split ring resonator technique. The split ring resonator effected to broaden the impedance bandwidth for the L-shaped patch antenna. The bandwidth range for this antenna is from 1.02 GHz to 2.03 GHz, improved compare the L-shaped patch antenna without SRR. Figure 14 shows the dual polarized L-shaped printed antenna with split ring resonator.



(a)

(b)

Figure 14: Dual polarized L-shaped printed antenna with split ring resonator, (a) front view, (b) ground view

Table 1 shows the review of size reduction effect on antenna design with addition of split ring resonator. The embedded of split ring resonator structure effect to reduce the size of

35.0 %, 21.9 % and 15.2 % for antenna [17], [18] and [19] respectively. The proposed WiMAX dual patch antenna with SRR at ground plane for 3 GHz shows a 47.0 % size reduction comparison with original patch antenna without split ring resonator. [20].

Table 1
Size reduction effect on antenna design with split ring resonator

Reference	Size reduction effect	Remarks
[17]	35.0 %	Using more expensive material of Roger 6010 RT/duroid
[18]	21.9 %	Effect small size but have reduction of return loss
[19]	15.2 %	Combine with coplanar waveguides (CPW) and coplanar strip lines (CPS) technique
[20]	47.0 %	For WiMAX application

Table 2 shows the review of multiband effect on 3 different antenna designs with split ring resonator. Antenna [21] and [23] shows the multiband effect at triple resonant frequencies while antenna [22], [24] and [25] effected to create dual band resonant frequencies.

Table 2
Review of multiband effect on antenna design with split ring resonator

Reference	Multiband effect	Remarks
[21]	Create new band at 5.9 GHz and 8.6 GHz, basic at 3.2 GHz	Combine with co-planar waveguide technique
[22]	Dual band at the range of 2.595 GHz –2.654 GHz and 3.185 GHz –4.245 GHz	Combine with closed ring resonator and co-planar waveguide technique
[23]	Create triple band at 2.32 GHz - 2.98 GHz, 4.06 GHz - 4.3 GHz and 5.0 GHz -6.3 GHz, basic only cover 2.5-5.5 GHz	Combine with co-planar waveguide fed technique, reduction of return loss
[24]	Create dual band range at 3.61 GHz and 5.15 Hz	Using hexagonal shaped geometry based on metamaterial structure
[25]	Create dual band at 1.52 GHz and 2.47 GHz	Using array SRR at patch antenna

V. Conclusion

This paper reviews the current research on split ring resonator (SRR) and its several applications such as in patch antenna, microwave absorber, frequency selective surface (FSS), oscillator and amplifier. It shows that the split ring resonator has a very good potential to improve the performance of several applications. Several example of the split ring resonator effect on the patch antenna also had been described in this paper.

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