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Metamaterial Inspired Circular Patch Antenna using Complementary Split Ring Resonator and Complementary Spiral Resonator

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ABSTRACT

This paper presents metamaterial inspired methodology to design compact circular patch antennas loaded with complementary split-ring resonators (CSRRs) complementary spiral resonators (CSRs) operating in ISM band. A metallic disk containing CSRRs or CSRs has been placed horizontally inside the dielectric between the patch and ground plane of the antenna and patch size is scaled down in both the models. The results of the disk, comprising CSRR/CSR, incorporated in circular patch antenna are evaluated and their performances are compared with traditional antenna design. The results reveal that the miniaturization of circular patch antenna with CSR disk loading offers great impedance match and characteristics comparable with those of unloaded patch antenna. The proposed CSR disk loaded antenna designs yield high levels of miniaturization and similar performance to the normal patch antenna operating in same frequency band (2.45GHz to 2.50GHz) than CSRR disk loaded patch antenna.

KEYWORDS Circular patch, Complementary Split Ring Resonator (CSRR), Complementary Spiral Resonator (CSR), Metamaterial Inspired Antenna.

1. INTRODUCTION

The field of electromagnetics had a remarkable beginning with the introduction of artificial materials such as metamaterials and their applications in microstrip patch antennas. Though the foremost and significant contributions to this subject were given by V.G. Veselago in 1968, yet metamaterials, with unusual properties, has become topic of interest over the last decade only. He defined such materials with term 'left handed medium' [1]. Being engineered material not occurring naturally, metamaterials are realized using Split Ring Resonators (SRR) and the Complementary Split Ring Resonator (CSRR) and are employed in antenna miniaturization [2-6]. A metamaterial structure firstly proposed by JB Pendry in (1998 and 1999), contain SRR that posses negative permeability [7] and thin wire elements that possess negative permittivity [8]. There are many structures of different types of SRR are available, such as double split SRR (DS-SRR), broadside couple SRR (BC-SRR), spiral SRR (S-SRR) and edge coupled SRR (EC-SRR). Due to the increased demand of compact devices, miniaturization of antennas is a necessity in the current scenario of communication devices. The condition is particularly challenging as the smaller size antennas supposed to maintain their impedance bandwidth properties effectively. Microstrip antennas are one of the most commonly used antenna types in hand-held devices, such as mobile phones due to their light weight, compact size and easy production. A lot of research work has been carried out to utilise metamaterials in various patch antenna designs and their miniaturization as given in [9-12]. The size of a patch antenna decreases with increasing its resonant frequency [13], hence patch size can be optimized to achieve desirable frequency of resonance. In 2004, Baena et al. proposed Spiral Resonators(SRs) to further condense the size of SRRs. SRs were suggested as a substitute to SRRs for generating metamaterial media having inclusions with size smaller than $\lambda_0/10$ [14]. The resonant frequency of the SR is affected with number of turns, width of the rings and distance between adjacent rings. With increasing the turns of the spiral resonator, both the length of rings and the length of slot increase. This results in increased effective inductance and capacitance of the spiral, hence resulting in a downward shift of the frequency of resonance.

In this paper, we have used complementary split ring resonators (CSRR) and complementary spiral resonator (CSR) with multiple turns to achieve high level miniaturization. This is accomplished with CSRR loading on patch cavity. Sub-wavelength resonance of patch antenna have been realized with optimizing CSRRs inserted between patch and ground plane, and excellent impedance match as well as radiation characteristics comparable to normal patch antenna are obtained.

2. ANTENNA DESIGN

In this design methodology, we consider a standard circular patch patch antenna of copper with radius 22.1mm placed above a cylindrical substrate Rogers RT/duroid 5870 with height 2.34mm and radius 46.2mm, aided with conducting ground surface of radius 46.2mm. The dielectric constant (ε_r) of substrate is 2.33 and dielectric loss tangent (δ) is 0.0012. The patch is excited with a copper microstrip line having impedance 50 Ω and 1.5mm width by means of SMA connector located at substrate boundary. The patch radius is optimized to achieve 2.45 GHz resonant frequency. The motive behind this design is to create smaller version of the circular patch antenna that perform similar to the standard patch operating in the same frequency band.

2.1. Design equations of circular patch antenna

The radius, r of a circular patch as given by (Balanis, 1982) [15] is.

$$r = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}}} \quad (1)$$

where
ε_r= substrate dielectric constant
h= substrate height
F is operational frequency given by equation (2)

$$F = \frac{8.791\times10^9}{f_r(\sqrt{\varepsilon_r})} \quad (2)$$

The equation (1) is without considering the fringing phenomena. Because fringing results in the electrically larger patch, the effective radius is considered and is given by

$$r_e = r\left\{1+\frac{2h}{\pi\varepsilon_r r}\left[ln\left(\frac{\pi r}{2h}\right)+1.7726\right]\right\}^{1/2} \quad (3)$$

Hence, the resonant frequency is given by

$$f_r = \frac{1.8412 v_0}{2\pi r_e\sqrt{\varepsilon_r}} \quad (4)$$

where v_0 is the free space speed of light.

2.2. Comparison between CSRR and CSR

CSR is a slot resonator which is an electrically small unit engraved in a metallic layer and possess resonant frequency lesser than CSRR with the factor of 2. As shown in Figure 1, inductance L_0 in CSRR is a parallel arrangement of all the inductances connecting incorporated disk to ground plane [16] whereas inductance L_0 in CSR, is the inductance of inter loop metal inside the entire boundary. Hence, inductance of CSR exceeds inductance of CSRR with factor of 4 and this explains that electrical length of CSR is ½ times that of CSRR designed for similar resonant frequency whereas the coupling capacitance c_c of both the structures remains the same.

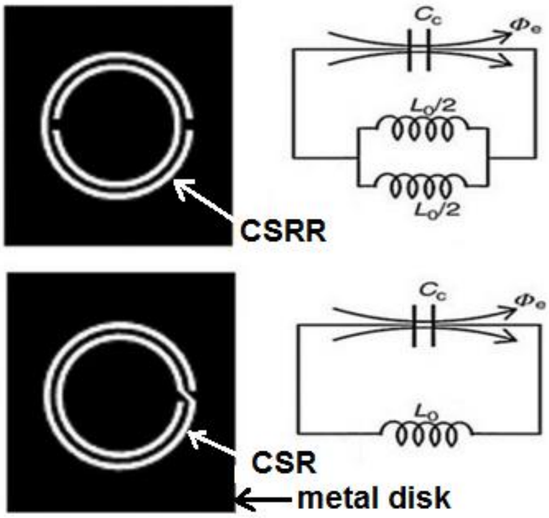

Figure 1. Equivalent circuit model of CSRR and CSR

2.3. Miniature patch antenna using CSRR

For miniaturization a metallic disk having three CSRR rings have been inserted 0.78mm below the conducting patch as shown in Figure 2. The disk radius r_d, 10.7mm is preferred to be smaller than the ground plane radius to keep it away from the SMA connection. The substrate chosen for this design is Rogers RT/duroid 5870 having height 2.34 mm and its radius is twice of the patch radius i.e 12mm, aided by a conducting ground with same radius. A microstrip feed line of width 1.5mm is taken to excite the circular patch .The patch radius is optimized to achieve 2.45GHz resonant frequency. The position of CSRR and CSR layer has been determined by available substrate thicknesses. The 0.78mm thick substrate used in this paper is standard commercially available value. Moreover additional optimizations with CSRR or CSR situated at a distance of 1.56mm beneath the patch presents the identical results as those gained for a distance of 0.78mm.

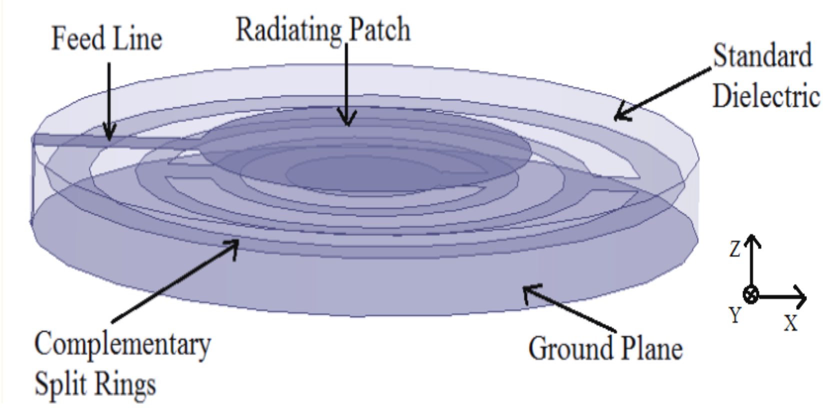

Figure 2. Patch antenna with CSRR loaded disk

The disk geometry, shown in Figure 3, is optimized by means of changing the number of rings, n, the outer ring radius, r_0, rings width, *a*, rings spacing, *s* and gap width, *g*. The different parameters used in this geometry are tabulated in Table 1.

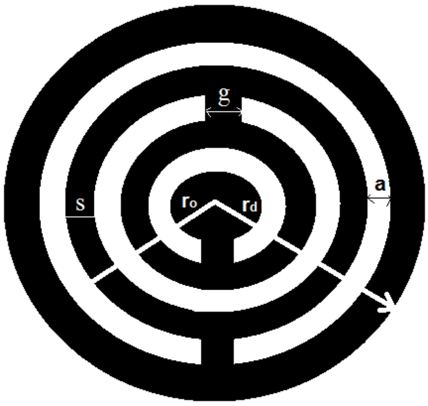

Figure 3. CSRR etched on circular disk (n=3)

Table 1: Parameters used in CSSR design

S.N.	Parameter	Value(in mm)
1	Disk radius(r_d)	10.7
2	Patch radius	6
3	No. of rings (n)	3
4	Ring width(a)	1.65
5.	Ring spacing (s)	1.05
6.	Gap width (g)	1.9
7.	The outer ring radius (r_0)	9.9

2.4. Miniature patch antenna using CSR

A metallic disk containing CSR is kept horizontally at the distance of 0.78mm below radiating patch (similarly as the CSRR was placed) as shown in Figure 4. The substrate, Rogers RT/duroid 5870 having height 2.34mm, radius 7mm is taken along with conducting ground plane of same radius. A microstrip feed line of width 1.5mm is taken to excite the circular patch. The patch radius is optimally reduced to achieve 2.45GHz resonant frequency.

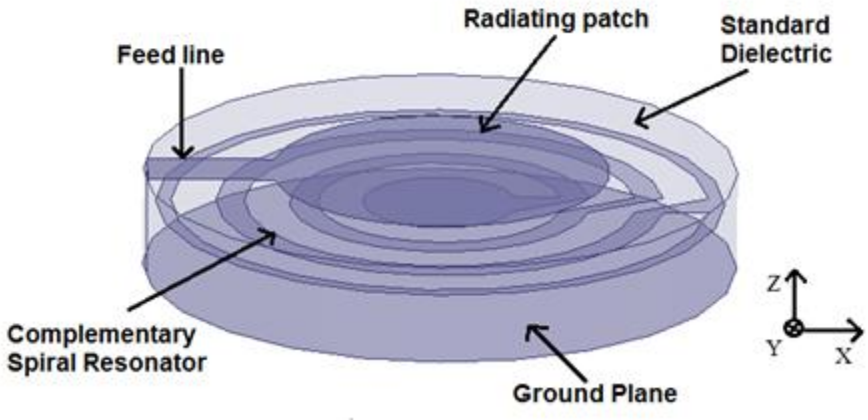

Figure 4. Patch antenna with CSR loaded disk.

The disk geometry with CSR shown in Figure 5, is optimized, by means of changing the CSR disk parameters and the substrate size is kept double to that of patch [17]. The different parameters used in geometry of SR are given in Table 2.

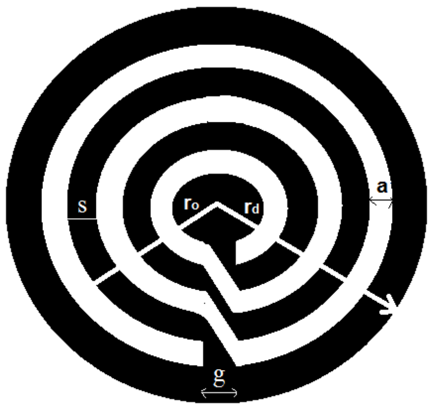

Figure 5. CSR etched on circular disk (n=3)

Table 2: Parameters used in CSR design.

S.N.	Parameter	Value(in mm)
1	Disk radius(r_d)	6.7
2	Patch radius	4
3	No. of rings (n)	3
4	Ring width(a)	1.056
5.	Ring spacing (s)	0.672
6.	Gap width (g).	1.216
7.	The outer ring radius (r_0)	6.336

3. RESULTS AND DISCUSSION

The traditional circular patch antenna and the proposed CSRR and CSR inspired circular patch antenna are numerically analysed with Ansoft HFSS software. The frequency response and return loss plot of conventional circular patch antenna is shown in Figure 6. It is visible from the Figure 6 that the traditional patch antenna resonates at 2.45 GHz with return loss of -11.3 dB and 20 MHz bandwidth.

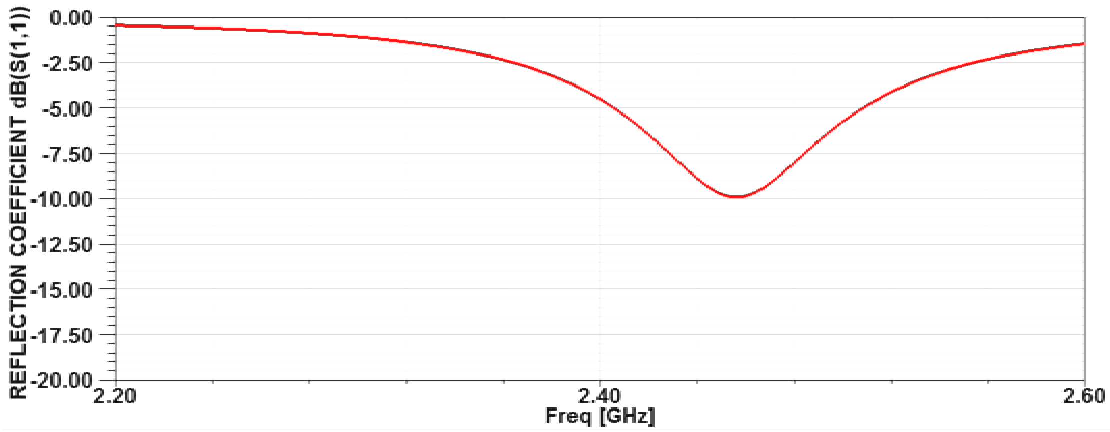

Figure 6. Reflection coefficient of conventional circular patch antenna.

The reflection coefficient of miniature version of circular patch antenna with CSRR comprised disk compared with traditional antenna in Figure 7. This antenna with CSRR loading produces VSWR of 1.07 as shown in Figure 8. The incorporation of CSRRs reduces the patch radius to 6mm leading to an area reduction of 1/14 of the traditional circular patch antenna without CSRR loading. The reflection coefficient of this antenna is below -25dB and its resonance frequency is 2.45 GHz and VSWR is nearly equal to 1. This presents very good impedance matching.

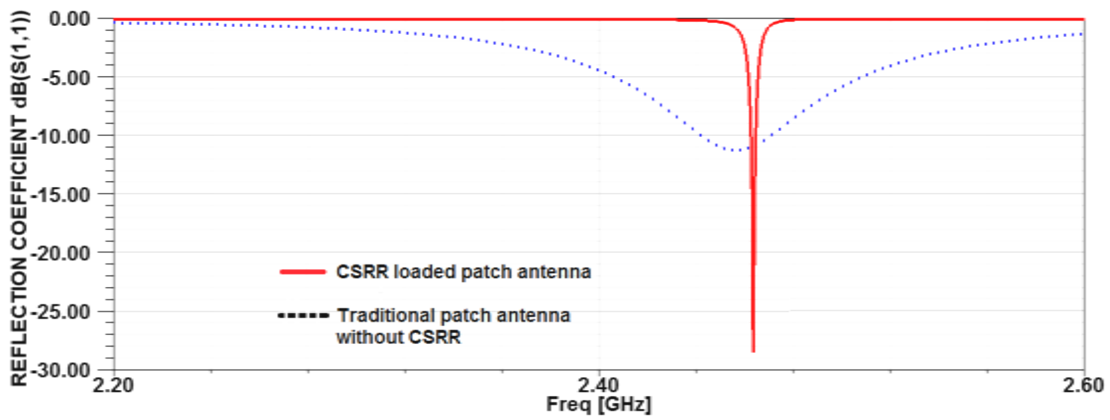

Figure 7. Reflection coefficient of miniaturized circular patch antenna containing CSRR and traditional circular patch antenna.

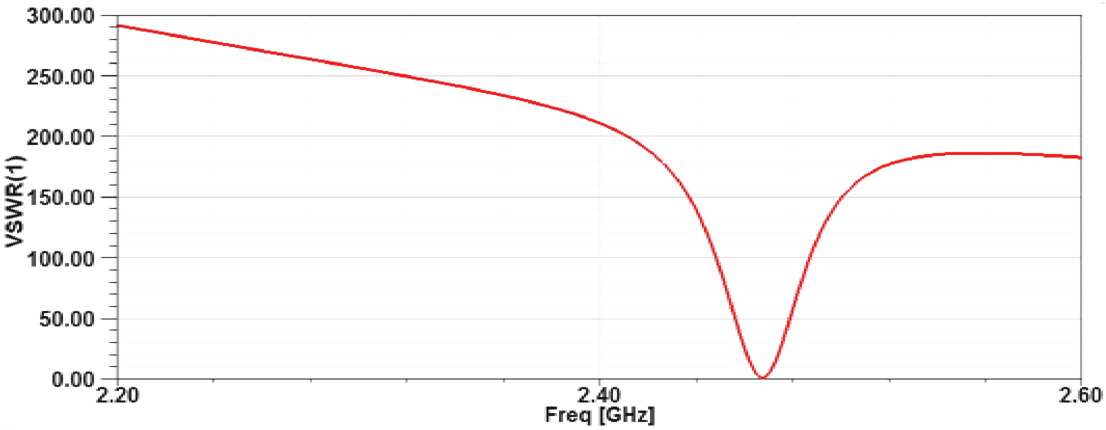

Figure 8. VSWR Plot of miniaturized circular patch antenna containing CSRR

The reflection coefficient of miniature version of circular patch antenna with CSR loading is compared with traditional antenna in Figure 9. This antenna with CSR loading produces VSWR of 1.03, shown in Figure 10, indicates excellent impedance matching. With the incorporation of CSR the patch radius reduces to 4mm resulting in an area reduction of 1/30 of the circular patch antenna without CSR loading. The reflection coefficient of CSR loaded antenna is below -35dB and its resonance frequency is 2.46 GHz as illustrated in Figure 9.

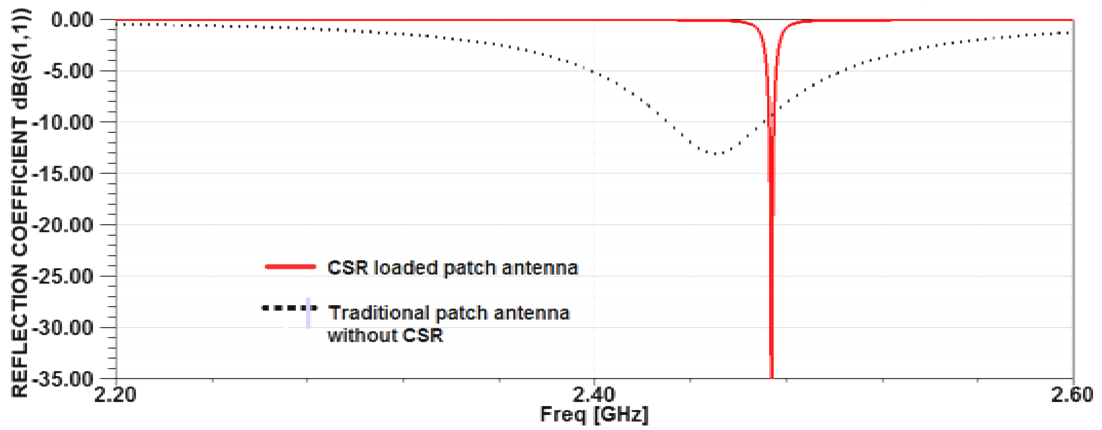

Figure 9. Reflection coefficient of miniaturized circular patch antenna containing CSR

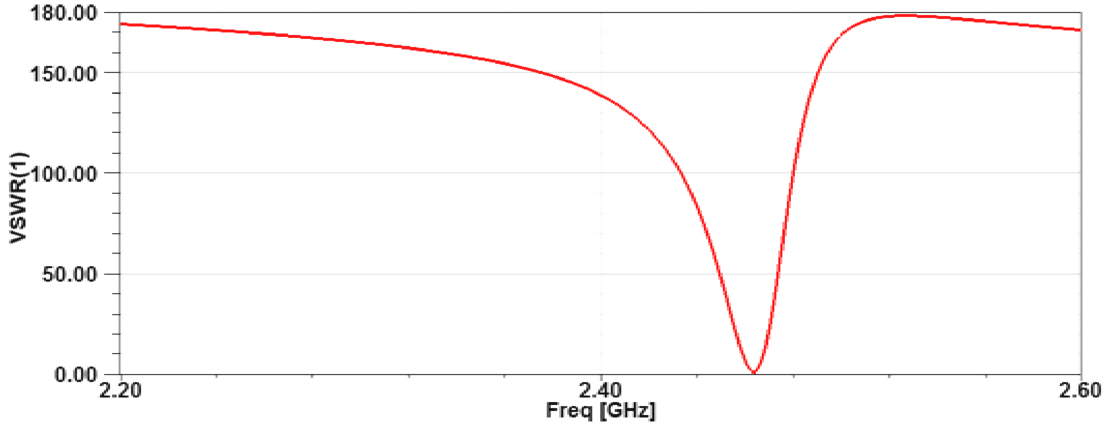

Figure 10 .VSWR of miniaturized circular patch antenna containing CSR

4. CONCLUSION

A new design methodology to produce highly miniaturized circular patch antenna have been presented. Incorporation of a metallic disk containing CSR into conventional patch, the radius of the patch can be decreased significantly with excellent impedance match in the same frequency band than CSRR disk comprised patch antenna. So, with CSR structure it is possible to realize more compact antennas without effecting antenna characteristics operating within the same frequency band. The construction of this miniature antenna is straightforward and even further reductions in the antenna size are possible. The given design can be used in other patch antenna designs like rectangular patch. Moreover, the proposed geometry will also be helpful in creating patch antennas for the multi-band operations.

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