Enhancement of Rejection Characteristics of Filter using an Array of CSRR for Notching the ISM Band in UWB Antennas

M. Sathish
Assistant Professor, Department Of Electronics And Communication Engineering, rajalakshmi Engineering College, Chennai, India, sathish.s@rajalakshmi.edu.in

S. Anitha
Assistant Professor, Department Of Electronics And Communication Engineering, rajalakshmi Engineering College, Chennai, India, anitha.s@rajalakshmi.edu.in

R. Bharathy
Assistant Professor, Department Of Electronics And Communication Engineering, rajalakshmi Engineering College, Chennai, India, bharathy.r@rajalakshmi.edu.in

U. Jhanani Shree
Assistant Professor, Department Of Electronics And Communication Engineering, rajalakshmi Engineering College, Chennai, India, jananishree.u@rajalakshmi.edu.in

M. Anithamary
Assistant Professor, Department Of Electronics And Communication Engineering, rajalakshmi Engineering College, Chennai, India, anithamary.m@rajalakshmi.edu.in

Abstract

This proposed work uses Complementary Split Ring Resonator (CSRR) to filter out the frequency bands. It is evident that any planar antenna will radiate in its resonant frequency as well as other frequencies. Those harmonics need to be eliminated from the radiation characteristics to have effective radiation. This filter is designed for 2.5GHz to remove those undesirable harmonics and hence a band elimination filter is approached using square and hexagonal ring configuration.

Keywords: *CSRR, DGS, S-CSRR, H-CSRR.*

1 Introduction

A Complementary Split Ring Resonator contains two concentric metallic rings with gap at opposite ends and it is created by etching out the conductor portion of the ground plane exactly below the feed line, this makes sure that CSRR are properly excited by the E field applied parallel to its ring axis [1]. An effective negative permittivity is observed in the CSRR due the presence of a deep stopband in the frequency response [3]. A CSRR occupies a more compact space than Split Ring Resonator (SRR).

Due to the electric field excitation, the CSRR behaves as an electric dipole. The resonant frequency of CSRR is dependent upon the dimensions of its structure such as length of the outer ring, width of the ring, gap etc. The resonant frequency of CSRR by treating it as a LC circuit, is given by [5].

$$f_0 = \frac{1}{2\pi \sqrt{LC}} \text{ Hz} \quad (1)$$

where,

L = Effective inductance (in Henry)

C = Effective capacitance (in Farad)

The dimension of CSRR is effectively reduced by the usage of metamaterials [7]. Using proper design of CSRR, a desired stop band filter characteristic is achieved [8]. A wide and very compact stop band characteristic filter can be achieved by cascading multiple CSRR of the same dimensions. This idea is named as array of filters. This improved Defected Ground Structure (DGS) can be used along with the planar antenna to enhance the quality of radiation characteristics by filtering the harmonics. This concept of combining antenna [2], [4], [6] with filter is named as filtenna.

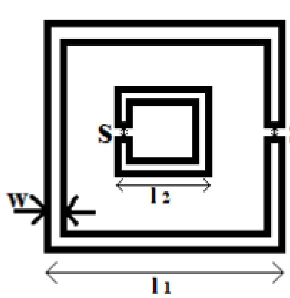
2 Filter Design

The proposed filter is realised by using the FR4 epoxy substrate whose relative permittivity, ϵ_r = 4.4 and thickness, h = 1.6mm. In this paper, square CSRR (S-CSRR) and hexagonal CSRR (H-CSRR) are investigated.

A. Design of square CSRR:

The structure of square CSRR is shown in Fig.1. Let L _1 and L _2 be circumference of the outer and inner square ring, W be width of the ring, S be the slit gap and l1 and l2 be outer and inner side length of the square. In order to determine the parameters of S-CSRR, the steps are follows;

Fig.1. Structure of S-CSRR



(i) Calculate the effective permittivity of the substrate, in accounting of fringing field

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{\left(1+12\frac{h}{w}\right)}}\right] \quad (2)$$

where,

ε_r = permittivity of the substrate

h = height of the substrate

w = width of the substrate

(i) By considering f_1 = 2.5GHz and letting f_2 = 37.5GHz. The circumference of the ring L_1 and L_2 are determined as follows.

$$f_1 = \frac{c}{2 L_1\sqrt{\varepsilon_{reff}}} \text{ Hz}$$
(3)

$$f_2 = \frac{c}{2 L_2 \sqrt{\varepsilon_{reff}}} \text{ Hz}$$
(4)

where,

f_1 = resonant frequency of outer ring

f_2 = resonant frequency of inner ring

(ii) Substitute S=W= 0.3mm and find l_1 and l_2.

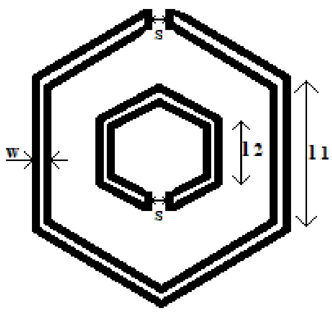
$$L_1 = 4l_1 - S - 4W$$
(5)

$$L_2 = 4l_2 - S - 4W$$
(6)

B. Design of hexagonal CSRR:

The structure of hexagonal CSRR is shown in Fig.2.Let L _1 and L _2 be circumference of the outer and inner hexagonal ring, W be width of the ring, S be the slit gap, l1 and l2 be outer and inner side length of the hexagon. In order to determine the parameters of H-CSRR, the steps are follows;

Fig.2. Structure of H-CSRR



Determine the values of L_1 and L_2 using equations (2), (3) and (4), by keeping f1 = 2.5GHz and f2 = 22.3GHz.

Substitute S = W = 0.3mm, find l1 and l2.

$$L_1=6l_1-S-6W \quad (7)$$

$$L_2=6l_2-S-6W \quad (8)$$

The design parameters are calculated for S-CSRR and H-CSRR and tabulated in Table I.

Table I: Parameters of CSRR

S-CSRR	H-CSRR
S = 0.3mm	S = 0.3mm
W = 0.3mm	W = 0.3mm
l_1 = 9.7mm	l_1 = 9.7mm
l_2 = 1mm	l_2 = 1mm

The designed square and hexagon filters is simulated and analyzed for frequency of 2.5GHz by using the Ansoft HFSS software.

3 Responses And Analysis Of Square CSRR Filters

The frequency response for the designed filters and their corresponding observation tables are as follows.

The analysis of single square CSRR is done by varying the slit gap and width of the S- CSRR and are tabulated in Table II and III respectively.

Table II: Investigation by slit gap variation

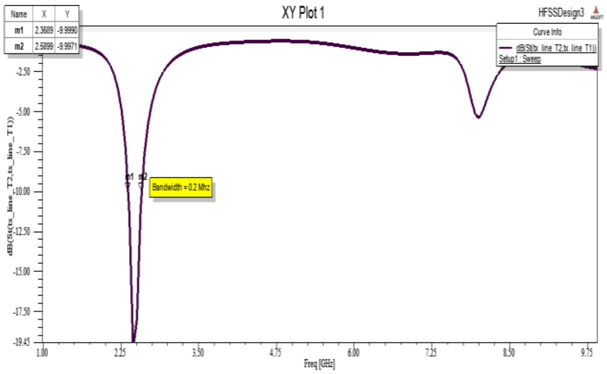
Slit Gap (mm)	Band of Elimination From	To	Elimination Bandwidth (GHz)	Centre Frequency (GHz)	Attenuation (dB)
0.3	2.37	2.59	0.22	2.50	-19.78
0.755	2.32	2.60	0.28	2.45	-25.36
1.275	2.29	2.59	0.30	2.45	-23.34
1.5	2.27	2.59	0.32	2.39	-22.90

Table III: Investigation by width variation

Width (mm)	Band of Elimination From	To	Elimination Bandwidth (GHz)	Centre Frequency (GHz)	Attenuation (dB)
0.1	2.41	2.57	0.16	2.5	-18.44
0.2	2.40	2.58	0.18	2.5	-19.22
0.3	2.39	2.59	0.19	2.5	-19.27
0.4	2.39	2.59	0.19	2.5	-19.269

An optimal value is chosen from the table II and III. S = 0.3mm is selected from Table II because the center frequency matches exactly with designed value. W = 0.3mm is selected from Table III because the center frequency matches with the designed frequency with highest elimination bandwidth. The frequency response of S-CSRR (S = W = 0.3mm) is shown in Fig.3.

Fig.3. Frequency response of Single S-CSRR

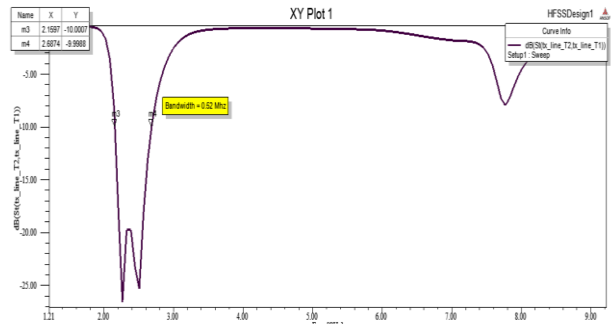


An improved bandwidth can be achieved by increasing the number of CSRR. In this paper, two (double) CSRR and three (triple) CSRR are investigated. At first, the analysis of double CSRR is carried out by varying the distance between the CSRR. Results are tabulated in Table IV. It is observed that the elimination bandwidth reaches the peak value of 0.58GHz when the distance between the two filters is chosen as 5.5mm. The response of double S-CSRR (S = W = 0.3mm, d= 5.5mm) is depicted in Fig. 4.

Table IV: Investigation by distance variation

Distance (mm)	Band of Elimination From	To	Elimination Bandwidth (GHz)	Attenuation (dB)
5	2.46	2.68	0.22	-20.23
5.5	2.11	2.69	0.58	-24.83
6	2.15	2.69	0.54	-25.32
7	2.17	2.66	0.49	-31.36
8	2.17	2.63	0.46	-44.98

Fig.4. Frequency response of Double R-CSRR



Further, to increase the elimination bandwidth an additional CSRR is cascaded with double CSRR. The frequency response of triple S-CSRR is shown in the Fig.5. The comparison between single, double and triple S-CSRR are tabulated in Table V.

Fig.5.Frequency response of Triple R-CSRR

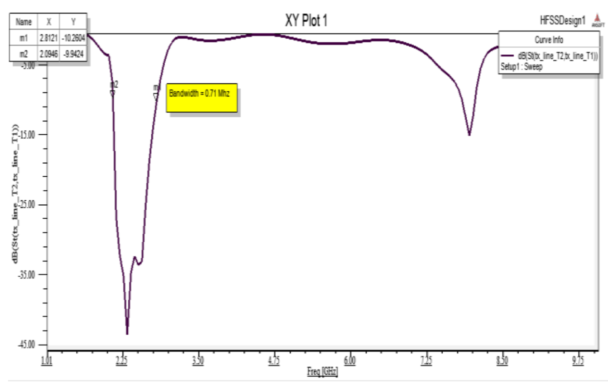


Table V: Comparison of all R-CSRR

No of filters	Elimination Bandwidth (GHz)	Peak Attenuation (dB)
1	0.20	-19.13
2	0.58	-25.32
3	0.72	-33.57

On comparing all the three S-CSRR filters it is observed that the bandwidth is increased and at the same time the attenuation is enhanced with increase of number of CSRR.

4 Responses And Analysis Of Hexagon CSRR Filters

The characteristics of H-CSRR is investigated as similar to S-CSRR. The analysis of single H-CSRR is carried out by varying the slit gap and width. Results are tabulated in Table VI and VII respectively. It is observed that the centre frequency exactly matches with the designed frequency at S = W = 0.3mm. Moreover, the elimination bandwidth attains the peak value of 0.23GHz. The frequency response of single H-CSRR (S = W = 0.3mm) is shown in the Fig.6.

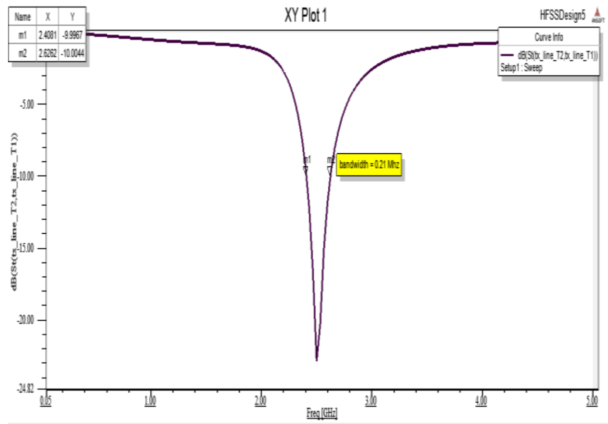
Table VI: Investigation by slit gap variation

Slit Gap (mm)	Band of Elimination From	To	Elimination Bandwidth (GHz)	Centre Frequency (GHz)	Attenuation (dB)
0.1	2.34	2.55	0.21	2.43	-22.63
0.3	2.40	2.63	0.23	2.50	-22.84
0.56	2.46	2.69	0.23	2.56	-22.92
0.8	2.50	2.73	0.23	2.59	-22.35
1.26	2.58	2.80	0.22	2.69	-23.22
1.5	2.60	2.80	0.20	2.73	-22.98

Table VII: Investigation by width variation

Width (mm)	Band of Elimination From	To	Elimination Bandwidth (GHz)	Centre Frequency (GHz)	Attenuation (dB)
0.1	2.44	2.61	0.17	2.53	-20.96
0.2	2.45	2.63	0.20	2.53	-22.68
0.3	2.40	2.63	0.23	2.50	-22.84
0.4	2.38	2.60	0.22	2.50	-23.52

Fig.6. Frequency response of Single H-CSRR



The analysis of double H-CSRR is done by varying the distance between two CSRR. The results are tabulated in Table VIII. It is observed that the maximum elimination bandwidth is attained at d = 8mm. The frequency analysis of double H-CSRR is shown in Fig. 8. The frequency response of triple H-CSRR is shown in Fig. 9. The comparative analysis of all three H-CSRR is tabulated in Table IX. The elimination bandwidth increases with increase of CSRR.

Table VIII. Investigation by distance variation

Distance (mm)	Band of Elimination From	To	Elimination Bandwidth (GHz)	Attenuation (dB)
7	2.28	2.81	0.53	-45.85
7.5	2.28	2.81	0.53	-41.33
8	2.28	2.88	0.60	-54.96
9	2.26	2.79	0.53	-52.38
10	2.30	2.69	0.39	-68.28

Fig. 8. Frequency response of Double H-CSRR

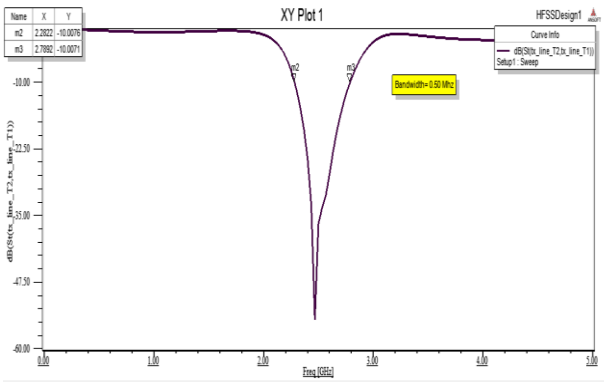


Fig. 9. Frequency response of Triple H-CSRR

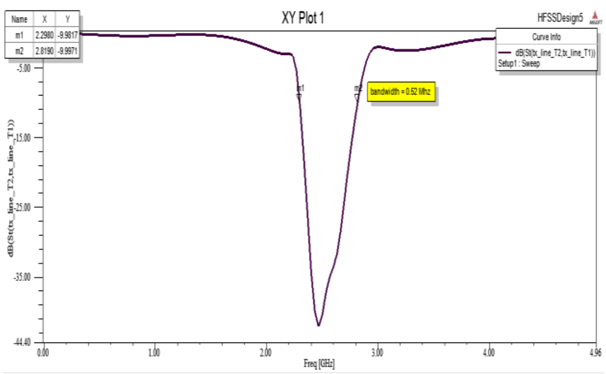


Table IX: Comparison of all H-CSRR

No of filters	Elimination Bandwidth (GHz)	Peak Attenuation (dB)
1	0.22	-22.84
2	0.50	-54.46
3	0.52	-42.06

Finally, the comparison between the S-CSRR and H-CSRR is tabulated in Table X. It is found that the S-CSRR performs much better than H-CSRR. The elimination bandwidth of S-CSRR is increased by 38.5% in comparison with H-CSRR for three numbers of CSRR

Table X: Comparison of S-CSRR and H-CSRR

No of filters	Elimination Bandwidth (For S-CSRR) (GHz)	Elimination Bandwidth (For H-CSRR) (GHz)	Attenuation (For S-CSRR) (dB)	Attenuation (For H-CSRR) (dB)
1	0.20	0.22	-19.13	-22.84
2	0.52	0.50	-25.32	-54.46
3	0.72	0.52	-35.57	-42.06

It is inferred from the Table X that triple S-CSRR has the maximum elimination bandwidth and enhanced attenuation when compared to triple H-CSRR.

5 Conclusion:

The undesirable harmonics were suppressed by the designed S-CSRR and H-CSRR filter. It is also observed that the elimination bandwidth is enhanced to a greater extent when an array of square filter is used. Therefore, it is concluded that the square CSRR filter can be used with an antenna for suppressing harmonics.

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