A Compact Multiband Proximity Coupled Rectangular Microstrip Antenna with Multiple CSRR for Wireless Applications

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Abstract - This article presents the design of compact, multiband proximity coupled rectangular microstrip antenna (PCRMSA) with multiple ring complementary split ring resonator (MCSRR) loaded on the radiating plane. These antennas are proposed for multiband operation by using low cost FR4 dielectric material with antenna size of 35 × 35 × 3.2 mm^3. Microstrip antennas with compact size, enhanced bandwidth and multiband operation by using metamaterial have been a candidate for the requirement in various wireless communication applications. Hence, proximity coupled rectangular microstrip antenna with a number of complimentary split ring resonators is proposed. The circular and square shapes have been considered to design the rings. These designs are simulated by using IE3D simulation software version 14.65. The circular and square multiple ring CSRR is considered on the top patch and increasing number of CSRRs has made the study. The measured results show that antenna with six square CSRR on the radiating patch is resonating at seven different frequency points i.e., 1.90 GHz, 5.19 GHz,7.04 GHz, 8.08 GHz, 9.28 GHz, 11.21 GHz and 13.80 GHz, whereas, antenna without CSRR i.e., conventional proximity coupled rectangular microstrip antenna (PCRMSA) is resonating at 5.77 GHz. The virtual size reduction of 68.63% is achieved. These antennas find application in wireless communications.

Keywords: Proximity coupled rectangular microstrip antenna, metamaterial, multiple ring CSRR, multiband operation

1. Introduction

Recent advancements in wireless communication technology and significant growth in the consumer demands demonstrate the need for smaller, more reliable and power efficient, integrated wireless systems. The ability to combine more than one wireless standard into a single system has become a significant demand for modern wireless communication devices. This shows that a modern antenna requires not only the function of providing a dual or multiband operation but also a simple structure and compact size [1].

For this reason, several research groups have, over the years, attempted to reduce the size of antennas [2-5]. Recently, the complementary split ring resonator (CSRR) structures have received considerable attentions because of its potential applications to the synthesis of negative permittivity and left-handed (LH) metamaterials in planar configuration [6, 7]. As discussed in [8], the CSRR is the dual counterpart of split ring resonator (SRR) initially proposed by Pendry [9]. The CSRR, composed of two concentric metallic ring slots with slits etched in each ring at its opposite sides, exhibits a strong electric response when driven by an external time-varying electric field parallel to the ring axis at its resonant frequency. This behavior has been interpreted by an effective medium with negative permittivity. In microstrip technology, CSRRs have been etched either in the conductor strip or at the ground plane [10-16].

In this paper, the technique of multiple ring complementary split ring resonators (MCSSR) on the radiating plane is employed to realize a compact, multiband proximity coupled rectangular microstrip antenna [17-22]. Experimental and simulation studies of the proposed antenna are presented and discussed.

2. Design of antenna and CSRR structure

The proposed conventional proximity coupled rectangular microstrip antenna (PCRMSA) structure is as shown in Figure 1. The patch antenna structure consists of a defined metallic rectangular patch on the top side of the substrate (h2) and metallic ground plane placed on another side of feed substrate (h1). The rectangular patch is fed by electromagnetically coupled microstrip feedline placed between two FR4 dielectric substrates which is a low-cost dielectric material with relative permittivity ε_r of 4.4 with thickness (h) of 1.6 mm for both the substrate. The conventional PCRMSA is designed for 5.8GHz with patch dimensions $L_P = 10$ *mm* and $W_P = 15$ *mm radiating* part, which is excited by simple 50 Ω microstrip feed having dimensional length $L_f = 20$ *mm* and width $W_f = 3$ *mm*. The feedline is centred with respect to the centre of the radiating patch of an antenna.

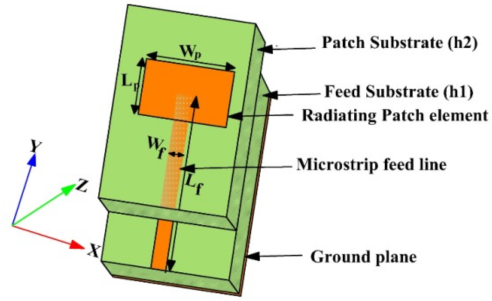


Fig.1. Geometry of proximity coupled rectangular microstrip antenna (PCRMSA)

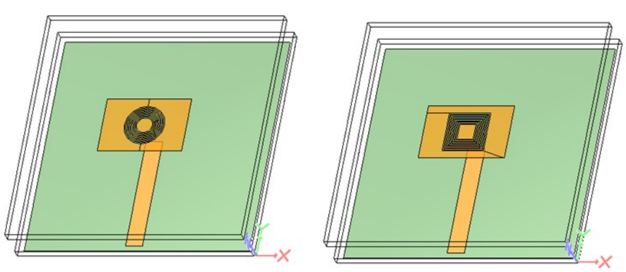
The ground plane length $L_g = 35\ mm$ and width $W_g = 35\ mm$ of the antenna is calculated by $L_g = 6h+L$ and $W_g = 6h+W$.

In the next step by keeping all the parameters similar to conventional PCRMSA, only the radiating part is etched with circular and square CSRR type metamaterial. Figure 2 shows the proposed models of Circular Multiple Complementary Split Ring Resonator loaded proximity coupled rectangular microstrip antenna (CMCSRR-PCRMSA) and Square Multiple Complementary Split Ring Resonator loaded proximity coupled rectangular microstrip antenna (SMCSRR-PCRMSA). Initially, the study is carried out by etching of circular CSRR at the centre of the radiating part and gradually increasing the number of rings to six and the antennas are named as Ant C1 for two rings, Ant C2 for three rings, Ant C3 for four rings, Ant C4 for five rings and Ant C5 for six rings. Similarly for square ring also the steps have been repeated and the antennas are named Ant S1 to Ant S5. Figure 3 shows Photographs of the PCRMSA, proposed Ant C5 and Ant S5.

Figure 4 shows five-steps in the process of designing the antenna. Figure 5 shows enlarged geometrical model of the CMCSRR and SMCSRR. The dimensions of CSRR are $S_L = 7.2mm$, $S_W = 0.2mm$, $S = 0.2mm$, $g = 0.2mm$, $d = 3.2mm$.

3. Results and discussions

All proposed antennas are simulated using the method of moment full wave electromagnetic IE3D simulation software [23] and the results are shown in Tables 1, 2 and 3. Table 1 gives the results for the five-steps of the process of designing the antenna with Circular CSRRs and Table 2 shows simulated results of five-steps of the process of designing the antenna with Square CSRRs. Table 3 shows the optimized simulated and measured results of the proposed antennas.



(a) (b)

Fig.2. Proposed models of (a) CMCSRR-PCRMSA and (b) SMCSRR-PCRMSA

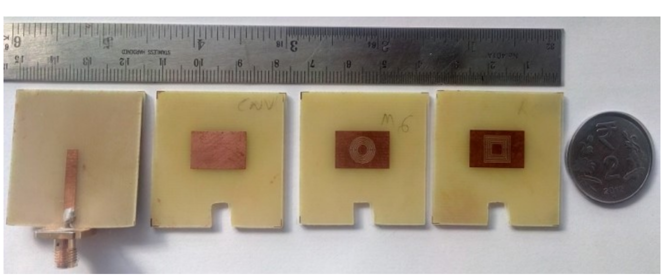


Fig.3. Photographs of the PCRMSA and proposed Ant C5 and Ant S5

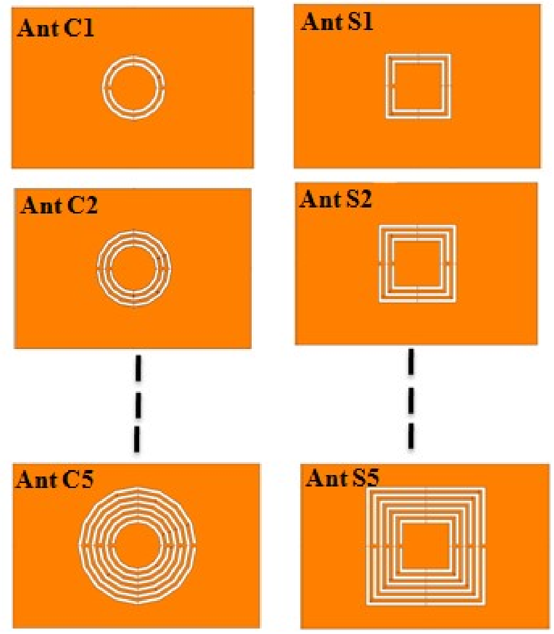
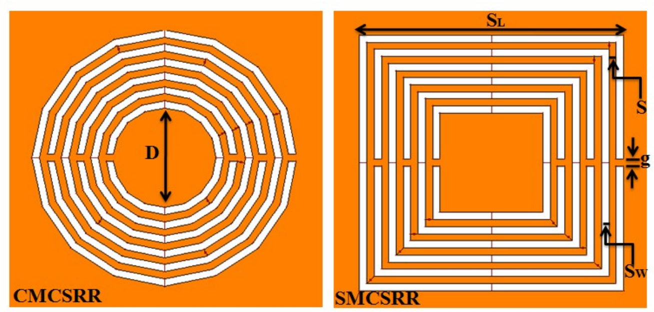


Fig.4. Five-steps in the process of designing the antennas



(a) (b)

Fig.5. Enlarged geometrical model of the (a) CMCSRR and (a) SMCSRR structures with six rings

Table 1: Simulated results of proposed CMCSRR loaded antennas

Antenna	Resonating Frequency (GHz)	Bandwidth (%)
Ant C1	5.61	11.17
Ant C2	5.61	8.23
	13.35	7.56
Ant C3	3.24	1.94
	5.55	7.40
	13.56	7.90
Ant C4	2.65	2.14
	5.45	6.45
	9.80	3.89
	13.58	8.18
Ant C5	2.23	1.92
	5.35	5.40
	8.66	1.80
	9.90	4.01
	11.39	-
	13.62	8.30

Table 2: Simulated results of proposed SMCSRR loaded antennas

Antenna	Resonating Frequency (GHz)	Bandwidth (%)
Ant S1	5.64	8.36
	13.22	8.22
Ant S2	3.30	1.78
	5.54	7.36
	10.69	1.88
	13.34	8.75
Ant S3	2.62	1.87
	5.45	6.16
	9.02	3.29
	10.69	3.28
	13.38	8.64
Ant S4	2.62	1.90
	5.42	6.16
	9.02	3.31
	10.68	3.67
	13.34	8.81
Ant S5	1.84	0.86
	5.19	3.46
	6.88	1.09
	7.85	1.60
	9.90	3.68
	10.82	3.53
	13.44	9.38

Table 3: Simulated and measured results of proposed optimized antennas

Antenna	Resonating Frequency (GHz)		Bandwidth (%)		Size reduction (%)	
	Sim.	Meas.	Sim.	Meas.	Sim.	Meas.
ConvAnt.	5.80	5.77	10.51	11.26	--	--
Ant C5	2.23	2.44	1.92	2.91	61.55	58.40
	5.35	5.31	5.40	6.59		
	8.66	8.89	1.80	4.16		
	9.90	10.06	4.01	11.72		
	11.39	11.64	-	19.41		
	13.62	-	8.30	-		
Ant S5	1.84	1.90	0.86	1.57	68.27	68.63
	5.19	5.19	3.46	5		
	6.88	7.04	1.09	1.84		
	7.85	8.08	1.60	1.97		
	9.90	9.28	3.68	24.78		
	10.82	11.21	3.53	5.17		
	13.44	13.80	9.38	15		

The antenna characteristics such as reflection coefficient, size reduction, bandwidth, and radiation pattern of all proposed configurations are obtained through simulation and verified experimentally by using German make (Rohde and Schwarz) Vector Network Analyzer (VNA) ZVK model (10MHz-40GHz). The simulated reflection coefficient versus frequency of CMCSRR and SMCSRR are plotted in Figures 6 and 7, respectively. It is observed that the performance of the Square Multiple Complementary Split Ring Resonator (SMCSRR) with six rings on driven patch is better as compared to Circular Multiple Complementary Split Ring Resonator (CMCSRR) with six rings. From the results, it is clear that by etching multiple rings on the proposed antennas, the resonant frequency decreases considerably which in turn gives the size reduction with multiple resonances [24].

Further, the simulated results of conventional PCRMSA and optimized antennas for both CMCSRR (Ant C5) and SMCSRR (Ant S5) are compared with the experimental results and plotted in Figures 8, 9, and 10 respectively. The simulated and measured results are found in good agreement. The optimized Ant C5 gives the size reduction of 58.40% with penta resonating frequencies of 2.44 GHz, 5.33 GHz, 8.89GHz, 10.06GHz and 11.64GHz with an overall bandwidth of 44.79%. Whereas Ant S5 gives the size reduction of 68.63% with hepta resonating frequencies of

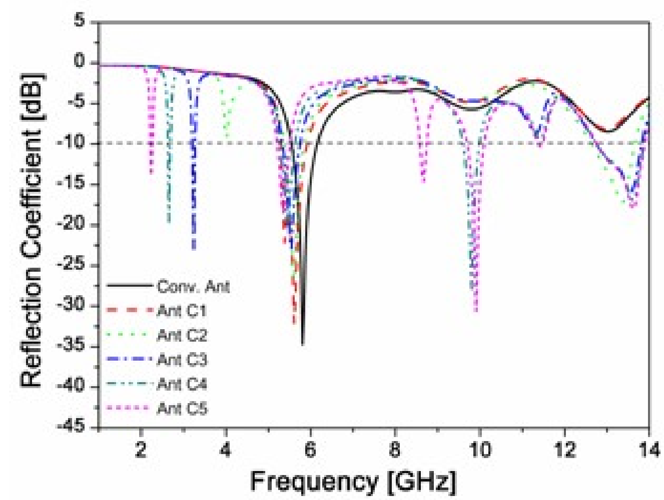


Fig.6. Simulated reflection coefficient versus frequency of circular multiple complimentary split ring resonator (CMCSRR) loaded antennas

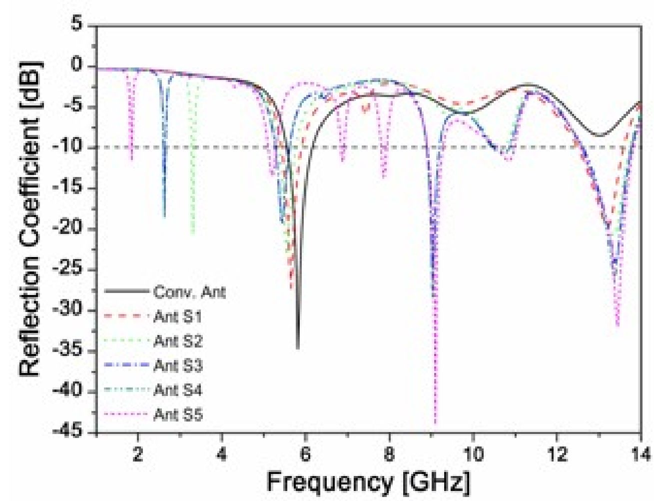


Fig.7. Simulated reflection coefficient versus frequency of square multiple complimentary split ring resonator (SMCSRR) loaded antennas

1.90 GHz, 5.19 GHz, 7.04GHz, 8.08GHz, 9.28GHz, 11.21GHz and 13.80GHz with an overall bandwidth of 55.33%. Hence, the proximity coupled rectangular microstrip antenna with multiple square complementary split ring resonator loaded antenna (Ant S5) is giving good virtual size reduction with hepta band of resonances.

Figure 11 shows the surface current distributions of PCRMSA (a) Ant C5 at lowest resonating frequency 2.23GHz, (b) Ant C5 at 5.35GHz, (c) Ant S5 at lowest resonating frequency 1.84GHz and (d) Ant S5 at 5.19GHz. The current is flowing in the almost entire patch, the different colors represent different magnitudes of the current. Figure 12 shows the radiation patterns of (a) Ant C5 at 5.35GHz and (b) Ant S5 at 5.19GHz. From these figures, it is observed that all radiation patterns are broadside in nature.

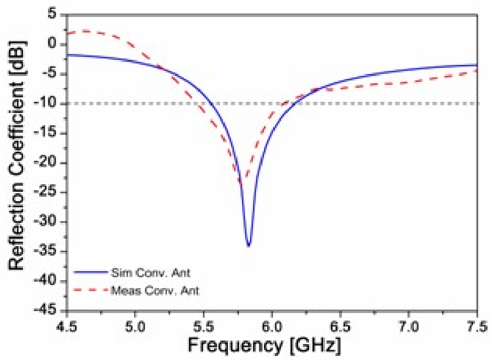


Fig.8. Simulated and measured reflection coefficient versus frequency of Conventional Antenna

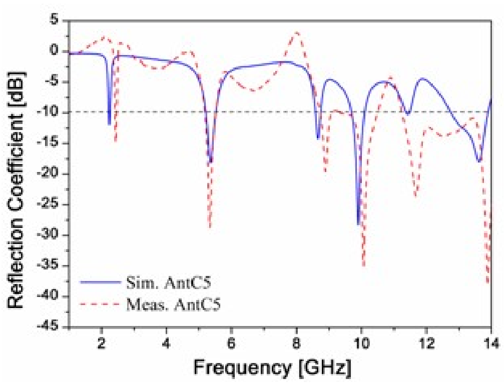


Fig.9. Simulated and measured reflection coefficient versus frequency of Ant C5

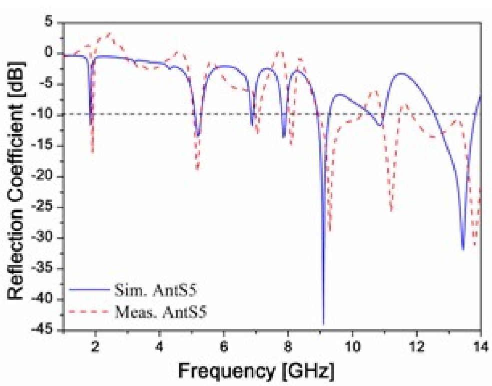
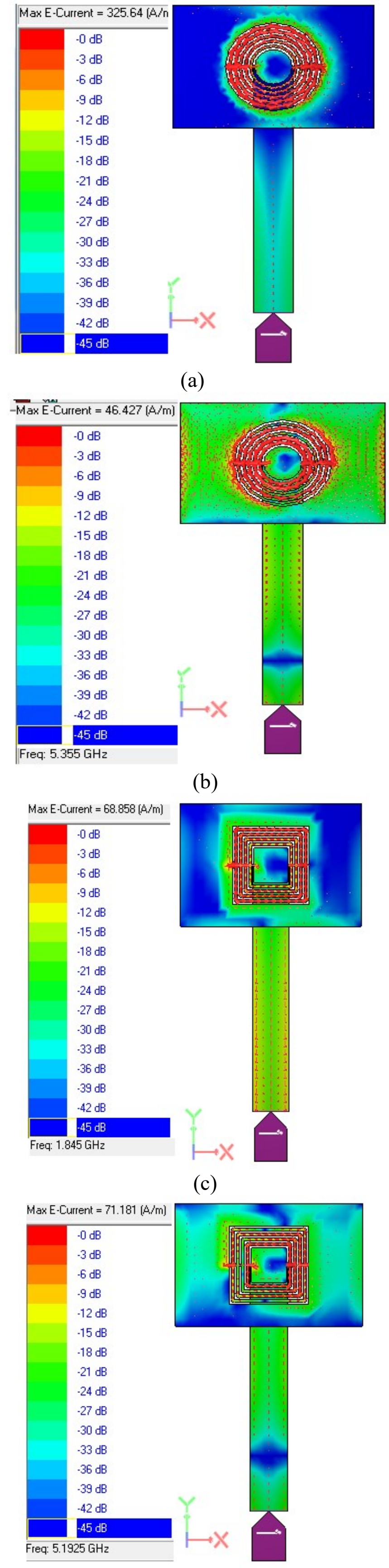
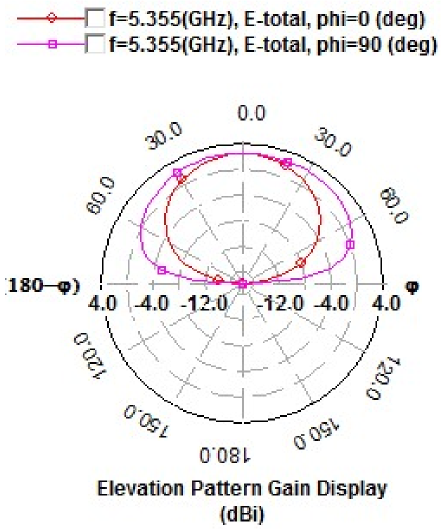


Fig.10. Simulated and measured reflection coefficient versus frequency of Ant S5

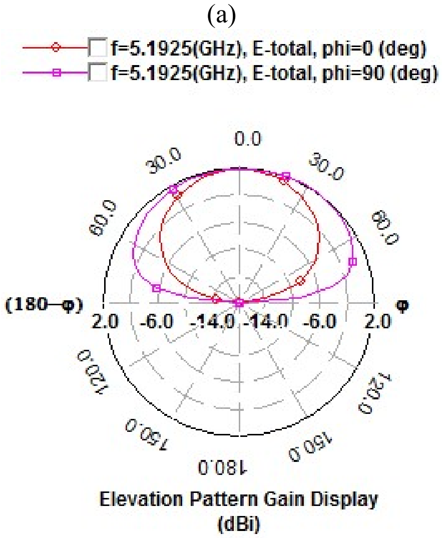


(a) (b) (c) (d)

Fig. 11. Current distributions of (a) Ant C5 at 2.23 GHz, (b) Ant C5 at 5.35 GHz, (c) Ant S5 at 1.84 GHz and (d) Ant S5 at 5.19 GHz



(a)



(b)

Fig. 12. Radiation patterns of (a) Ant C5 at 5.35 GHz and (b) Ant S5 at 5.19 GHz

4. Conclusion

A compact multiband proximity coupled rectangular microstrip antenna with multiple CSRR for wireless applications is proposed. The multiband characteristic of the antenna is achieved due to the loading of multiple CSRR on the radiating part of microstrip patch antenna. The performance of the square CSRR is good compared to circular CSRR. However, both designs help to achieve the reduction in antenna size and improvement in the impedance bandwidth of a microstrip antenna with multiple resonances. The results presented in this paper are promising for designing metamaterial loaded proximity coupled rectangular microstrip antenna for wireless applications.

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