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Compact Broadband Multi-Frequency CSRR with Fishnet Metamaterial Microstrip Antenna for Wireless Communication

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ABSTRACT: In this paper, a novel design and fabrication of multiband rectangular microstrip patch antenna with fishnet and complementary spilt ring resonator (CSRR) metamaterial on the radiating patch and ground plane with different configurations have been proposed. The optimized antenna with the combination of CSRR on the radiating patch and fishnet structure at 1.6mm above the ground plane is giving good virtual size reduction of 72% and multiband operation with overall bandwidth of 68.04%. The proposed microstrip patch antenna finds application in wireless communications.

KEYWORDS: microstrip patch antenna, fishnet, CSRR, return loss, miniaturization, bandwidth.

I. INTRODUCTION

Veselago in 1968 [1] first proposed the concept of left-handed material (LHM), and Pendry in 1999 was first developed negative permeability medium, which consist of an array of split ring resonators (SRRs) [2]. It was not until 2000 that the first artificial LHM was implemented by Smith in a two dimensional periodic array of SRRs and long wire strips [3].

As a basic particle for design of artificial media, SRRs have been applied in many applications. The most attractive feature of this structure is its ability to exhibit a quasi-static resonant frequency at wavelengths that are much smaller than its own size. Therefore, the application of SRRs for designing small antennas is of great interest. By considering the concepts of duality, the negative permittivity nature of CSRR can be derived from the negative permeability nature of SRR in a straightforward way, which has strong potential applications in designing simple planar compact antennas, circularly polarized antennas and dual-band and multiband antennas [4-6].

In this paper, we propose a novel multiband microstrip patch antenna realized by etching CSRR in the ground and radiating patch along with fishnet structure which is embedded in between ground and radiating patch. The designed and fabricated antenna parameters are measured by using Vector Network Analyzer.

II.DESIGN OF ANTENNA, CSRR AND FISHNET STRUCTURE

2(a) Design of reference antenna:

Fig. 1(a) shows the geometry of the reference antenna (RA) [7-9], where a low cost glass epoxy FR4 dielectric material with relative permittivity *(ε_r)* of 4.4 with thickness *(h)* of 1.6mm is chosen. The conventional RA is designed for 6GHz with dimensions *L=11.33mm* and *W=15.24mm* as radiating part, which is excited by simple *50* Ω microstrip feed having dimensions length *Lf=6.15mm* and width *Wf=3.05mm* using quarter wave length transformer of dimension length *Lt=4.90mm* and *Wt=0.50mm* for their impedance matching. The length Lg=*40mm* and *Wg=40mm* of the ground

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plane of the RA is calculated by using *Lg=6h+L* and *Wg=6h+ W*. Fig. 1(b) shows the 3D view of proposed microstrip antenna with fishnet structure.

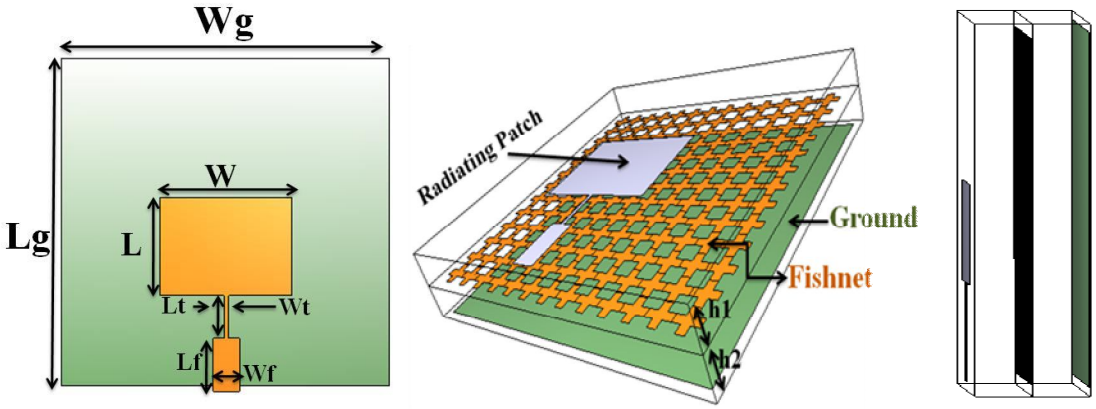

Fig. 1(a) Fig. 1(b) Fig. 1(c)

Fig. 1: Geometry of (a) reference antenna (b) 3D view of Antenna 1 (c) side view

2(b) Design of metamaterial CSRR and fishnet structure:

According to the Babinet principle [10], the complementary of a planar metallic structure is obtained by replacing the metal parts of the original structure with apertures, and the apertures with metal plates. Split-ring resonator is the dual of its complementary one. Hence, due to the duality theorem, these two structures have approximately the same resonant frequency. The main difference between SRR and CSRR is that SRR has negative permeability characteristics, while CSRR has negative permittivity characteristics. Fig. 2(a) shows the geometry of CSRR when the physical dimensions of the CSRR are optimized to S_L = 7.2mm, Sw = 0.2mm, S=0.2mm, g = 0.2mm and the relative permittivity of the substrate is εr = 4.4 with a thickness of 1.6mm. Fig. 2(b) shows the enlarged typical fishnet structure [4-5] with parameters G=1mm and square D=2mm.

Later by using the above optimized geometries, the study is carryout with four different combinations, CSRR on top and bottom ground plane of the antenna. Initially, embedding only fishnet structure in between radiating patch and ground plane i.e., Antenna 1, secondly embedding CSRR on radiating patch along with fishnet structure i.e., Antenna 2, in the third step embedding CSRR on ground plane along with fishnet structure i.e., Antenna 3 and finally embedding CSRR on both radiating patch and ground plane along with fishnet i.e., Antenna 4. Fig. 3 shows the photographs of fabricated antennas. The results of these are discussed in next section.

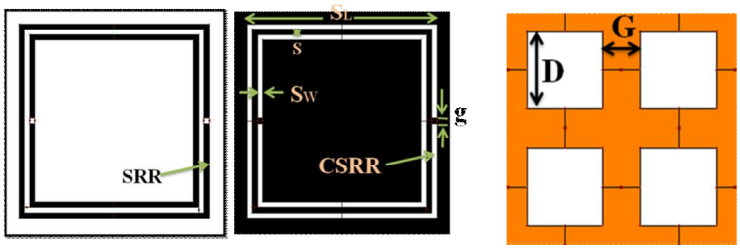

Fig. 2 (a) Fig. 2 (b)

Fig. 2: Geometry of (a) SRR & CSRR (b) Enlarged fishnet structure

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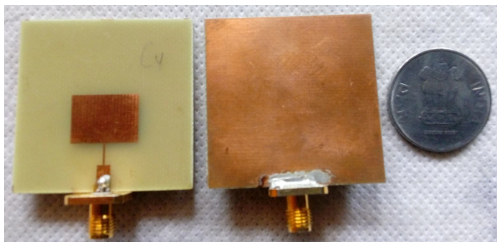

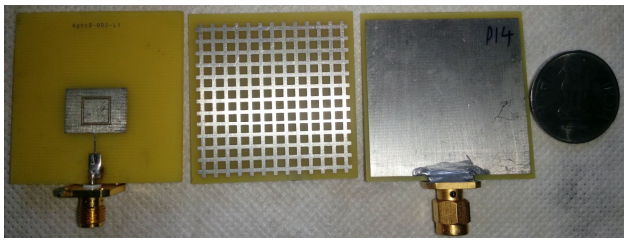

Fig. 3 (a) Fig. 3 (b)

Fig. 3 Photographic view of the proposed microstrip patch antenna (a) reference (b) optimized Antenna 2

III.RESULTS AND DISCUSSIONS

The prototype antennas with the proposed geometry have been fabricated and measured experimentally using Vector Network Analyzer (Rohde and Schwarz, Germany-made ZVK model 1127.8651). Fig. 4 shows the measured return loss characteristics of reference antenna.From this figure it is observed that, the reference antenna resonating at 5.99GHz with bandwidth of 250MHz (4.18%). The impedance bandwidth over return loss less than -10dB is determined by using the equation

$$BW = \left[\frac{f2 - f1}{fc} \right] \text{x}100\%$$

Where, *f*1 and *f2* are the lower and upper cut-off frequencies of the band respectively, when its return loss reaches -10dB and f_C is the centre frequency between *f1* and *f2*.

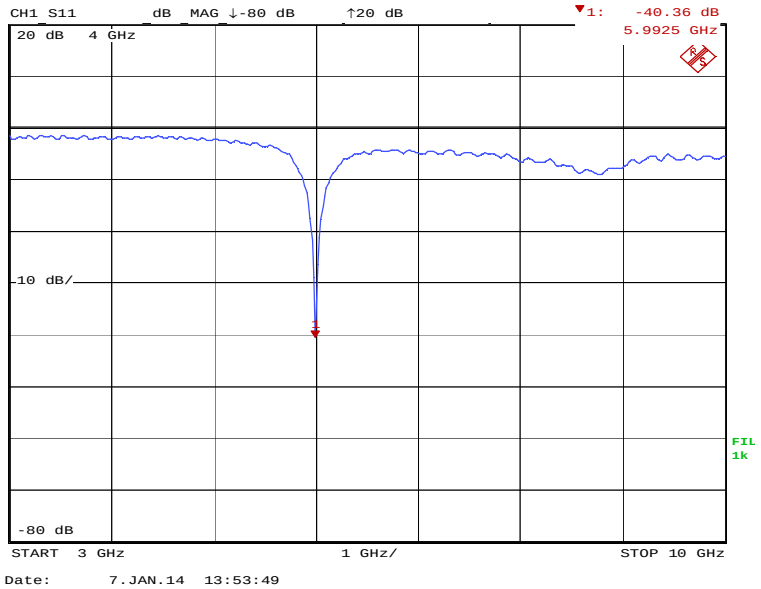

Fig. 4 Measured return loss characteristics of reference antenna

Measured return loss characteristics of Antenna 1 is shown in Fig. 5. From the figure it is observed that the antenna is resonating for five frequency points i.e., 1.74 GHz, 5.83GHz, 6.58GHz, 7.12GHz and 7.73GHz with bandwidths of 2.29%, 9.77%, 3.50%, 3.65% and 19.01% respectively.

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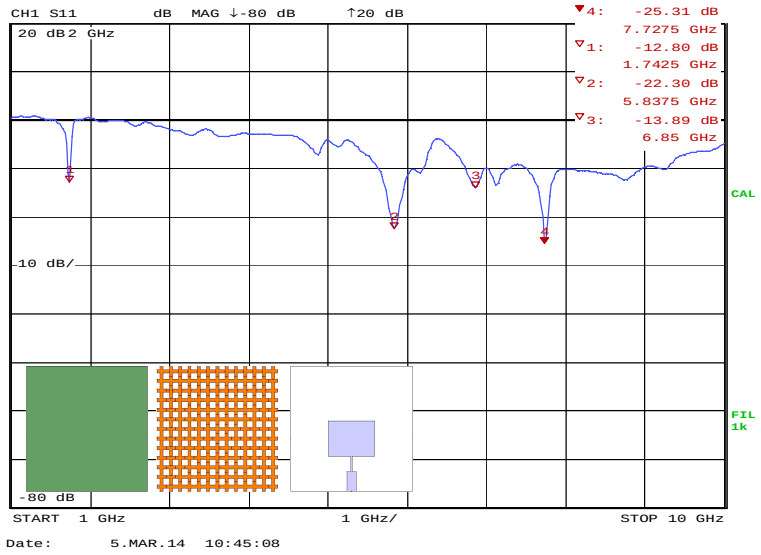

Fig. 5 Measured return loss characteristics of Antenna 1

Fig. 6 shows the measured return loss characteristics of Antenna 2 which is resonating for four frequency points 1.71GHz, 3.75GHz, 4.31GHz and 6.51GHz with bandwidths of 1.75%, 1.33%, 32.25% and 32.71% respectively.

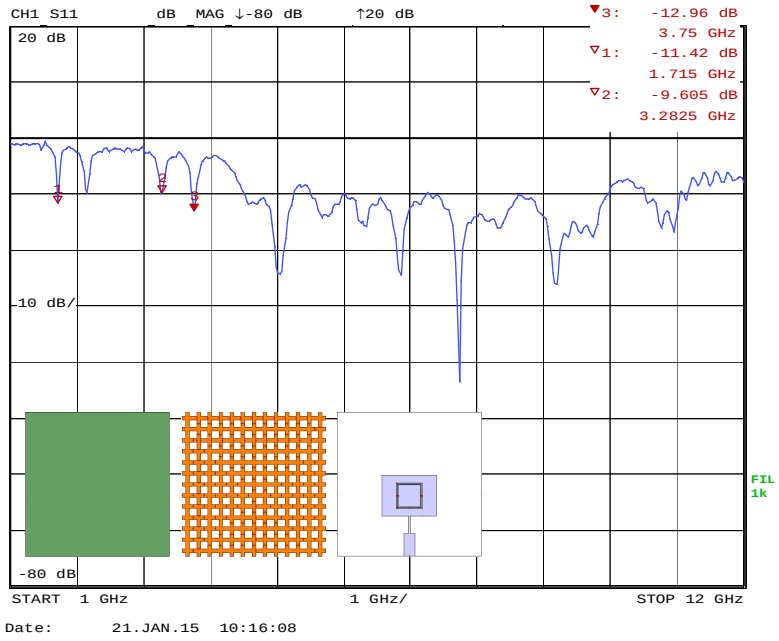

Fig. 6 Measured return loss characteristics of Antenna 2

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Fig. 7 shows the measured return loss characteristics of Antenna 3 which is resonating for six frequency points 1.68GHz, 4.22GHz, 5.68GHz, 6.49GHz, 7.62GHz and 8.02GHz with bandwidths of 2.38%, 9.71%, 8.62%, 11.81%, 3.54% and 2.86% respectively.

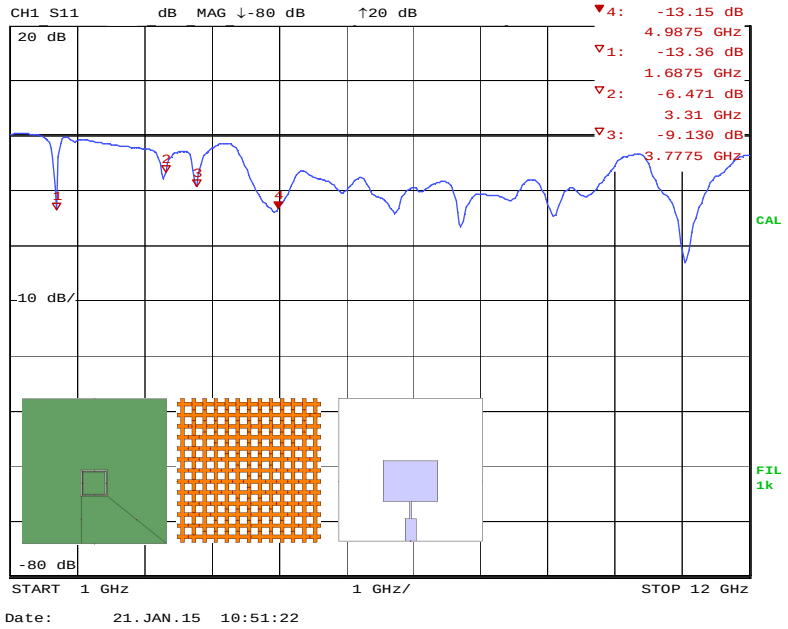

Fig. 7 Measured return loss characteristics of Antenna 3

The measured return loss characteristic of Antenna 4 is shown in Fig. 8. From the figure it is observed that the antenna is resonating for four frequency points 1.71GHz, 5.65GHz, 7.19GHz and 7.78GHz with bandwidths of 2.92%, 7.43%, 5.42% and 17.86% respectively.

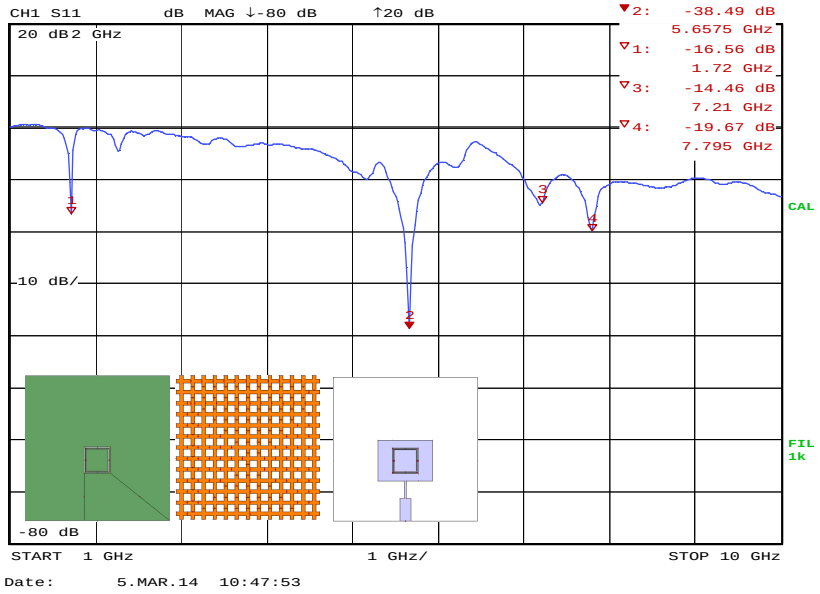

Fig. 8 Measured return loss characteristics of Antenna 4

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Table 1 shows the measured results of the proposed antennas. From the table it is cleared that by using the combinations of CSRR and fishnet structures all configurations are giving size reduction. Antenna 2 i.e., the combination of CSRR on radiating patch along with fishnet structure is giving good bandwidth of 68.04%. Also all proposed configurations are giving multiband frequencies and the Antenna 3 i.e., the combination of CSRR on ground plane along with fishnet structure is resonating for six bands with good size reduction of 72%.

Table 1: Measured parameter results of proposed antennas

Antenna configurations	Resonating Frequency (GHz)	Returnloss (dB)	Bandwidth (MHz, %)	Overall Bandwidth (%)	Size reduction (%)
Refrecne Antenna	5.99	-40.36	250,4.18	4.18	---
Antenna 1 (with only fishnet)	1.74	-12.80	40,2.29	57.43	71
	5.83	-22.30	570,9.77		
	6.85	-14.02	240,3.50		
	7.12	-13.05	260,3.65		
	7.73	-25.25	1470,19.01		
Antenna 2 (CSRR on radiating patch with fishnet)	1.71	-11.42	30,1.75	68.04	71.5
	3.75	-12.96	50,13		
	4.31	-21.79	1390,32.25		
	6.51	-27.35	2130,32.71		
Antenna 3 (CSRR on ground plane with fishnet)	1.68	-13.36	40,2.38	38.92	72
	4.22	-13.76	410,9.71		
	5.68	-13.72	490,8.62		
	6.49	-16.48	820,11.81		
	7.62	-13.46	270,3.54		
	8.02	-11.43	230,2.86		
Antenna 4 (CSRR on both radiating patch and ground plane with fishnet)	1.71	-16.56	50,2.92	33.63	71.5
	5.65	-46.55	420,7.43		
	7.19	-14.90	390,5.42		
	7.78	-19.53	1390,17.86		

The radiation patterns of all antennas have been studied and they are broad side radiations. Fig. 9 shows measured typical radiation patterns of (a) reference antenna at 5.99GHz and (b) Antenna 2 at 3.75GHz.

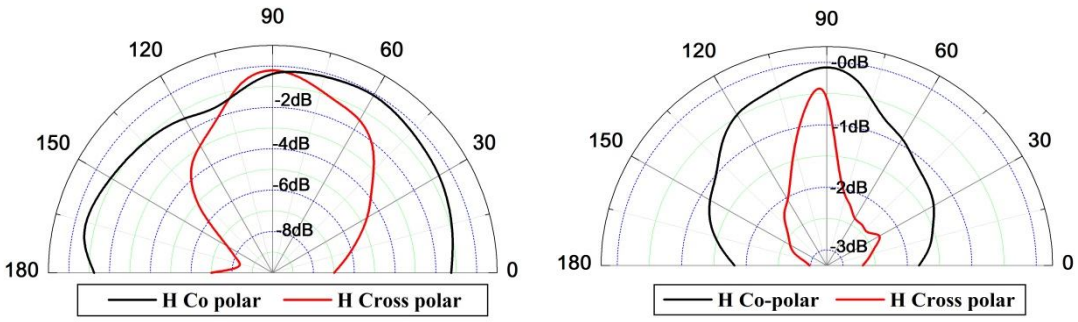

Fig. 9 Typical radiation patterns of reference antenna at 5.99GHz and Antenna 2 at 3.75GHz

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IV. CONCLUSIONS

From the detailed experimental study it is concluded that, by using the combinations of CSRR and Fishnet metamaterial structures i.e., CSRR on the ground plane along with fishnet gives resonance for six frequency points and virtual compactness of 72%. Further by using the combination of CSRR on the radiating patch along with fishnet structure the antenna is giving highest overall bandwidth of 68.04%. To best of our knowledge this is the first design of patch antenna by employing both CSRR and fishnet metamaterial for enhanced performance of microstrip patch antenna. The proposed antennas are simple in their design and we have used low cost substrate material. These antennas may find application in wireless communication systems.

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BIOGRAPHY

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