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Research paper

Metamaterial extended CSRR based monopole antenna for wideband applications

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Abstract

A metamaterial extended microstrip rectangular patch antenna with CSRR loading and defected ground structures(DGS) is proposed for wideband applications with band notching at the frequencies of K_U band. The proposed antenna is designed by embedding it on Rogers RT/Duroid 5880 substrate with good impedance matching of 50 Ω at the feedline. The high frequency structure simulator (HFSS) is used to design and simulate the antennas parameters in the operating band. Measurement results confirm the antenna characteristics as predicted in the simulation with a slight shift in frequencies.

Keywords: *CSRR; DGS; Metamaterial; UWB*

1. Introduction

With the growing demand for compact and portable wireless communication devices, metamaterials also known as left handed metamaterials (LHMs) have attracted much attention in the recent years. LHMs have been a field of tremendous research activity with remarkable progress in the past decade [1]. Metamaterials are artificially engineered materials exhibiting negative values of dielectric permittivity (€) and magnetic permeability (μ). They increase gain and bandwidth of a patch antenna and allows for miniaturization of antenna by reducing its overall size. LHMs have the unique characteristics of supporting a negative refractive index, fundamental backward wave and infinite wave with non-zero group velocity which makes them attractive for antenna applications [2].

When metamaterials are applied in microstrip antennas, they can promote a capacitive filter effect, which works rejecting some frequencies and increasing the antenna return loss, reduction of antenna's dimensions maintaining its main characteristics, and other effects [3]. The use of metamaterials applied to antennas has been successfully studied by many authors[4-8]. The phenomenon of interest, which is explored throughout this work, is the minimization of the electromagnetic near-field mutual coupling. The metamaterial behavior can be synthesized by the inclusion of non-homogenous elementary geometries in specific points of the structure and CSRRs are the widely used structures to synthesize metamaterials [9].mConventional microstrip antennas had some limitations, that is, single operating frequency, low impedance bandwidth, low gain, larger size, and polarization problems [10]. Defected Ground Structure (DGS)has gained popularity among all the techniques reported for enhancing the antenna parameters due to its simple structural design [11-14]. Slots or defects integrated on the ground plane of microwave planar circuits are referred as defected ground structure. DGS is adopted as an emerging technique for improving the various parameters of microwave circuits, that is, narrow bandwidth, cross-polarization, low gain, and so forth [15-18]. In this paper the technique of DGS has been used along with the concept of metamaterials and CSRR [19-22].

In table I we have compared dimensions, bandwidth, gain and resonating frequencies of other antennas for UWB applications. We can observe from the table that overall bandwidth has been improved in this paper. Left handed metamaterials is used to improve the efficiency and the bandwidth. The proposed antenna shows advantages in terms of the bandwidth, compact size, low-fabrication cost, low-cross polarization level and the multi-band operation with flexible polarization states.

Table 1: Comparison Results of Other Antennas

Ref. No.	Dimensions	Bandwidth (GHz)	Rejection Band(GHz)	Max. Return Loss(dB)
[2]	30x30x1.57	5.5-11	8.6-8.9	-23.93
[3]	32x28x0.794	3.5-7.9	-	-23
[4]	38x32x0.794	3.5-7.9	-	-35
[6]	150x70x1.6	0.5-2.5	0.95-1.5	-41
[7]	30x30x1.6	3.1-10.6	(5.15-6.4) and (8.4-9.4)	-28
[8]	45x45x0.794	8.4	5.2-6.4	-37
This paper	30.6x35.3x0.8	3.5-15.2	13-13.5, 13.8-14	-35

2. Metamaterial Antenna Design

2.1 Model

Figure 1 and 2 shows the geometry of the proposed metamaterial microstrip antenna. It is mounted on substrate which is a nonmagnetic circuit material, Rogers RT/Duroid 5880 with a relative permittivity of 2.3 and loss tangent of 0.0004. Substrate thickness is 0.8 mm. Figure 1 shows the top plane of the rectangular microstrip patch antenna where 12 complementary double ring resonators are incorporated in a 3 x 4 array. Another 2-dual complementary split ring resonators (CSRR) are introduced on both sides of the line feed for enhancing the bandwidth. The defected ground plane [Fig 1] consists of periodically distributed cross stripline gaps. The patch antenna is feed by a microstrip line which is 3mm in width and length of the feed line is 8mm. Figure 2(a) and 2(b) shows the LHM unit cell and the CSRR which is incorporated in the substrate. The other geometrical dimensions are given in Table 1. All the parameters have been optimized for their best performance. The fabricated antenna is shown in figure 3(a) and 3(b). The proposed antenna has been tested with the help of network analyzer. It has been observed that the measured results are well matched with the simulated results.

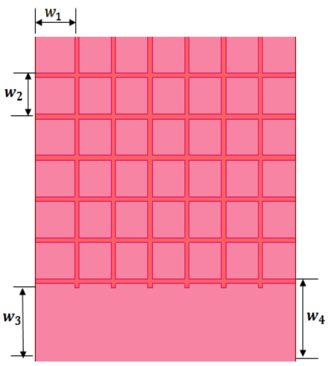


Fig 1: Ground Plane

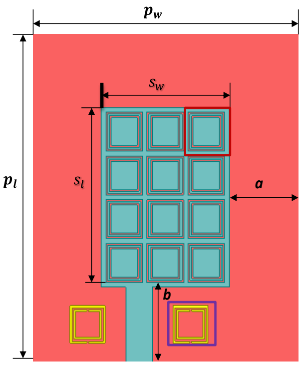


Fig 2: Top View

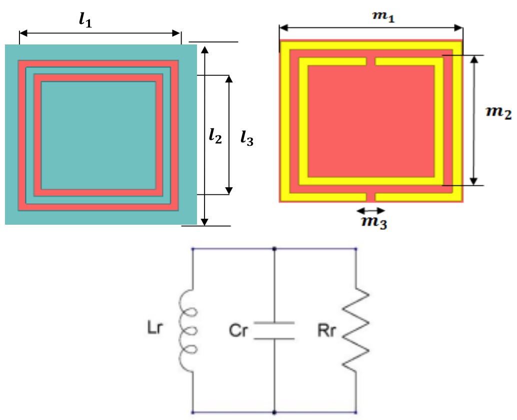


Fig 2 (a): Ring Resonators (b): CSRR (c):Equivalent Circuit

Table 2: Antenna Dimensions

Dimensions	p_w	p_l	s_w	s_l	a	b	l_1	l_2
mm	30.6	35.3	14.6	19.3	5.5	8	4.2	5.2

Dimensions	l_3	m_1	m_2	m_3	w_1	w_2	w_3	w_4
mm	3.5	4	3.6	0.3	4.5	4.5	8	8.2

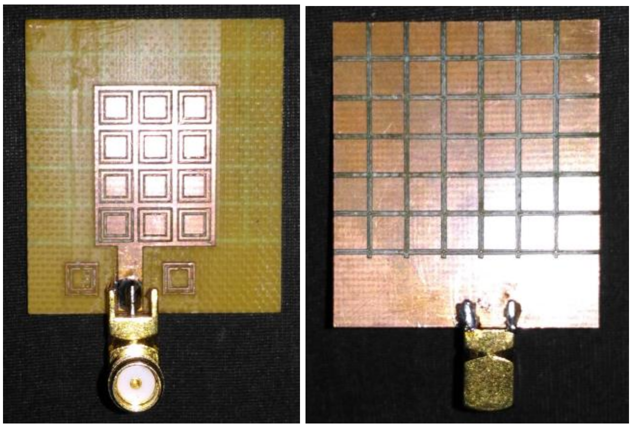


Fig 3: Prototyped Antenna (a): Fabricated Top Plane, (b): Fabricated Ground Plane

2.2 Design specification

The parameters of the antenna patch are calculated from the formulas given below.

2.2.1 Calculation of width (W):

$$w = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{c}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (1)$$

Where
c= free space velocity of light
ε_r= Dielectric constant of substrate

2.2.2 The effective dielectric constant of the microstrip patch antenna

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + \frac{12h}{w}}} \right) \qquad (2)$$

2.2.3 The actual length of the patch(L)

$$L = L_{eff} - 2\Delta L \qquad (3)$$

Where $$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{eff}}} \qquad (4)$$

2.2.4 Calculation of length extension

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \qquad (5)$$

We have considered four antenna configurations with the same basic design considerations. Figure 4,5,6 are the 3 different model designs considered. Figure 4 shows the basic model of a microstrip patch antenna. Figure 5 shows the basic patch antenna with defected ground structures whereas Figure 6 shows the rectangular microstrip patch antenna array with 12 dual ring resonators in a 3x4 array. The studies carried out in this paper have showed that the proposed model (figure 1(a) and 1(b) can perform effectively with the introduction of another 2-dual complementary split ring resonators on both sides of the line feed and it can be seen from the return loss curves of all the models in figure 7

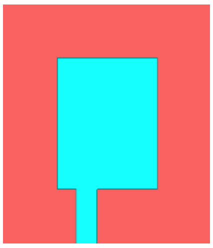
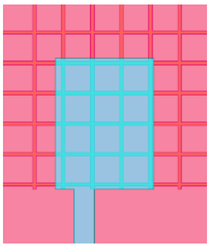
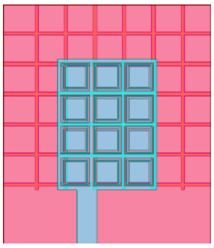




Figure 4 **Figure 5** **Figure 6**

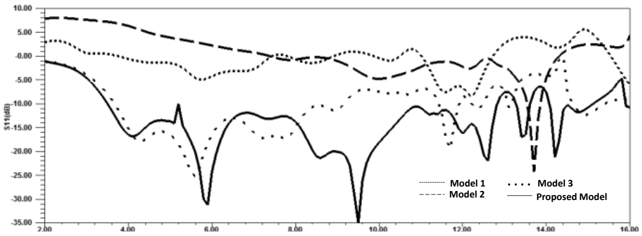


Fig 7: Return Loss Curve for all models.

2.3 Complimentary split ring resonator

A split-ring resonator (SRR) is one of the metamaterial particles that offers negative permeability [23], while CSRR, the duality of SRR, interacts with the electric field and introduces negative permittivity [24]. A schematic diagram is shown in Fig. 1(a). The electrical length of a metamaterial unit cell is much smaller than the wavelength of the operating wave, making it an ideal candidate for microwave component miniaturization. A CSRR can be modelled as a parallel - tank as shown in Fig. 2(c) when the loss is neglected. The resonating frequency f_o of the CSRR can be given as:

$$f_o = \frac{1}{2\pi\sqrt{L_r C_r}} \qquad \text{---(6)}$$

where L_r and C_r are the equivalent inductance and capacitance of the CSRR, respectively [11]. R_r accounts for both dielectric and conductor losses. The detailed properties for the CSRR is presented in [25], including the analytical calculation of the resonance frequency. The dimension and extracted equivalent lumped element values of the designed CSRR are given in Table 1.

3. Parametric Analysis

The proposed model dimensions have been optimized for the best possible performance and it is evident from the following observations. The variations in the return loss have been observed by varying several parameters as discussed below:

3.1 Effect of feed length:

The antenna is fed with a standard inset line feed, and the location of the feed would be expected to affect the tuning of the antenna. The effect of the feed was evaluated by changing the length to 7.8mm and 7.9mm. The length b(8mm) of our proposed design is giving the best results covering the entire UWB as shown in figure 8.

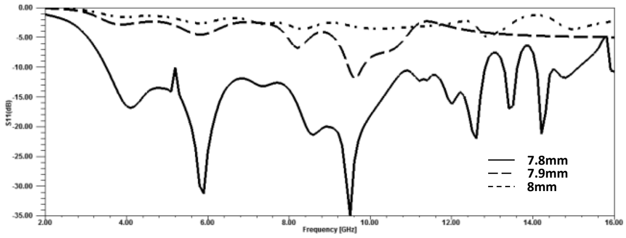


Fig 8: Return loss by varying length of feed

3.2 Effect of feed width:

Variation in return loss has been observed by increasing and decreasing the width of the feed to 2mm and 4mm. Optimum return loss is obtained for the original width of the feed(3mm) proposed in this paper as shown below in figure 9.

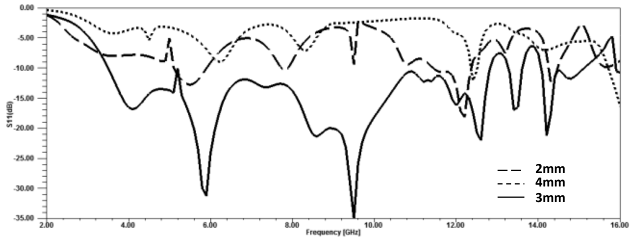


Fig 9: Simulated Return loss by varying feed width

3.3 Effect of slot width of ground:

Slot width of the ground structure is varied by reducing the original dimension used in this paper to 0.3 mm and 0.4mm respectively to observe the return loss. The original width-0.5mm of our proposed design is giving the best results covering the entire bandwidth for UWB applications as shown in figure 10.

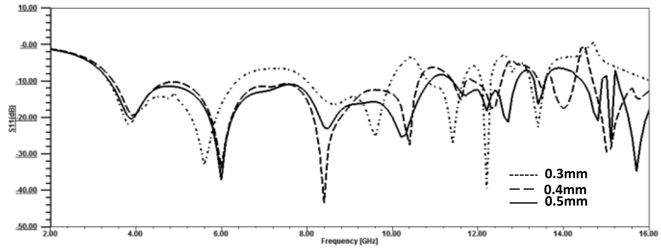


Fig 10: Simulated Return loss by varying slot width of ground

3.4 Effect of split ring resonator width:

Return loss is observed by varying the width of the complimentary dual ring resonators to 0.2mm and 0.4mm. The width m_3=0.3mm of our proposed design is giving the best results as shown in figure 11.

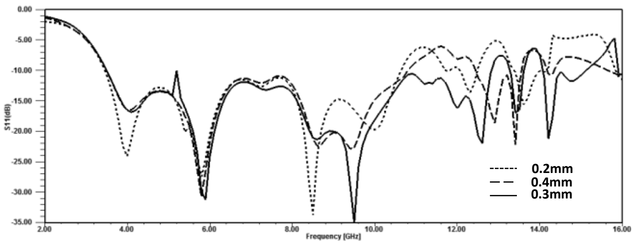


Fig 11: Simulated Return loss by varying width of splitters

4 Results and Discussion

Ansoft High Frequency Structure Simulator (HFSS) is utilized to simulate the properties of proposed antenna.

4.1 Reflection Co-Efficient and Current Distributions

The simulated reflection coefficient pattern for the proposed antenna is shown in figure 12. It is observed that the proposed antenna can work efficiently for UWB applications. The reflection coefficients of the fabricated antenna were measured by Agilent E8363 Vector Network Analyzer. Figure 13 shows the measured reflection coefficients for fabricated antenna. It has been observed that the measured results are well matched with the simulated results.

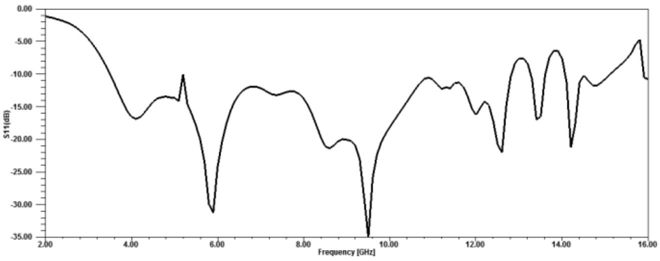


Fig 12: Simulated reflection coefficient

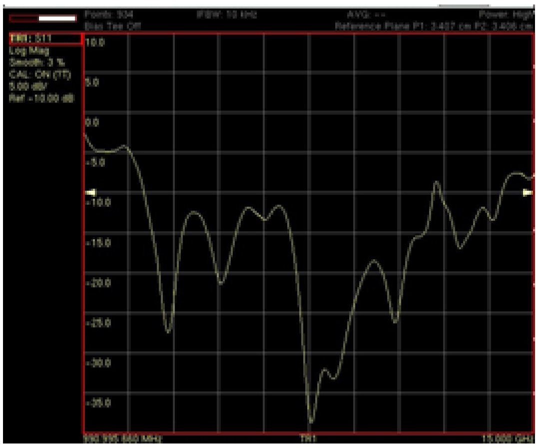
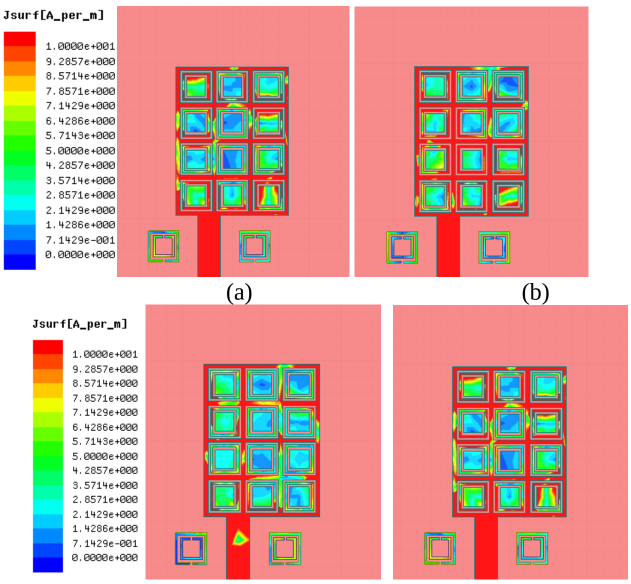
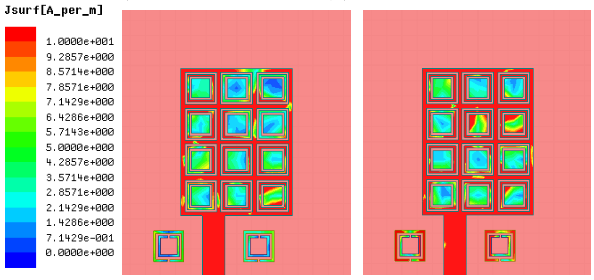


Fig 13: Measured reflection coefficient

The simulated current distributions are observed for all the operating frequencies: 4.1, 5.9,9.5,12.6,13.5,14.2 GHz and is shown in figure 14 (a), (b), (c), (d), (e) and (f) respectively. It can be seen that current is distributed almost evenly in the patch surrounding all the dual ring resonators arranged in 3 x 4 array while with the use of CSRRs, the completed dual ring is splitted in between.



(a) (b)



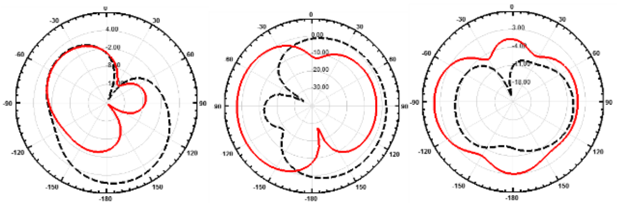
(c) (d)

(e) (f)

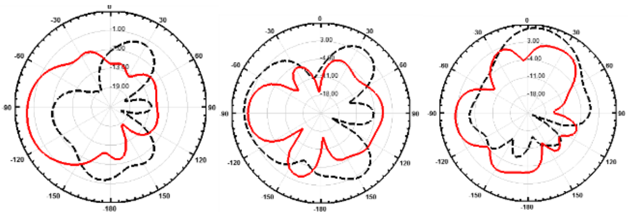
Fig 14: Simulated surface current distributions for antenna with different operating frequencies. (a) 4.1 GHz (b) 5.9 GHz (c) 9.5 GHz (d) 12.6 GHz (e) 13.5 GHz (f) 14.2 GHz

4.2 Radiation Pattern

The radiation patterns for both the H and E planes are shown in figure 15 and 16 respectively for different operating frequencies. Because of the transmission characteristics of left-handed materials, the wave propagation along the patch induces the strongest radiation in the horizontal direction rather than the vertical direction of a conventional patch antenna [13]. In the H plane, the radiated energy is mainly focused in the horizontal direction in the case of the co-polarization whereas in the E plane, radiated energy is mainly in the vertical direction and the cross-polarized radiation pattern is always orthogonal with the co-polarized radiation pattern. Across the full frequency range, the radiation pattern of the proposed antenna maintains good performance.

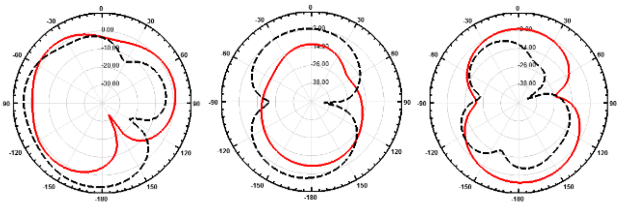


(a) (b) (c)

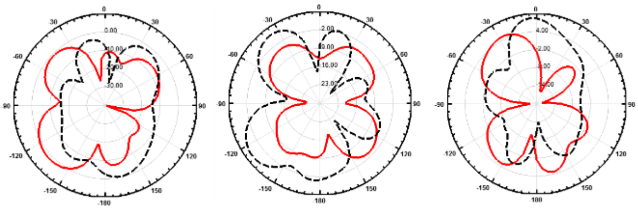


(d) (e) (f)

Fig 15: Simulated radiation patterns in H plane for antenna at different operating frequencies. (a) 4.1 GHz (b) 5.9 GHz (c) 9.5 GHz (d) 12.6 GHz (e) 13.5 GHz (f) 14.2 GHz



(a) (b) (c)



(d) (e) (f)

Fig 16: Simulated radiation patterns in E plane for antenna at different operating frequencies. (a) 4.1 GHz (b) 5.9 GHz (c) 9.5 GHz (d) 12.6 GHz (e) 13.5 GHz (f) 14.2 GHz

5 Conclusion

In this paper, metamaterial extended microstrip patch antenna with CSRR loading and defected ground structure for ultra wide band applications is proposed. Due to the transmission characteristics of LHM materials, the overall size of this patch antenna is smaller than the conventional patch antennas. The antenna radiation characteristics can be easily controlled by changing the configuration of the CSRRs. These CSRR loaded patch antennas are compact, simple in structure, and can be used in a variety of applications. The covered BW at RL>10dB is 3.5-15 GHz with good impedance matching and rejecting 2 bands 12.8-13.3GHz and 13.6-14GHz of the K_U band. The proposed antenna can be applied in wideband system, for the operating frequencies 3.5-8 GHz, it is suitable for applications in X band and medical engineering, for the other operating band, frequencies between 8.0 and 12.7 GHz, which allows the application in some IEEE 802.11 WLAN channels and in X-band.

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