Progress In Electromagnetics Research C, Vol. 81, 115–124, 2018

A Compact Non-Bianisotropic Complementary Split Ring Resonator Inspired Microstrip Triple Band Antenna

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Abstract—A Compact Non-Bianisotropic Complementary Split Ring Resonator (NB-CSRR) based microstrip triple band antenna is presented in this paper. The antenna has a simple structure compared to other antennas for triple band operation. The antenna consists of a microstrip-fed NBCSRR loaded radiating element and partial ground plane. The designed antenna has a compact size of $29.4\,\mathrm{mm} \times 26\,\mathrm{mm} \times 1.6\,\mathrm{mm}$. Two NBCSRR slots are etched on the radiating patch. Bottom NB-CSRR is used to generate new resonance, and top NB-CSRR is used to improve the return loss. The measured data show that the antenna covers the frequency ranges of 2.5 GHz–3.61 GHz, 4.06 GHz–4.69 GHz, 4.80 GHz–6.07 GHz with impedance bandwidth of (< -10 dB) of 1.11 GHz, 0.63 GHz and 1.27 GHz. The results show that the antenna can cover WLAN and C band applications.

1. INTRODUCTION

The design of a compact multiband antenna plays vital role in recent modern wireless communication systems. Microstrip antennas have got lot of attention for multiband antenna design due to their interesting features such as low profile, low cost, simple excitation technique and easy integration with other MIC components. The rectangular, trapezoidal slots etched ground plane and additional strips were used to generate triple resonance frequency [1]. Five dipoles were used to generate triple resonances [2]. Open complementary split ring resonator loaded elliptical coplanar waveguide (CPW)-fed rectangular patch was designed to cover triple frequency band [3]. A microstrip fed circular ring with y-shape strip and defected ground structure was used to cover WLAN and WIMax bands [4]. A rectangle slot with multiple strips was used to generate multiple resonances [5]. A microstrip antenna with different shapes such as face-shape slot with eye-like patches was used to cover triple bands [6]. Various techniques have been studied using complicated patches and etching slots.

In recent years, metamaterial inspired elements have received great attention for the design of multiband antennas due to the promising features. Vesalago's paper on electrodynamics of substances with simultaneously negative values of ε and μ was the origin for all the researches on metamaterial [7]. As predicted by Vesalago, metamaterial is not a natural material but an artificial structure designed to display simultaneously values of ε and μ in the same frequency range of interest. A transmission line model of metamaterial was introduced by Caloz and Itoh [8]. In contrast to a conventional transmission line, a series arm consists of a capacitor, and a shunt element consists of an inductor. A metamaterial inspired antenna was studied for the design of a compact antenna [9], broadband antenna [10], multiband antenna [11], and high gain antenna [12]. The multiband conductor backed CPW-fed antenna was designed by complementary split ring resonator (CSRR) on back side of the substrate [13]. The microstrip with left offset fed CSRR slots loaded patch was designed for triple-band antenna [14]. The multi-resonance was generated by placing the CSRR slots at the optimum place of the patch. A CPW fed Split Ring Resonator (SRR) radiating element was used to cover WLAN

Received 30 October 2017, Accepted 10 January 2018, Scheduled 13 February 2018
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applications [15]. The basic elements of metamaterial such as SRR and CSRR are designed to exhibit negative permeability and negative permittivity. The equivalent circuits of SRR and CSRR are dual networks [16]. The dual networks have the same solution. Hence, the resonant frequency of CSRR is the same as resonant frequency of SRR for the same dimensions. SRR and CSRR based antennas have been studied for the design of multiband antennas.

The objective of this paper is to study the performance of an NB-CSRR loaded rectangular microstrip patch antenna for triple-band operation. The NB-CSRR is used to avoid bianisotropic effect that the conventional SRR exhibits. The performance of the antenna is studied in detail. The NBCSRR band characteristics are studied to validate the results. The highlight of this work is that without any complicated structure, a multiband antenna is designed.

2. ANTENNA STRUCTURE AND DESIGN

The design starts with a microstrip-fed rectangle patch, which is used to generate dual resonances of 2.83 GHz and 5.6 GHz. The evolution of the proposed antenna is shown in Figure 1. As shown in stage A, the microstrip antenna has a partial ground plane. In the next step, NB-CSRR slots are etched on the patch. The NB-CSRR loaded patch is used to generate dual bands. The first band has resonance at 2.8 GHz, and the second band has dual resonances of 5.1 and 5.7 GHz. The bottom NB-CSRR is used to generate a new resonance of 5.1 GHz. In the third step, one more NB-CSRR of the same dimension is introduced in the radiating patch. Configuration C provides triple bands with resonance frequencies of 2.7 GHz, 4.40 GHz and 5.6 GHz. This study clearly shows that bottom NB-CSRR is used to generate the new resonance of 5.1 GHz. By introducing one more NB-CSRR, the resonance frequencies are shifted to 2.7 GHz from 2.8 GHz, 4.4 GHz from 5.1 GHz and 5.6 GHz from 5.66 GHz. Also Configuration C is used to provide good return loss for the second and third bands. The proposed antenna with two NB-CSRRs is used to provide triple bands having frequency ranges 2.28–3.6 GHz, 4.30–4.92 GHz and 5.0–5.97 GHz with resonance frequencies of 2.7 GHz, 4.40 GHz and 5.6 GHz, respectively.

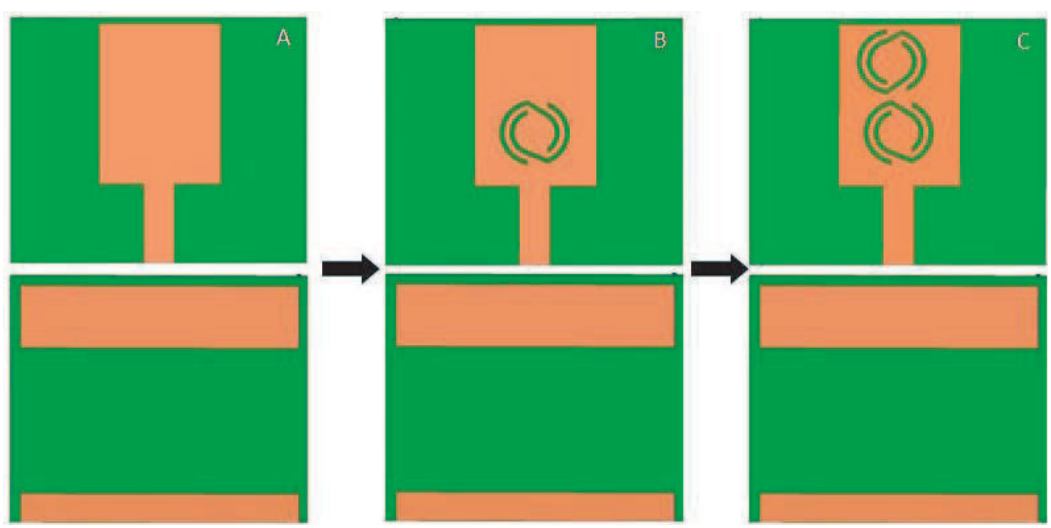

Figure 1. Evolution stage of proposed antenna.

The simulated return losses of antenna evolution stages are shown in Figure 2. The top and bottom views of the antenna geometry are shown in Figures 3(a) and (b). The antenna is printed on an FR4 substrate with $L_S = 26$ mm, $W_s = 29.4$ mm, thickness 1.6 mm, and dielectric constant 4.4. The antenna is fed by 50 Ω microstrip feed having $L_f = 8.38$ mm, $W_f = 3$ mm. The rectangular patch has length $L_P = 17$ mm and $W_P = 12$ mm. The NB-CSRRs of same size are etched on the radiating patch. The NB-CSRR structure is similar to CSRR, and two slots are connected together through slots. The radius of outer slot (R_1) is 3.5 mm, and the radius of inner slot (R_2) is 2.5 mm. The metal ring width (R_w)

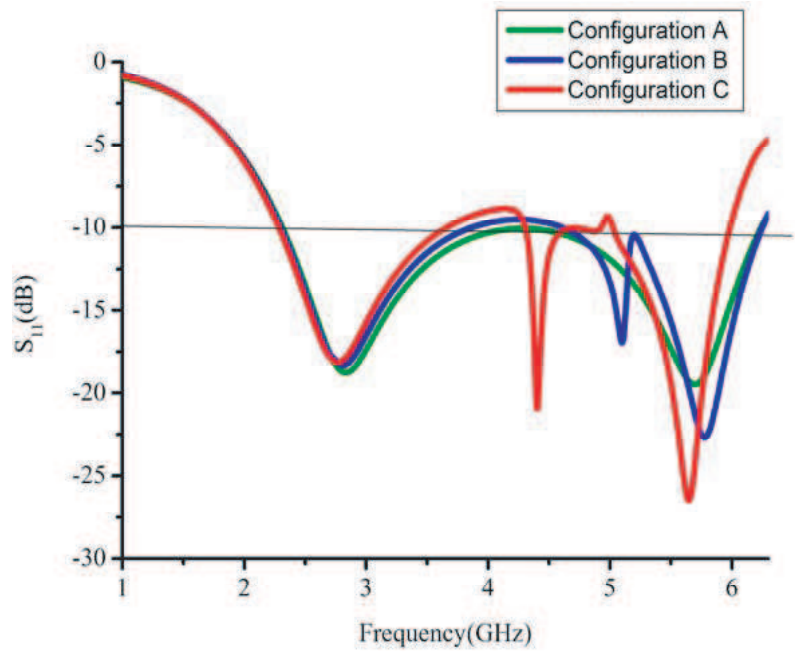

Figure 2. Simulated S_{11} (dB) of proposed antenna evolution stages.

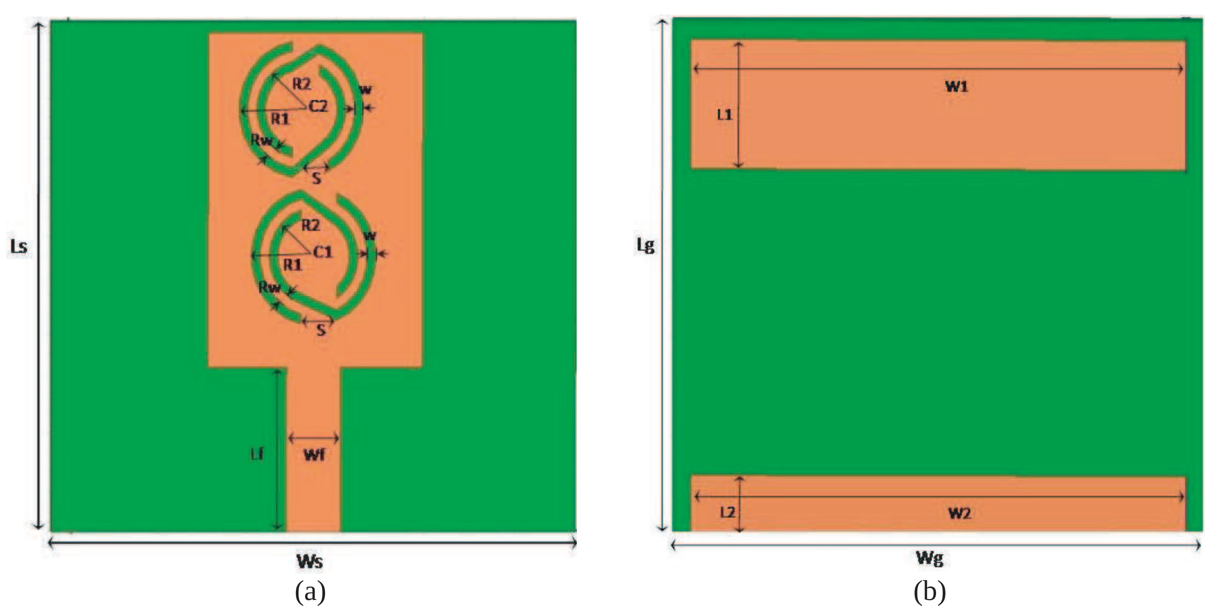

Figure 3. Geometry of proposed antenna. (a) Top view of proposed antenna. (b) Bottom view of proposed antenna.

between two slots is 0.5 mm, and slit width (S) is 2 mm. The slot width (w) of NB-CSRR is 0.5 mm. The bottom NB-CSRR centre point (c1) is 13.7 mm, 14 mm, 1.6 mm, and the top NB-CSRR centre point (C2) is 13.7 mm, 21.5 mm, 1.6 mm. The defected ground plane dimensions are as follows: $L1 = 6.5$ mm, $W1 = 27.39$ mm, $L2 = 3$ mm, $W2 = 27.39$ mm.

Surface current distribution of the proposed antenna is observed at resonant frequencies 2.7 GHz, 4.4 GHz and 5.6 GHz, shown in Figure 4. The surface current distribution is good in microstrip feed at 2.7 GHz. At 4.4 GHz, the surface current distribution is good in feed, near bottom NB-CSRR and between slots of the top NBCSRR. At 5.6 GHz, current distribution is good around the top NBCSRR and bottom NB-CSRR. This clearly indicates that the introduction of NBCSRR alters the current distribution for new resonance frequency generation and good impedance matching.

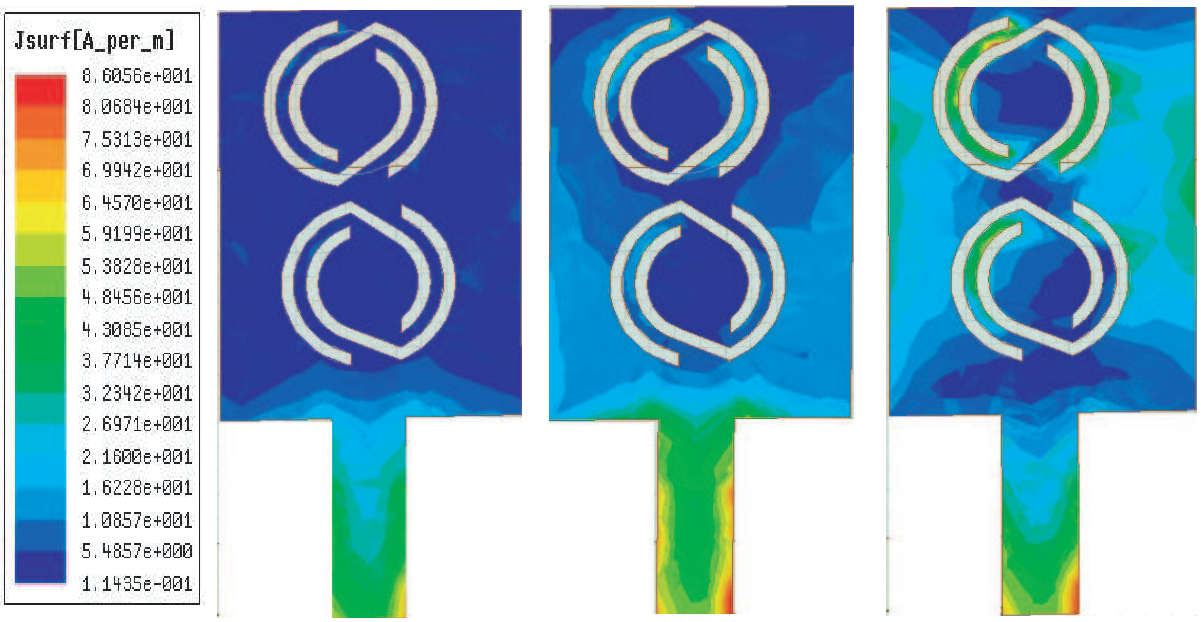

Figure 4. Surface current distribution at 2.7 GHz, 4.4 GHz and 5.6 GHz.

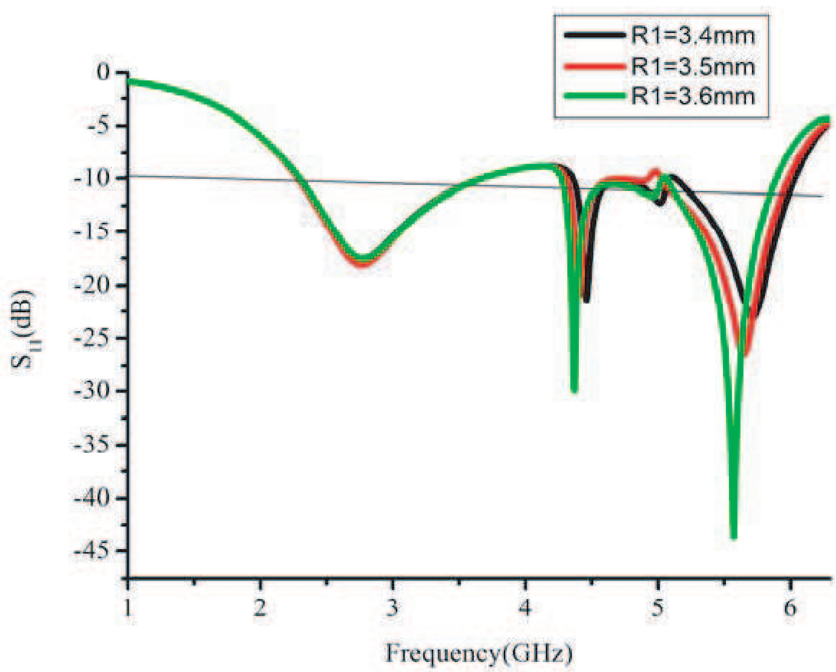

Figure 5. Simulated S_{11} (dB) for various R_1.

3. PARAMETRIC STUDY ON NB-CSRR

The parametric study is done on various parameters of NB-CSRR. The radius of the outer slot (R_1) is varied from 3.4 mm to 3.6 mm, and the return loss characteristics for various R_1 are shown in Figure 5. As radius R_1 increases, the resonance frequency is decreased, but for $R_1 = 3.6$ mm sudden transition from second band to third band is observed. Hence, the radius of outer slot is assigned as $R_1 = 3.5$ mm. The inner slot radius R_2 is varied from 2.4 mm to 2.6 mm, and the corresponding return loss plot is

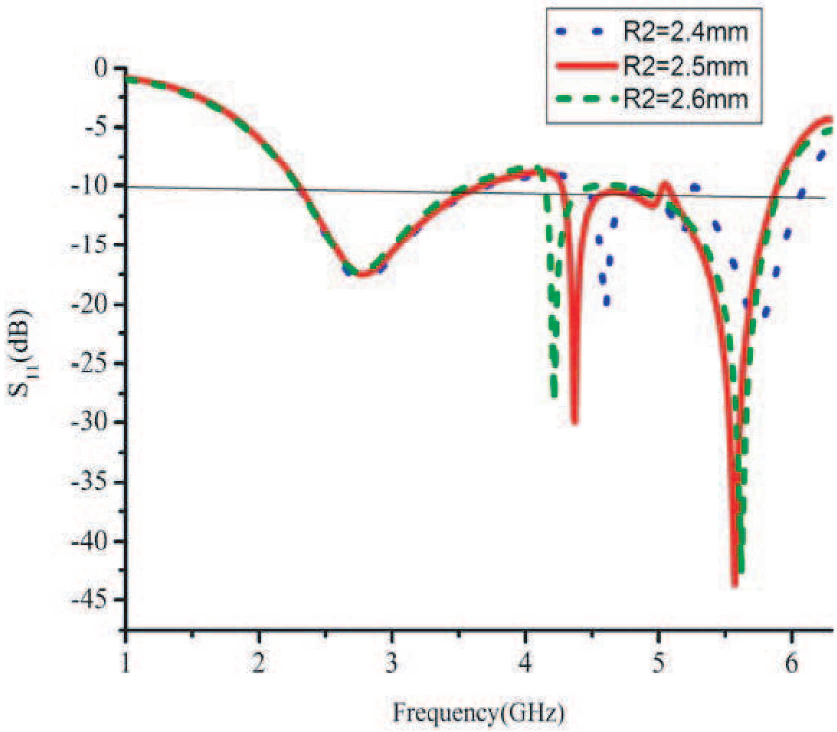

Figure 6. Simulated S_{11} (dB) for various R_2.

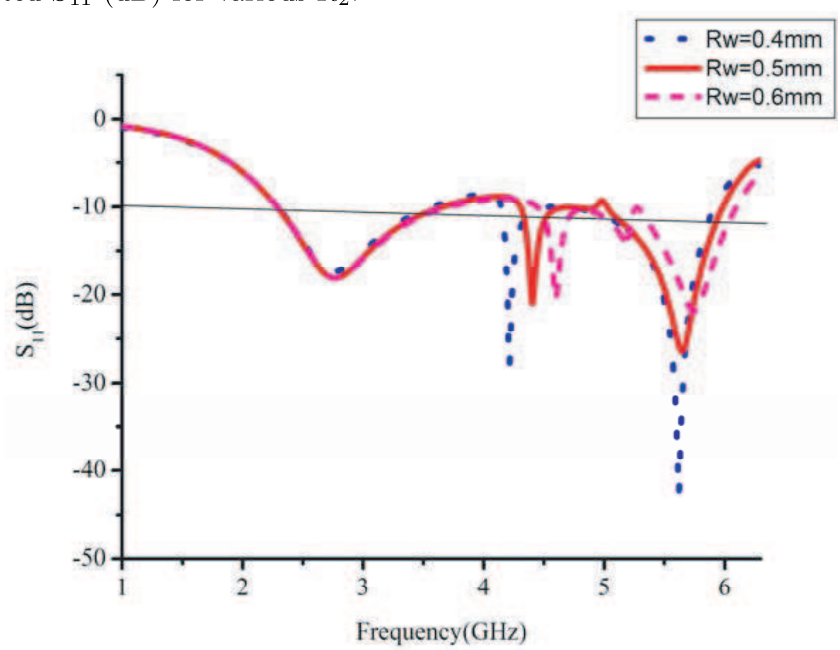

Figure 7. Simulated S_{11} (dB) for various R_w.

shown in Figure 5. The variation in inner slot radius R_2 has no effect on the first band and affects the second and third band resonances. Good return loss is observed for $R_2 = 2.5\,\text{mm}$. The metal ring width (R_w) between slots is varied from $R_w = 0.4\,\text{mm}$ to $R_w = 0.6\,\text{mm}$. The simulated return losses for various ring widths (R_w) are shown in Figure 7. As ring width decreases, resonant frequency is decreased. The variation in ring width has no effect on the first band. The overall parametric study shows that parameters of NB-CSRR have no effect on the first band and affects only the second and third band characteristics.

4. ANALYSIS OF NB-CSRR

The NB-CSRR is dual element of NB-SRR. In NB-SRR, two concentric rings are connected through a small metal ring. So, NB-CSRR is obtained by replacing metal rings of the NBSRR by slots and slots by metal rings. The resonant frequency of NB-SRR is the same as SRR. The resonant frequency of NB-CSRR is the same as NB-SRR using duality principle. The equivalent circuit model and resonant frequency are the same as CSRR [17]. The resonant frequency of NBCSRR is determined from reflection coefficient. The interested readers are directed to [18] for extraction of reflection coefficient from waveguide. The negative permeability can be calculated using Nicolson-Ross-Weir approach [19]. The reflection coefficients of bottom and top NBCSRRs are shown in Figure 8. The resonant frequency of bottom NBCSRR is 5.1 GHz, and top NBCSRR is 5.6 GHz. From Figure 8, it is clear that bottom NBCSRR is used to generate new resonance of 5.1 GHz, and top NBCSRR can be used to improve the return loss of upper band.

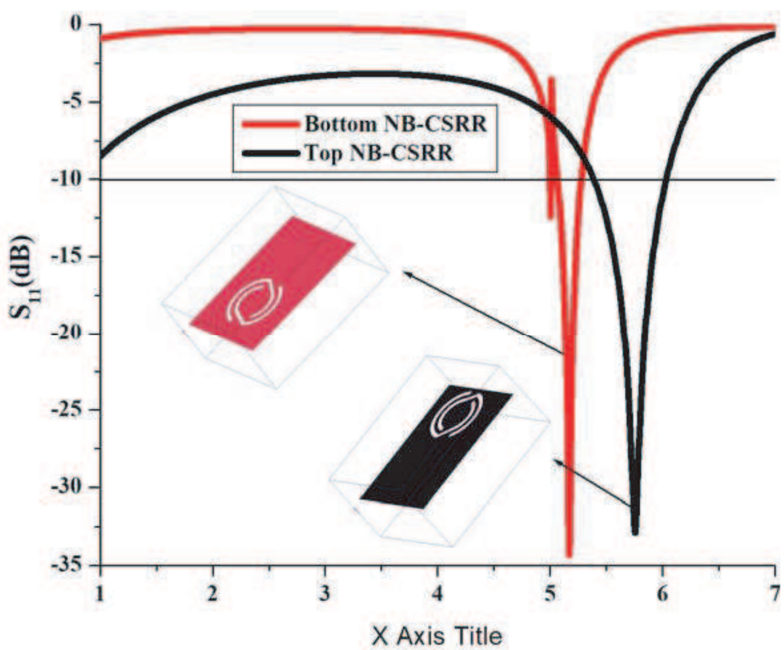

Figure 8. Simulated return loss characteristics of bottom and top NBCSRRs.

5. RESULTS AND DISCUSSION

The proposed antenna is compared with already reported antennas, and the comparison table is shown in Table 1. From Table 1, it is clear that the proposed antenna size is small compared with the antenna listed in reference. Photographs of the antenna are shown in Figure 9. To validate the simulated results, return loss of the antenna is measured by using vector network analyzer. The simulated and measured return loss characteristics of the antenna are shown in Figure 10. The measured data

Table 1. Comparison of the proposed antenna and already reported antenna.

Reference	Year	Patch details	Dimensions ($L \times W$) mm^2	Frequency (GHz)
1	2010	Rectangle slot	35×30	2.7, 3.5, 5.6
2	2009	Five strips	100×60	2.4, 3.5, 6
3	2015	Rectangle	40×30	2.6, 3.4, 5
4.	2011	Circular	38×25	2.5, 3.5, 5.5
5	2010	Rectangle	40×40	2.4, 3.5, 5.5
6	2014	Rectangle slot	34×28	2.5, 3.5, 5.5
Proposed Antenna		NBCSRR Loaded Rectangular Patch	29.4.x26	2.76, 4.39, 5.64

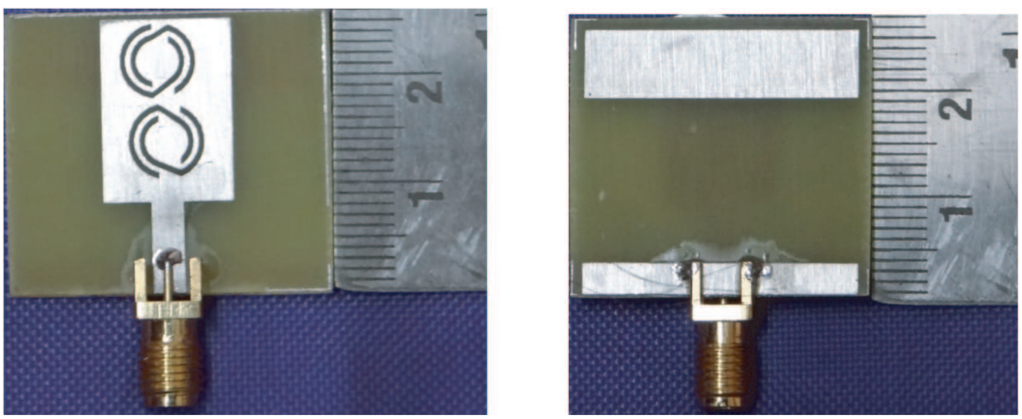

Figure 9. Photograph of top view and bottom view of the antenna.

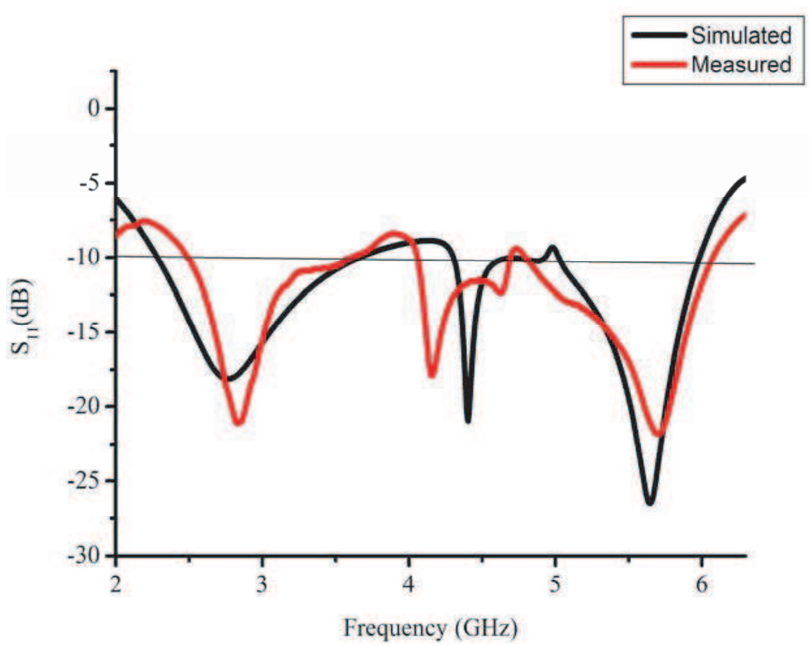

Figure 10. Simulated and Measured return loss of antenna.

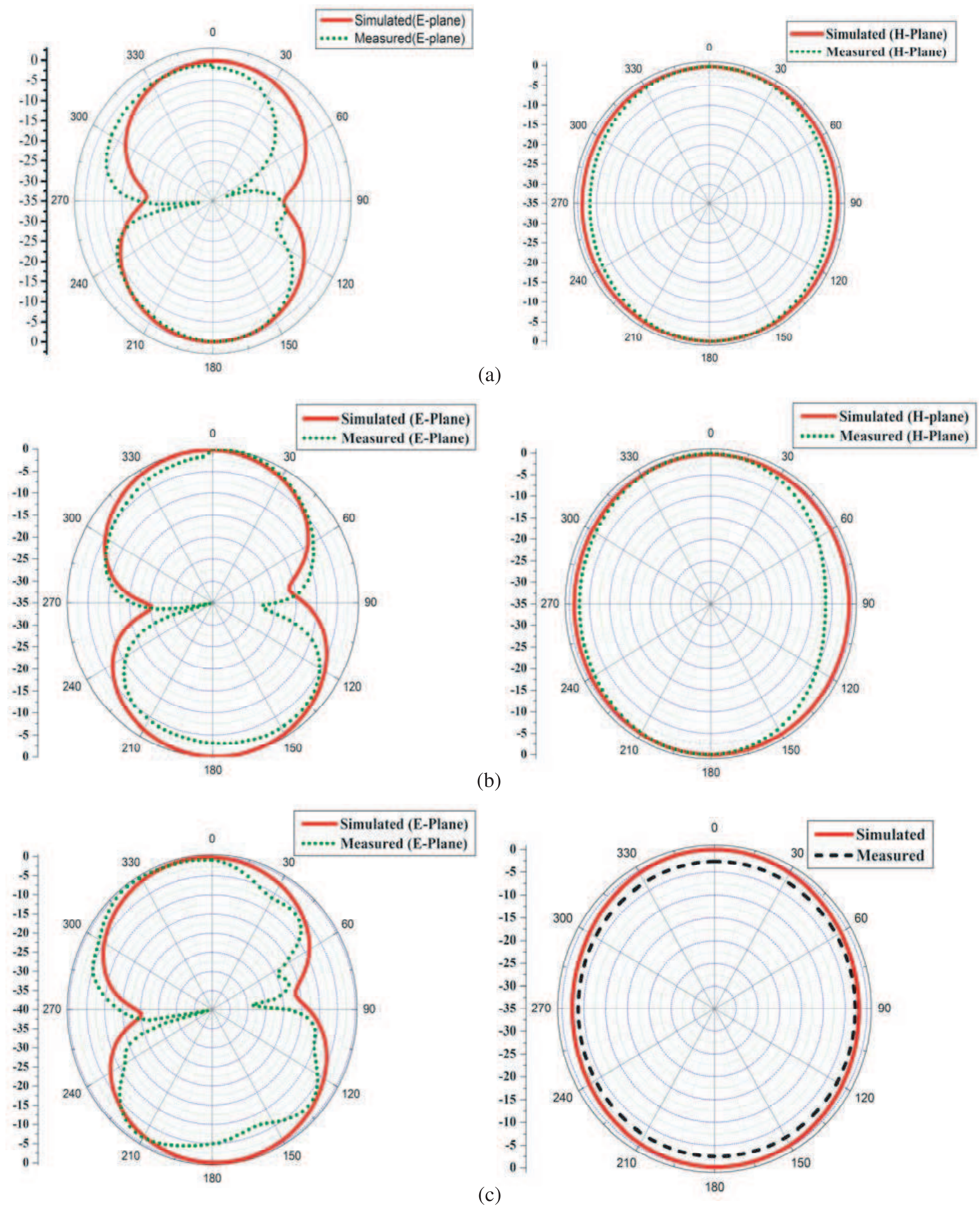

Figure 11. Radiation pattern of proposed antenna at 2.84 GHz, 4.16 GHz and 5.7 GHz. (a) Radiation pattern in E-plane and H-plane at 2.84 GHz. (b) Radiation pattern in E-plane and H-plane at 4.16 GHz. c) Radiation pattern in E-plane and H-plane at 5.7 GHz.

show that the antenna covers the frequency ranges of 2.5 GHz–3.61 GHz, 4.06 GHz–4.69 GHz, 4.80 GHz–6.07 GHz with resonant frequencies of 2.84 GHz, 4.16 GHz and 5.7 GHz respectively. The simulated and measured far-field radiation patterns in E- and H-planes at 2.84 GHz, 4.16 GHz and 5.7 GHz are shown in Figures 11(a), (b), (c). The expected characteristics are obtained in both E- and H-planes.

6. CONCLUSION

A triple-band microstrip antenna is reported using an NB-CSRR loaded patch. The proposed antenna has compact size of $29.4 \times 26 \times 1.6\,\text{mm}^3$. The triple bands are obtained by etching NB-CSRRs slots on the radiating patch. The parametric study is done to validate the results. The reflection coefficient and transmission coefficient of NB-CSRR are studied to show the role of NB-CSRR. The proposed antenna is designed, fabricated and tested. The antenna is suitable for WLAN and C-band applications.

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