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SRR and NBCSRR Inspired CPW Fed Triple Band Antenna with Modified Ground Plane

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Abstract—In this paper, a novel CPW-fed triple band metamaterial inspired antenna with modified ground plane is presented. The metamaterial inspired structures such as split ring resonator (SRR) and non bianisotropic complementary split ring resonator (NBCSRR) are embeded in this antenna for triple band operation. The proposed antenna with a compact size of $25 \times 31.7 \times 1.6\,\text{mm}^3$ is fabricated and tested. The antenna with good radiation characteristics is suitable for WIMAX, C band and WLAN applications. The simulated and measured results are discussed and are in good agreement with each other.

1. INTRODUCTION

In recent years, metamaterial inspired antennas are becoming popular due to the proven extraordinary electromagnetic properties. Planar metamaterial inspired antennas are designed by using metamaterial inspired structures such as SRR and CSRR [1]. Metamaterial is an artificial structure synthesized to display amazing properties not yet found in natural material [2]. Due to the unusual electromagnetic property, many researches have been done for the performance improvement of the antenna. SRR is basically a μ-negative metamaterial structure. The Complementary Split Ring Resonator (CSRR) is complementary dual element of SRR. CSRR is a ε-negative metamaterial. SRR and CSRR are resonant structures. The Double Negative (DNG) metamaterial is constructed by combining μ-negative metamaterial and ε-negative metamaterial. The equivalent circuit of SRR was useful to find the metamaterial characteristics [3].

Metamaterial inspired structures embedded antennas were studied for size miniaturization, multiband operation, bandwidth and gain enhancement. An electrically small antenna was designed by combining a coaxial fed small rectangle shaped patch and a μ-negative metamaterial [4]. An open complementary split ring resonator (OCSRR) filled monopole antenna was designed for multiband operation [5]. OCSRR was introduced in the monopole for new resonance frequency generation, and new resonance was generated by not changing the basic monopole size. Bandwidth was improved by a rectangle shape SRR stuffed substrate without any change in basic monopole shape and dimensions [6]. Gain of the inset-fed microstrip antenna was enhanced by CSRR loaded ground plane [7].

SRR and CSRR inspired antennas were studied for multiband operation. Transmission line representation of metamaterial loading was explored for broadband antenna with dual mode operation [8]. A dual-band CPW-fed antenna was made by combining resonant structures such as SRR and closed ring resonator (CRR) [9]. A compact UWB antenna was designed by a small size circular disc and circular spiral ring resonator [10]. Due to the miniature size of SRR, CPW feed was combined with quarter wave transformer for good impedance matching. A CSRR loaded rectangle-shaped microstrip patch with left offset feed was designed for multiband operation [11]. Rectangle-shaped CSRR was introduced on the top right corner of the ground plane for triple band operation [12].

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A CSRR filled conductor backed CPW antenna was proposed for triple band operation [13]. The antenna beam reconfigurability was attained by CSRR loaded ground plane without any change in fundamental resonance frequency [14]. SRR was used as notch element in UWB antenna [15]. The notch operation was achieved by choosing optimum dimensions for SRR. The novel UWB antenna was constructed by using many SRRs [16], and each SRR was able to generate one resonance and leads to ultra-wideband. The objective of this work is to study the performance of SRR, NBCSRR loaded antenna for multiband operation. Some modifications have been done on the ground plane in order to get triple band operation. This paper discusses the outcome of a metamaterial inspired CPW-fed antenna with modified ground plane.

2. ANTENNA STRUCTURE AND SIMULATED RESULTS

The antenna evolution stages are depicted in Figure 1. The design starts with a CPW-fed circular patch antenna (Stage A), which is used to generate single band. In the next step, CSRR is introduced on the patch (Stage B). A CSRR loaded patch is used to generate two bands. Next, CSRR is replaced by NBCSRR (Stage C), which is used to improve the return loss for both bands. In the fourth step, SRR is introduced on the back side of the substrate (Stage D). SRR is used to improve the bandwidth of the second band and decreases the resonance frequency of the first band. Dual-resonance is observed in the second band. In the last step, rectangular ground plane is modified (Stage E) as shown in Figure 1. SRR is introduced on the back side of the substrate from the fourth step. Hence, the back side of the substrate is shown for stages D and E only. The simulated return loss characteristics of the evolution stages are shown in Figure 2. The proposed antenna covers three frequency bands 3.47–3.52 GHz, 3.99–4.63 GHz, 4.67–6.9 GHz with resonant frequencies of 3.49 GHz, 4.44 GHz and 4.93 GHz, respectively. The proposed antenna is fabricated on an FR4 substrate with relative permittivity of 4.4 and thickness

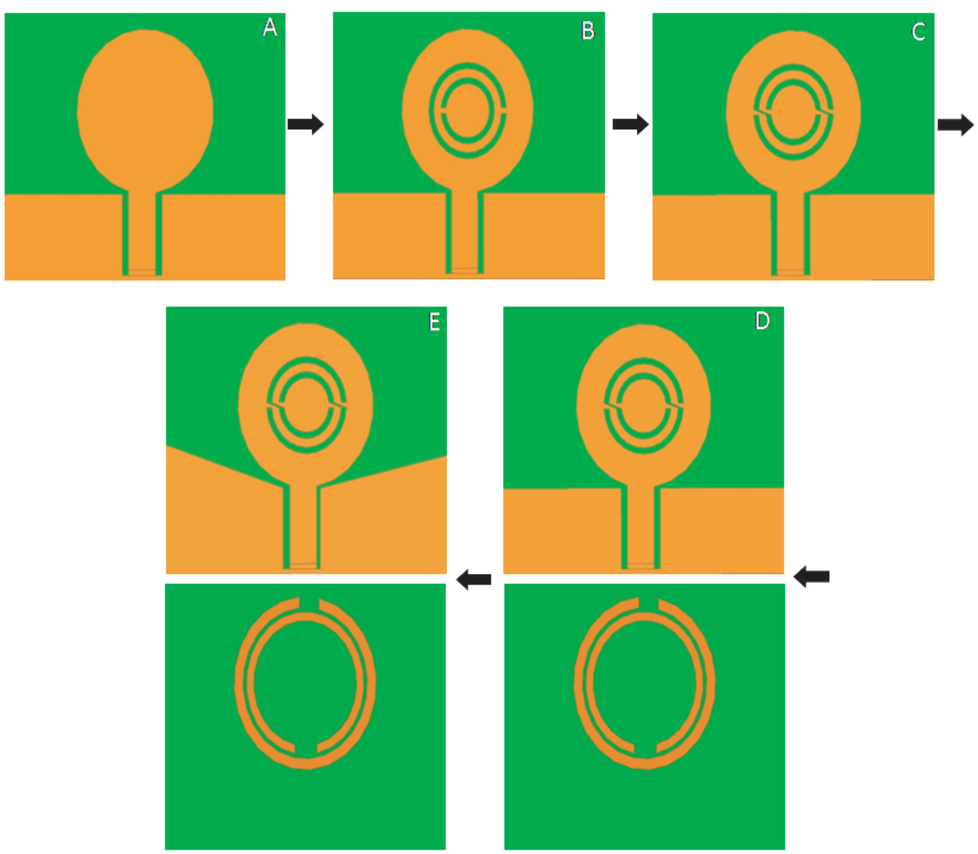


Figure 1. Antenna evolution stages.

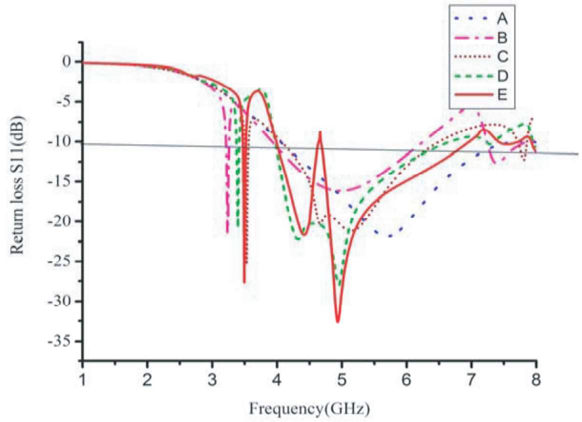
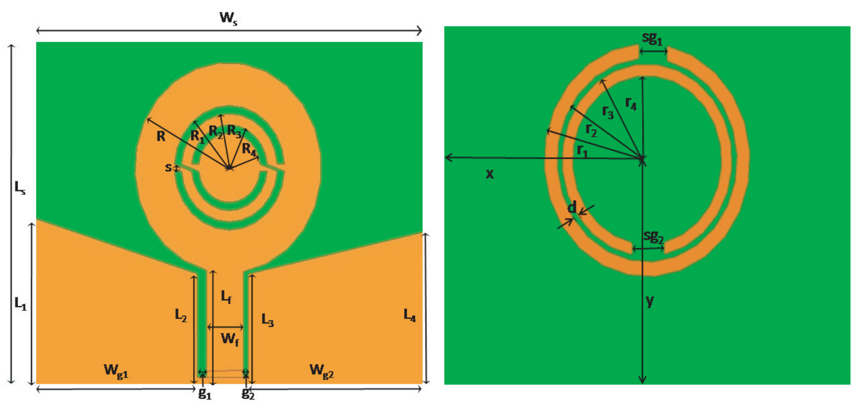


Figure 2. Simulated return loss of S_{11} (dB) of antenna evolution stages.



(a) (b)

Figure 3. (a) Antenna geometry — top view. (b) Antenna geometry — bottom view.

of 1.6 mm. The top and bottom views of the proposed antenna geometry are shown in Figures 3(a) and 3(b), respectively. The radius of the circular patch is 7.6 mm. The length and width of the feed are 8.26 mm and 3 mm, respectively. The slot width (S_w) of NBCSRR slot is 0.6 mm, and the slit width (S) of NBCSRR is 0.5 mm. The width of the metal ring between the slots is 0.8 mm. The width of the outer split ring resonator is 1 mm, and width of the inner split ring resonator is 0.8 mm. The split width of the outer split ring resonator is 2.2 mm and inner split ring resonator is 2.5 mm. The distance between the two concentric split rings is 0.4 mm. The other parameters are as follows: $Ls = 25$ mm, $Ws = 31.7$ mm, $g_1 = 0.8$ mm, $g_2 = 0.4$ mm, $L_1 = 12$ mm, $L_2 = 8$ mm, $L_3 = 8$ mm, $L_4 = 11$ mm, $Wg_1 = 13.2$ mm, $Wg_2 = 14.2$ mm, $L_F = 11$ mm, $W_F = 3$ mm, $R = 7.6$ mm, $R_1 = 4.5$ mm, $R_2 = 3.9$ mm, $R_3 = 3.1$ mm, $R_4 = 2.5$ mm, $S = 0.5$ mm, $r_1 = 8$ mm, $r_2 = 7$ mm, $r_3 = 6.6$ mm, $r_4 = 5.8$ mm, $Sg_1 = 2.2$ mm, $Sg_2 = 2.5$ mm, $d = 0.4$ mm, $x = 9.35$ mm, $y = 15.85$ mm.

3. PARAMETERS EXTRACTION OF NBCSRR AND SRR

The structure of SRR and its equivalent circuit are shown in Figure 4. The equivalent circuit consists of LC circuit. The inductance (L) of SRR is due to metallic ring, and capacitance (C) is due to the split gap and slots betweens the metal rings. The structure of NBCSRR and equivalent circuit are shown in Figure 5. The inductance of NBCSRR is due to metallic strip between the slots, and capacitance is due to the slots between the metallic strips. The NBCSRR is dual-element of NBSRR. In NBCSRR the slots are etched on the metallic surface, and its electric and magnetic properties are interchanged with respect to NBSRR. In NBCSRR structure, two slots are joined together through small slot. The

NBCSRR has the same electrical size as NBSRR. The NBCSRR's equivalent circuit is dual-network of NBSRR's equivalent circuit. Like CSRR, NBCSRR is also one kind of metamaterial structure used to provide negative permittivity.

The negative permittivity and permeability of NBCSRR and SRR are studied in order to validate the results. The waveguide setups to extract the characteristics of NBCSRR and SRR are shown in Figures 6(a) and 6(b), respectively. From Figure 7, it is understood that the resonance frequency of the NBCSRR is 3.5 GHz, and permittivity is negative around the frequency 3.5 GHz. Hence, it is validated that the proposed NBCSRR exhibits negative permittivity property. The proposed NBCSRR is used to improve the return loss around 3.5 GHz.

The permeability characteristics of SRR is extracted using waveguide setup shown in Figure 6. The permeability characteristic of SRR is shown in Figure 8. From Figure 8, it is noted that the resonance

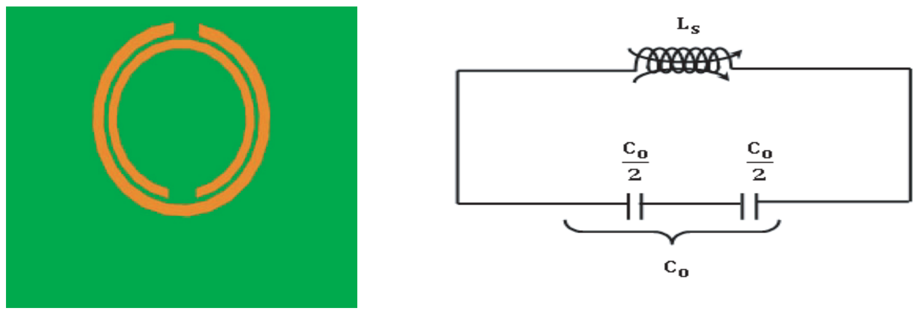


Figure 4. SRR structure and its equivalent circuit.

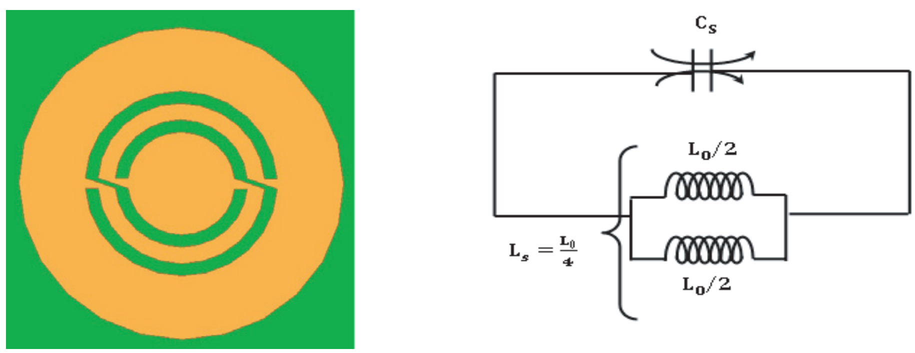


Figure 5. NBCSRR structure and its equivalent circuit.

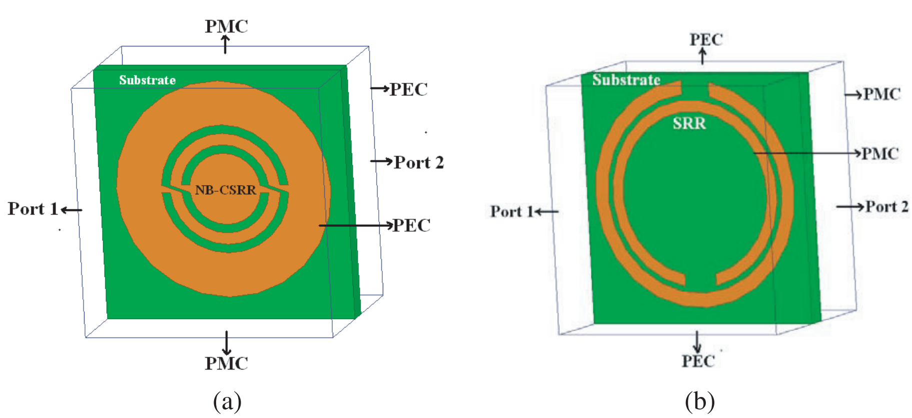


Figure 6. (a) Waveguide setup of NBCSRR. (b) Waveguide setup of SRR.

frequency of the SRR is 4.65 GHz. The negative permeability is observed around the resonance frequency 4.65 GHz. The negative permeability (stopband) frequency range is used for notch function in UWB antenna [15]. The permeability of SRR is positive above and below the resonance frequency of SRR. Hence, it is proved that the proposed SRR structure exhibits metamaterial property and can be used for bandwidth improvement. The permeability is positive over the antenna desired frequency band. The proposed SRR loaded substrate is used for good impedance matching and bandwidth improvement.

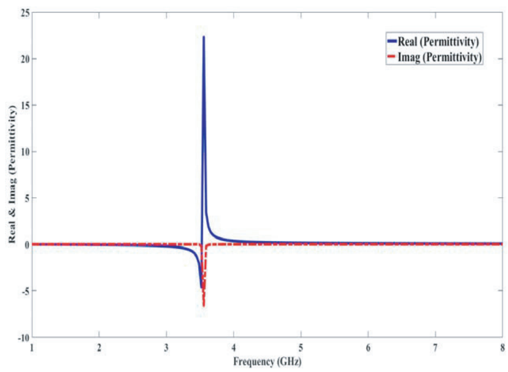


Figure 7. Permittivity characteristics of NBCSRR.

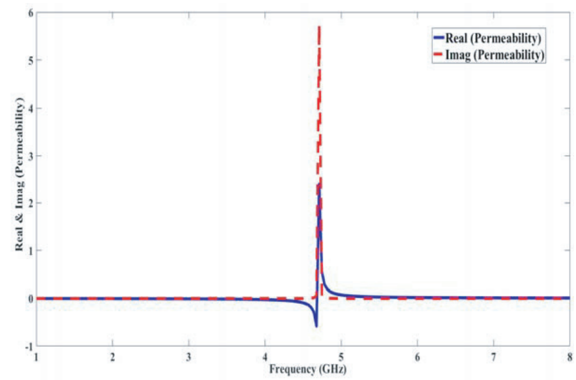
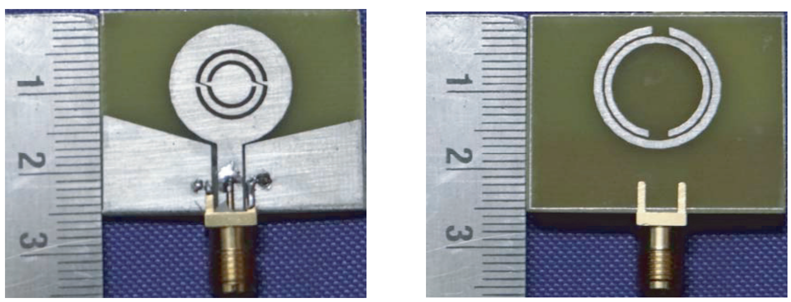


Figure 8. Permeability characteristics of SRR.



(a) (b)

Figure 9. (a) Photograph of the fabricated antenna — top view. (b) Photograph of the fabricated antenna — bottom view.

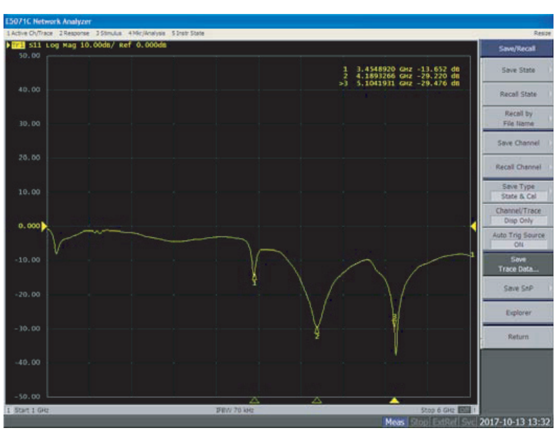


Figure 10. Measured S_{11} (dB) of the proposed antenna.

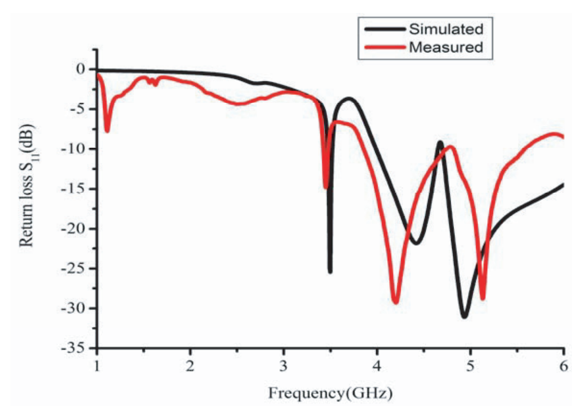
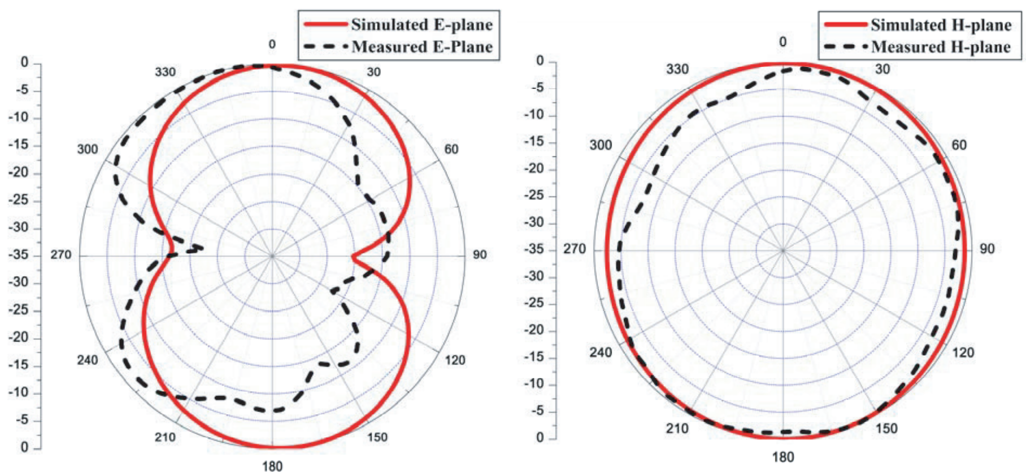


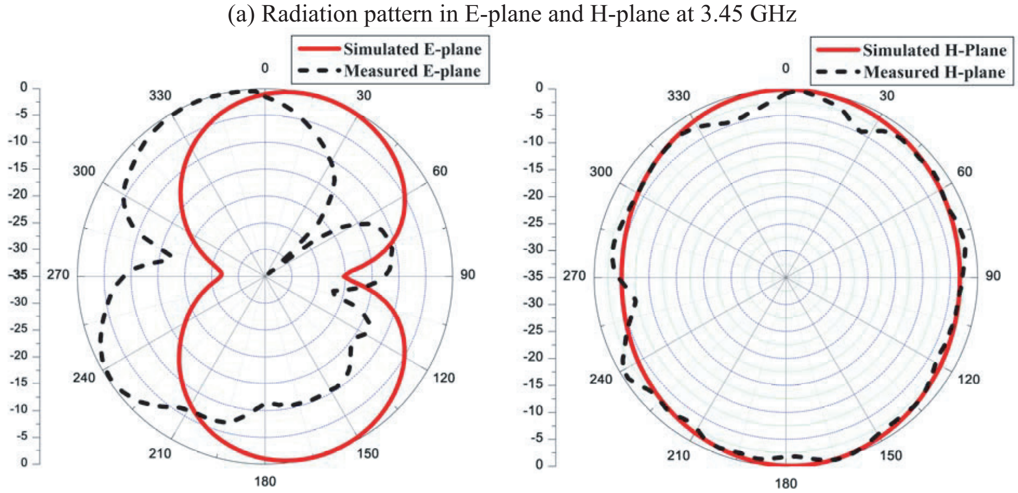
Figure 11. Simulated and measured S_{11} (dB) of the proposed antenna.

4. RESULTS AND DISCUSSION

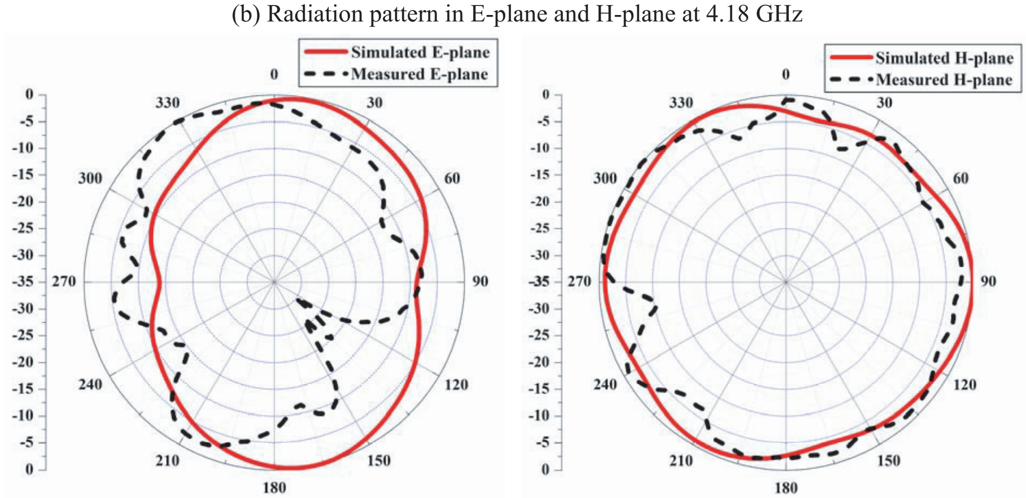
Photographs of the top and bottom views of the fabricated antenna are shown in Figures 9(a) and 9(b), respectively. The return loss characteristic of the antenna is measured by using vector network analyzer,



(a) Radiation pattern in E-plane and H-plane at 3.45 GHz



(b) Radiation pattern in E-plane and H-plane at 4.18 GHz



(c) Radiation pattern in E-plane and H-plane at 5.10 GHz

Figure 12. Radiation pattern of proposed antenna at (a) 3.45 GHz, (b) 4.18 GHz, (c) 5.10 GHz.

and measured return loss is shown in Figure 10. The simulated and measured return loss characteristics are shown Figure 11. The measured results show that the proposed antenna is covers triple bands with frequency range of 3.43 GHz–3.47 GHz, 3.86 GHz–4.74 GHz, and 4.82 GHz–5.58 GHz and impedance bandwidth (return loss < -10 dB) of 40 MHz, 88 MHz and 786 MHz. The proposed antenna has three resonance frequencies of 3.45 GHz, 4.18 GHz and 5.10 GHz. The simulated and measured radiation patterns in E plane and H plane at measured resonance frequencies are shown in Figures 12(a), 12(b) and 12(c). The radiation shows omnidirectional pattern in H-plane and bidirectional pattern in E-plane.

5. CONCLUSION

A novel SRR and NBCSRR based triple band antenna is discussed. SRR loaded substrate is used for bandwidth improvement. The NBCSRR loaded monopole is used to provide good return loss. The triple frequency bands are obtained by SRR and NBCSRR loaded antenna with modified ground plane. The NBCSRR and SRR characteristics are explained in order to validate the results. The proposed antenna has measured resonance frequencies of 3.45 GHz, 4.18 GHz and 5.10 GHz. The proposed antenna with compact size could be useful for WIMAX, C band and WLAN applications.

REFERENCES

1. Pandeeswari, R., S. Raghavan, and K. Ramesh, "A compact split ring resonator loaded antenna," *PIERS Proceedings*, 37–40, Moscow, Russia, Aug. 19–23, 2012.
2. Caloz, C. and T. Itoh, *Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications*, Wiley-IEEE Press, New York, 2005.
3. Baena, J. D., J. Bonache, F. Martin, R. M. Sillero, F. Falcone, T. Lopetegi, M. A. G. Laso, J. Garcfa-Farcfa, I. Gil, M. F. Portillo, and M. Sorolla, "Equivalent-circuit models for split-ring resonators and complementary split-ring resonators coupled to planar transmission lines," *IEEE Trans. Microwave Theory Tech.*, Vol. 53, 1451–1461, 2005.
4. Joshi, J. G., S. S. Pattnaik, S. Devi, and M. R. Lohokare, "Electrically small patch antenna loaded with metamaterial," *IETE Journal of Research*, Vol. 56, 373–379, 2011.
5. Pandeeswari, R. and S. Raghavan, "A CPW-fed triple band OCSRR embedded monopole antenna with modified ground for WLAN and WIMAX applications," *Microwave and Optical Technology Letters*, Wiley Interscience, Vol. 57, 2413–2418, 2015.
6. Pandeeswari, R. and S. Raghavan, "Broadband monopole antenna with split ring resonator loaded substrate for good impedance matching," *Microwave and Optical Technology Letters*, Vol. 56, 2388–2392, 2014.
7. Pandeeswari, R. and S. Raghavan, "Microstrip antenna with complementary split ring resonator loaded ground plane for gain enhancement," *Microwave and Optical Technology Letters*, Vol. 57, No. 2, 292–296, 2015.
8. Antoniades, M. A. and G. V. Eleftheriades, "A broadband dual-mode monopole antenna using NRI-TL metamaterial loading," *IEEE Antennas Wireless Propagation Letters*, Vol. 8, 258–261, 2009.
9. Si, L. M., W. Zhu, and H. J. Sun, "A compact, planar, and CPW-fed metamaterial-inspired dual-band antenna," *IEEE Antennas Wireless Propagation Letters*, Vol. 12, 305–308, 2013.
10. Si, L.-M., H.-J. Sun, Y. Yuan, and X. Lv, "CPW-fed compact planar UWB antenna with circular disc and spiral split ring resonators," *PIERS Proceedings*, 502–505, Beijing, China, Mar. 23–27, 2009.
11. Samson Daniel, R, R. Pandeeswari, and S. Raghavan, "Offset-fed complementary split ring resonators loaded monopole antenna for multiband operations," *Int. J. Electron. Commun. (AEÜ)*, Vol. 78, 72–78, 2017.
12. Samson Daniel, R., R. Pandeeswari, and S. Raghavan, "Multiband monopole antenna loaded with complementary split ring resonator and C-shaped slots," *Int. J. Electron. Commun. (AEÜ)*, Vol. 75, 8–14, 2017.

13. Boopathi Rani, R. and S. K. Pandey, "CSRR inspired conductor backed CPW-fed monopole antenna for multiband operation," *Progress In Electromagnetics Research C*, Vol. 70, 135–143, 2016.
14. Cao, W., Y. Xiang, B. Zhang, A. Liu, T. Yu, and D. Guo, "A low-cost compact patch antenna with beam steering based on CSRR-loaded ground," *IEEE Antennas Wireless Propagation Letters*, Vol. 10, 1520–1523, 2011.
15. Sousa Neto, M. P., H. C. C. Fernandes, and C. G. Moura, "Design of a ultrawide band monopole antenna using split ring resonator for notching frequencies," *Microwave and Optical Technology Letters*, Vol. 56, 1471–1473, 2014.
16. Yang, X., Z. Yu., Q. Shi., and R. Tao, "Design of novel ultra-wideband antenna with individual SRR," *Electronics Letters*, Vol. 44, No. 19, 1109–1110, 2008.