

A novel ACS fed multi band antenna loaded with mirrored S and L shaped strips for advanced portable wireless communication applications

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Abstract A compact ($0.15\lambda \times 0.33\lambda$) tri-band printed antenna with Asymmetric Coplanar Strip (ACS) feeding is proposed. The proposed structure is consisting of a half wavelength (0.5λ) meandered mirrored S shaped strip to excite the first resonant frequency at 2.35 GHz, a 0.29λ electrical length mirrored L shaped radiating branch is chosen to generate second operating at 3.45 GHz and an quarter wavelength (0.25λ) ACS monopole has been used to achieve third operating band centered at 5.2 GHz. All the three radiating branches with various optimized lengths have been chosen strategically to fulfill compact size feature. A prototype of the proposed design has been printed on a 1.6 mm thickness low cost substrate (FR4) and verified its performance characteristics experimentally. The measured and simulated results shows that the triple operating bandwidth with -10 dB return loss is about 180 MHz from 2.28–2.46 GHz, 300 MHz from 3.33–3.63 GHz and 350 MHz from 5.05–5.4 GHz, respectively. The proposed ACS fed tri band antenna is able to cover LTE 2300/2.3 GHz WiBro/RFID/WiBree/Zigbee/2.4/5 GHz ISM/2.4/5.2 GHz WLAN and 3.5 WiMAX applications. Further, the design offers omnidirectional radiation patterns with a constant peak gain of 1.85 dBi in the three operating bands.

1 Introduction

The demand for multi band antennas with compact size has increased drastically due to the recent advancements in wireless communication technologies such as Long Term Evolution (LTE) application in the 2.3/2.5 GHz frequency bands, Wireless Local Area Network (WLAN) in the 2.4/5.2/5.8 GHz frequency bands, Wireless Broadband (WiBro) in 2.3 GHz frequency band, Worldwide Interoperability for Microwave Access (WiMAX) application in the 2.5/3.5/5 GHz operating bands and 2.4/5 GHz ISM band applications. In the literature (Li et al. 2013a, b, c, 2014; Deepu et al. 2007, 2009; Naidu and Kumar 2014; Song et al. 2008; Naidu and Malhotra 2015a, b, c; Naidu 2016; Chen et al. 2014a, b; Naidu et al. 2015; Rajkumar and Usha Kiran 2016; Ansal and Shanmuganatham 2014; Ashkarali et al. 2012), many designs serving to different multi band (dual and triple band) applications have been reported. Such as, meandered shape (Li et al. 2013a), F-shape (Deepu et al. 2009; Naidu et al. 2015), inverted omega-shape (Naidu and Kumar 2014), Inverted L-shape (Liu et al. 2014), C-shape (Naidu and Malhotra 2015a), U-shape (Li et al. 2013c), V-shape (Naidu 2016), circular arc-shape (Chen et al. 2014b) etc. Although the reported antennas (Li et al. 2013a; Deepu et al. 2007, 2009; Naidu and Kumar 2014a, b, c; Song et al. 2008; Liu et al. 2014; Naidu and Malhotra 2015a, b, c; Li et al. 2013b, b; Naidu 2016; Chen et al. 2014a, b; Naidu et al. 2015; Rajkumar and Usha Kiran 2016; Ansal and Shanmuganatham 2014; Ashkarali et al. 2012; Vummadisetty and Kumar 2016; Kumar et al. 2014; Kim and Park 2005; Naidu and Kumar 2015a, b; Lee et al. 2005; Thomas and Sreenivasan 2010; Zhang 2011; Wu et al. 2004) have multi band performance, the sizes of these reported antennas are relatively large and geometries are relatively complex.

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Fig. 1 **a** Proposed antenna geometry, **b** fabricated prototype, **c** simulated VSWR curve

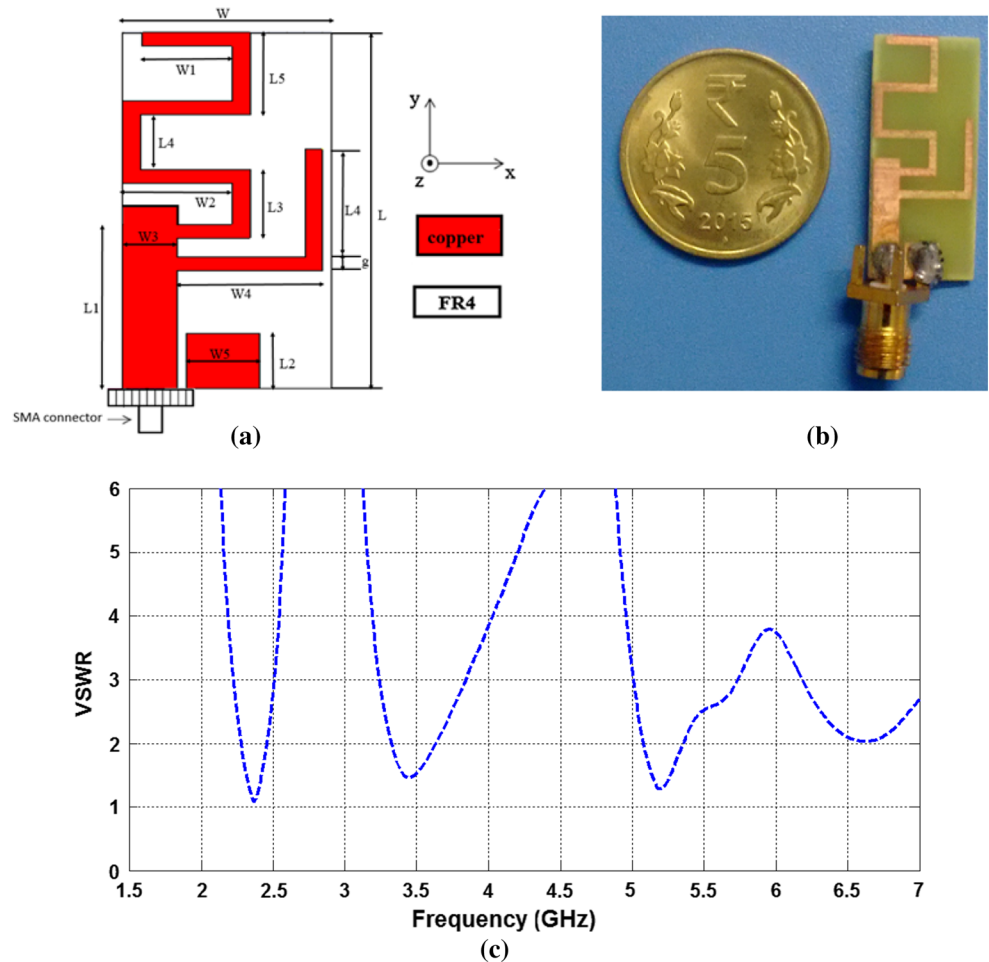


Table 1 Optimized parameter values of the proposed tri band ACS fed antenna

Parameters	W	L	L1	L2	L3	L4	L5
Value (mm)	11.5	26	12	4	5	4	6
Parameters	W1	W2	W3	W4	W5	g	
Value (mm)	4.9	6	3	8	4	1	

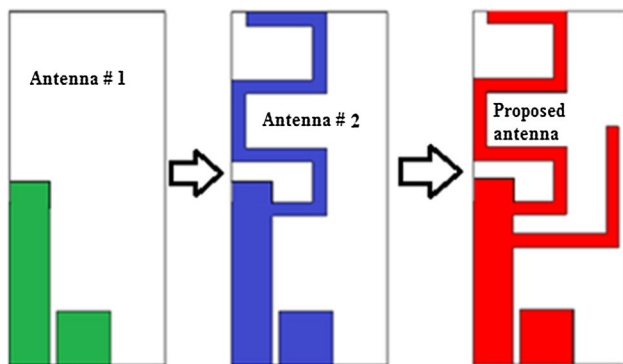


Fig. 2 Evolution stages of the proposed ACS fed triple band antenna

In this paper, a new triple band ACS fed antenna loaded with mirrored S and L shaped strips for LTE 2300/WiBro/RFID/WiBree/Zigbee/ISM/WLAN and WiMAX applications is presented. Multi band characteristics have been achieved by using mirrored S and L shaped radiating branches. The proposed structure is simulated and optimized by using CST microwave studio package. An 11.5mm × 26 mm size low cost FR4 substrate with thickness of 1.6 mm, dielectric constant of 4.4 and loss tangent of 0.02 has been used in the simulations. The antenna performance properties like impedance bandwidth, radiation patterns and peak gains have been simulated and its detailed analysis and results has been given in the following sections.

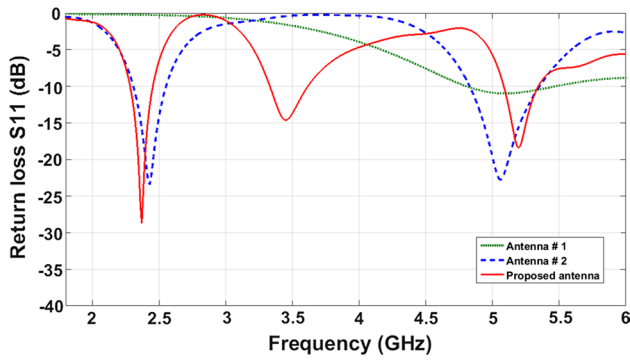


Fig. 3 Return loss curves of various antennas involved in the design evolution process

2 Antenna design, analysis and evolution process

The pictorial representation of proposed ACS fed antenna geometry in Fig. 1a, b is rendered in which mirrored S and L shaped radiating strips are employed to deal with advanced wireless communication applications. Substantially, monopole structure of the proposed antenna utters about the capability to accomplish stunning properties such as easiness, simplicity and light weight by deployment of two radiating strips on top side of it. Combination of each radiating branch and square shaped finite

ground plane admit that designed structure occupy a very small area of $26 \times 11.5 \times 1.6 \text{ mm}^3$ in all respective dimensions. It can be figured out that all radiating strips are composed in tri band operation to bear independent excitation mechanism at 2.45, 3.5 and 5.25 GHz central frequencies as shown in Fig. 1c (VSWR = 2). Abide by 50Ω characteristics impedance, signal feedline W3 (3 mm) is integrated with simple monopole structure vertically and transfer richness of electrical power from feeding point at bottom side. The 3-D electromagnetic simulation software CST microwave studio is used to construct the compact shaped multiband antenna. Moreover, the optimized results of reflection coefficient curves are justified in such a way that reported antenna is well matched, and offer a better performance to improve the radiation characteristics. Details of the optimized parameters values (designed structure) are mentioned in Table 1.

Figure 2 provided an adequate development of the various evolution stages of the proposed tri band antenna in a decent manner to reach the purpose of each radiating strip. Further in Fig. 3, corresponding frequency versus reflection losses curves are generated with the help of transient time domain solver (CST MWS) step by step to satisfy the concept of antenna evolution stages involved in it. The excogitation of a novel

Fig. 4 Surface current distribution of the evolution stages (Antenna #1 and Antenna #2)

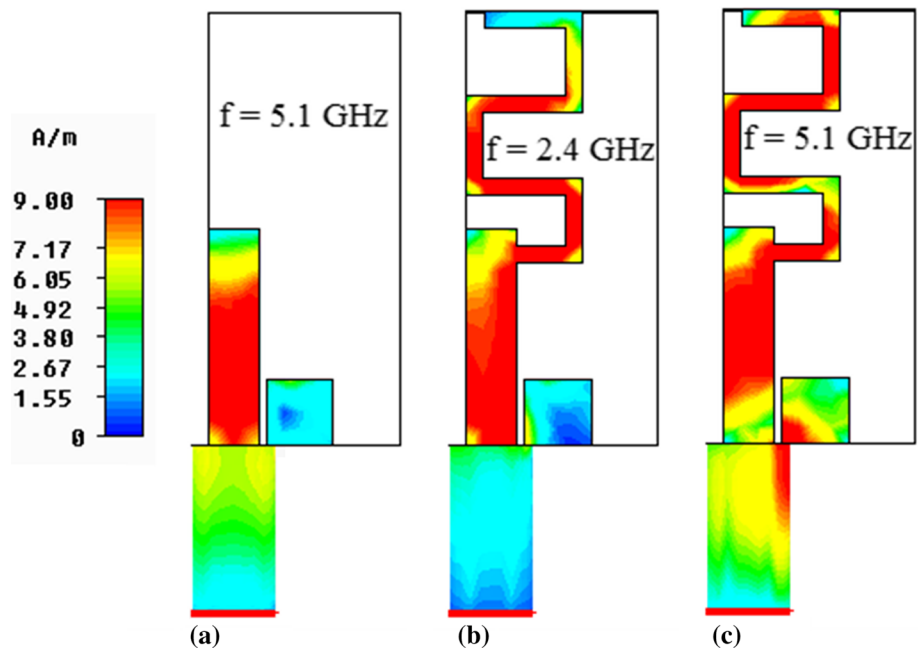
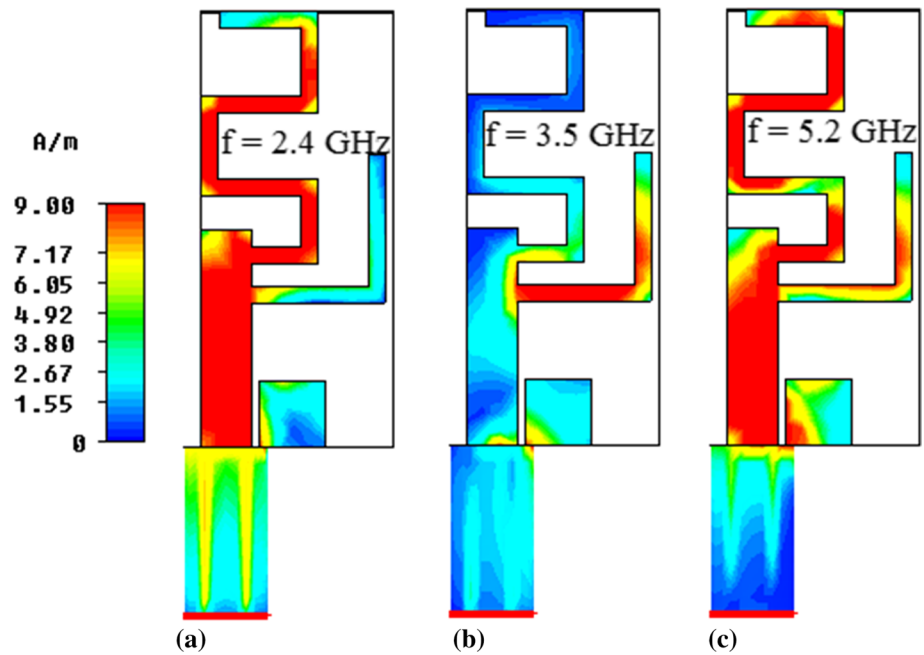


Fig. 5 Simulated surface current distribution of the proposed antenna at 2.4, 3.5 and 5.2 GHz



structure tri band antenna for wireless communication system is commenced from Antenna #1 that is build up as a simple monopole structure in form of rectangular shaped radiator (light green color in Fig. 2). However, monopole structure is extended up to a certain limit to obtain 5.25 GHz centric frequency resonance. It can be seen from the figure that first resonant frequency (f_1) is originated from Antenna #2 by attachment of mirrored S shape radiating branch near to the extreme point of Antenna #1 (indicated as light blue color in Fig. 2). To induce another resonating frequency (f_1) at 3.5 GHz, mirrored L shape strip is inserted to Antenna #2 with termination of evolution procedure's end stage. The

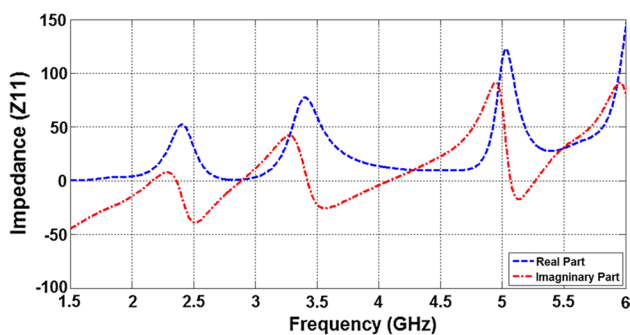


Fig. 6 Impedance curves of the proposed tri band ACS fed antenna

similar justification can be evolved from the simulated surface current distribution curves given in Figs. 4 and 5. Finally proposed antenna (indicated as red color in Fig. 2) structure is carried out having the tri band operation successfully with three independent resonating frequencies in separate operating bands. The presented antenna achieves three impedance bandwidths from 2.28–2.46 GHz, 3.33–3.63 GHz and 5.05–5.4 GHz, respectively.

The effect of the radiating branches on the antenna impedance is shown in Figs. 6 and 7a via Z parameters and smith chart, respectively. In these figure both the real and imaginary parts are plotted over frequency of operation. It can be seen from the figure the real part gets closer to 50 Ohms while the imaginary part gets closer to the 0 ohm line as a result better impedance matching over three operating bands have been achieved. The triple band ACS fed antenna is composed of mirrored S and L shaped monopole strips, and a rectangular-shaped signal strip attached to the feed line. The desired three operating bands are obtained from the excitation of resonances due to these strips (Fig. 7b). In the proposed design, the resonant lengths of the monopole, mirrored L-shaped and meandered S shaped monopole are set close to quarter-wavelength, 0.29λ and half-wavelength, respectively of the resonant frequencies which they are supposed to

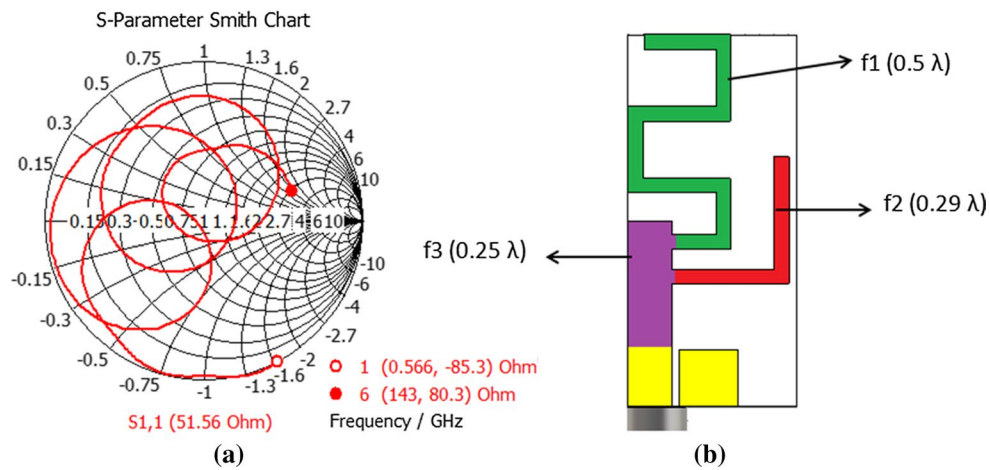


Fig. 7 **a** Simulated smith chart of the proposed tri band ACS fed antenna, **b** antenna geometry corresponding to three resonance frequencies

excite (Fig. 7b). These electrical lengths are calculated by using Eqs. 1 and 2.

$$f_r = c / (\lambda_g \sqrt{\epsilon_{eff}}) \tag{1}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} \tag{2}$$

The design equations of an ACS feed antenna (Simons 2004; Naidu and Malhotra 2015c; Rajkumar and Usha Kiran 2016; Ansal and Shanmuganatham 2014; Ashkarali et al. 2012) for the perfect impedance matching are given below

$$Z_0 = \frac{60\pi}{\sqrt{\epsilon_{eff}}} \frac{K(k)}{K(k^1)} \tag{3}$$

where, $k = a/b$, $K^1 = \sqrt{1 - k^2}$, and $\frac{K(k)}{K(k^1)}$ is the elliptical integral of first kind given by

$$\frac{K(k)}{K(k^1)} = \begin{cases} \frac{\pi}{2 \ln \frac{1+\sqrt{k^1}}{1-\sqrt{k^1}}} & 0 \leq k \leq \frac{1}{\sqrt{2}} \\ \frac{1}{\pi \ln \frac{2(1+\sqrt{k})}{(1-k)}} & \frac{1}{\sqrt{2}} \leq k \leq 1 \end{cases} \tag{4}$$

3 Parametric studies

The role of key parameters is examined by modifying the length of radiating strips associated with the proposed ACS fed tri band antenna. It is carried out by the investigation of parameters such as L4, W1 and L1 in such a way that only desired resonating frequencies give rise in magnitude of their respective operating band exclusively.

Figure 8a depicts about the astir of simulated reflection coefficient curves of s_{11} when a bit of length addition and fragment took place in mirrored L shaped (L4) radiating branch. It is clearly emphasized by gradually changing the dimension of L4 radiator as amidst frequency leads to appropriate shift at 3.5 GHz central frequency resonant mode. As one can notice, expand in uttermost point of mirrored L shaped strip (L4) shifts a second resonating frequency towards the left direction, and opposite to it shorten in length migrate second resonant frequency in position of right direction. Finally it is observed that L4 comport as a perfect resonating element for middle operating band from 3.4 to 3.6 GHz to achieve wireless communication applications.

Figure 8b demonstrates the effect in lower impedance bandwidth of tri band operation when length of

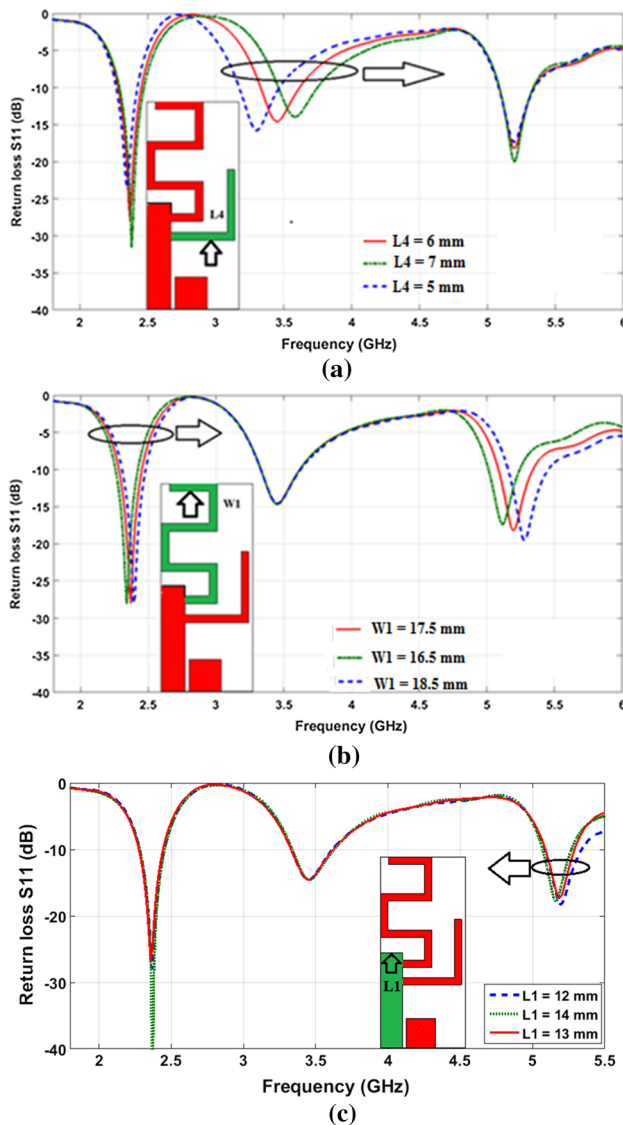


Fig. 8 **a** Simulated return losses of the proposed antenna when L_4 is varying. **b** Simulated return losses of the proposed antenna when W_1 is varying. **c** Simulated return losses of the proposed antenna when L_1 is varying

design parameter W_1 vary from 16.5 to 18.5 mm. Reduction in the length of mirrored S shaped radiating branch have tendency to move lower resonating frequency in the

direction of higher resonance and vice versa. Secondly, it has been encountered that higher resonating frequency affecting during this experiment because of electromagnetic coupling between mirrored S and rectangular shaped radiating elements. Similarly, effect of rectangular strip length on tri band performance has been simulated and given in Fig. 8c.

4 Experimental and simulated results

The proposed triple band geometry is simulated, fabricated and tested by using R&S ZVA 40 vector network analyzer. The prototype photograph and return loss curves are given in Fig. 9a–c, respectively. The measured and simulated results shows that the triple operating bandwidth with -10 dB return loss is about 180 MHz from 2.28–2.46 GHz, 300 MHz from 3.33–3.63 GHz and 350 MHz from 5.05–5.4 GHz, respectively. Both the measured and simulated results show good agreement with little error that may be caused due to fabrication tolerance and uncertainty in dielectric constant of the substrate. The proposed ACS fed tri band antenna is able to cover LTE 2300/2.3 GHz WiBro/RFID/WiBree/Zigbee/2.4/5 GHz ISM/2.4/5.2 GHz WLAN and 3.5 WiMAX applications.

Figures 10 and 11 shows the realized peak gain and normalized E and H plane radiation patterns of the proposed antenna in the three operating band frequencies. From Fig. 10, it can be seen that in the first operating band (i.e. at 2.4 GHz band) gain varies from 0.8 to 1.85 dBi, over second operating band (i.e. at 3.45 GHz band) it varies from 1 to 2 dBi and for the third operating band (i.e. at 5.2 GHz band) gain varies from 1 to 3 dBi respectively. In Fig. 11, E-plane and H-plane co and cross polarization patterns have been plotted over three resonant modes (i.e. at 2.35, 3.5 and 5.2 GHz) and nearly bi-directional and omnidirectional patterns are achieved. The gain increases in the high frequency region due to an increase in the effective area of the antenna at shorter wavelengths (Naidu and Kumar 2014b; Kumar et al. 2014; Kim and Park 2005; Naidu and Kumar 2014, 2015a, b; Lee et al. 2005; Thomas and Sreenivasan 2010; Zhang 2011).

Fig. 9 **a** Antenna geometry, **b** fabricated photograph, **c** measured and simulated return loss curves

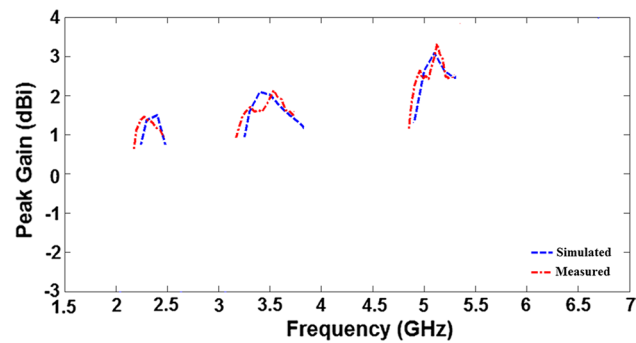
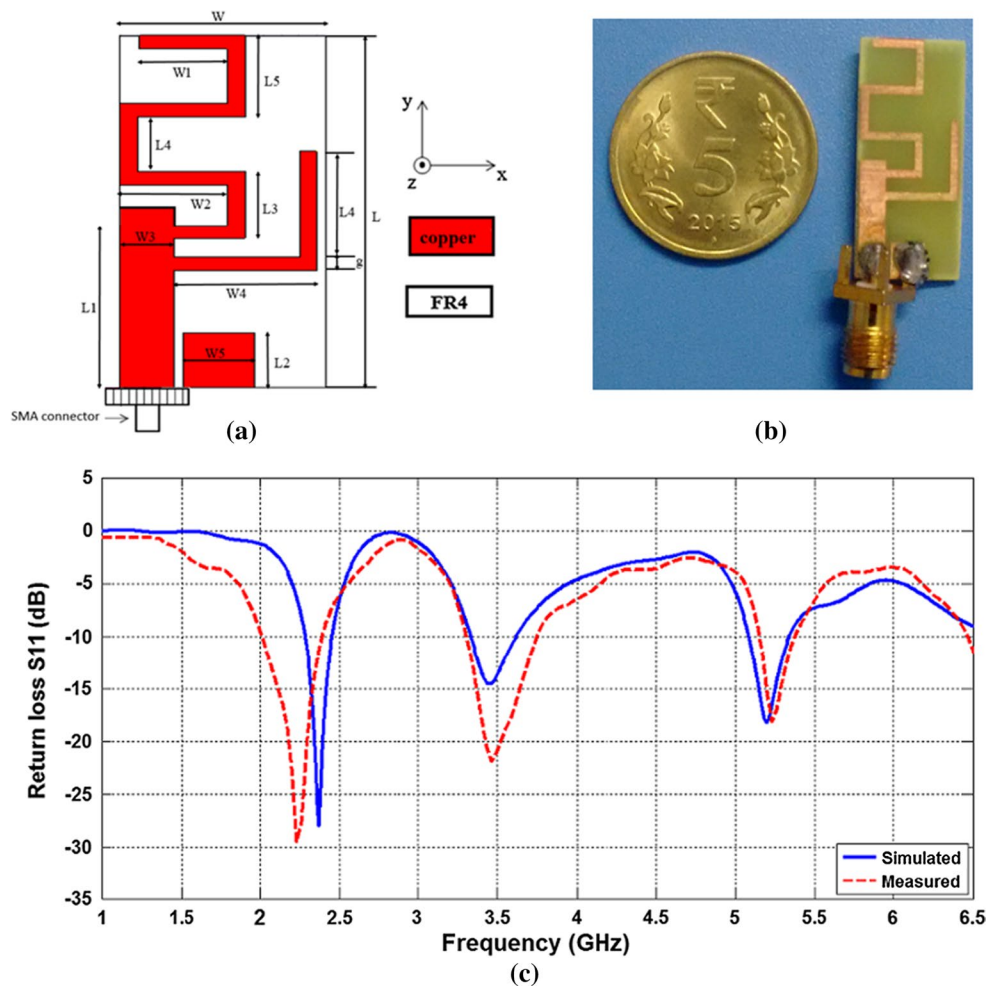


Fig. 10 Realized peak gains of the proposed antenna

5 Conclusion

A novel, small size ($0.15\lambda \times 0.33\lambda$) asymmetrical coplanar strip (ACS) feed triband printed antenna loaded with mirrored S and L shaped strips for advanced portable wireless communication applications has been proposed, developed and its performance has been validated both numerically and experimentally. Three radiating strips have been integrated to basic ACS fed monopole structure to generate the desired frequency bands for LTE 2300/2.3 GHz WiBro/RFID/WiBree/Zigbee/2.4/5 GHz ISM/2.4/5.2 GHz WLAN and 3.5 WiMAX communication applications. Both the

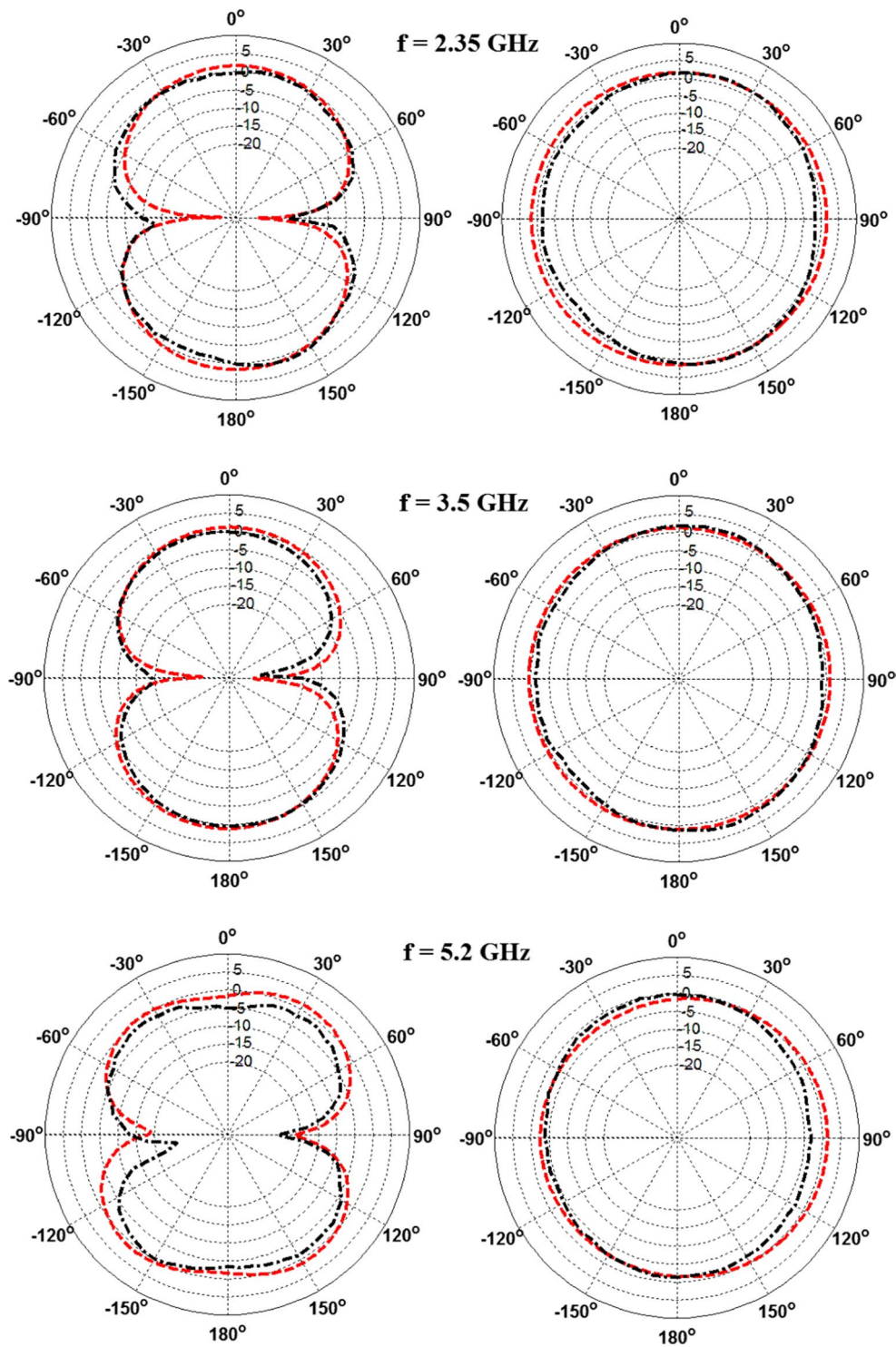


Fig. 11 E and H plane radiation patterns of the proposed ACS fed tri band monopole antenna at three resonant frequencies (*red color* indicates simulated results and *black color* represents measured results) (color figure online)

simulated and measured results demonstrated that the proposed antenna can provide three independent wide frequency bands, average peak gains of 1.85 dBi and omnidirectional radiation patterns that makes a suitable element for portable wireless communication applications.

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