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TECHNICAL PAPER

A very small asymmetric coplanar strip fed multi-band antenna for wireless communication applications

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Abstract In this paper, a compact tri-band monopole antenna with asymmetric coplanar strip (ACS)-fed structure is proposed for long term evolution (LTE), Wireless Broadband (WiBro), Worldwide Interperability for Microwave Access (WiMAX), wireless local area network (WLAN) and 4.9 GHz public safety applications. The proposed antenna consists of an F-shaped radiating element along with a meanderd line structure, which occupy a compact size of 10 × 17.5 mm^2 including the ground plane. The desired resonant frequencies at 3.5/5.5 GHz for WiMAX and 5.2/5.8 GHz WLAN can be achieved by properly selecting the length of the two horizontal branches in F-shaped patch and by introducing a meanderd line structure, another desired resonant frequency at 2.3 GHz for LTE/WiBro has been achieved. A prototype of the proposed antenna is designed, fabricated and validated experimentally. The measured results demonstrate that the proposed antenna has −10 dB impedance bandwidth of 120 MHz (2.3–2.42 GHz), 450 MHz (3.3–3.75 GHz), and 1500 MHz (4.5–6.0 GHz) along with good onmi-directional radiation patterns and acceptable peak gains in all the three operating bands.

1 Introduction

Nowadays, so much attention has been paid by the researchers towards the design and development of various multi-band antennas for different wireless communication applications. Especially there is a huge demand generated in the design of a compact antenna that supports multiple advanced wireless protocols such as LTE/WiBro (2.30–2.40 GHz), WiMAX (3.40–3.69 and 5.25–5.85 GHz), public safety band (4.94–4.99 GHz) and WLAN (5.15–5.35 and 5.72–5.85 GHz), because of its wide range of usability in all most all modern telecommunication devices. Thus different types of antennas, such as microstrip antennas, coplanar waveguide-fed antennas and slot antennas with dual-band (Sun et al. 2012, 2014; Lin et al. 2012; Lee et al. 2009; Xie et al. 2012; Flores-Leal et al. 2012; Papantonis and Episkopou 2011; Tsai 2014; Liu et al. 2010; Sayidmarie and Nagem 2012; Huang and En-Zo 2011; Basaran 2012; Singh et al. 2014; Kaur and Khanna 2014) and tri-band (Ren et al. 2011; Huang et al. 2014; Zhang et al. 2012; Liu et al. 2014a; Zhao et al. 2010; Bao et al. 2014; Chen et al. 2014; Mehdipour et al. 2012; Xu et al. 2011; Lu and Lee 2013) characteristics have been reported in the open literature (Sun et al. 2012, 2014; Lin et al. 2012; Lee et al. 2009; Xie et al. 2012; Flores-Leal et al. 2012; Papantonis and Episkopou 2011; Tsai 2014; Liu et al. 2010; Sayidmarie and Nagem 2012; Huang and En-Zo 2011; Basaran 2012; Singh et al. 2014; Kaur and Khanna 2014; Ren et al. 2011; Huang et al. 2014; Zhang et al. 2012; Liu et al. 2014a; Zhao et al. 2010; Bao et al. 2014; Chen et al. 2014; Mehdipour et al. 2012; Xu et al. 2011; Lu and Lee 2013; Naidu and Kumar 2014a). A detailed comparitive study in terms of parameters like antenna size, antenna purpose and its frequency of operation has been given in Table 1. From this comparitive study table, it has been observed that most of the reported antennas have limitations like complex in structure or large in size or limited frequency of operation.

Thus to overcome these limitations and to further decrease the size of the antenna, some other designs have

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Table 1 Comparisons of antenna size among proposed antenna and other compact antennas

S. no.	Published literature	Antenna purpose	Dimensions (mm^2)	Frequency of operation (GHz)
1.	Sun et al. (2014)	Dual-band	25 × 25	2.4/5.2/5.8
2.	Lin et al. (2012)	Dual-band	50 × 50	2.4/5.2/5.8
3.	Lee et al. (2009)	Dual-band	40 × 35	2.4/3.5/5.2
4.	Xie et al. (2012)	Dual-band	40 × 40	3.4/5.2/5.5/5.8
5.	Flores-Leal et al. (2012)	Dual-band	40 × 40	2.4/5.2/5.5/5.8
6.	Papantonis and Episkopou (2011)	Dual-band	48 × 30	2.4/5.2/5.8
7.	Tsai (2014)	Dual-band	60 × 45	2.4/5.2/5.8
8.	Liu et al. (2010)	Dual-band	30 × 25	2.4/5.2/5.8
9.	Sayidmarie and Nagem (2012)	Dual-band	26 × 36	2.4/5.2/5.8
10.	Huang and En-Zo (2011)	Dual-band	50 × 30	2.4/5.2/5.8
11.	Başaran (2012)	Dual-band	22× 26	2.4/5.2
12.	Sun et al. (2012)	Dual-band	40 × 30	2.4/5.2/5.8
13.	Singh et al. (2014)	Dual-band	15 × 15	2.4/5.2
14.	Kaur and Khanna (2014)	Dual-band	60 × 70	3.5/5.2/5.5/5.8
15.	Ren et al. (2011)	Tri-band	14 × 34	2.4/3.5/5.8
16.	Huang et al. (2014)	Tri-band	30 × 20	2.4/2.5/3.5/5.5
17.	Zhang et al. (2012)	Tri-band	25× 18	2.4/3.5/5.2/5.5/5.8
18.	Liu et al. (2014)	Tri-band	26.5 × 12	2.4/3.5/5.8
19.	Zhao et al. (2010)	Tri-band	40× 40	2.4/3.5/5.2/5.5/5.8
20.	Bao et al. (2014)	Tri-band	16 x 30	2.4/3.5/5.8
21.	Chen et al. (2014)	Tri-band	18 × 28	2.4/3.5/5.2/5.5/5.8
22.	Mehdipour et al. (2012)	Tri-band	22 × 29	2.4/3.5/5.2/5.5/5.8
23.	Xu et al. (2011)	Tri-band	34.5 × 18	2.4/3/5/5.2/5.5/5.8
24.	Lu and Lee (2013)	Tri-band	22 × 28	2.6/3.5/5.5
25.	Proposed work	Tri-band	10 × 17.5	2.3/3.5/4.9/5.2/5.5/5.8

been reported in (Liu et al. 2014b; Song et al. 2008; Deepu et al. 2007, 2009; Li et al. 2013; Ashkarali et al. 2012; Naidu and Kumar 2014b) by using the concept of asymmetric coplanar strip (ACS)-fed. In comparison to general coplanar waveguide (CPW)-fed antenna, an ACS-fed antenna structure will consume only 50 % area by considering only half of the ground plane of CPW-fed structure. Though some of the above reported ACS-fed antennas have compact size but again these structures are having limitations of narrow bandwidth and limited frequency of operation of LTE/WiBro/WLAN/WiMAX bands. So to over come these drawbacks, a very small ACS-fed tri-band antenna which covers all these applications has been proposed and discussed in detail in this paper. The proposed design is not only has compact size but also exhibits wider impedance bandwidth along with simple structure and feeding mechanism.

In this paper, a compact ACS-fed printed monopole antenna for tri-band frequency of operation is proposed and validated experimentally. The three operating frequency bands are realized by adding an F-shaped radiating element which consists of two horizontal rectangular shaped branches and a meandered element to the monopole structure. The antenna evaluation process in generating multiple operating bands with size reduction technique is simulated and studied in detail. The effects of key structural parameters like length and position of meandered line and horizontal strips of F-shape structure on antenna performance are also simulated and analyzed. The measured −10 dB impedance bandwidth of the proposed antenna is about 120 MHz from 2.3 to 2.42 GHz, 450 MHz from 3.3 to 3.75 GHz, and 1500 MHz from 4.5 to 6.0 GHz respectively, which can be used for 2.3 GHz LTE/WiBro, 4.9 GHz public safety band, 5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX applications.

2 Antenna design

2.1 Coplanar waveguide (CPW)—fed antenna design (reference antenna)

The initial stages involved in the evolution process of the proposed ACS-Fed tri-band antenna are shown in

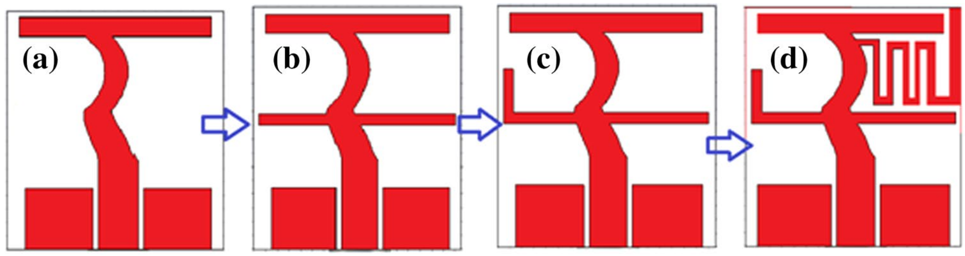


Fig. 1 Evolution process of the CPW-Fed rupee shaped monopole antennas

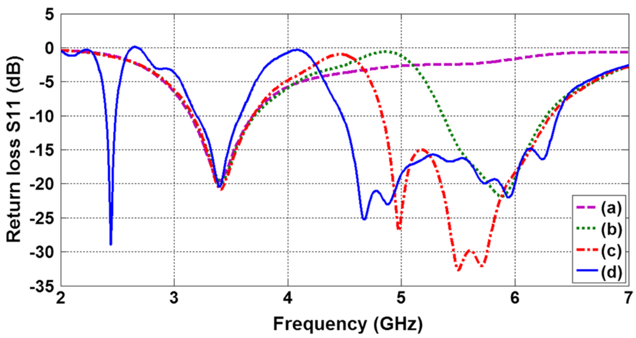


Fig. 2 Simulated return loss curves of various stages that are involved in the evolution process

Fig. 1. All the CPW-fed antenna structures are designed on 1.6 mm thick FR4 substrate having relative permittivity of 4.4. The 3D-electromagnetic simulation software CST Microwave Studio package was used to perform the design and analysis. The CPW-fed line has a signal strip width of 3.1 mm and a gap of 0.4 mm between the signal strip and the coplanar ground plane, which corresponds to the 50-Ω characteristic impedance. The rupee shaped antenna (Naidu and Kumar 2014, 2015) (17.5 × 17.5 mm^2) structure shown in the Fig. 1a is a simple monopole reference antenna, which can excite one resonant mode (pink line Fig. 2) near the 3.5 GHz (3.2–3.7 GHz) WiMAX frequency band. When a horizontal rectangular strip is added to the monopole of Fig. 1b, a second resonant mode is generated at about 5.7 GHz WLAN frequency band (green line in Fig. 2). In order to satisfy the 5.2 GHz WLAN and 5.5 WiMAX bands along with existing 5.7 GHz WLAN band, the overall impedance bandwidth has been enhanced by modifying the horizontal rectangular strip into an L-shaped strip (Fig. 1c) and the return loss achieved with this structure indicates dual band performance (red line in Fig. 2). Finally, a meander shape strip is introduced on one side of the patch (Fig. 1d) to create a third resonant mode at 2.3 GHz LTE/WiBro band without disturbing the other two modes and thus the triple-band CPW-fed antenna is obtained (blue line in Fig. 2).

2.2 Asymmetric coplanar strip (ACS)-fed antenna design (proposed antenna)

The desired compactness has been achieved by converting the 17.5 × 17.5 mm^2 size rupee shaped CPW-fed antenna structure into 10 × 17.5 mm^2 size ACS-fed antenna, without compromising on antenna performance. Figure 3 shows the geometry of the proposed tri-band ACS-Fed antenna printed on 1.6 mm thick FR4 substrate having a dielectric constant of 4.4 and a loss tangent of 0.02 for LTE/WiBro, WLAN/WiMAX and public safety applications. The proposed ACS-fed line has a signal strip width of 3.1 mm and a gap of 0.4 mm between the signal strip and the coplanar ground plane, which is same as in case of CPW-fed antenna. The optimized dimensions of the proposed antenna are given in Table 2. Figure 4 shows the evolution stages of the proposed ACS-fed tri-band monopole antenna and its corresponding simulated reflection coefficient curves are given in Fig. 5. Antenna 1 in Fig. 4 is the reference ACS-fed monopole, which consists of an

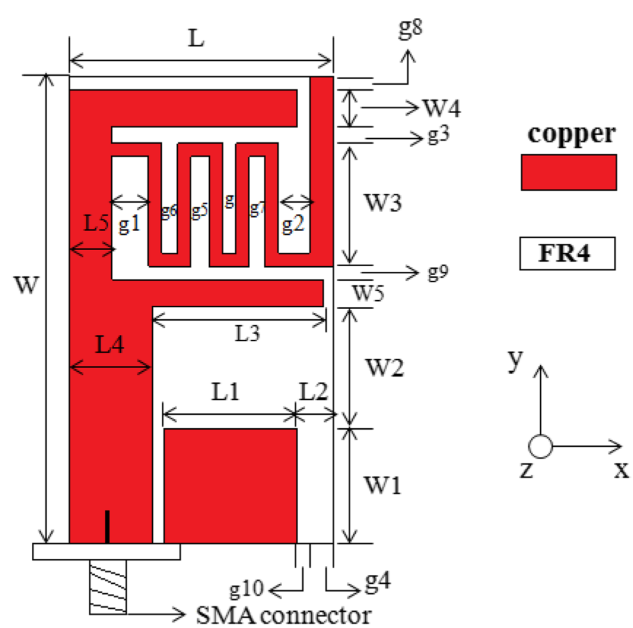


Fig. 3 Geometry of the proposed ACS-fed tri-band antenna

Table 2 Optimized parameter values (see Fig. 3)

Parameter	W	L	W1	W2	W3	W4	W5	L1
Value (mm)	17.5	10	4.3	8.9	4.6	1.4	1	5.1
Parameter	L2	L3	L4	L5	g	g1	g2	g3
Value (mm)	1.4	7.5	3.1	1.6	0.5	1.4	1.2	0.6
Parameter	g4	g5	g6	g7	g8	g9	g10	
Value (mm)	0.9	0.7	0.6	0.6	0.5	0.5	0.5	

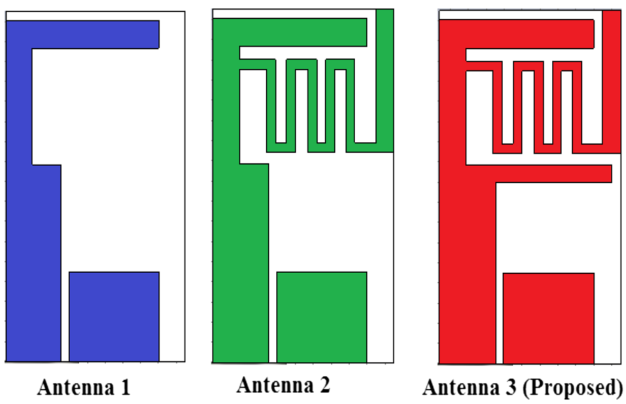


Fig. 4 Evolution process of the proposed ACS-fed Tri-band antenna

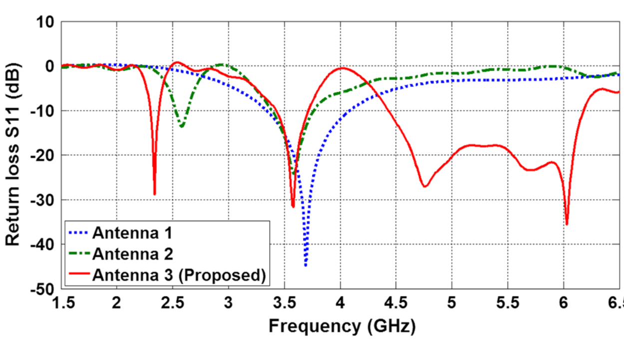


Fig. 5 Simulated return loss curves of the proposed tri-band ACS-fed antenna

ACS-fed structure and a horizontal strip attached to it. The monopole structure looks like a tilted L-shaped branch. As shown in Fig. 5, the resonant mode generated with this structure was about at 3.5 GHz. Then a λ/2 length meandered line is added to the monopole (Antenna 2 in Fig. 4) to generate another resonant mode at lower frequency side near 2.3 GHz. But it can be seen from Fig. 5 that after introducing the second resonant mode the first band at 3.5 GHz is slightly shifted towards lower frequency side along with shift in the second resonant mode due to coupling between two branches. In order to generate a new resonant mode

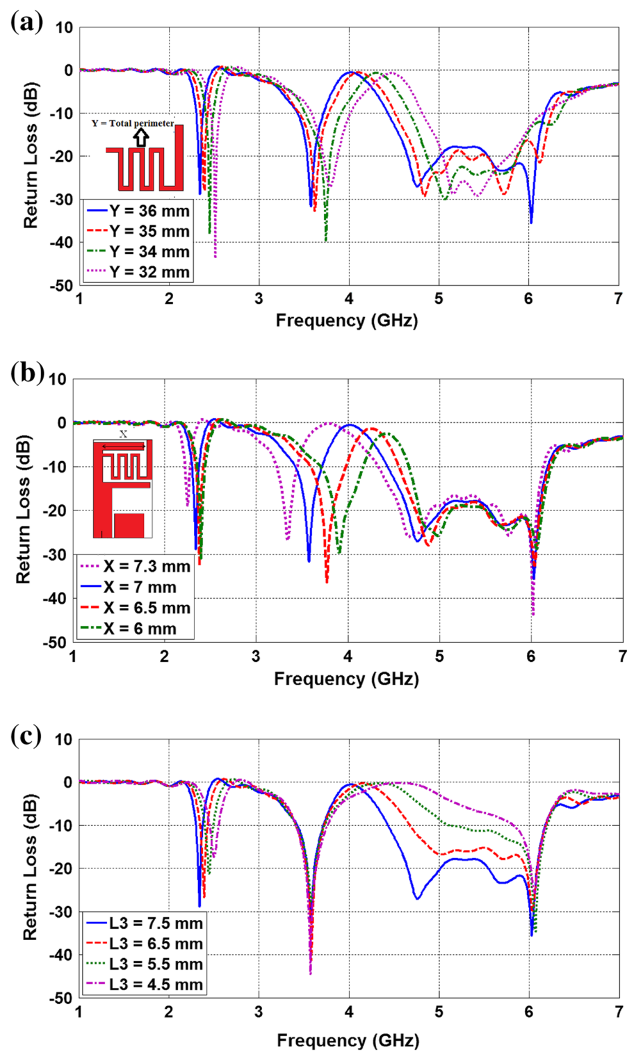


Fig. 6 **a** Effect of the meander-shape strip length on return loss of proposed antenna. **b** Effect of the upper horizontal strip length (X) on return loss of the antenna. **c** Effect of the horizontal strip length (L3) on return loss of the antenna

at 5.7 GHz a horizontal branch is added to the monopole (Antenna 3 in Fig. 4). It can be seen from the Fig. 5 that after introducing third resonant mode the performance of

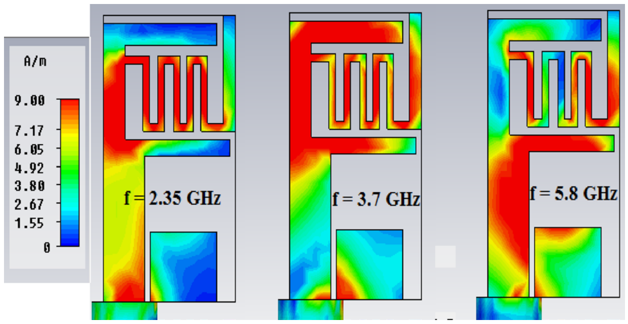


Fig. 7 Simulated surface current distribution of the proposed tri-band antenna at resonant frequencies

the tri-band antenna is improved (the S11 at all the three frequencies have improved and the lower resonant band shifted from 2.6 GHz to 2.3 GHz due to electromagnetic coupling). Finally with the structure 'Antenna 3' (shown in Fig. 4) tri-band antenna for 2.3 GHz LTE/WiBro, 5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX applications have been achieved.

The performance of the proposed antenna is affected by several key parameters including length of the L-shaped branch (X), horizantal branch (L3) and meandered element (Y). Figure 6a shows the simulated return loss of the proposed tri-band antenna when the length of the meander strip 'Y' varies from 32 mm to 36 mm. It can be seen that with an increase in length of 'Y', the first band shifts towards the lower frequencies side. This indicates that the electrical length 'Y' of the meander strip determines the first resonant frequency and at the same time both second and third bands are also slightly affected due to the electromagnetic coupling between meander line and horizontal branches.

Figure 6b illustrates the return loss characteristics for different lengths of the upper horizontal strip 'X'. With a decrease in the value of 'X', the second resonant frequency shifts towards higher side without much disturbing the other resonances. Similarly, the effect of the horizontal strip length 'L3' on the return loss of proposed tri-band antenna is shown in Fig. 6c. It can be observed that the impedance matching in the third band is highly disturbed by changes in 'L3'. Also, the resonance frequency near 5.0 GHz reduces with increase in 'L3'. This follows the explanation given previously, where the horizontal rectangular shaped strip length was responsible for this resonance. For obtaining good tri-band characteristics, L3 was set at 7.5 mm.

The simulated surface current distribution of the proposed ACS-fed antenna at 2.35, 3.7 and 5.8 GHz were carried out by using CST Microwave Studio package and given in Fig. 7. It can be seen that the current distributions at three resonant frequencies are different. For the first resonant frequency at 2.35 GHz, the surface current is mainly concerated on the meandered strip, whereas for second resonant frequency near at 3.7 GHz, the current distribution is observed along the upper L-shaped branch and meandered strip. For the third resonant frequency at 5.8 GHz, the surface current distributed along the lower horizontal rectangular strip. It indicates that the meandered strip, L-shaped branch and horizontal rectangular branches are the main radiating elements for generating three resonant frequencies.

The resonances seen in the final version of the antenna (near at 2.35 GHz, 3.7 GHz and 5.8 GHz) can be attributed to the combination of different parts (stubs) of the antenna structure behaving like a monopole or a dipole. These resonance frequencies can be given by Eqs. (1), (2) and (3).

$$f_1 = \frac{c}{2l_l\sqrt{\varepsilon_r},\mathrm{eff}} \quad (1)$$

$$f_2 = \frac{c}{4l_2\sqrt{\varepsilon_r},\mathrm{eff}} \quad (2)$$

$$f_3 = \frac{c}{4l_3\sqrt{\varepsilon_r},\mathrm{eff}} \quad (3)$$

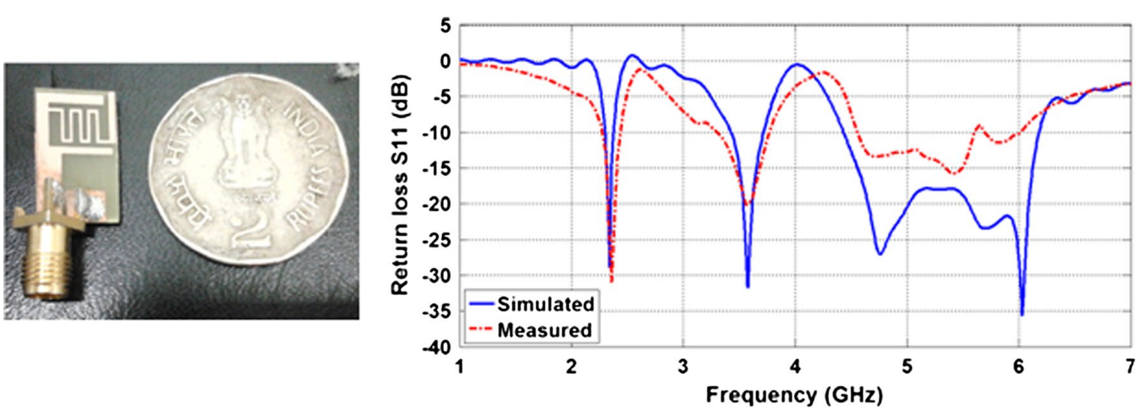
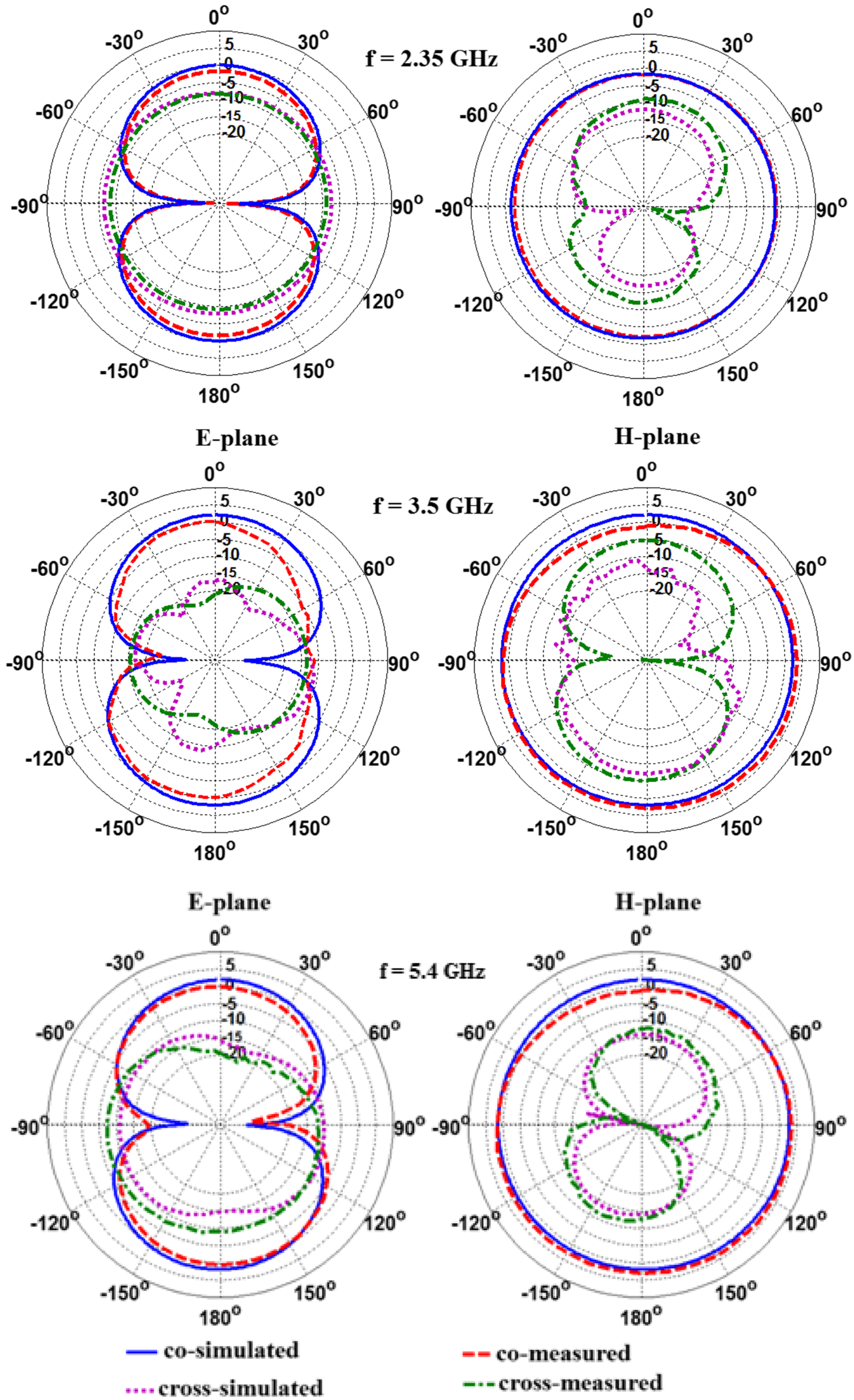


Fig. 8 Photograph of the fabricated ACS-fed tri-band antenna along with simulated and measured return loss

Fig. 9 Measured and simulated radiation patterns of the proposed tri-band antenna at 2.35, 3.5 and 5.4 GHz



$$l_1 = Y \quad (4)$$

$$l_2 = X + (W - W2) \quad (5)$$

$$l_3 = L3 \quad (6)$$

$$\epsilon_{r,eff} = \frac{\epsilon_r + 1}{2} \quad (7)$$

Here, c stands for the velocity of light in free space, l_1 is the total perimeter of the meandered strip obtained as shown in Eq. (4), while $\varepsilon_{r,eff}$ is the effective relative permittivity to be calculated from Eq. (7). The second resonance is obtained by the length of the L-shaped branch. The third resonances is contributed by the horizontal strip attached to the monopole. Expressions for f_2 and f_3 are shown in Eqs. (2) and (3) in terms of the its various lengths are given in Eqs. (5) and (6). For calculating the effective relative permittivity, it is assumed that for an ACS-fed monopole, half of the established field lies in air while the remaining half is distributed in the substrate.

3 Results and discussion

A prototype of the proposed ACS-fed tri-band antenna along with its simulated and measured return loss curves were shown in Fig. 8. The return loss of the proposed antenna was measured by using Rohde and Schwarz Vector Network Analyzer (ZVA-40). It can be seen that both the simulated and measured results show good agreement. The slight variation between measured and simulated results may be due to fabrication tolerances and quality of SMA connector. The measured impedance bandwidth for $S_{11} < -10$ dB for ACS-fed tri-band was about 120 MHz (2.3–2.42 GHz), 450 MHz (3.3–3.75 GHz), and 1500 MHz (4.5–6.0 GHz).

3.1 Radiation performance and peak gains

The radiation patterns of the proposed tri-band antenna were simulated in both E and H planes using CST Microwave Studio package and measured in an in-house anechoic chamber using antenna measurement system. A standard double ridged horn antenna was used as a reference antenna. The simulated and measured radiation patterns at different frequencies are shown in Fig. 9. The H-plane radiation patterns are seen to be omnidirectional in nature while the E-plane radiation patterns are bidirectional (dumb bell shaped). For the proposed ACS-fed antenna, the simulated and measured results are found to be in close agreement with a little difference due to measurement and alignment errors. The measured and simulated peak gains of the proposed tri-band antenna across the operating bands were given in Fig. 10. The simulated peak gain remains between 0 and 5 dBi in the useful bands and shows an increase in the high frequency region, which is due to the increased effective area of the antenna at shorter wavelengths.

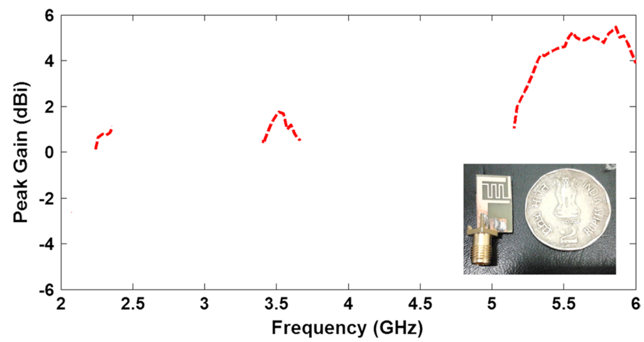


Fig. 10 Measured peak gain of the proposed ACS-fed tri-band antenna

4 Conclusion

A very small size (10 × 17.5 mm^2) ACS-fed monopole antenna with tri-band operation for 2.3 GHz LTE/WiBro, 3.5/5.5 GHz WiMAX, 5.2/5.8 GHz WLAN and 4.9 GHz US public safety applications has been designed and validated experimentally. In the proposed antenna design, three independent resonant frequencies have been generated by using an F-shaped radiating element and a meandered strip. The measured results show good omnidirectional radiation patterns in H-plane and bi-directional patterns in E-plane with stable peak gains variation between 0.2 and 5 dBi. Further the proposed antenna is very simple and easy to design, fabricate and integrate with any RF, MIC/MMICs communication devices.

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