

Printed V-shape ACS-fed compact dual band antenna for bluetooth, LTE and WLAN/WiMAX applications

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Abstract In this research article, a novel technique to design a compact multi-band antenna with asymmetric coplanar strip (ACS) feeding is proposed and discussed for 2.4 GHz Bluetooth/WLAN, 3.6 GHz LTE and 3.4 GHz WiMAX applications. The proposed design is printed on a low cost FR4 substrate with thickness of 1.6 mm and having an overall dimensions of $14.75 \times 26 \text{ mm}^2$ only. By integrating a rectangular shaped strip and a tilted V-shaped strip to the basic ACS-monopole, desired dual frequency operation is achieved. Simulated and experimental results of the proposed compact monopole antenna are presented and discussed. The experimental results shows that the proposed V-shaped dual-band antenna is having an impedance bandwidth ($S_{11} \leq -10 \text{ dB}$) of 320 MHz from 2.2 to 2.52 GHz and 900 MHz from 3.3 to 4.2 GHz, respectively. Additionally, the proposed dual-band antenna is also having omnidirectional radiation patterns and constant peak gains with good radiation efficiency.

1 Introduction

Nowadays, long term evolution (LTE), wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) are the three popular wireless communication protocols that are using for high data rate applications. So, to serve these technologies in an electronic device/system, a compact antenna which will integrate multiple operating bands with wide impedance

bandwidth characteristics is desired. Recently, various antenna structures/designs with different feeding techniques have been reported for multi-band applications. To address the WLAN and WiMAX communication protocols, various types of printed multi-band antennas have been reported in the literature.

Liu and Chen (2004) presented a $20 \times 30 \text{ mm}^2$ size meandered patch antenna for dual frequency operation. The proposed antenna consists of CPW feeding with uniplanar rectangular radiating element. The antenna provides a -10 dB impedance bandwidth of 260 MHz from 1.92 to 2.18 GHz and 710 MHz from 4.99 to 5.7 GHz, respectively, which can support both the UMTS and WLAN bands. Though the reported structure was simple, it was not able to cover 3.5 GHz WiMAX band. In order to integrate 3.5 GHz WiMAX band, Song et al. (2007) designed a triangular shape CPW-fed multiband antenna for WLAN/WiMAX applications. Adjustable strips were used to enhance the impedance bandwidth in the higher frequency band. Even though the reported antenna covers wider impedance bandwidth, it occupies a very large area of 840 mm^2 .

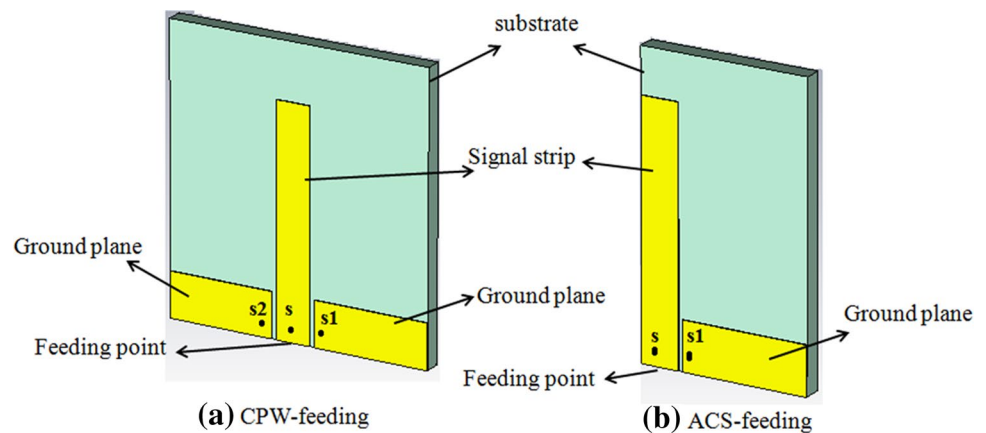
Krishna et al. (2008) designed a $28.5 \times 33.5 \text{ mm}^2$ size fractal monopole antenna for dual frequency WLAN and WiMAX applications. The achieved operating bands were from 2.38 to 3.95 GHz and 4.95 to 6.05 GHz. A $40 \times 35 \text{ mm}^2$ dual-band antenna having a U-shaped open stub was proposed by Lee et al. (2009) to cover the 2.45 GHz WLAN and the 3.1–5.2 GHz DS-UWB applications. Similarly, Liu et al. (2010a) reported a $22 \times 41 \text{ mm}^2$ size tri-band monopole antenna suitable for 2.4/5.0 GHz WLAN and WiMAX applications. In the reported design, by inserting a U-shaped strip into a monopole, two resonances for WLAN band were achieved and by integrating two symmetrical L-shaped slits into a defect ground-plane, another resonance at WiMAX band was achieved. Again these

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Table 1 Reported multi-band antennas performance summary

Published literature	Antenna type	Antenna size (mm ²)	Substrate material	Antenna purpose			Avg peak gain (dBi)
				WLAN	WiMAX	LTE	
Liu and Chen (2004)	Dual-band	20 × 30	FR4	Yes	–	–	2.2
Zhao et al. (2007)	Dual-band	16 × 32	FR4	Yes	–	–	3.5
Liu et al. (2010a, 2010b)	Dual-band	30 × 25	FR4	Yes	–	–	3.5
Huang and Yu (2011)	Dual-band	50 × 30	FR4	Yes	–	–	2.6
Sun et al. (2012)	Dual-band	40 × 30	FR4	Yes	–	–	1.0
Teng et al. (2012)	Tri-band	28 × 26	FR4	Yes	–	–	3.0
Lin et al. (2012)	Dual-band	50 × 50	FR4	Yes	–	–	3.5
Sun et al. (2014)	Dual-band	25 × 25	FR4	Yes	–	–	2.5
Tsai (2014)	Dual-band	60 × 45	FR4	Yes	–	–	3.2
Proposed work	Dual-band	14.75 × 26	FR4	Yes	Yes	Yes	1.4

Fig. 1 Schematic of CPW and ACS feeding techniques (s , s_1 and s_2 are the coaxial feeding points and we can see almost 44 % reduction with ACS-feeding)**Table 2** Reported ACS-fed antenna performance summary

Published literature	Antenna type	Antenna size (mm ²)	Substrate material	Antenna purpose			Avg peak gain (dBi)
				WLAN	WiMAX	LTE	
Song et al. (2008)	Tri-band	31 × 15	FR4	Yes	–	–	2.6
Deepu et al. (2009)	Dual-band	21 × 19	FR4	Yes	–	–	1.8
Ashkarali et al. (2012)	Dual-band	37.5 × 24	FR4	Yes	–	–	1.21
Li et al. (2013a)	Dual-band	17 × 12	FR4	Yes	–	–	0.8
Li et al. (2013b)	Dual-band	17 × 12	FR4	Yes	–	–	2.0
Proposed work	Dual-band	14.75 × 26	FR4	Yes	Yes	Yes	1.4

reported designs were having limitations of large size and complex structure.

A simple monopole printed CPW-fed antenna was presented by Chu and Ye (2010) for wireless communication applications. The reported antenna supports dual operating frequencies that resonate at 2.5 and 5 GHz, respectively to support all the WLAN and WiMAX frequency standards. Liu et al. (2010a, b) proposed a 30 × 25 mm² size

monopole antenna, which consists of simple rectangular patch geometry. By properly choosing the optimized electrical lengths of radiating slots, dual frequency operation of 2.4/5.0 GHz WLAN and 4–8 GHz C-band operations was obtained. Even though both the reported antennas cover wider impedance bandwidth, it occupies a very large area.

Huang and Yu (2011) design and developed a novel monopole slot antenna with embedded rectangular parasitic

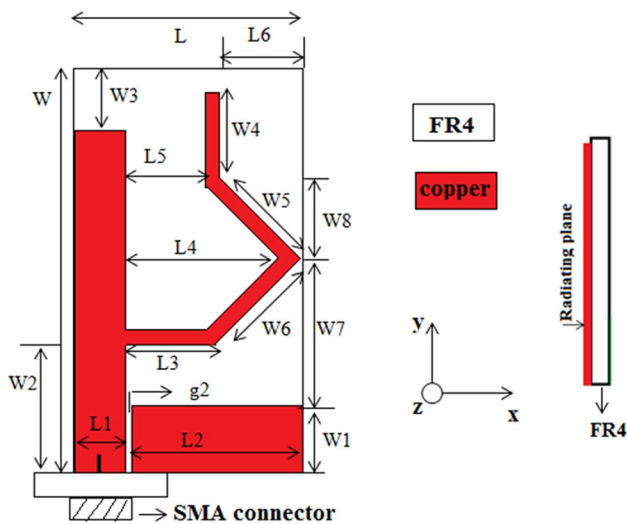


Fig. 2 Geometry of the proposed ACS-fed V-shape dual-band antenna

elements for dual-band applications. Though the reported antenna was having wider impedance bandwidth, it was having drawback of large dimensions i.e. $30 \times 50 \text{ mm}^2$ including ground plane. In order to support, all the frequency standards of WLAN and WiMAX, a slot monopole antenna (Hu et al. (2011)) with tri-band frequency of operation was obtained. The reported antenna has three operating band from 2.34 to 2.82 GHz, 3.16 to 4.06 GHz, and 4.69 to 5.37 GHz, respectively, which can cover WLAN and WiMAX bands.

Lin et al. (2012) reported a very large size ($50 \times 50 \text{ mm}^2$) rhombus shaped slot antenna for dual frequency operation. By properly selecting the feeding structure and rectangular strips, two independent resonant frequencies having -10 dB bandwidths of 607 MHz resonated at 2.45 GHz and 1451 MHz resonated at 5.5 GHz were achieved. In order to cover RFID band along with the WLAN band, Teng et al. (2012) proposed a CPW-fed triangular shaped antenna with a dimensions of $28 \times 26 \text{ mm}^2$. In the design, a Π -shaped slot and a T-shaped strip were introduced to generate two separate impedance bandwidths ranging from 2.36 to 2.50 GHz and from 5.01 to 6.33 GHz, respectively. Though the reported structure was small and simple, it was not able to cover 3.5 GHz WiMAX band.

Huang et al. (2014) proposed a multi-band CPW-fed antenna for various wireless communication applications. By using three different radiating elements namely, folded open stub, L-shaped open stub, and Y-shaped resonator, triple operating bands working at 2.5/3.5/5.5 GHz was achieved. Similarly, to meet WLAN and WiMAX applications, a bow tie shaped CPW-fed slot antenna was proposed by Tsai (2014). In the reported design, an M-shaped patch at the centre of the slot is used as a radiating element. The

developed antenna achieves a dual frequency operation from 2.26 to 2.57 GHz and 4.81 to 6.56 GHz and has dimensions of $60 \text{ mm} \times 45 \text{ mm}$. Again the reported design was having limitations of large size and narrow impedance bandwidth.

A detailed comparative study of the recently reported CPW-fed multi-band antennas in terms of its performance characteristics are given in Table 1. From the table, it is seen that even though the CPW feeding is having many advantages such as uniplanar structure, simple to design and has less cost of fabrication (one side printing), all the reported antennas are having drawbacks of large size, narrow bandwidth and limited frequency of operation. Hence there is a need for designing small size multi-band antenna having wide impedance bandwidth characteristics.

To decrease the overall size of the antenna, recently some designs have been reported in the literature (Naidu and Kumar 2015a, b), Naidu et al. (2015), Naidu and Malhotra (2015a, b, c, d) by using the concept of asymmetric coplanar strip (ACS) feeding. As shown in Fig. 1, in comparison to general coplanar waveguide (CPW)-fed antenna, an ACS-fed antenna will have smaller size ($\sim 44 \%$ size reduction) as it considers only half of the ground plane of CPW-fed structure. Table 2 shows the reported ACS-fed antennas performance summary in terms of its size, operating bands and average peak gains. From the table it can be seen that, although some of these antennas are compact in size but again they are having drawbacks of complex structure, narrow bandwidth and limited/no access of WLAN, LTE and WiMAX frequency bands.

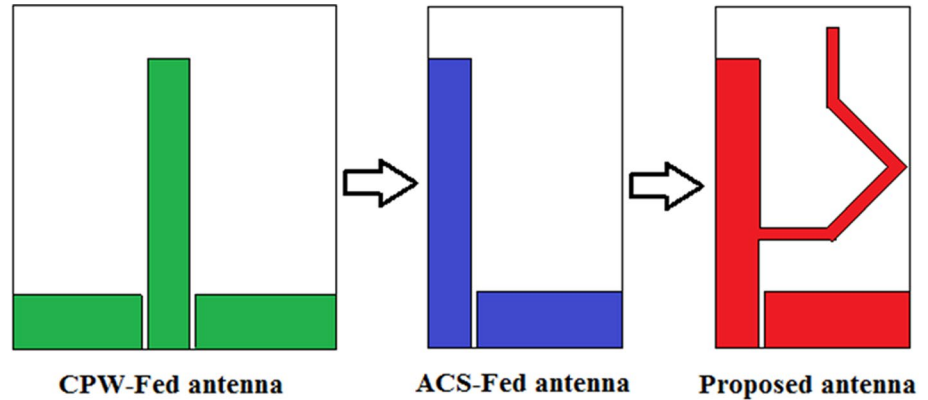
In order to integrate multiple wireless communication standards into a single antenna, in this research article, a novel, simple antenna design to reduce antenna size (approximately 44 % size reduction in compared with a basic CPW-fed antenna) along with generation of multiple operating bands by using asymmetrical coplanar strip (ACS) feeding is proposed for 2.4 GHz Bluetooth/WLAN, 3.6 GHz LTE and 3.4 GHz WiMAX applications. In the proposed structure, a basic ACS monopole with a vertical rectangular strip and tilted V-shaped strip are used to generate desired dual frequency operation. The measured impedance bandwidth (return loss $\leq -10 \text{ dB}$) is about 320 MHz from 2.2 to 2.52 GHz and 900 MHz from 3.3 to 4.2 GHz, respectively. The details of antenna working principle with its design strategy and its simulated and measured results are explained and given in the following sections.

2 Antenna design

The proposed geometry with its optimized dimensions of the dual-band antenna with ACS feeding technique is given in the Fig. 2. For the simulation, analysis and validation purpose CST microwave studio package is used.

Table 3 Optimized parameter values (see Fig. 2)

Parameter	W	L	W1	W2	W3	W4	W5	W6	W7
Value (mm)	26	14.75	4.3	8.2	4	5.43	7.36	6.64	9.6
Parameter	W8	L1	L2	L3	L4	L5	L6	g	
Value (mm)	5.4	3.3	11	5.34	9.8	5.2	5.4	0.5	

Fig. 3 Design evolution stages of the proposed V-shape dual-band antenna

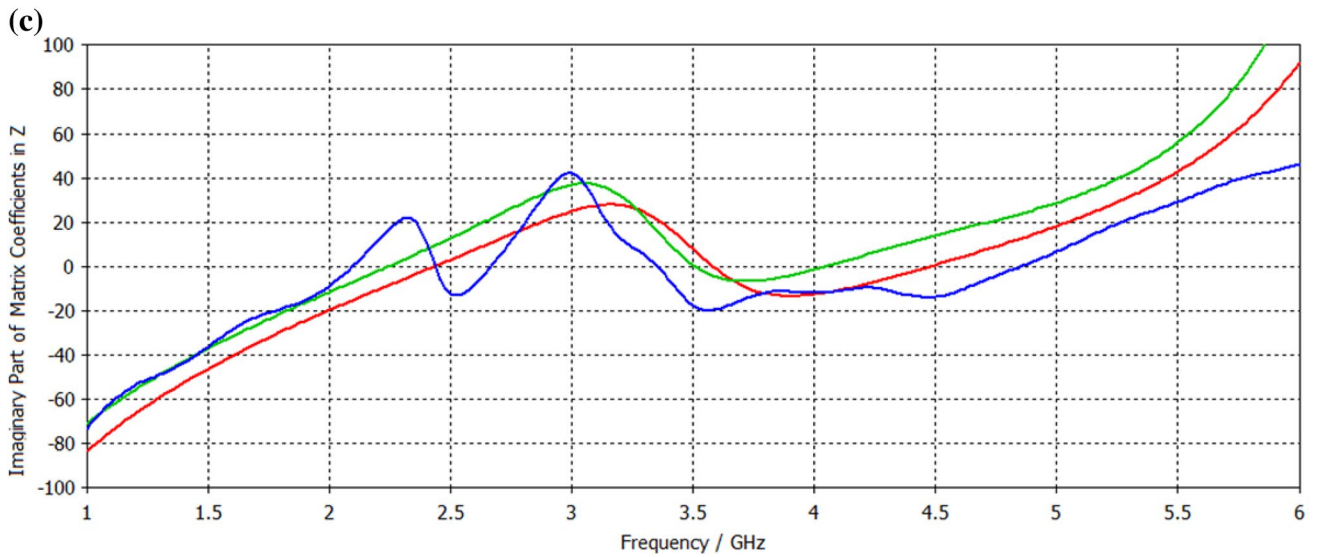
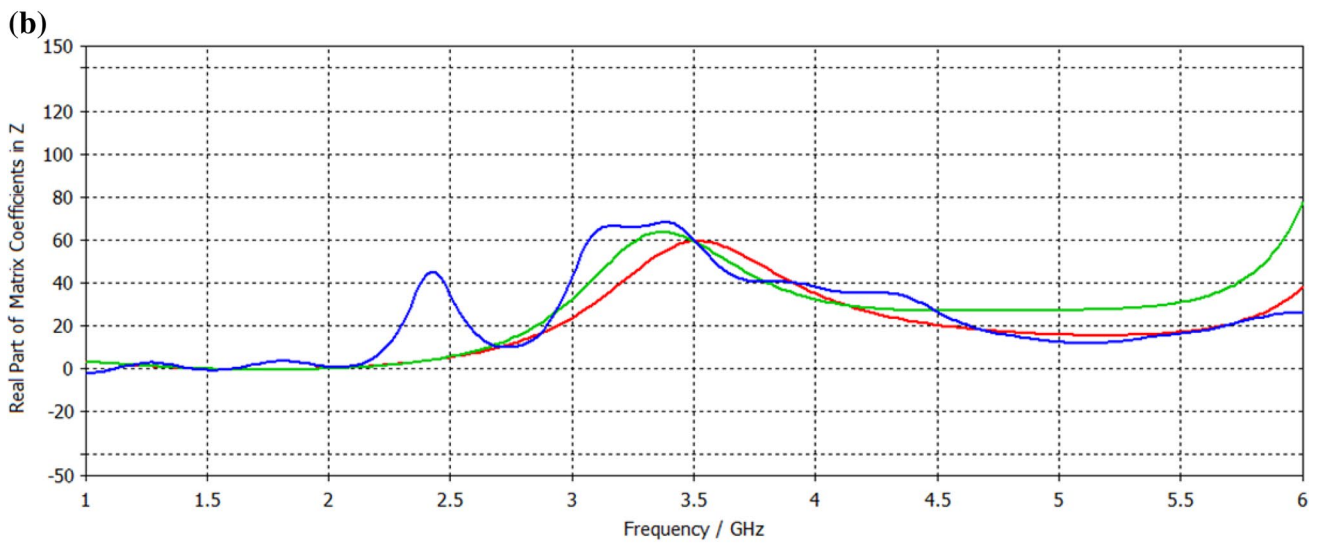
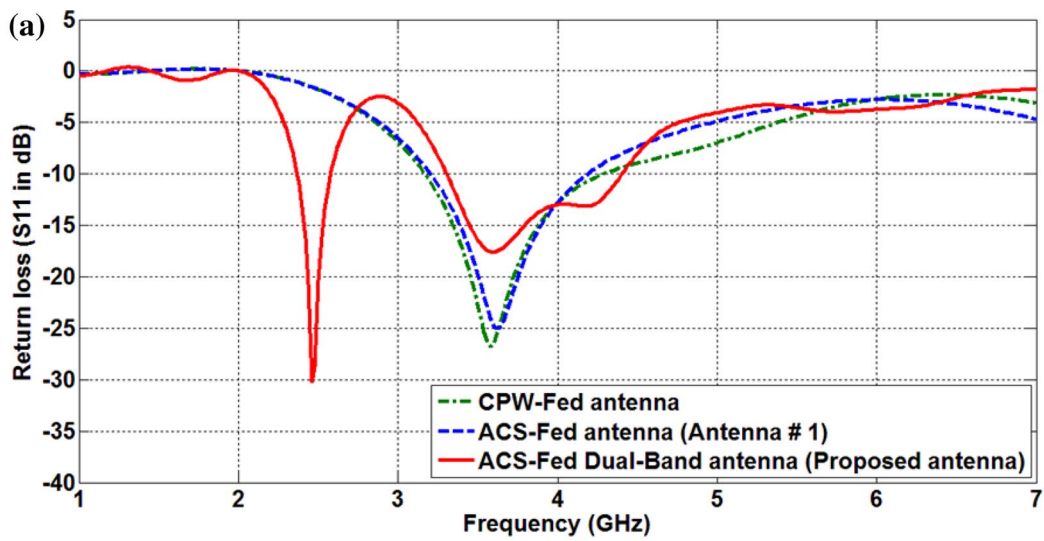
In the design, all the radiating strips/elements and ground plane are printed on one side of the low cost 1.6 mm thick FR4 substrate having dielectric constant of 4.4 and loss tangent $\tan \delta = 0.02$. In order to achieve 50 Ω characteristic impedance, a signal strip of width $L1 = 3.3$ mm and a gap of $g2 = 0.5$ mm between the signal strip and ground plane, is considered. By integrating a rectangular strip and tilted V-shaped strip to the basic ACS-monopole, desired dual frequency operation for 2.4 GHz Bluetooth/WLAN, 3.6 GHz LTE and 3.5 GHz WiMAX applications is achieved. The optimized parameter dimensions of the proposed ACS-fed V-shaped dual-band antenna are given in Table 3.

Different design stages involved for achieving the final proposed dual-band antenna structure is analyzed and shown in Fig. 3 and the corresponding reflection coefficient or return loss curves for each design are given in Fig. 4. As shown in Fig. 3, the evolution process begins with a basic CPW-fed monopole antenna structure (green color) consisting of two symmetrical ground planes beside the signal strip with an extended rectangular strip ($\sim 0.33\lambda$) having an overall dimensions of 26×26.25 mm² (682.5 mm²). The impedance bandwidth ($S_{11} \leq -10$ dB) achieved with the design is 1.0 GHz from 3.2 to 4.2 GHz. Next, to reduce the antenna size by without compromising on antenna performance, only half of the ground plane of CPW-fed structure is considered and named as ACS-fed antenna (blue color) in Fig. 3. With the newly formed ACS-fed geometry almost 44 % size reduction has been achieved with same impedance bandwidth of 1.0 GHz from 3.2 to 4.2 GHz. Next, to achieve one more resonant frequency at 2.45 GHz, a titled V-shaped strip ($\sim 0.33\lambda$) has been attached (red color) to the

Fig. 4 a Simulated return loss curves of various stages involved in the evolution process. b Real part of input impedance for the CPW-fed (green), ACS-fed (red) and the proposed antenna (blue). c Imaginary part of input impedance for the CPW-fed (green), ACS-fed (red) and the proposed antenna (blue)

ACS-fed monopole structure. From Fig. 4, it can be seen that two independent resonant modes are excited, one at 2.45 GHz WLAN band due to titled V shaped branch and the other at 3.4 GHz WiMAX/LTE band due to vertical rectangular strip. Therefore, with the final antenna geometry (red color) shown in Fig. 3, two independent operating bands from 2.2 to 2.52 GHz and from 3.3 to 4.2 GHz for LTE/WLAN and WiMAX applications is achieved. To better understand the behavior of the proposed ACS-fed antenna with the V-shaped strip and uniplanar ground plane, a plot of the input impedance i.e. Z parameters real and imaginary parts of the of the antenna is shown in Fig. 4b and c, respectively. It can be observed that, when compared to the simple CPW-fed, and basic ACS-fed structure, the proposed ACS design, with the V-shaped geometry, the deviations with frequency of the Z-real part of the impedance from the 50 Ω line are less. Similarly, the Z-parameter imaginary part of the impedance is closer to the 0 Ω line. Both these observations indicate better impedance matching.

To further understand the working principle/operation of the proposed V-shaped ACS-fed dual-band antenna, the surface current distributions at two resonant frequencies are simulated by using CST microwave studio package and shown in Fig. 5. In the figure, maximum and minimum current densities are shown with red and blue colors respectively. It



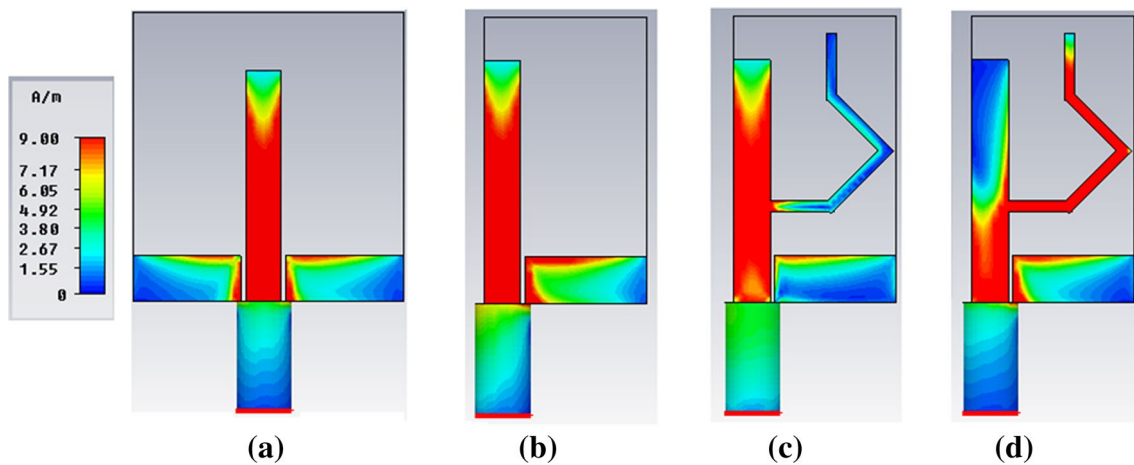
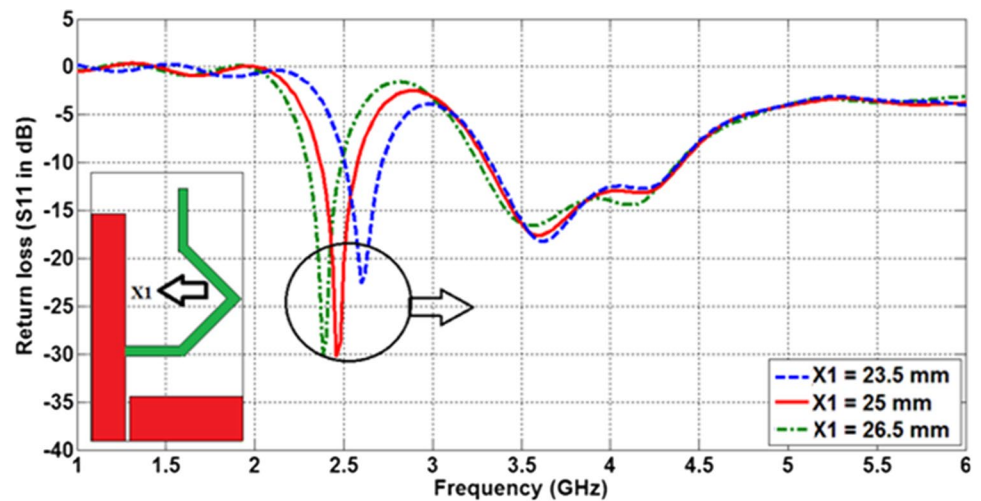


Fig. 5 Surface current distribution **a–c** $f = 3.5$ GHz **d** $f = 2.45$ GHz

Fig. 6 Simulated return losses of the proposed antenna when X_1 is varying



can be seen that at 3.5 GHz frequency, a large surface current is concentrated on the vertical rectangular strip of CPW, ACS and ACS with V-shape strip antennas. This indicates that vertical strip ‘Y1’ $= W - W_3 - W_1 = (\sim 0.33\lambda)$ acts as a radiator to generate higher (second) resonant/operating mode. Whereas at 2.45 GHz frequency, most of the current is observed on titled V-shape strip $[X_1 = (\sim 0.33\lambda) = W_4 + W_5 + W_6 + L_3 + (W_2 - W_1)]$ and minimum/no surface current on rectangular strip. This indicates that the first operating band is generated due to the $\lambda/3$ length V-shape structure. The expression for the same can be given in Eqs. 1, 2, 3. This justifies the reason for obtaining two independent resonant modes.

$$f_1 = \frac{c}{3X_1\sqrt{\epsilon_{r,eff}}} \quad (1)$$

$$f_2 = \frac{c}{3Y_1\sqrt{\epsilon_{r,eff}}} \quad (2)$$

$$\epsilon_{r,eff} = \frac{\epsilon_r + 1}{2} \quad (3)$$

In the Eqs. (1) and (2), c is velocity of light in free space, in Eq. (3) $\epsilon_{r,eff}$ is the effective relative permittivity of the substrate. For calculating the effective relative permittivity, similar to CPW-fed, it is assumed that for a ACS-fed monopole, half of the established field lies in air while the remaining half is distributed in the substrate.

To further investigate and understand the independent tuning property of the proposed V-shape ACS-fed dual-band antenna, two important parameters (i.e. length of two radiating strips ‘X1’ and ‘Y1’) that influence the antenna performance are studied and given in Figs. 6 and 7 respectively. The effects of varying the length of titled V-shape strip ‘X1’ on return loss is given in Fig. 6. It can be seen from the Fig. 6 that as the length of the titled V-shaped strip ‘X1’ decreases from 26.5 to 23.5 mm, the first resonant

Fig. 7 Simulated return losses of the proposed antenna when Y1 is varying

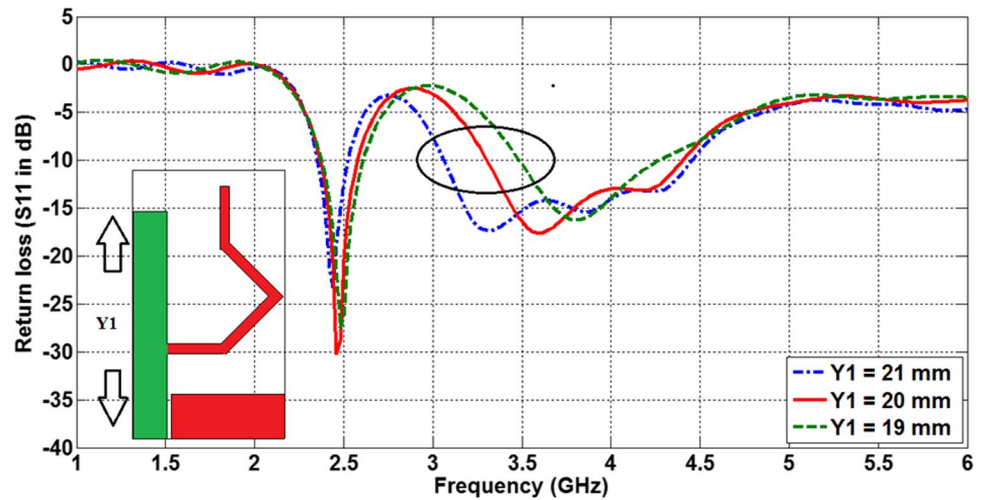
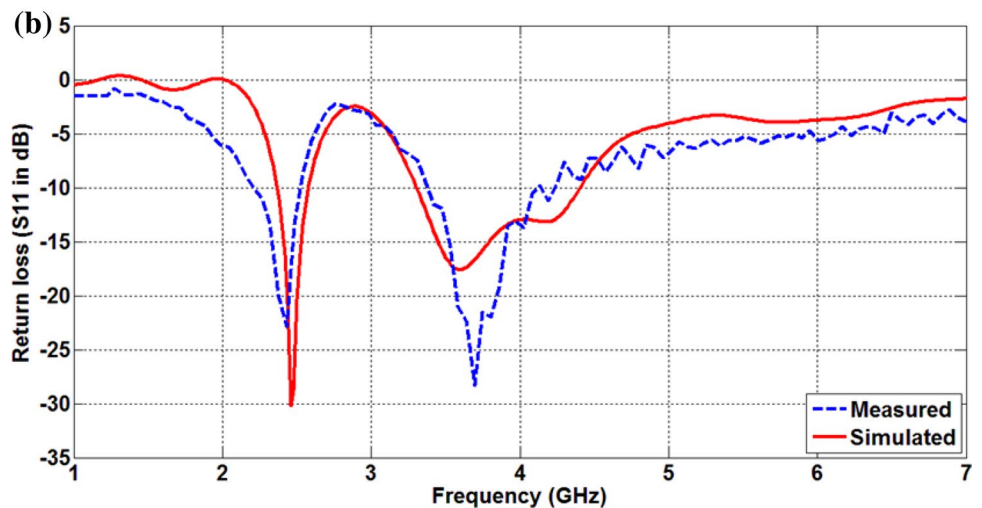
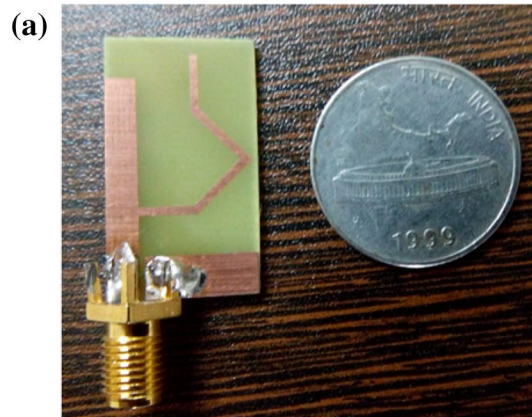


Fig. 8 Fabricated prototype with its simulated and measured return loss against frequency



frequency shifts towards higher frequencies without disturbing the second operating band impedance bandwidth. Similarly, Fig. 7 plots the return loss curves by varying the electrical length of the vertical rectangular strip ‘Y1’. From the figure it can be seen that as the length of the parameter ‘Y1’ decreases, the lower frequency limit of second

operating band shifts towards higher frequency side. As a result the overall second operating band impedance bandwidth reduces with shift in resonant frequency. Also, it is observed that the first operating band characteristics are remain unchanged, as a result independent tuning property is achieved.

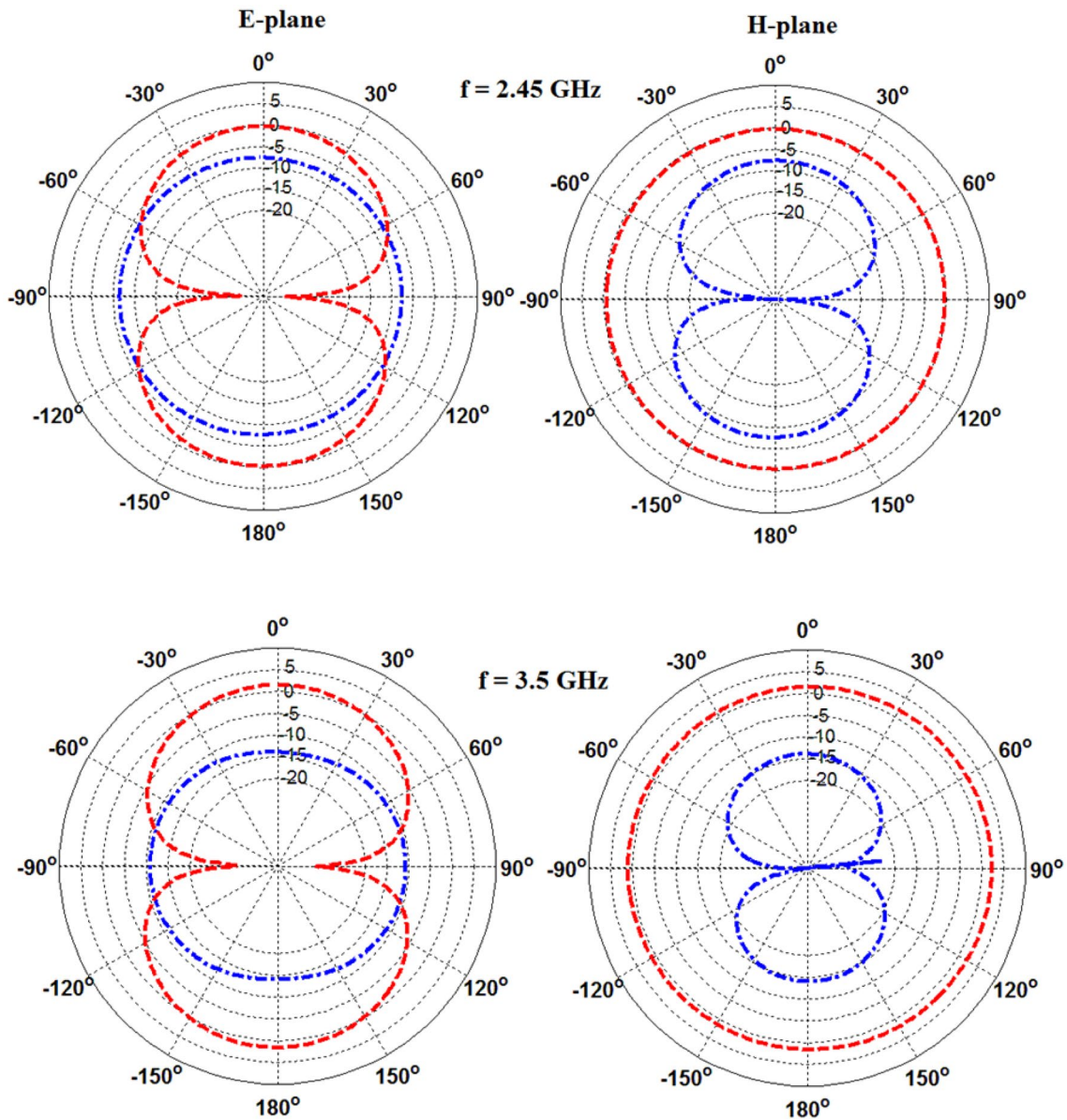


Fig. 9 Radiation patterns of the proposed dual-band antenna at 2.45 and 3.5 GHz. [E-plane, $\phi = 0$ (xz-plane), H-plane, $\phi = 90$ (yz-plane)]

3 Simulated and measured results

For the proposed V-shape dual-band ACS-fed antenna, simulations and analysis are carried out by using CST microwave studio package and then the final antenna geometry prototype is fabricated (Fig. 8) on a low cost FR4 substrate having thickness of 1.6 mm by using photo lithography technique. In order to validate its simulated return loss characteristics, R&S ZVA 40 vector network analyzer is used and the comparison of simulated and measured return loss curves with respect to frequency is given in Fig. 8. The experimental results shows that the proposed V-shaped dual-band antenna is having bandwidth (-10 dB)

of 320 MHz from 2.2 to 2.52 GHz and 900 MHz from 3.3 to 4.2 GHz. Which can be used for 2.4 GHz Bluetooth, 2.4 GHz WLAN, 3.6 GHz LTE and 3.4 GHz WiMAX applications. The slight frequency shift seen in the first operating band is probably due to small size, small ground plane, manufacturing tolerances, uncertainty of the thickness and/or the dielectric constant of the FR4 substrate and quality of SMA connector used.

The far-field normalized radiation patterns (co and cross polarization) in E-plane (xz-plane, spherical angle $\phi = 0^\circ$) and H-plane (yz-plane, spherical angle $\phi = 90^\circ$) at 2.45 GHz, and 3.5 GHz are shown in Fig. 9. In the figure red and blue colors indicates co and cross polarizations,

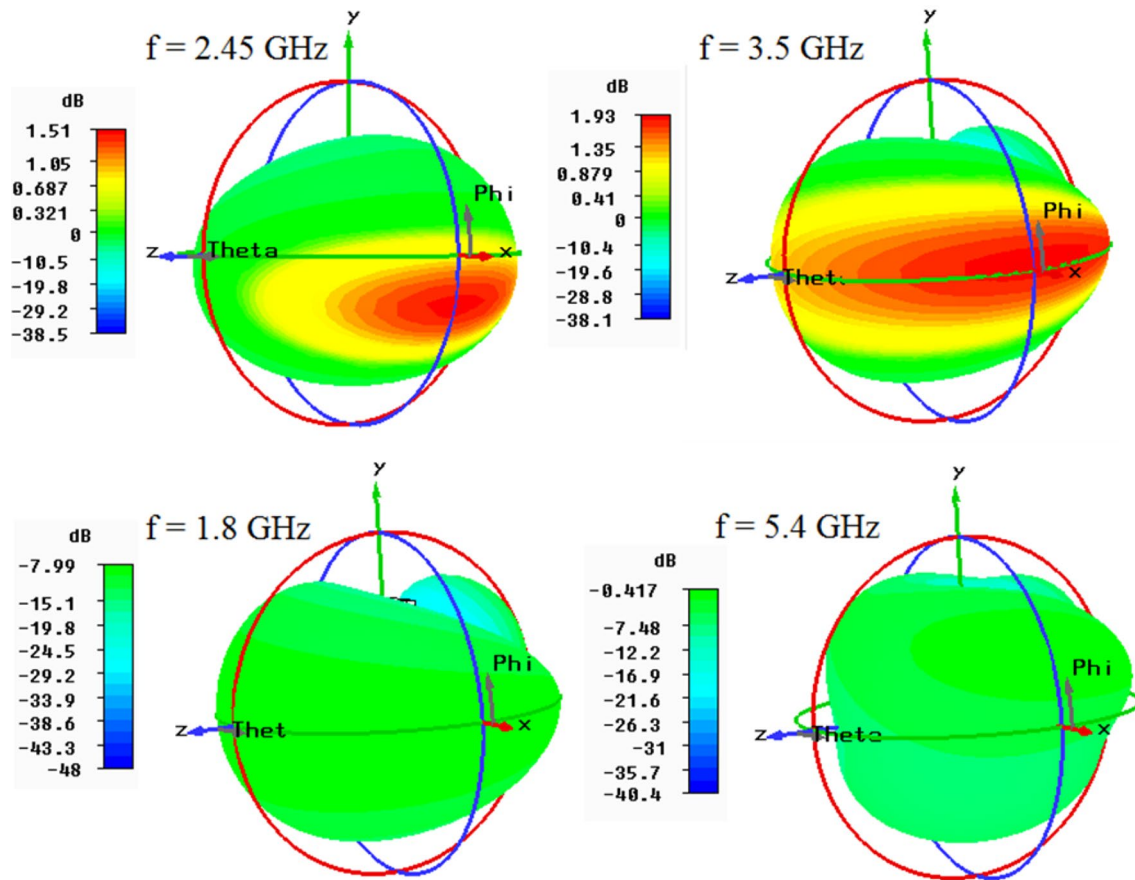
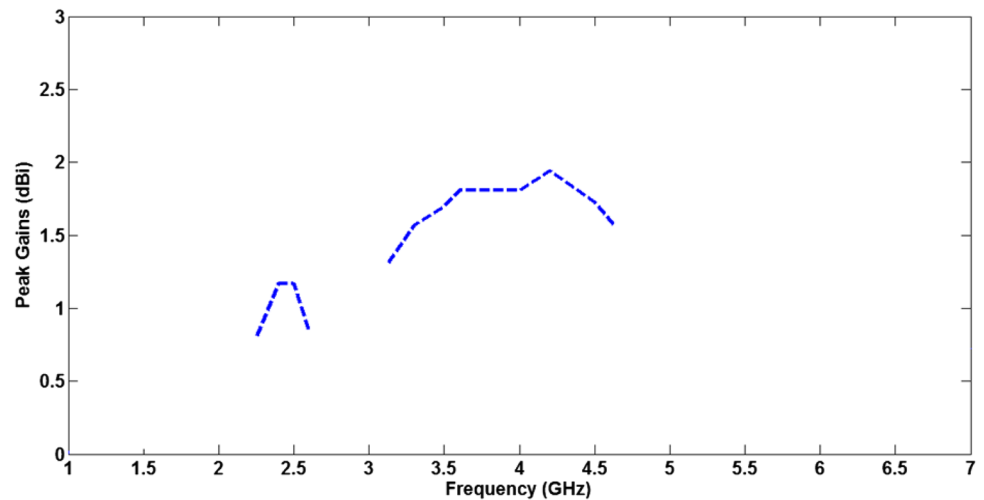


Fig. 10 Simulated 3D-radiation patterns at different frequencies

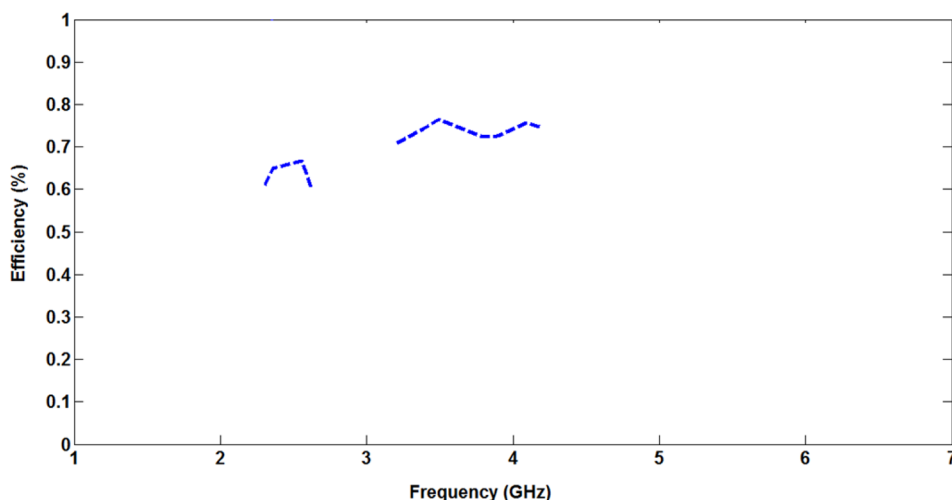
Fig. 11 Peak gains of the proposed V-shape ACS-fed dual-band antenna



respectively. Figure 10 shows the 3D-gain of the proposed V-shaped ACS-fed dual-band antenna at two resonance frequencies and at two non resonating frequencies. The plot indicates the maximum radiation in direction with respect to different values of theta and phi. At higher resonant frequency, directivity is increased so that gain is improved.

For the proposed antenna, nearly bi-directional (eight-shape) radiation patterns in E-plane and omnidirectional patterns in H-plane are observed over the operating band frequencies with an average peak gain of 1.6 dBi (Fig. 11). The simulated radiation efficiency of the proposed V-shape ACS-fed dual-band antenna is calculated by using CST

Fig. 12 Radiation efficiency of the proposed V-shape ACS-fed dual-band antenna



MWS package and given in Fig. 12. The average efficiency is about 70 % in both the operating bands.

4 Conclusion

In this paper, a small titled V-shaped asymmetric coplanar strip (ACS) fed dual-band printed monopole antenna is presented for 2.4 GHz Bluetooth/WLAN, 3.6 LTE and 3.4 GHz WiMAX applications. The proposed geometry is printed on a low cost FR4 substrate having an overall dimensions of $14.75 \times 26 \text{ mm}^2$, which much smaller than the antennas reported in the literature for similar dual-band applications (Tables 1, 2). By integrating a rectangular shaped strip and a tilted V-shaped strip to the basic ACS-monopole, desired dual frequency operation is achieved. Both the operating bands can be easily controlled by changing the electrical length of the radiating elements. The simulated and experimental results shows that the proposed V-shaped dual-band antenna is having omnidirectional radiation patterns with wider impedance bandwidths ($S_{11} \leq -10 \text{ dB}$) of 320 MHz from 2.2 to 2.52 GHz and 900 MHz from 3.3 to 4.2 GHz, respectively.

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