Compact Uniplanar Multi Band ACS Monopole Antenna Loaded With Multiple Radiating Branches for Portable Wireless Devices

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Abstract

This research article presents, a compact 0.19 λ x 0.32 λ size (with respect to 2.3 GHz frequency) ACS fed printed monopole wideband antenna loaded with multiple radiating branches suitable for LTE2300/WiBro, 5 GHz WLAN and WiMAX applications. The proposed triple band uniplanar antenna encompasses of C shaped strip, L shaped strip, rectangular shaped strip and a lateral ground plane. All the radiating strips and ground plane are etched on the 26 × 15 mm^2 size low cost FR4 epoxy substrate. This designed geometry evoked three independent reonanant frequencies at 2.3 GHz, 3.5 GHz and 5.5 GHz with precise impedance matching over each operating band. The reflection coefficient (S_{11}) response of the presented antenna demonstrates three distinct resonant modes associated with -10 dB bandwidths are about 2.24-2.40 GHz, 3.38-3.83 GHz and 5.0-6.25 GHz respectively. From the study, it is also observed that the proposed design works perfect with microstrip as well as CPW feedings. Hence the designed Multi Feed Multi Band (MFMB) antenna can be easily deployed in to any portable wireless device that works for 2.3/3.5/ 5 GHz frequency bands.

1. Introduction

The present scenario of advanced high speed telecommunication systems, demands integration of multiple wireless standards into a single gadget that leads to the research towards the design of portable multi-band printed antennas. Therefore, to serve the end user requirements, several printed antenna with various geometries have been reported in the literature [1-16]. For the greater part of the applications, many monopole antennas are developed and reported with microstrip feeding and coplanar waveguide (CPW) feeding techniques. Even though the popular antenna feeding techniques used in literature (microstrip & CPW) offers desired characteristics such as omnidirectional radiation characteristics, higher efficiency, light in weight, low priced, wide impedance band, constant peaks etc, further in order to reduce the overall size, an advanced feeding namely Asymmetric Coplanar Strip (ACS) has been developed [1-11, 15-16]. As shown in Fig. 1(c), a size reduction of 44% can be achieve with ACS feeding as it consists only one half of ground plane of CPW-fed structure. A summary table of literature is given in Table 1. It is found from the Table.1 that most of the reported CPW-fed, microstrip fed, ACS-fed dual-band antennas are large in size with limitations of complex structure, lower efficiency and narrow impedance bandwidth.

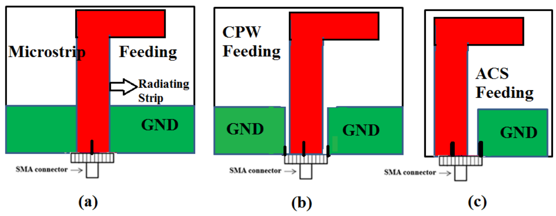


Figure 1: (a) Microstrip Feed (b) CPW Feed (c) ACS Feeding (almost size reduction of 44%)

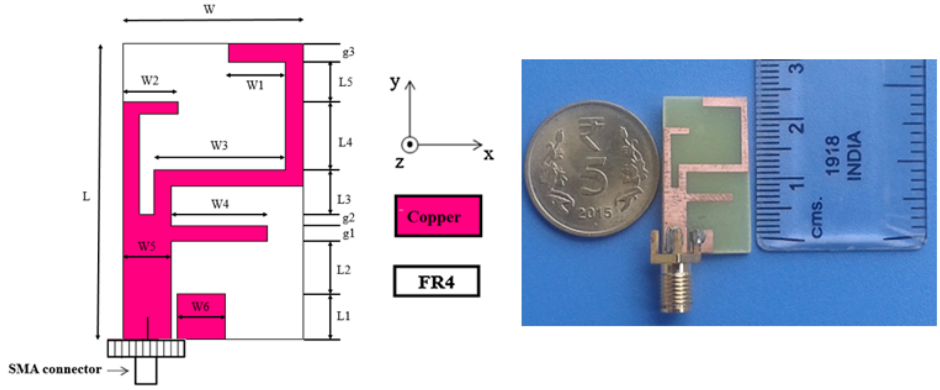
Table 1: Summary of literature

Ref	Bands (GHz)	No of Bands	Gain (dBi))	Size (mm^2)	Application
[1]	2.4/3.5	2	~2	28 x 30	WLAN/WiMAX
[2]	2.4/3.5/5	3	~2.5	10 x 17.5	WLAN/WiMAX
[3]	2.4/3.5/5.8	3	~2.9	35 x 19	WLAN/WiMAX
[4]	2.5/5 GHz	3	NA	14 x 26	WLAN/WiMAX
[5]	2.5/5 GHz	3	~ 1.85	11.5 x 26	WLAN/WiMAX
[6]	2.4/5 GHz	3	~1.76	35 x 15	WLAN/WiMAX
[7]	2.4/5 GHz	3	~2.76	31 x 15	WLAN/WiMAX
[8]	2.4/5 GHz	3	~1.87	21 x 19	WLAN
[9]	2.4/3.5/5	3	~1.7	36 x 20	WLAN/WiMAX
[11]	2.4/3.5	2	~1.3	14.75 x 26	WLAN/WiMAX
Work	2.3/3.5/5.8	3	~3.3	26 x 15	WLAN/WiMAX

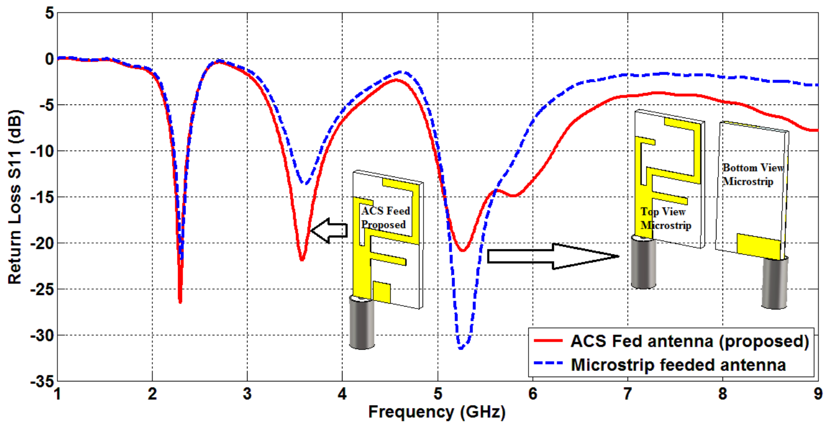
By applying the concept of ACS feeding, in this research a novel and simple uniplanar antenna design has been proposed for triple wideband WiBro/LTE/WLAN/WiMAX applications. Three independent tunable operating bands have been generated by using multiple radiating branches. The experimental results shows that the developed ACS antenna has -10 dB bandwidths about 2.24 GHz -2.40 GHz, 3.38 GHz -3.83 GHz and 5.0 GHz - 6.25 GHz respectively in the all operating bands. Further, detailed analysis on proposed ACS antenna has been discussed in the following sections.

2. ACS Fed Antenna Design & Analysis

A compact 0.19 λ x 0.32 λ size (with respect to 2.3 GHz frequency) prototype and geometry of the triband ACS-fed antenna loaded with multiple branches for WLAN/WiMAX applications is given in Fig 2(a), which is imprinted on a 26×15 mm^2 FR-4 substrate with a thickness of 1.6 mm, a dielectric permittivity of 4.4 and a loss tangent of 0.02. The proposed uniplanar configuration is framed by a C shape, L shape and rectangular shape radiators. The width of 50Ω ACS transmission line is taken as 3 mm by keeping the minimum gap distance of 0.5 mm between feedline and lateral ground plane. Meanwhile, RF power is delivered to each radiating strip with connection of SMA connector from bottom side. The most efficient and popular 3D EM simulator CST microwave studio is used to design and modify presented tri band antenna construction. The corresponding frequency versus S_{11} plots for ACS and ACS structure with microstrip feeding are given in Fig 2(b). It is observed that both the feedings have given desired results, which clearly indicates the unique property of the proposed geometry.



(a)



(b)

Figure 2: (a) Hardware prototype with geometry (b) $|S_{11}|$ versus frequency.

The designed structure of tripleband uniplanar ACS fed monopole antenna was constructed by first adding a rectangular shaped strip (Antenna # 1 in Fig 3(a)) to the basic ACS monopole, From the corresponding return loss curve in Fig. 3(b), it is seen that rectangular shape stub act as a key component in excitation of higher resonance (indicated as green color) from 4.2 to 6.1 GHz frequency band. In the sequence of another resonance excitation, mirrored C shaped radiating branch adjoined to Antenna # 1 for lower operating band (f_1) of triple frequency operation as showed in Fig. 3(a). It can be seen that Antenna # 2 emphasized to dual resonance associated with unlike radiators, which is followed by their optimized electrical length. Finally, inverted L-shape radiator is united with combination of C and rectangular shape radiators (in pink color of Fig. 3(a)) to drive three independent resonances for WiBro/LTE/WLAN/WiMAX applications. As a result, three impedance bandwidths ($S_{11} \leq -10$) are achieved about to 2.21-2.38 GHz, 3.38-3.83 GHz and 4.9-6.25 GHz respectively. The overall design process followed in this research is given in Fig.4. (W5 = 3 mm, W6 = 4 mm, L1 = 4 mm, L2 = 4.6 mm, g1 = 1.4 mm, g2 = 1 mm, L3 = 3.9 mm, L4 = 6 mm, L5 = 3.5 mm, g3 = 1.6 mm, L = 26 mm, W = 15 mm, W4 = 8 mm, W3 = 10.9 mm, W2 = 4.6 mm, W1 = 6.7 mm).

The targeted operating frequency (f_r) for a uniplanar printed antenna is found by using equation (1). The mathematical expressions of simple ACS feed antenna for the perfect impedance matching can be derived by using equation (2-4). [1-16].

$$f_r = c \, / \, (\lambda_g \sqrt{\varepsilon_{eff}}) \quad (1)$$

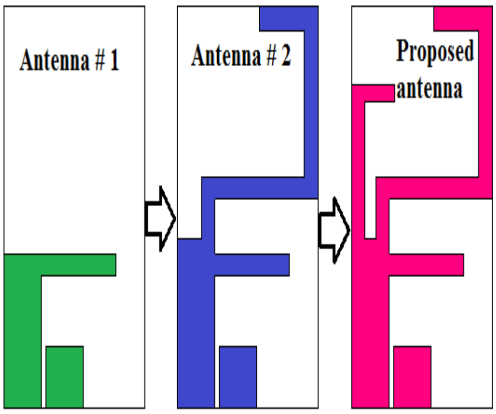
$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \quad (2)$$

$$Z_0 = \frac{60\pi}{\sqrt{\varepsilon_{eff}}} \frac{K(\kappa)}{K(\kappa^1)} \quad (3)$$

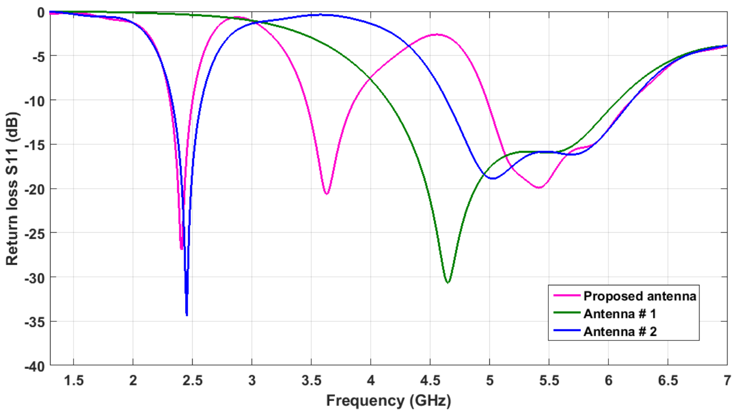
Where κ = a/b, $\kappa^1 = \sqrt{1-\kappa^2}$, and $\frac{K(\kappa)}{K(\kappa^1)}$ is referred to the elliptical integral of 1^{st} kind acknowledged by

$$\frac{K(\kappa)}{K(\kappa^1)} = \begin{cases} \dfrac{\pi}{\ln \dfrac{2\left(1+\sqrt{\kappa^1}\right)}{\left(1-\sqrt{\kappa^1}\right)}} & 0 \le \kappa \le \dfrac{1}{\sqrt{2}} \\[2ex] \dfrac{1}{\pi \ln \dfrac{2\left(1+\sqrt{\kappa}\right)}{\left(1-\sqrt{\kappa}\right)}} & \dfrac{1}{\sqrt{2}} \le \kappa \le 1 \end{cases} \quad (4)$$

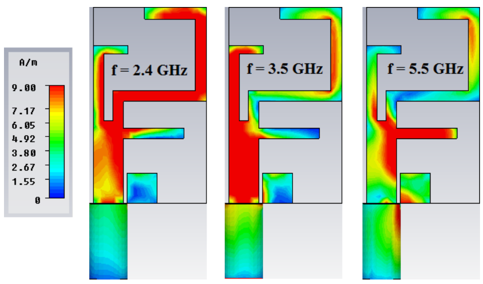
To define and validate the origin of triple independent frequency, a comprehensive study of different parameter has been carried out successfully as appeared in Fig. 5. Here, it has been visualized that mainly three radiating strips are formulated to bear triple band operation over 2.4/5.2/5.8 WLAN and 3.5/5.5 WiMAX bands. Fig. 5(a) illustrates that increasing the electrical length of mirror C-shaped radiator identifies an exact shifting (pointed with arrow remark) in lower resonant frequency with a minor change in middle resonance. This experiment confirmed that lower operating band is generated with insertion of C shaped radiator and can be controlled explicitly from it. Likewise, alteration in the measurement of inverted L and rectangular shape radiator urged to a visible shift in middle and higher resonant frequencies with small displacement in lower operating frequency as showed in Fig. 5(b & c). Next, surface current distribution (in Fig.3(c)) gave validation that richness of current travel along C, inverted L and rectangular shape strip at 2.4 GHz, 3.5 GHz and 5.5 GHz centered frequency, respectively.



(a)



(b)



(c)

Figure 3: (a). Various design stages with current distribution (b). Frequency versus $|S_{11}|$ curves (c) Surface current distribution

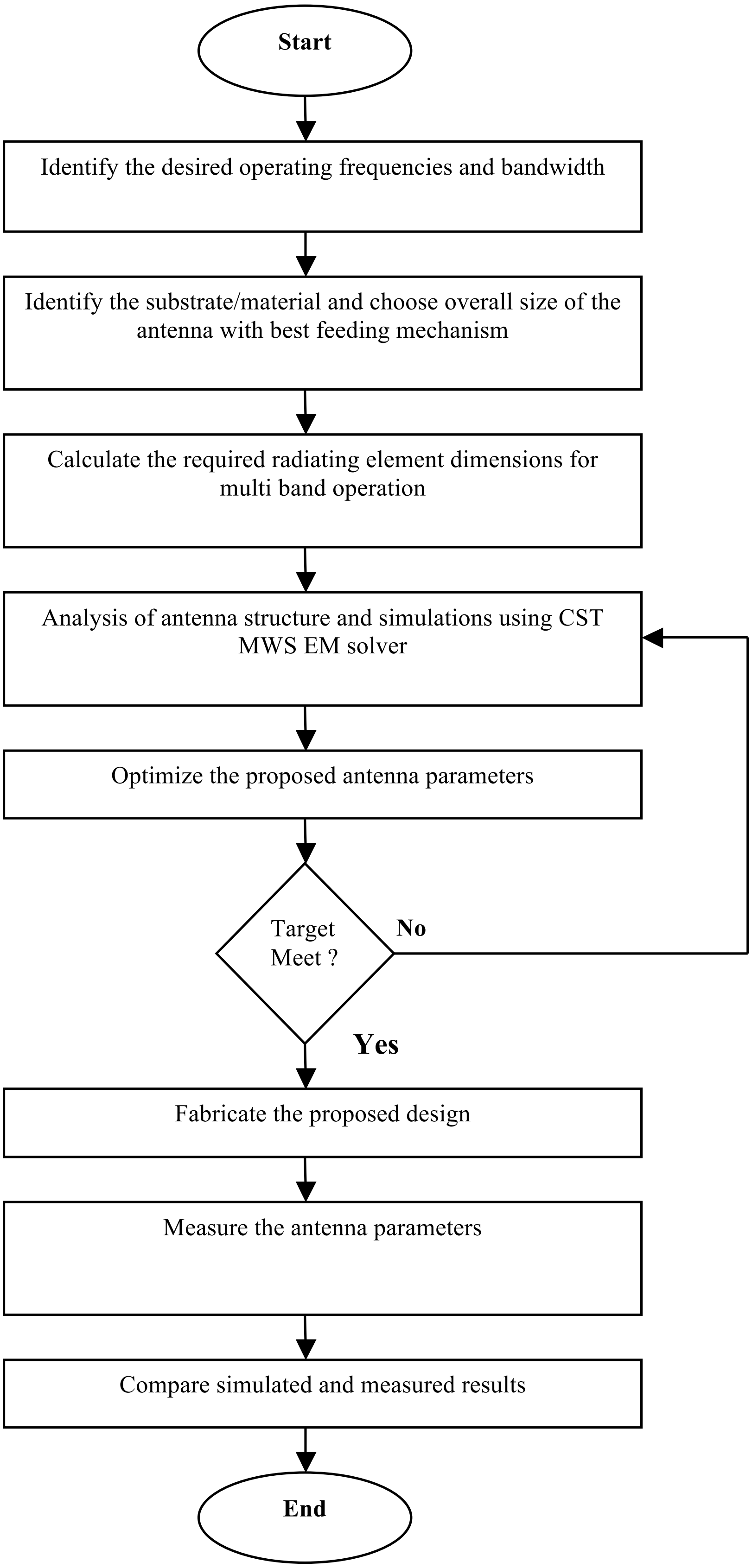
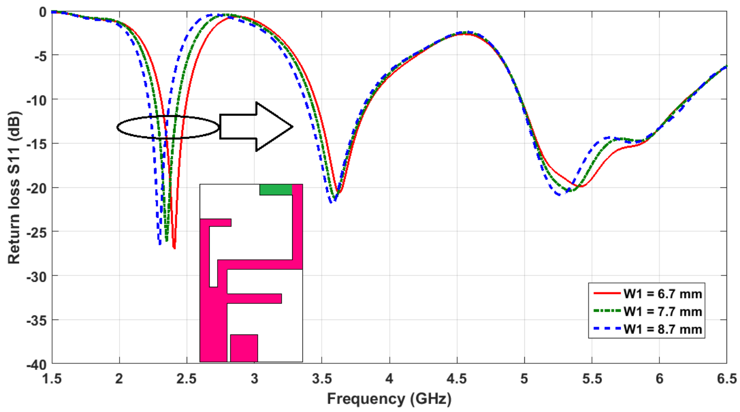
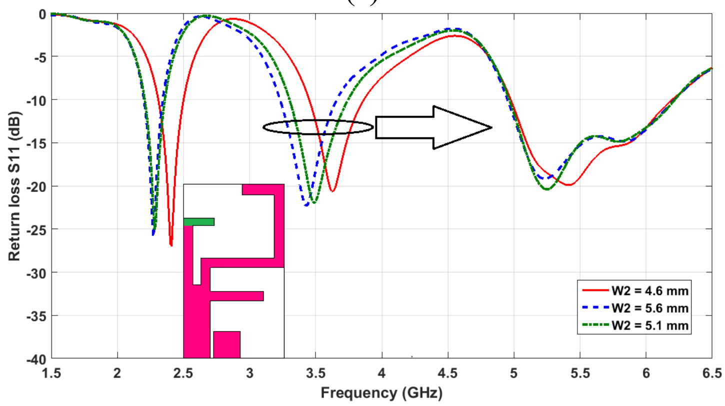


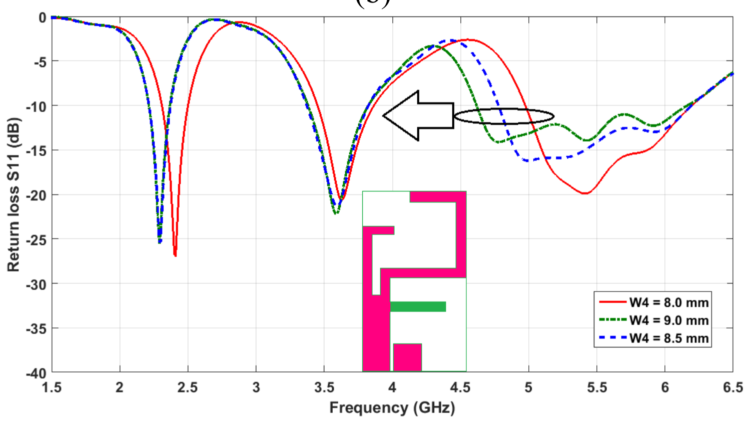
Figure 4: Design flow of meandered shaped ACS fed uniplanar wideband antenna.



(a)



(b)



(c)

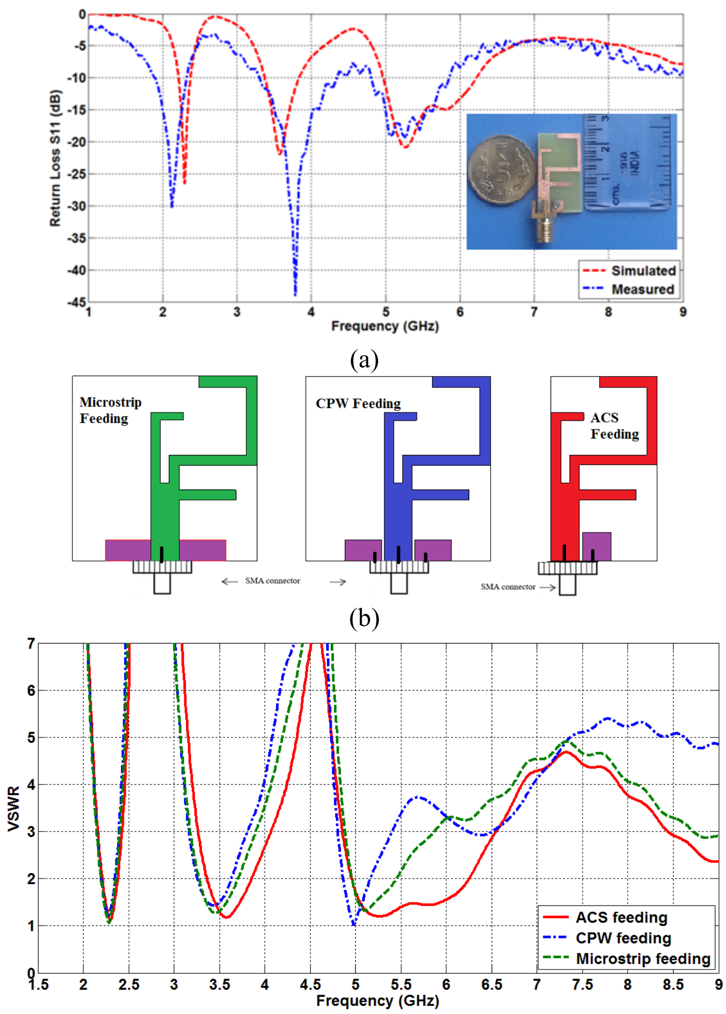
Figure 5: Effect of varying (a) W1 (b) W2 (c) W4

3. Results

To manifest the potentiality of proposed multiband antenna configuration, a fabricated component of designed structure is tested. Fig 6(a) shows the prototype of multiple branches loaded printed antenna which is developed under lithography procedure to validate the simulated results. A 50 Ω SMA connector is utilized in entire measurement to excite the novel design for perfect impedance matching. Meanwhile, the interpretation of measured and simulated reflection coefficient ($S_{11} \leq 10$) emerged from triple band uniplanar ACS fed monopole antenna is showed up in Fig.6(a). As an outcome, a similarity index was encountered from this comparative analysis with little deviation probably due to manufacturing tolerance, superiority of SMA connector and uncertainty of substrate material thickness. Also, to further validate the proposed compact design, two popular feeding are applied as shown in Fig 6(b) and from the analysis and experimental study (Fig 6(c)), it is concluded that the proposed structure works perfectly with microstrip as well as CPW feedings. Also for better understanding purpose, a summary table between microstrip, CPW and ACS feedings is given in Table 2. From the table it can be clearly observed that almost 42% size reduction has been achieved without compromising on the antenna characteristics (when it compared with microstrip and CPW feedings). The normalized radiation patterns (electric field in dB) of triple band monopole structure loaded with multiple radiating elements are measured and further investigated in dual plane (E (xz-plane) and H plane (yz-plane) as depicted in Fig. 7) with proper assistance of an in-house anechoic chamber. As an illustration, measured results evinced the closely dumbbell (figure of eight shape) and omnidirectional pattern in E-plane and H-plane. It has recognized that little deterioration appeared in power pattern due to asymmetry (compared to CPW) in presented design. The realized gain of proposed antenna is shown in Fig. 8.

Table 2: Result analysis

S.No	Feeding	Size (mm x mm)	Area (mm^2)	Bands	Applications	Size Reduction	Avg Peak Gain
1.	CPW	26 x 26	676	2.3/3.5/5 GHz	LTE/WLAN & WiMAX	------	~ 3.3
2.	Microstrip	26 x 26	676	2.3/3.5/5 GHz	LTE/WLAN & WiMAX	------	~3.2
3.	**ACS**	**26 x 15**	**390**	**2.3/3.5/5 GHz**	**LTE/WLAN & WiMAX**	**~ 42 %**	**~3.3**



(c)

Figure 6: (a) Experimental results with prototype (b) Feeding configurations (c) VSWR plots

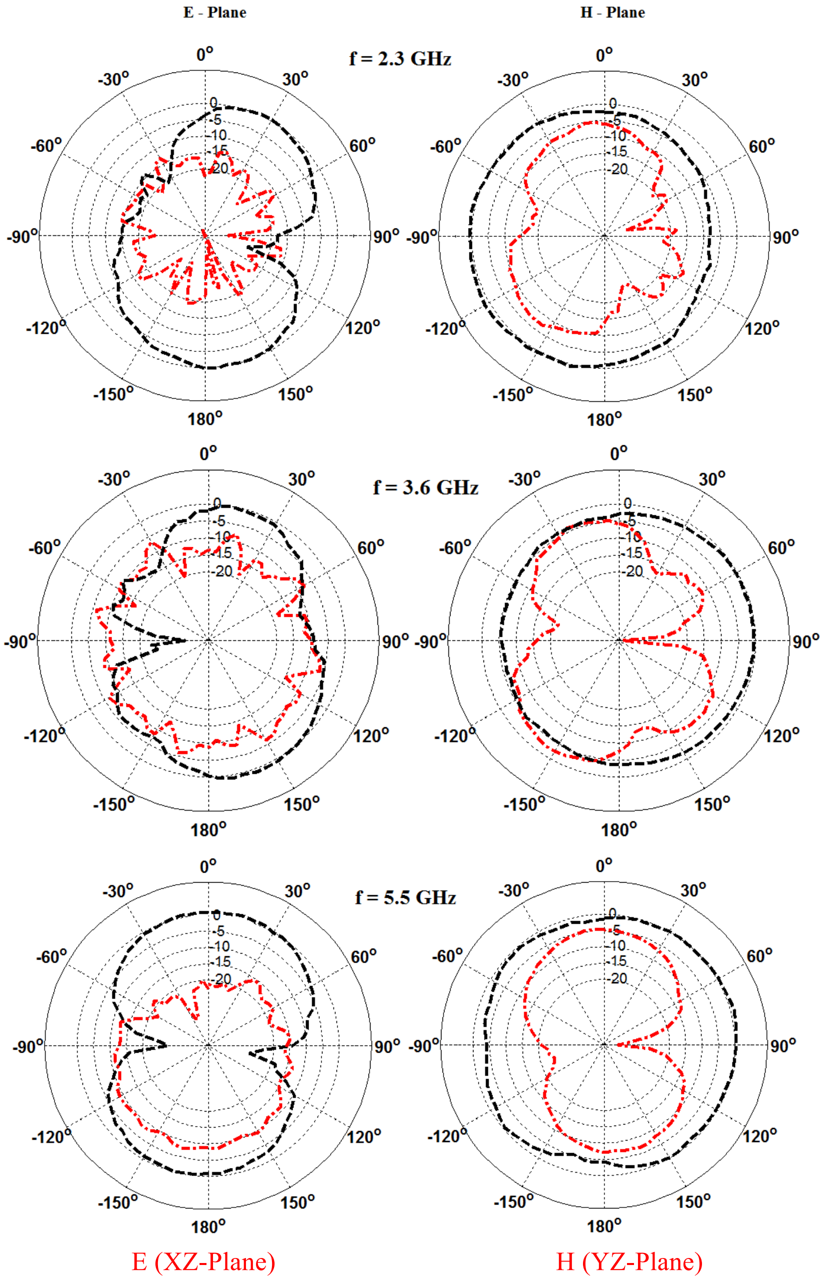


Figure 7: Uniplanar triple wideband band ACS fed antenna measured patterns. (red color indicates Croos- Pol and black color indicates Co-Pol)

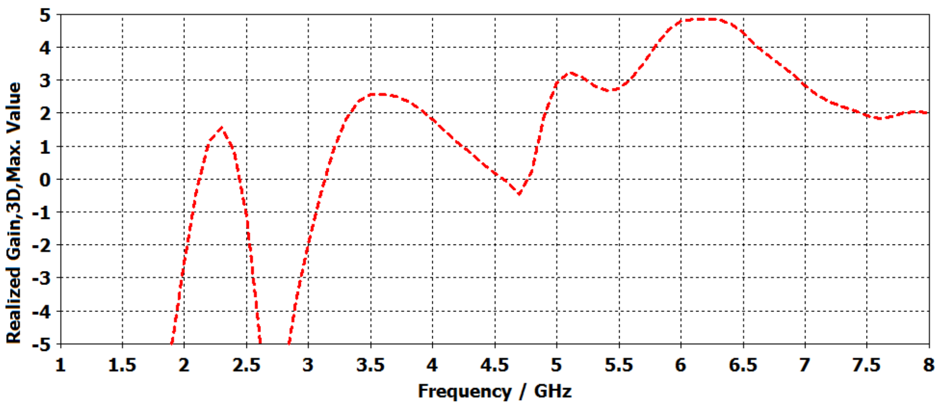


Figure 8: Uniplanar triple band ACS fed antenna peak gains.

4. Conclusion

A simple, very small ACS fed printed antenna loaded with multiple radiating branches is presented for portable wireless devices. The presented uniplanar antenna has a less complex structure and is simple to be imprinted on FR4 substrate with little area of around 26 × 15 mm^2. Moreover, depict the fact that the proposed antenna demonstrates a less complex structure and reduced size, it can produce triple wider impedance bandwidths centered at about 2.3 GHz, 3.5 GHz and 5.5 GH to cover 2.4/5.2/5.8 GHz WLAN and 3.5/5.5 WiMAX bands. The proposed antenna demonstrates omnidirectional radiation characteristics with moderate gain over each operating band, which are appealing for reasonable application in the WLAN/WiMAX specialized gadgets.

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