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Design & Development of Compact Uniplanar Semi-Hexagonal ACS Fed Multi-Band Antenna for Portable System Application

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Abstract—In the present work, a compact size, dual-band antenna is proposed for WLAN/WiMAX/LTE 2500/DMB applications. The designed antenna is fed by a 50 Ω coplanar line. The radiating component of the composed antenna consists of radiating strips with half hexagonal and vertical rectangular shapes and square-shaped ground plane which are printed on the same layer. The overall size of the antenna substrate is only $10 \times 24 \times 1.6\,\text{mm}^3$. The simulated and measured results of the proposed antenna show that it operates in the frequency range from 2.5 GHz to 2.75 GHz and 5.0 GHz to 6.7 GHz, respectively.

1. INTRODUCTION

Long-Term Evolution (LTE) 2500, Wireless Local Area Network (WLAN) IEEE 802.11 a/b/g and Worldwide Interoperability for Microwave Access (WiMAX) IEEE 802.16 are three popular advanced communication standards meant for point to point high-speed data communication applications. According to Federal Communications Commission (FCC) guidelines, each communication protocol is designated with a band of frequencies for different regions of the world, such as IEEE 802.11 a (5.150–5.350 GHz and 5.725–5.825 GHz) for WLAN, 5.5 GHz band (5470–5725 MHz) for Europe LAN/HIPERLAN2, 2.5 GHz band (2500–2690 MHz) for LTE 2500 and WiMAX, 2.6 GHz band (2600–2660 MHz) for digital multimedia broadcasting (DMB) system applications. In practice, if the deployed inbuilt antenna in a communication system is not capable of operating at these multiple frequencies, then the product developer/end user needs to modify or replace existing antenna element with advanced versions. Hence, to address these problems, researchers around the world focus on the design of electrically small multiband antennas with wide impedance bandwidth characteristics. Distinct shaped antennas with dual [1–6] and triple operating bands [7–12] with different substrates have been reported in the literature, which are fed by microstrip [4–6, 9, 10, 20] and coplanar waveguide (CPW) [1–3, 7, 8].

A smart feeding configuration, ACS, which adopts the principle of Coplanar Waveguide (CPW) feeding has been recently described in [11–19, 21–24]. These antennas are generally smaller than simple coplanar waveguide (CPW)-fed antenna. Fig. 1 shows a basic ACS-fed antenna which has one-half of the ground plane so that it has a smaller size than a simple coplanar waveguide CPW-fed antenna [11–19]. Most of the reported printed antennas (tri-band and dual-band) are larger in size and only operate at limited frequency in WLAN/WiMAX bands. For example, an antenna reported in [11] is a tri-band antenna with large size ($299\,\text{mm}^2$) and does not cover 2.5/5.5 GHz WiMAX and 5.8 GHz WLAN application bands, Similarly, the antenna in [24] is large in size ($318\,\text{mm}^2$) and does not support 5.2 GHz WLAN and 2.5 GHz LTE band. However, the printed antenna reported in [23] is relatively small, but it is not capable of covering 5.8 GHz WLAN and 5.5 GHz WiMAX bands. Hence, in this research, a dual wide band monopole antenna is presented. The designed antenna comprises two radiating arms, and it

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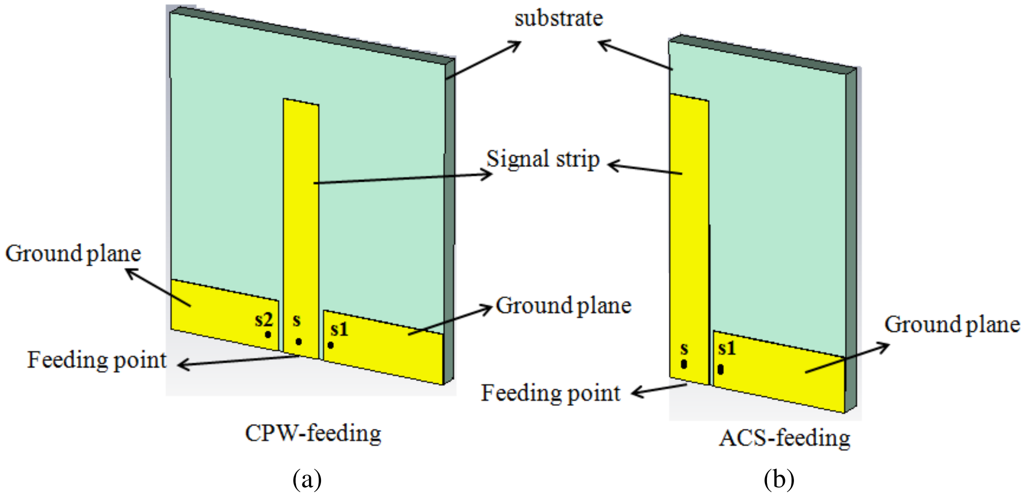


Figure 1. Overview of coplanar waveguide (CPW) and ACS (Asymmetric coplanar strip) methods (s, s_1 and s_2 are denoting to the coaxial feed location).

generates two operating bands from 2.5 GHz to 2.75 GHz and from 5.0 GHz to 6.7 GHz as the first and second bands, respectively. This developed antenna is suitable to operate in 2.5 GHz WLAN/DMB, 2.5/5 GHz WiMAX and LTE 2500 frequency bands.

2. ANTENNA DESIGN

The CST MWS 3D model, geometry and fabricated prototype photograph of the proposed half hexagonal ACS fed antenna are shown in Fig. 2. The corresponding Smith chart is given in Fig. 3(a). As highlighted in the literature, in order to show the advantages and benefits of the proposed ACS feeding concept over other feeding techniques (such as microstrip and CPW), the proposed half hexagonal geometry performance is validated with microstrip configuration without changing any parameter dimensions in the design. Fig. 2(a) and Figs. 3(b), (c) illustrate the configuration of the dual-band ACS and microstrip feed monopole antennas, which are printed on a 10 mm × 24 mm FR4 substrate of 1.6 mm thickness, with loss tangent $\tan\delta$ of 0.002 and permittivity 4.4. In both the feeding techniques, antenna radiating elements are the same with rectangular shape, open half hexagonal shape radiators with a square ground plane as depicted in Figs. 3(b), (c). Both the feeding techniques are excited by a 50 Ω feed line, and its simulated frequency versus VSWR plots is shown in Fig. 4. It can be clearly observed that wide impedance bandwidth (second operating band) is achieved with ACS technique compared with microstrip feeding. The parameter values used in the antenna geometry are shown in Table 1. In the design process, the length of the open half hexagon- and rectangle-shaped radiating strips is chosen approximately equal to half of the wavelength ($\lambda/2$) at the desired operating frequency. The resonance frequency (f_r) of the half wavelength resonator is given by Equation (1).

$$f_r \approx \frac{V_c}{2\ell\left(\sqrt{\frac{\varepsilon_r+1}{2}}\right)}, \tag{1}$$

$$z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}}\frac{\mathrm{K}(\kappa)}{\mathrm{K}(\kappa^1)} \tag{2}$$

where ℓ is the electrical length of the corresponding strip, V_c the speed of light, and ε_r the dielectric constant. Since the operating mechanism of ACS fed antenna is very similar to CPW-fed antenna, Equations (2) and (3) of a simple ACS-fed antenna [11, 12, 15–18] are considered for 50 ohm impedance matching of our proposed compact antenna as given below.

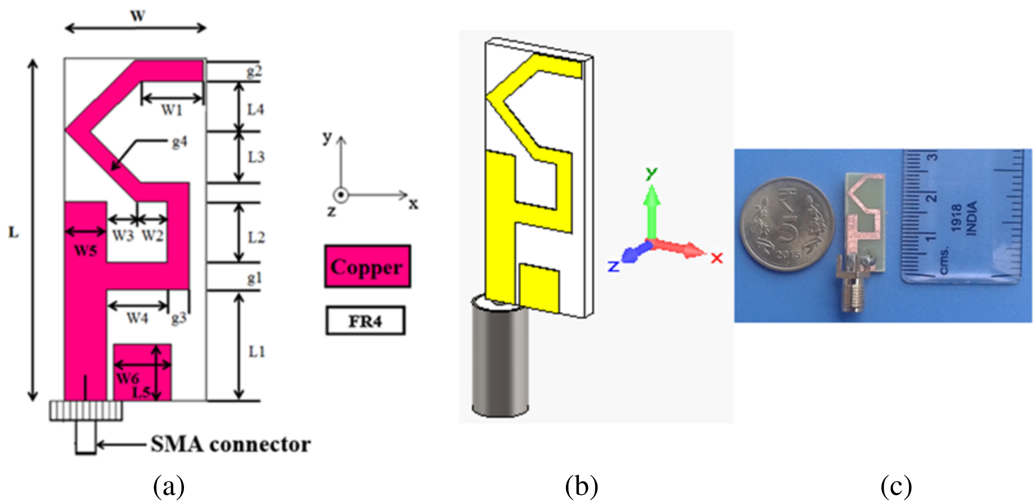


Figure 2. (a) Geometry of the compact tunable meandered ACS fed antenna. (b) Proposed antenna 3D model. (c) Fabricated prototype antenna photograph.

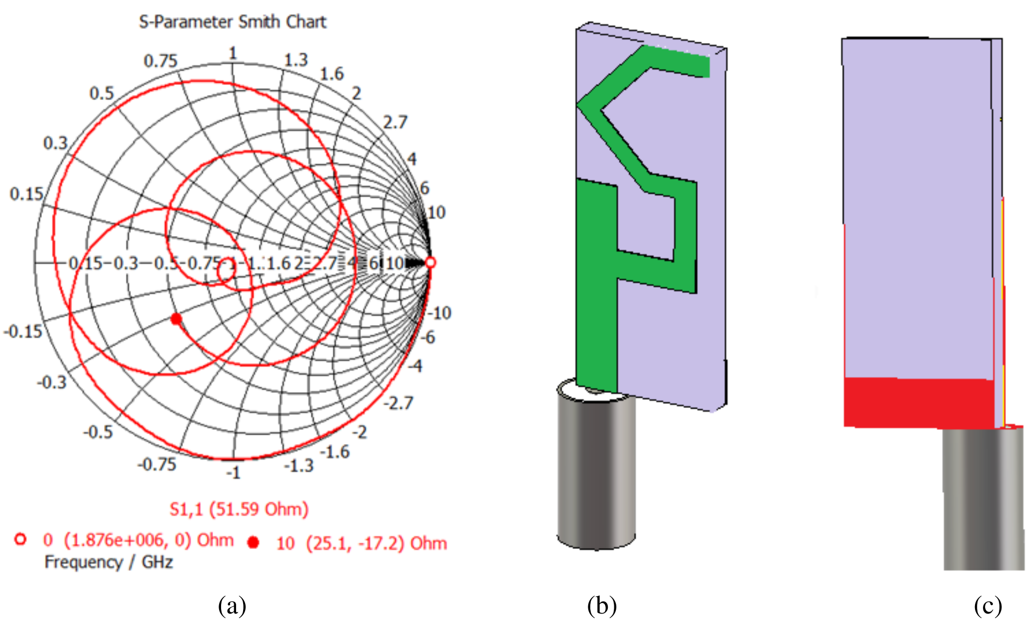


Figure 3. (a) Impedance smith chart of the presented compact tunable half hexagonal ACS fed dual band antenna. (b) Microstrip fed antenna 3D model with SMA connector (Top view). (c) Microstrip fed antenna 3D model (Bottom view).

$\frac{\mathrm{K}(\kappa)}{\mathrm{K}(\kappa^1)}$ (the elliptical integral of first kind) is represented mathematically as:

$$\frac{\mathrm{K}(\kappa)}{\mathrm{K}(\kappa^1)} = \begin{cases} \dfrac{\pi}{\ln \frac{2\left(1+\sqrt{\kappa^1}\right)}{\left(1-\sqrt{\kappa^1}\right)}} & 0 \leq \kappa \leq \dfrac{1}{\sqrt{2}} \\ \dfrac{1}{\pi \ln \frac{2\left(1+\sqrt{\kappa}\right)}{\left(1-\sqrt{\kappa}\right)}} & \dfrac{1}{\sqrt{2}} \leq \kappa \leq 1 \end{cases} \tag{3}$$

The proposed antenna evolves from the two stages namely basic monopole (Antenna #1) and proposed antenna as shown in Fig. 5(a) and (c). As illustrated in Fig. 5(b) and Fig. 6, a resonant mode

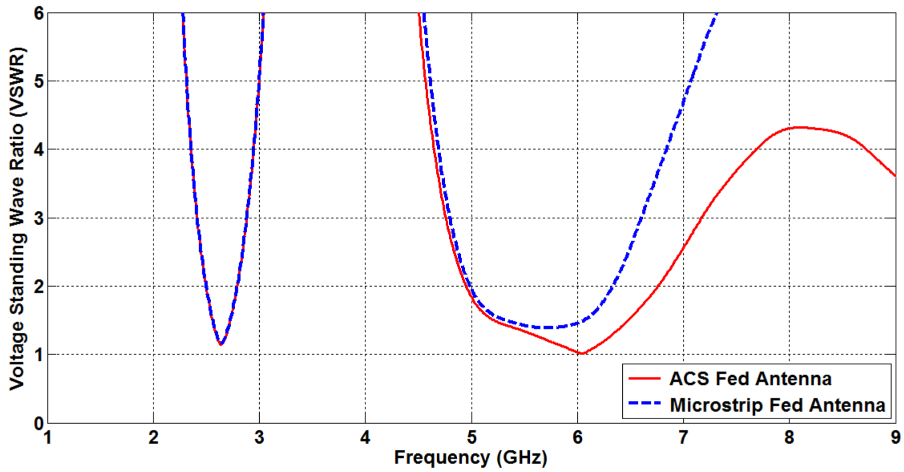


Figure 4. VSWR corresponding to ACS fed antenna and Microstrip fed antenna.

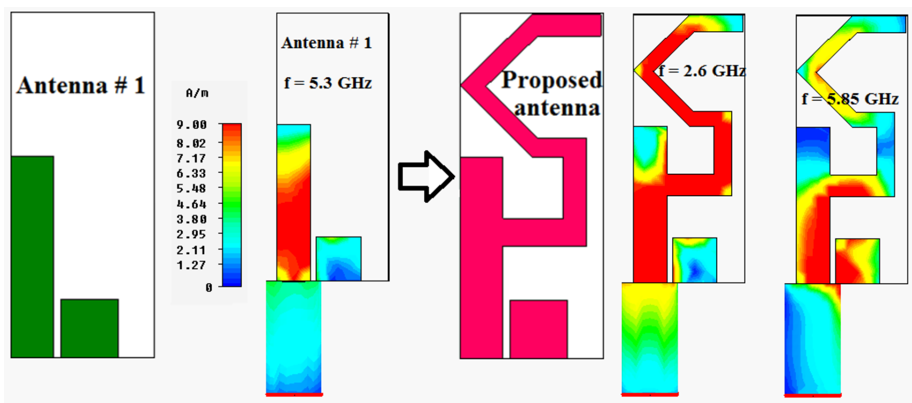


Figure 5. Surface current distribution characteristics of the presented compact tunable ACS fed semi hexagonal multiband antenna antenna at 2.6 GHz, 5.3 GHz and 5.85 GHz.

between 5 to 6 GHz is achieved with a simple rectangular strip attached to the ACS feedline (Antenna 1). To generate one more operating band at lower frequency, a half wavelength open half hexagonal radiating strip is added to Antenna 1 (Figs. 5(c) and (d) and Fig. 6). The design and optimization procedure of compact meandered shape ACS-fed antenna is carried out by CST MWS software. For better understanding about the independent tuning property of the proposed semi-hexagonal patch antenna, a detailed parametric study is carried out by using CST MWS toolbox, and its frequency versus return loss plots are given in Figs. 7(a) and (b).

Table 1. Half hexagonal shape ACS fed antenna geometry values.

Parameters	L	$W6$	W	$L2$	$W3$	$g1$	$L5$	$g4$	$W2$
Value (mm)	24	4	10	4.3	2	1.9	4	1.3	2.2
Parameters	$g2$	$W1$	$g3$	$L3$	$W5$	$L4$	$W4$	$L1$	G
Value (mm)	1.6	4.4	1.6	3.7	3	3.4	4.2	7.8	0.5

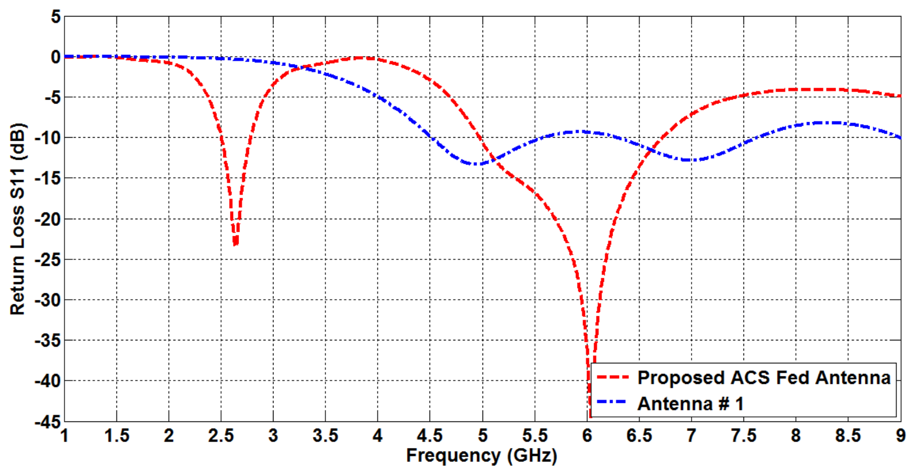
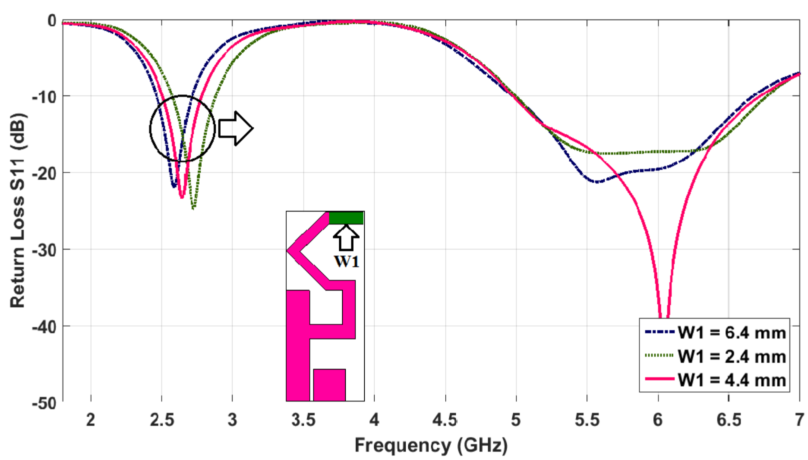
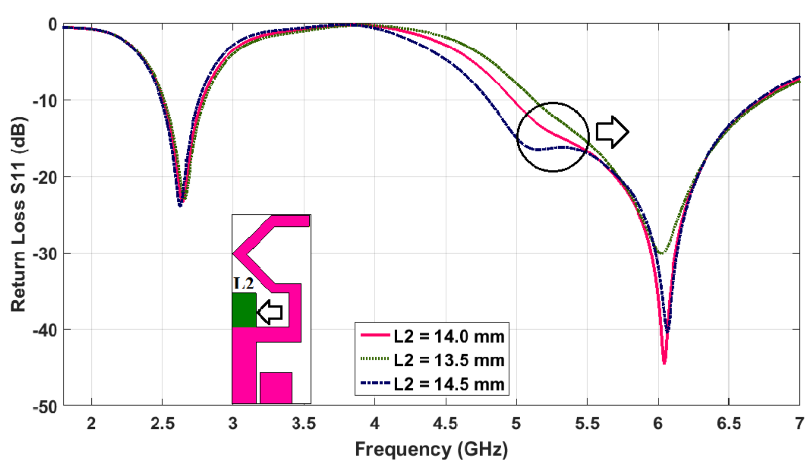


Figure 6. S_{11} corresponding to the evolutionary stages of compact tunable meandered ACS fed dual band antenna.



(a)



(b)

Figure 7. Return loss verses frequency plot (effect of varying $W1$). Return loss verses frequency plot (effect of varying $L2$).

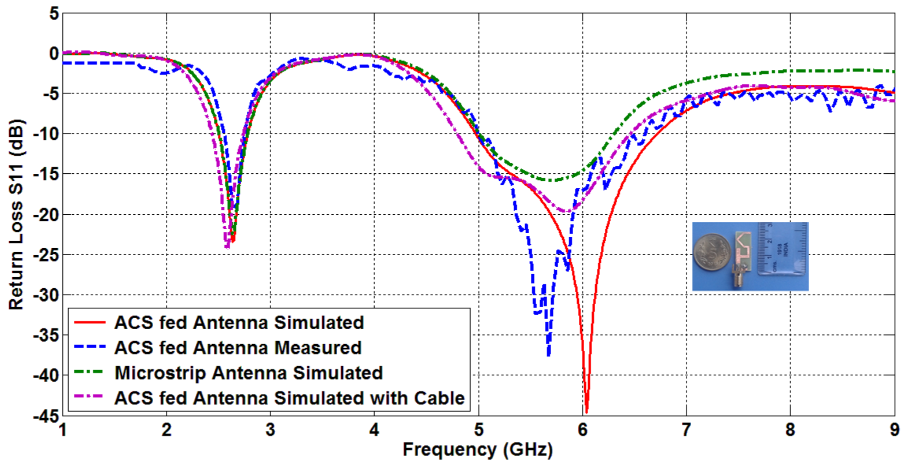


Figure 8. Semi hexagonal ACS fed antenna measured and simulated return loss results with fabricated prototype phograph.

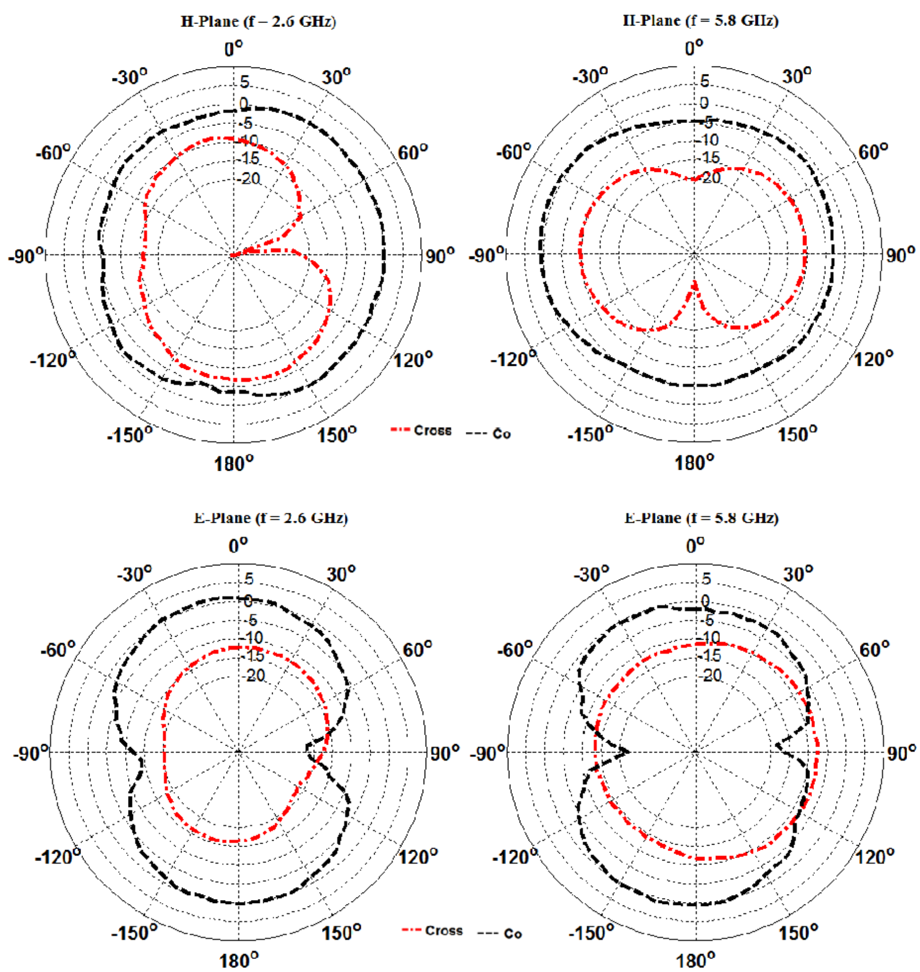


Figure 9. Measured far field radiation patterns of the presented semi hexagonal dual band ACS-fed at 2.6 GHz and 5.8 GHz. (black color denotes co-polarization and red color denotes cross-polarization).

3. SIMULATED AND MEASURED RESULTS

A static picture of the fabricated antenna is displayed in Fig. 8. The Return Loss (S_{11}) characteristics of a very small half hexagonal shape antenna printed on an FR4 epoxy substrate are measured by using PNA network analyzer N5222A. To quantify advanced wireless communication application, the mature design of compact tunable meandered ACS-fed antenna contributes to a wide range of bandwidth in the dual operating bands as shown in Fig. 8. Moreover, the reported structure is contrived to dual-feeding technique, accordance with the cogent evidence of broader impedance bandwidth rendered by ACS feed as well as microstrip feed technology. From Fig. 8, it can be seen that simulated results obtained by microstrip-fed and ACS-fed antennas demonstrate a good agreement with the measured results in dual-resonance mode at 2.4 GHz and 5.5 GHz centric frequencies. Finally, the measured −10 dB impedance bandwidths are recorded about 250 MHz from 2.5 GHz–2.75 GHz and 2700 MHz from 5.0 GHz to 6.7 GHz. In the case of compact printed antennas, the currents may flow in external coaxial ground of connector and cable, which may disturb the return loss. So the proposed antenna is also simulated by considering the effect of coaxial cable with SMA connector having dimensions corresponding to the actual connector and cable used for measurements. From Fig. 8, it can be observed that a similar return loss result can be observed with and without considering cable connected to SMA connector in the simulation.

In the result, a little discrepancy is found between measured and simulated results due to the soldering, fabrication tolerance, calibration cable effects, etc. Measurement of far-field radiation pattern is executed in an anechoic chamber where a standard double-ridged horn antenna is utilized as a reference antenna. In Fig. 9, it is figured out that dumb-bell shape (bidirectional) and nearly omnidirectional patterns are achieved in E-plane and H-plane. From this figure, it is manifested that measured radiation pattern is leaned because of the asymmetrical ground plane and alignment errors. The co-polarization level positions are maximum compared to cross polarization in each stage of E-plane and H-plane.

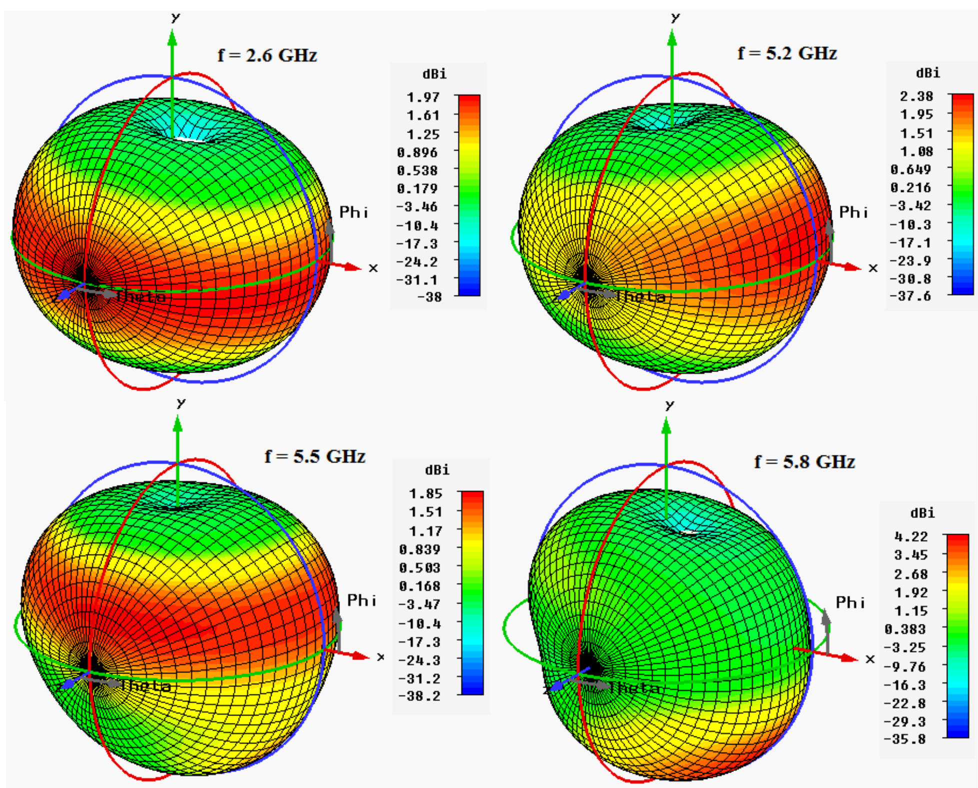


Figure 10. (b) Simulated 3-dimensional radiation characteristics of compact half hexagonal shape ACS fed antenna at four operating frequencies.

Figs. 10, 11 depict the 3D radiation pattern and simulated peak gain of the proposed meandered shape antennas as a function of frequency for dual operating bands. From simulated results of VSWR < 2 in Fig. 4, it is speculated in view of ACS feed that performance of the designed compact tunable antenna can be proclaimed better by the comparative analysis with microstrip and other feeding techniques (Table 2). This compact structure is finally perceived as a suitable candidature of portable systems as well as to cover the LTE/WLAN/WiMAX applications. The CST MWS simulated radiation efficiency characteristic of the proposed antenna is calculated, and in the first operating band, efficiency is about 82% while in the second operating band, it is about 88%.

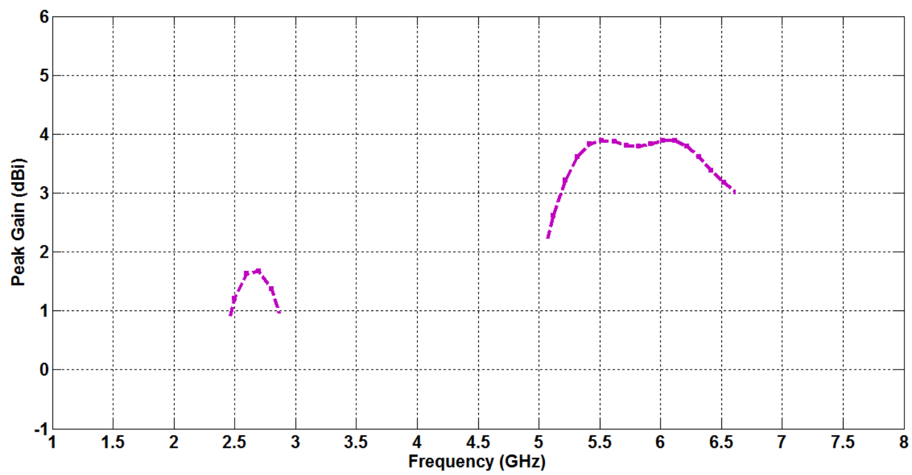


Figure 11. Dual operating peak gains of the presented compact tunable half hexagonal ACS fed antenna.

Table 2. Proposed compact ACS fed antenna performance comparison with literature.

Ref	**Size**	**Area (mm^2)**	**Application**	**Avg. Peak Gain (dBi)**	**Efficiency**	**Operating Band (for $S_{11} \leq -10$ dB)**
[1]	33×20	660	WLAN/WiMAX	NA	NA	2.2–3.5 GHz and 4.5–5.2 GHz
[3]	30×35	1050	WLAN/WiMAX	NA	NA	2.28–2.77 and 5–6.3 GHz
[4]	40×30	1200	WLAN/WiMAX	~ 2	75%	2.39–2.5 and 5–6.1 GHz
[5]	40×40	1600	WLAN/WiMAX	~ 3.6	NA	3.15–3.7 and 5.05–5.97 GHz
[6]	37×40	1480	WLAN/WiMAX	~ 2.1	NA	2.28–4.16 and 4.97–7.19 GHz
[7]	27×30	810	WLAN/WiMAX	~ 1.9	NA	2.39–2.54, 3.37–3.73 and 5.02–6.19 GHz
[8]	25×14.5	362.5	WLAN/WiMAX	~ 2.4	NA	2.35–2.61, 3.38–4.01 and 4.25–6.65 GHz

[9]	12 × 32	384	WLAN/WiMAX	∼ 2.9	NA	2.4–2.5, 3.4–3.6 and 5.6–6.0 GHz
[10]	35 × 25	875	WLAN/WiMAX	∼ 2.6	NA	2.36–2.54, 3.27–3.69 and 5.16–5.48 GHz
[11]	11.5 × 26	299	WLAN/WiMAX	∼ 1.9	NA	2.28–2.46 GHz, 3.33–3.63 GHz and 5.05–5.4 GHz
[14]	35 × 19	665	WLAN/WiMAX	∼ 2.2	NA	2.38–2.5 GHz, 3.35–3.67 GHz and 4.76–6.55 GHz
[15]	13.75 × 26	357.5	WLAN/WiMAX	∼ 3.2	76%	2.40–2.60 GHz and 3.2–6.0 GHz
[16]	13.4 × 22.7	304.2	WLAN/WiMAX	∼ 2.9	NA	2.45–2.7 GHz and 3.9–6.0 GHz
[17]	20 × 22	440	WLAN/WiMAX	∼ 2.1	NA	2.3–2.5 GHz, 3.4–5.85 GHz and 7.7–8.4 GHz
[18]	18 × 22	396	WLAN/WiMAX	∼ 2.8	87%	1.8–2.2 GHz and 3.0–7.6 GHz
[19]	22.1 × 12	265.2	WLAN/WiMAX	∼ 2.2	NA	2.37–2.53 GHz, 3.37–3.71 GHz and 4.93–6.35 GHz
[20]	34 × 28	952	WLAN/WiMAX	∼ 3.1	90%	2.37–3.98 GHz and 4.95–5.94 GHz
[21]	26.5 × 12	318	WLAN/WiMAX	∼ 1.95	NA	2.32–2.53 GHz, 3.22–3.64 GHz and 5.53–5.98 GHz
[22]	32 × 12	384	WLAN/WiMAX	∼ 1.85	NA	2.36–2.70 GHz, 3.35–2.74 GHz and 5.01–6.12 GHz
Propo sed	**24 × 10**	**240**	**LTE/WLAN/ WiMAX/DMB**	**∼ 2.95**	**85%**	**2.5–2.75 GHz and 5.0–6.7 GHz**

4. CONCLUSION

A compact monopole half hexagon-shaped antenna has been proposed for dual-band operation. The antenna is printed on a 10 × 24 mm2 size FR4 substrate. Dual resonances are accomplished by inserting a meander shape (half hexagon) radiating arm with the cooperation of vertically positioned rectangular shape strip along with coaxial feed points. The CST simulated and tested results of the proposed tunable dual-band antenna indicate that the impedance bandwidths are from 2.5 GHz to 2.75 GHz and from 5.0 GHz to 6.7 GHz, respectively, which is desirable for covering the LTE 2500, 5.2/5.8 GHz WLAN bands and 2.5/5.5 GHz WiMAX bands. Due to wide-band functioning, the proposed antenna can support broad range of applications in recently available wireless communication standards.

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