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RESEARCH PAPER

Compact asymmetric coplanar strip fed Sinc shaped monopole antenna for multiband applications

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A compact asymmetric coplanar strip fed Sinc shaped monopole antenna suitable for multifrequency operations is proposed for portable wireless devices. The proposed Sinc shaped monopole antenna with truncated half ground plane operates at three frequency bands, 2110–2380, 4180–4600, and 5200–5678 MHz, showing fractional impedance bandwidths of 12, 9, and 8.8%, respectively, suitable for Universal Mobile Telecommunications System, Long Term Evolution handheld devices, Worldwide Interoperability for Microwave Access, Wireless Local Area Network, Hyperlan-2, and aeronautical navigation applications. Proposed antenna shows a dual mode of polarization. Finally a prototype model is developed for a typical configuration and the simulated results are validated experimentally.

Keywords: Asymmetric coplanar strip (ACS), Circularly polarized antenna, Monopole antenna, Multifrequency antenna, Multiband antenna, Printed antenna, Sinc antenna

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I. INTRODUCTION

Printed monopole antennas are suitable for many practical portable wireless devices because of properties such as light weight, planar conformal construction, low cost, easy to fabricate, and integrate with radio frequency (RF) devices, etc. Unlike the classical microstrip antennas, it shows broadband characteristics at operating frequencies. The co-planar waveguide (CPW) fed monopole antennas fabricated on a single metallic layer are best suited for wireless devices due to ease in integration with active devices and broadband characteristics. Several techniques have been reported in the literature to realize multifrequency printed monopole antennas using CPW feed. Some of the notable structures are loading the slot antennas with slits [1], broadband dual-frequency cross-shaped slot CPW fed monopole antenna for Wireless Local Area Network (WLAN) operation [2], tapered bent folded monopole for dual-band WLAN [3], wideband CPW fed monopole antenna with parasitic elements and slots [4], dual-frequency meandered CPW-fed monopole antenna [5], square slot antennas with a widened tuning stub [6], and a dual-Band CPW-fed inductive slot-monopole hybrid antenna [7]. Asymmetric coplanar strip (ACS) fed monopole antennas [8–10], possessing only half of the truncated ground plane provides high level of compactness without compromising on the antenna characteristics in terms of impedance matching, bandwidth (BW), gain, efficiency, radiation pattern, etc. Circular polarization (CP) is another requirement for the antennas mounted on the portable devices. Microstrip fed broadband circularly polarized antenna [11], circularly polarized Y-shaped monopole antenna [12], circularly polarized regular-hexagonal slot antenna [13] etc. have been designed in the past.

In the present work, a novel monopole antenna is proposed where the shape of the monopole resembling a truncated Sinc strip is derived from Sinc function. By changing the Sinc geometrical parameters, the antenna can be made to operate at the desired band of frequencies. The Sinc shaped microstrip configuration was first proposed by Yang et al. [14] and then Gupta et al. [15] also used similar configuration to realize multifrequency antenna. However, in both these configurations the shape of the antenna was only Sinc alike and not exactly derived from the Sinc function. In the proposed work, a truncated Sinc shaped printed monopole antenna geometry is obtained directly from the Sinc function giving rise to one of the compact monopole configurations. In order to further minimize the overall size of the multiband monopole antenna the ACS fed Sinc shaped configuration is introduced. The overall size of the proposed ACS fed Sinc shaped monopole antenna can be reduced to about one-half of the CPW fed Sinc shaped monopole antenna. The simulation is performed for several truncated Sinc shaped monopole geometries printed on a low cost glass epoxy substrate. Finally a prototype is developed and the results are validated with the simulation and experimental results.

The proposed antennas are useful for several wireless applications such as, Universal Mobile Telecommunications System (UMTS, 2110–2170 MHz), Long Term Evolution (LTE-TDD,

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2300–2400 MHz), Worldwide Interoperability for Microwave Access (WiMAX, 2305–2320 and 2345–2360 MHz), aeronautical navigation (4200–4400 MHz), Fixed mobile (4000–4500 MHz), WLAN (5250–5350 MHz), Hyperlan-2 (5470–5725 MHz).

II. ANTENNA DESIGN

There is always a need of an antenna which is compact, simple to design, has good impedance matching and BW characteristics, suitable for multiband operation and preferably possessing multi-polarization characteristics. One such antenna is Sinc shaped monopole antenna printed on a truncated half ground plane. The Sinc shaped strip can provide many advantages such as, larger length can be accommodated in smaller area thus realizing a compact structure. Secondly the shape can be generated by a simple mathematical Sinc function. Thirdly, single, dual or multi band operation can be realized, simply by selecting a specific length of the Sinc strip or ground plane parameters [16]. The impedance matching is not a problem at all as the monopole strip width is maintained same as the width of coplanar strip. Unlike the meander line strip where there is more opposition of current vectors in parallel section of strips leading to diminishing self-inductance, in the proposed Sinc strip configuration, the current vectors reinforce along the total strip length thus adding to more self-inductance. Therefore for the given length of the strip these antennas will exhibit a lower resonant frequency than the meander strip monopole. This in turn is helpful in realizing a compact antenna. The monopole configurations show wide BW due to the absence of the ground plane below the radiating structure. Finally, the truncated half ground plane helps in transition of mode from linearly polarized configuration to circularly polarized mode apart from providing compactness. The geometry of the proposed ACS fed Sinc shaped antenna is generated from $Sinc(2x)$ function and truncated to desired length and printed in the form of a strip on a substrate. The proposed ACS fed antenna with $Sinc(2x)$ strip configuration along with prototype model is shown in the Fig. 1.

The geometry of the Sinc is obtained from the mathematical expression of the Sinc function using MATLAB and then imported to the IE3D, a full-wave method of moments based simulation software package from Zeland. The desired strip thickness is then set by setting the thickness of the line equal to the 50 Ω strip line width. The vertex of Sinc function imported from MATLAB is then multiplied with the desired factor in order to operate the antenna at specific band. In the proposed antenna the imported geometry is multiplied with a factor of 10. Then the width and the length of Sinc strip is considered equal to Wp and Lp, respectively. The 50 Ω strip line with the length of $Lg + g$ (where Lg is ground length and g is feed gap) and width of Ws is considered for feeding to Sinc strip. Then the truncated asymmetric ground plane with dimension of $Wg \times Lg$ is designed at the gap of S from the feeding strip as shown in Fig. 1. The radiation characteristic of the Sinc shaped antenna is examined with respect to several design parameters. The various parameters are selected as : dielectric constant $(\varepsilon_r) = 4.4$, loss tangent $(\tan\delta) = 0.018$, dielectric thickness $(h) = 1.57$ mm, width of the 50 Ω strip line $(Ws) = 3.0$ mm, feed gap $(g) = 1$ mm, gap between 50 Ω microstrip line and ground plane $(S) = 0.5$ mm, the ground plane size $Wg = 11$ mm $(0.14\ \lambda_{g1})$, $Lg = 28$ mm $(0.35\ \lambda_{g1})$. The proposed geometry of the monopole strip is derived from $Sinc(2x)$ function and other Sinc parameters are assumed as: $Lp = 20$ mm $(0.25\ \lambda_{g1})$, $W = 22$ mm $(0.28\ \lambda_{g1})$ and $L = 54$ mm $(0.68\ \lambda_{g1})$ for ACS fed Sinc shaped monopole antenna, where λ_{g1} is guided wavelength of first resonating mode which is given by equation (1). A comparison of the resonance characteristics of the proposed antenna with full and truncated half ground plane is shown in Fig. 2. It is shown that the first resonance frequency which is mainly due to the length of the strip remains unaffected while a small shift in the resonant frequencies for the next two higher order modes are evident.

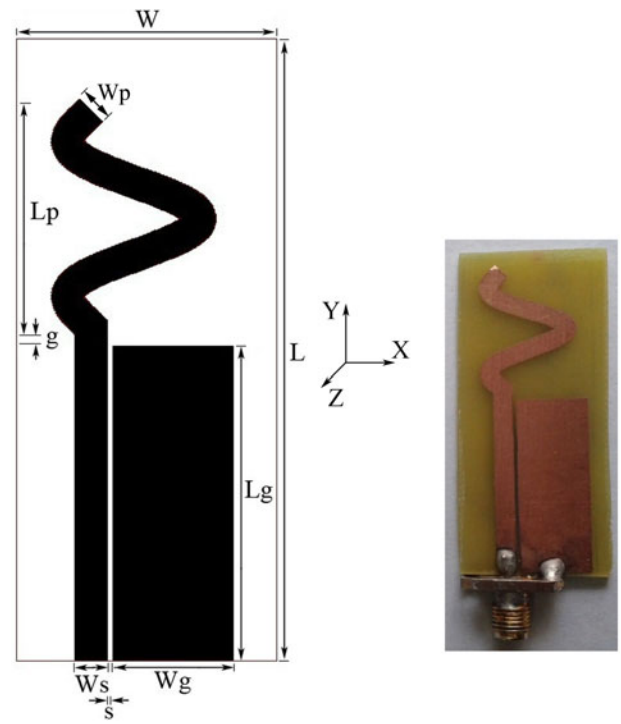

Fig. 1. Proposed ACS fed Sinc shaped monopole antenna.

$$\lambda_{g1} = \frac{\lambda_{01}}{\sqrt{\varepsilon_{eff}}}, \quad (1)$$

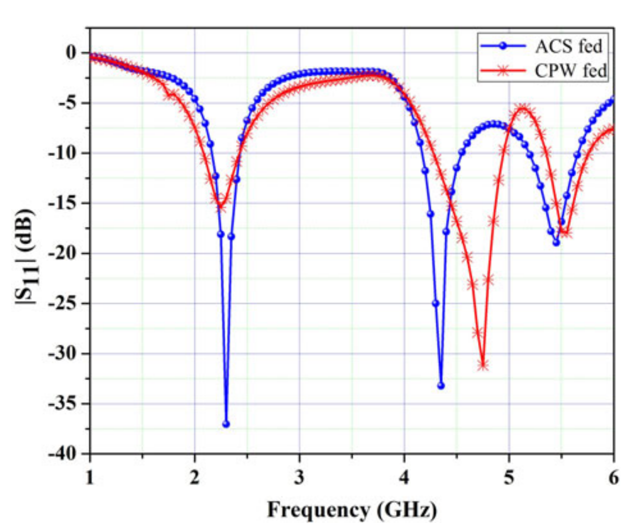

Fig. 2. Reflection coefficient ($|S_{11}|$) comparison of ACS and CPW fed Sinc shaped monopole antenna.

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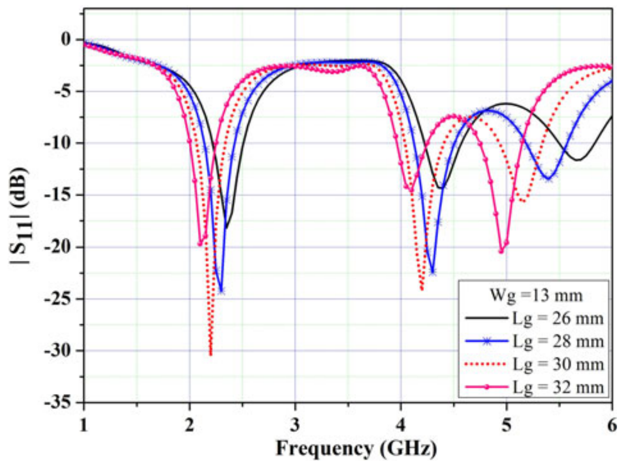

Fig. 3. Effect of ground plane length (Lg) variations on$|S_{11}|$.

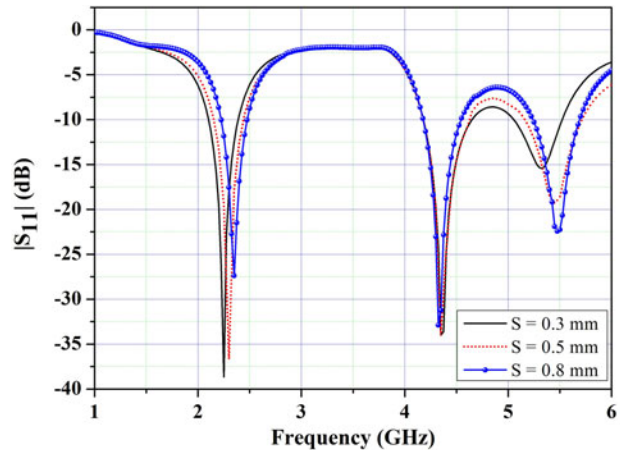

Fig. 5. Effect of gap (S) variations on$|S_{11}|$.

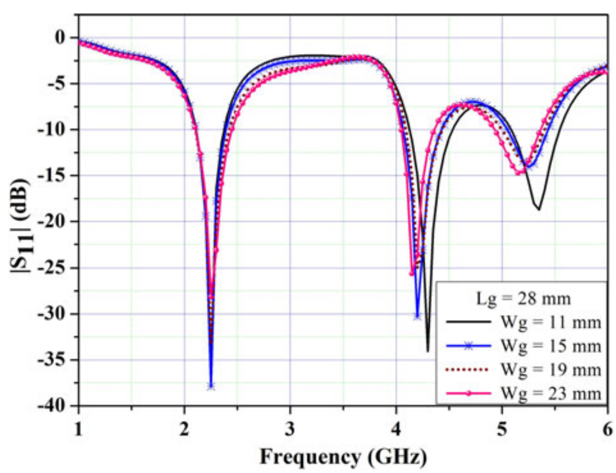

Fig. 4. Effect of ground plane width (Wg) variations on$|S_{11}|$.

where λ_{o1} is free space wavelength of first resonating mode and ε_{eff} is effective dielectric constant of dielectric material.

III. PARAMETRIC STUDY

A) Effect of the ground plane

The ground plane dimensions (Lg, Wg) are very important parameters in the design of monopole antenna because of the strong dependence of gain, BW, and antenna efficiency on ground plane size. The dimensions of the ground plane have significant effects on the antenna performance. As the size of the ground plane is reduced, there is an increase in the back lobe radiation due to the diffraction. Secondly, it also changes the impedance of the antenna which deteriorates the impedance matching. Simulations are performed with various ground plane parameters and the effects of ground plane size on resonant frequencies are studied.

1) effect of ground plane length (Lg) variations on $|S_{11}|$

As shown in Fig. 3, the ground plane length (Lg) affects all the resonant frequencies of ACS Sinc shaped monopole configuration. By increasing length (Lg), a decrease in all three resonance frequencies is evident. The BW of first and second resonance frequencies first increases and then decreases with increasing Lg, while for the third resonance frequency it increases with increasing Lg.

2) effect of ground plane width (Wg) variations on $|S_{11}|$

The effect of ground plane width on antenna characteristics is shown in Fig. 4. As evident from the figure, the ground plane width (Wg) does not affect the first resonant frequency; however it has some impact on the BW. Moreover, the second and third resonant frequencies get influenced as it decreases by increasing Wg due to the coupling between the proximate horizontal Sinc strip and the ground plane width.

B) Effect of feed gap (g) variations on $|S_{11}|$

Next the effect of the feed gap on the characteristics of the antenna is examined. The effect of the feed gap on resonant

Table 1. Effect of feedgap on ACS fed Sinc shaped monopole antenna parameters.

Feed gap (mm)	f_1 (GHz)	$\|S_{11}\|$ (dB)	BW (MHz)	f_2 (GHz)	$\|S_{11}\|$ (dB)	BW (MHz)	f_3 (GHz)	$\|S_{11}\|$ (dB)	BW (MHz)
0	2.35	−23.21	260	4.35	−25.50	283	5.43	−20.74	466
1	2.30	−36.65	287	4.35	−34.04	470	5.40	−19.12	478
2	2.25	−31.62	267	4.30	−28.68	422	5.26	−16.89	449
3	2.19	−22.95	262	4.29	−22.18	426	5.20	−15.58	429
4	2.14	−20.21	259	4.25	−19.19	420	5.15	−14.31	398
5	2.10	−19.18	256	4.25	−16.58	403	5.10	−13.14	358

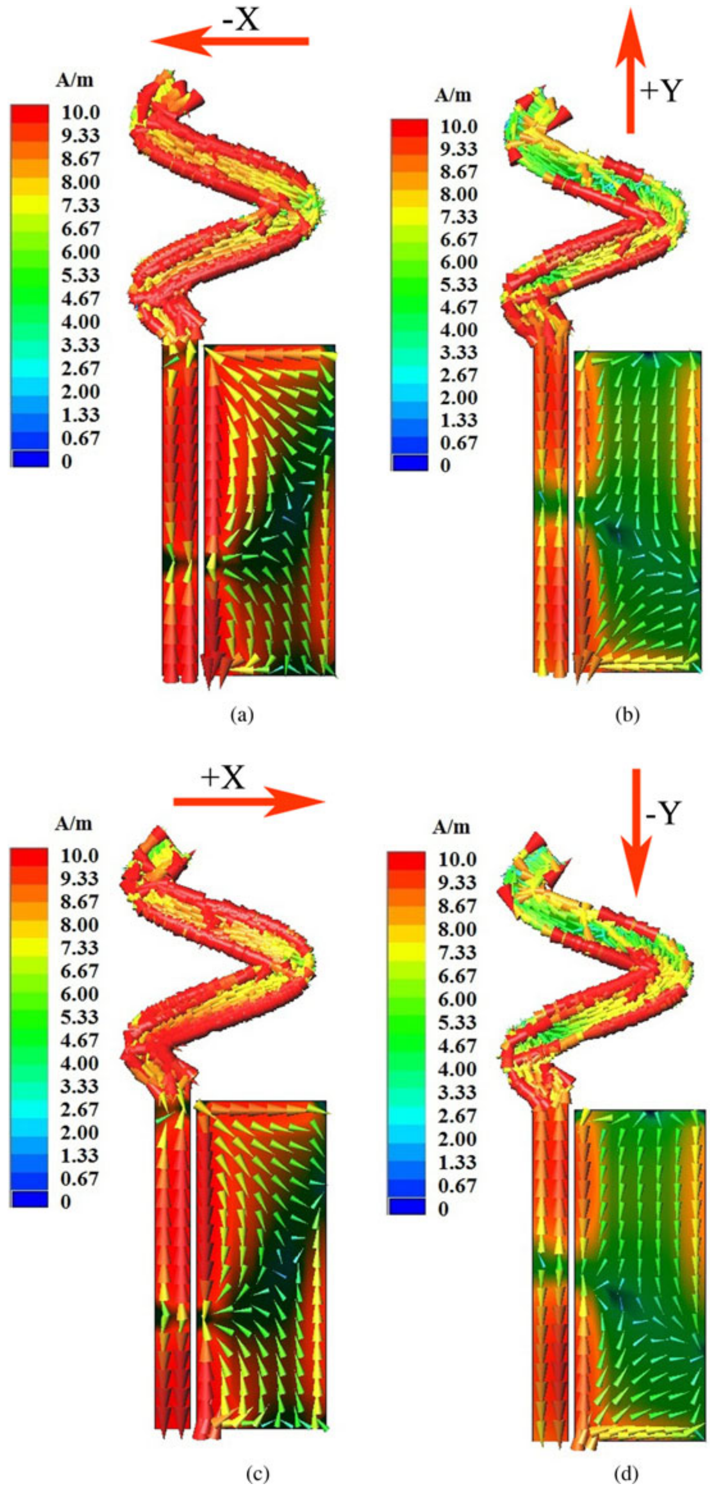

Fig. 6. Surface current distribution of ACS fed Sinc shaped monopole antenna at 5.40 GHz for various phases (a) 0°, (b) 90°, (c) 180°, and (d) 270°.

frequency and reflection coefficient is shown in Table 1. For the different feed gaps (*g*) between the Sinc strip and ground plane, it is shown that the first and third resonance frequencies reduce with increasing feed gap (*g*), while change in feed gap has little impact on second resonance frequency. However, the BW of all three resonance modes first increases and then decreases with increasing feed gap (*g*). This is due to the fact that larger feed gap offers an extra inductance to the Sinc length, and deteriots the matching.

C) Effect of gap (*S*) variations on $|S_{11}|$

The gap (*S*) between the feeding strip and ground plane has major influence to the reflection coefficient. Figure 5 shows that the reflection coefficient ($|S_{11}|$) of the proposed ACS

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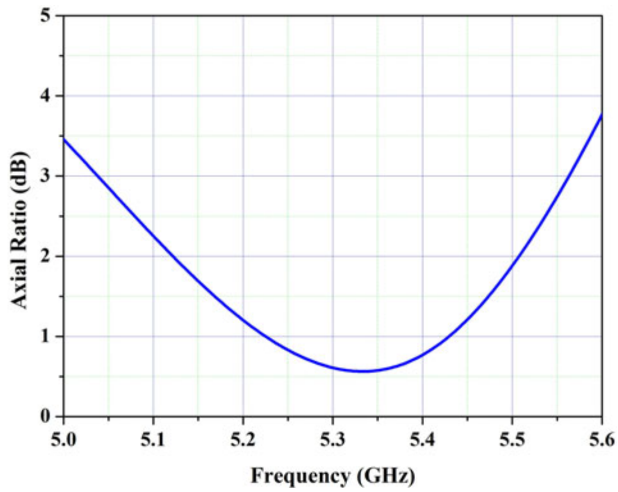

Fig. 7. Simulated axial ratio of ACS fed Sinc shaped monopole antenna for CP polarized band.

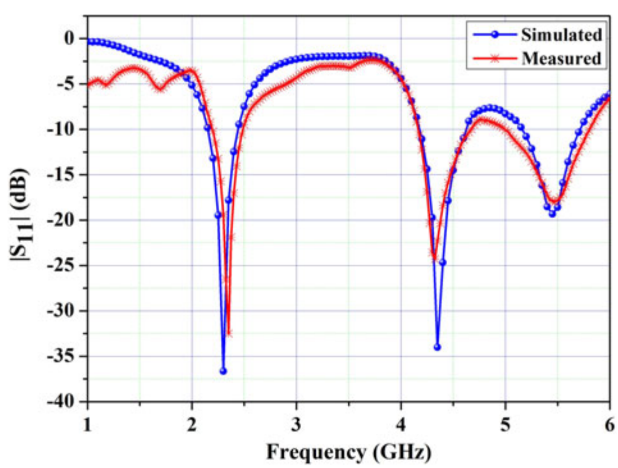

Fig. 8. Simulated and measured reflection coefficient ($|S_{11}|$) of ACS fed Sinc shaped monopole antenna.

Fig. 9. Radiation pattern measurement experimental setup.

fed Sinc shaped monopole antenna for 0.3, 0.5, and 0.8 mm gaps (S). For the proposed antenna it is observed that the resonance frequencies of first and third resonating mode shifts towards the higher resonating band with increasing gap (S), while the second resonance frequency has very small influence of gap (S). However the impedance matching of first and second resonating modes are deteriots with increasing gap (S), while it improves for the third resonating mode with increasing gap (S). Figure 5 shows that $S = 0.5$ mm gives good impedance matching and wide frequency range of operation for all the bands, therefore 0.5 mm gap (S) is considered for the proposed antenna.

Table 2. Gain performance of simulated and measured antenna.

Resonance Frequency (GHz)	Gain Simulated/measured (dBi)
2.30	2.35/2.15
4.35	3.12/3.42
5.40	5.64/5.01

IV. CURRENT DISTRIBUTION AND POLARIZATION

The proposed antenna depicts CP behavior at 5.40 GHz. The CP mechanism [17, 18] can very well be explained from the surface current distribution plot as shown in Fig. 6 for four different phases such as 0°, 90°, 180°, and 270°. The surface current distribution for 0° and 180° are seen to be equal and opposite while the surface current distribution for 90° and 270° are equal and opposite. Moreover the dominant current for 0° is in $-X$-direction, for 90° it is in $+Y$-direction, for 180° in $+X$-direction and for 270° it is in $-Y$-direction, depicting right hand circular polarization (RHCP) phenomenon. The CP mode is further justified from the axial ratio plot as shown in Fig. 7 with 3 dB axial BW of 510 MHz.

V. EXPERIMENTAL RESULTS

Finally, the prototype model is developed on glass epoxy FR-4 substrate as shown in Fig. 1 and the experimental reflection coefficient ($|S_{11}|$) characteristic of the proposed antenna is obtained using PNA-L series of Vector Network Analyzer (VNA). The experimental reflection coefficient of ACS fed Sinc shaped monopole antenna is compared with the simulation results as shown in Fig. 8. Two similar proposed ACS fed Sinc shaped monopole antennas are connected to each port of the VNA as shown in Fig. 9, and the radiation pattern and gain measurements are performed using absolute gain measurement technique as given by [19–21] and by using the transmission formula (Friis transmission equation) determined the gain. The simulated and measured peak gain of ACS fed Sinc shaped monopole antenna is shown in Table 2. The simulated and measured normalized radiation patterns of ACS fed Sinc shaped monopole antenna in *xz*- and *yz*-plane at 2.30 and 4.35 GHz are shown in Fig. 10. Nearly omni-directional radiation patterns are obtained in *xz*-plane for 2.30 and 4.35 GHz bands. The radiation pattern for circularly polarized mode at 5.40 GHz is shown in Fig. 11. A good agreement is evident between the simulated and measured results.

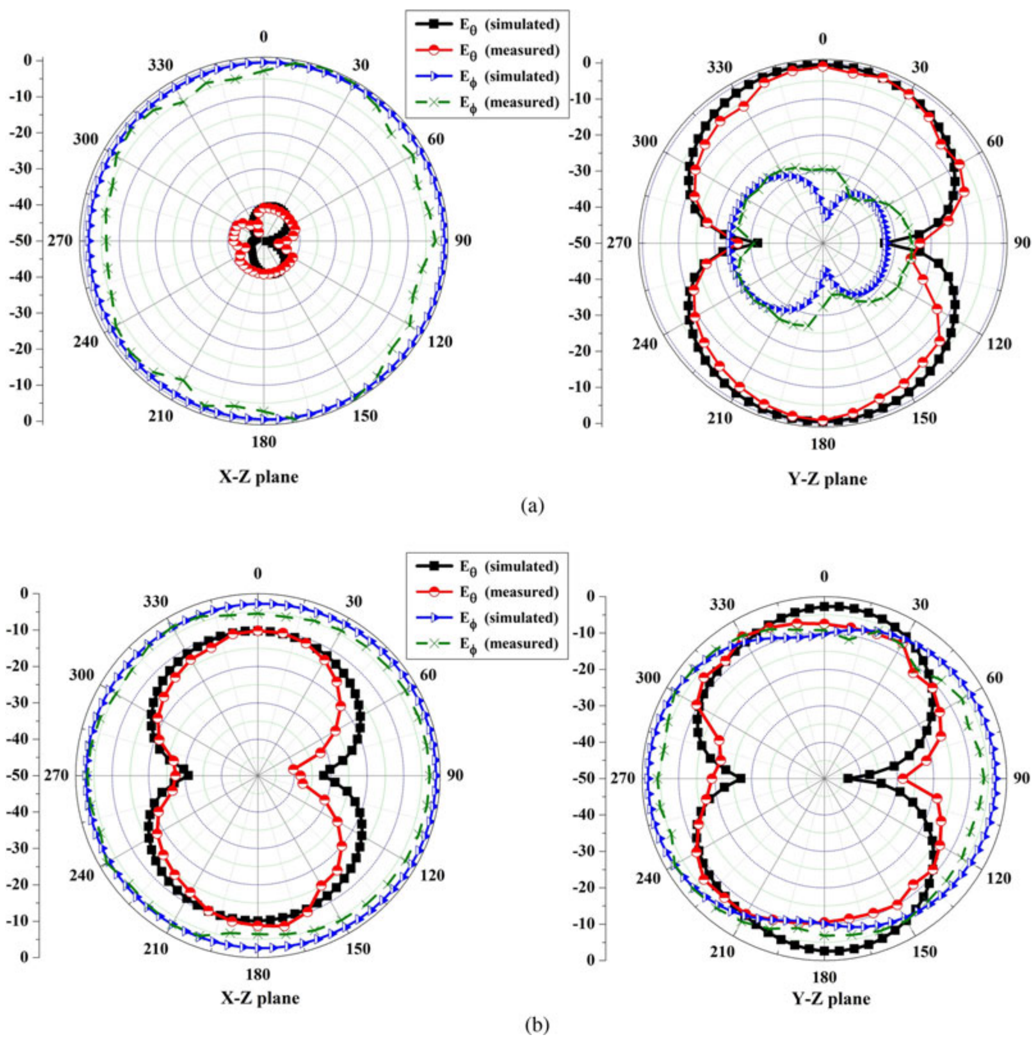

Fig. 10. Normalized radiation patterns for ACS fed Sinc shaped monopole antenna at (a) 2.30 GHz, and (b) 4.35 GHz.

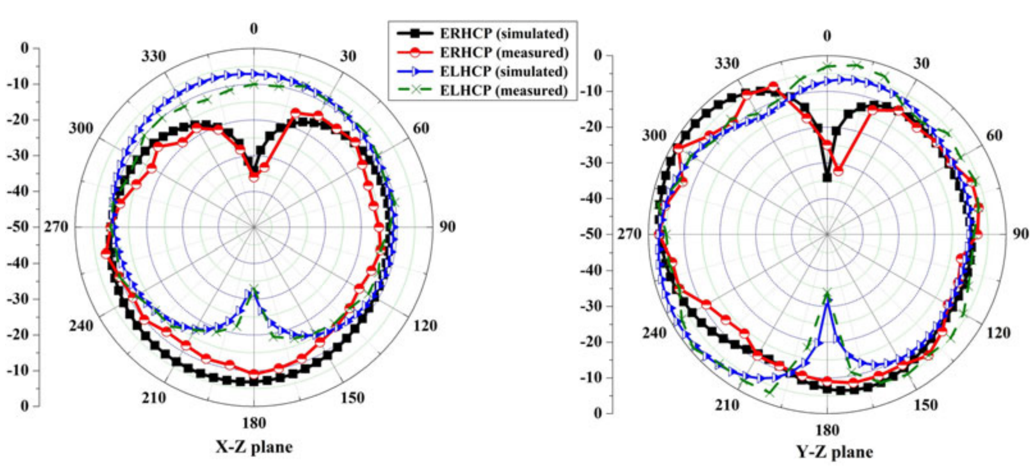

Fig. 11. Normalized radiation pattern of ACS fed Sinc shaped monopole antenna for CP polarized mode at 5.40 GHz.

VI. CONCLUSION

A simple low profile, low cost, and compact monopole antenna with asymmetric feed and truncated half ground plane is proposed. The proposed configuration shows dual polarization and multiband characteristics with wide impedance BW along with good gain and efficiency. A wide axial ratio BW is also depicted at third resonant frequency. The proposed antenna is useful for several applications such as

LTE, WiMAX, WLAN, Hyperlane-2, aeronautical navigation and fixed mobile communication.

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