

# A Low-Profile Compact Micro Strip Circularly Polarized Antenna with Superstrate for 5G Wireless Local Area Network and X-Band Application

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## ABSTRACT

This research paper introduces a novel compact Circularly Polarized (CP) antenna tailored for 5G Wireless Local Area Network (WLAN) and X-band applications. The antenna design includes a circular patch, minimized ground, and a superstrate. Four V-shaped slits are embedded along the boundary of the circular patch, strategically positioned to generate circular polarization operating across multiple frequency bands. The antenna resonates in the ranges between 4.9 GHz and 5.6 GHz, 7.74 GHz and 8 GHz, and 10.9 GHz and 11.2 GHz. The design's effectiveness is verified through a compact antenna with dimensions of  $0.636 \lambda_0 \times 0.636 \lambda_0 \times 0.21 \lambda_0$ . The results demonstrate 10-dB impedance bandwidths of 13.2%, 3.16%, and 2.7% for 4.9-5.6 GHz, 7.74-8 GHz, and 10.9-11.2 GHz, respectively. In addition, the findings revealed gains of 8 dBi, 6.89 dBi, and 8 dBi at resonant frequencies of 5.3 GHz, 7.9 GHz, and 11.1 GHz, respectively. With a radiation efficiency exceeding 97% across all resonant frequencies, the addition of a superstrate enhances gain by 3 dBi. Comparison between measured and simulated results confirms the accuracy of the proposed design. The triple-band CP compact antenna, augmented by a superstrate, showcases promising characteristics for 5G WLAN and X-band applications.

**Keywords-circular polarization; microwave communication; superstrate; defected ground structure; 5G WLAN application; x-band application**

## I. INTRODUCTION

The increasing demand for wireless communication in terms of speed, flexibility, mobile broadband and compatibility with other devices. 5G technology exhibits great demand in mobile high-speed communication. The federal communication commission released a new regulation for 5G band, as IEEE 802.11ac for WLAN application ranges from 5.125 GHz to 5.925 GHz [1, 2]. Furthermore, X-band is becoming popular for high-bit rate and ranges from 8 GHz to 12 GHz. In the classical configuration, the type of antennas cannot provide the necessary gain and techniques. To improve the gain requires increased aperture area of the antenna by employing array configuration leading to a complex feeding network. X-band provides suitable communication for military users by utilizing different characteristics of several frequency bands. Modern communication systems, vehicular applications, WLAN, air traffic control, defense tracking, modern radars, remote sensing, and Wireless Personal Area Network (WPAN) operate within X-band frequency range requiring compact antennas. This can be achieved through printed microstrip antennas [2-4].

The performance characteristics of the antenna can be improved by loading on a superstrate. A CP antenna is chosen for wireless communication to avoid multipath interference, suppressing polarization mismatch, and providing a high probability of communication link as well as spectral efficiency and superior mobility. Circularly polarization is achieved by introducing two orthogonal modes of equal amplitude and quadrature phase shift. CP Antennas (CPA) are utilized in the GPS, WLAN, and radio frequency identification technologies [5-10]. CP microstrip antennas require protection from environmental hazards. The dielectric superstrate protects the metallic structured antenna from uncertain weather conditions.

The superstrate technique is demonstrated first in a resonant cavity for high gain and simple microstrip configuration [11]. Different shapes of patches loaded on top of the superstrate for improved bandwidth [12]. A superstrate is positioned at the top of the simple microstrip antenna with a spacing of  $\lambda/4$  introduced for enhancement of axial ratio, gain, and impedance bandwidth.

## II. ANALYSIS AND CONFIGURATION OF CP V-SHAPED SLIT PATCH ANTENNA WITH SUPERSTRATE

The geometry of the proposed V-shaped slit circular patch antenna is shown in Figure 1. Its 3D model was created in Ansoft HFSS software as illustrated in Figure 2. Slitting is a technique to exploit multiband or wideband and radiation efficiency characteristics of the antenna. It eliminates a certain metallic part from the patch of various shapes. Cutting tiny slits into the patch's radiating boundaries lowers the fundamental resonance frequency. The patch is covered with a dielectric superstrate to be protected from environmental hazards.

By placing a dielectric, the fringing fields between the patch and the ground plane vary. This change is taken into consideration when evaluating the substrate's effective relative permittivity. As a result, the resonance frequency of CP V-

shaped slit antenna's can vary. In the proposed design,  $r$  is the radius of the circular patch, RT Duroid 5880 is the chosen substrate material with dielectric constant  $\epsilon_{r1}$  and for the superstrate  $\epsilon_{r2}$ .

The proposed CP V-shaped patch antenna is fed by a coaxial probe feed. The patch is miniaturized through four slits out of which one slit has radius  $a'$  and the remaining three have  $a$ . Due to the asymmetry in dimension, orthogonal fields are developed at the edges resulted in circular polarization.

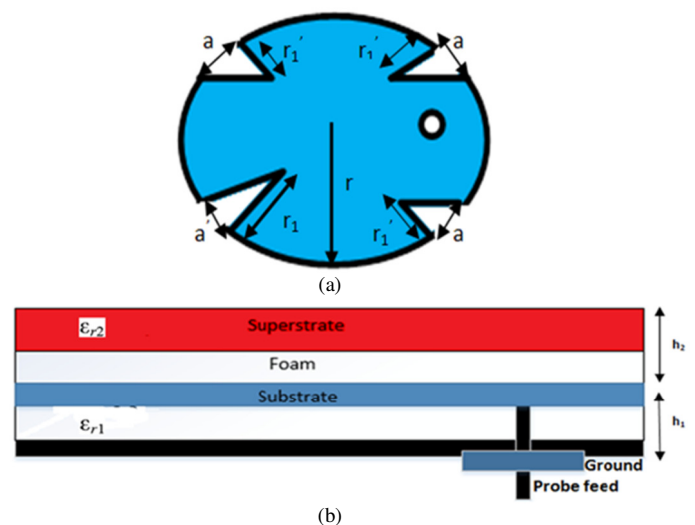


Fig. 1. (a) V-shaped slit patch and (b) crosssectional view of a patch antenna with a circular polarization and a superstrate.

The positioning of a dielectric superstructure changes the substrate's effective relative permittivity by adjusting the fringing fields between a patch and the ground plane. During the assessment of the typical performance of the suggested antenna the aforementioned positioning is also considered. Moreover, the effect of radius and performance of the circular patch with circular polarization from the effective dielectric constant is analyzed. In Figure 2,  $h_1$  represents the height of the dielectric substrate and  $h_2$  that of superstrate. The effective dielectric constant of the substrate is calculated as follows:

$$\epsilon_{reff} = \epsilon_{r1}p_1 + \epsilon_{r1}(1 - p_1)^2 x [\epsilon_{r2}^2 p_2 p_3 + \epsilon_{r2} p_2 p_4 + (p_3 + p_4)^2] [\epsilon_{r2}^2 p_2 p_3 p_4 + \epsilon_{r1}(\epsilon_{r2} p_3 + p_1) x (1 - p_2 - p_4)^2 + \epsilon_{r2} p_4 \{p_2 p_4 + (p_3 + p_4)^2\}]^{-1} \quad (1)$$

where:

$$p_1 = 1 - h/w * \ln((\pi w_e/h_1) - 1 - p_4) \quad (2)$$

$$p_1 = 1 - p_1 - p_3 - 2p_4 \quad (3)$$

The above formula and the parameters similar to  $p_2$ ,  $p_3$  and  $p_4$  are obtained from [13].

$$w = r(\pi - 2) \quad (4)$$

By applying the iteration method,  $w_e$  and  $\epsilon'_r$  parameters are calculated with initial value  $\epsilon'_r = \epsilon_{r1}$  and  $\epsilon_{reff} = \epsilon'_r$ . By incorporating a superstrate Duroid 5880 with dielectric constant  $\epsilon_{r1}$  and for superstrate  $\epsilon_{r2}$  with appropriate thickness on the patch reduces the surface waves to a certain extent. To account for this, new dielectric constant and effective radius of the circular patch are defined as:

$$a_{eff} = r\sqrt{(1 + q)} \tag{5}$$

$$\epsilon_{re} = \epsilon_{r1}/\epsilon_{reff} \tag{6}$$

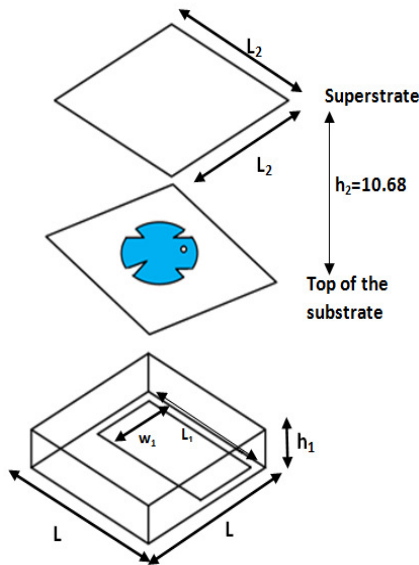


Fig. 2. Proposed V-shaped slit circular patch antenna 3-D design.

TABLE I. ANTENNA SPECIFICATIONS

Parameter	Value
Radius of the circular patch ( $r$ )	10.4 mm
Substrate Thickness ( $h_1$ )	1.5748 mm
Dimension of V-shape slit ( $r_1$ )	7 mm
Dimension of V-shape slit ( $r_1'$ )	3.89 mm
Size of the substrate	36 mm×36 mm
Length of the bottom partial Ground plane ( $L_1$ )	35 mm
Length of the bottom partial Ground plane ( $L_2$ )	28 mm
Width of the bottom partial Ground plane ( $w_1$ )	16 mm
Probe position	0.5 mm

The suggested design entails an etched circular patch with a minimized ground on RT Duroid 5880 with  $\epsilon_r$  value of 2.2 and  $h_1$  equal to 1.5748 mm. A foam thickness ( $t_f$ ) of 7.5 mm is placed between the substrate and superstrate FR4 with  $\epsilon_r$  equal to 4.4 and  $h_2$  of 3.18 mm. In addition, an  $r$  with a value of 10.4 mm and V-shaped slits are cut on the four quadrants of the metallic circular patch as shown in Figure 1(a). At one corner, the slit is cropped deeper to create asymmetry in the structure to obtain circular polarization. Here, the distance  $r_1$  is different from the other three similar distances ( $r_1'$ ). Furthermore, the position of probe feed (0, 5) is also optimized to generate

circular polarization. The structure is designed in High-Frequency Structure Simulator (HFSS) software and resonates at 5.3 GHz, 7.9 GHz, and 11.1 GHz. Optimum design parameters of the antenna are presented in Table I.

A. Surface Current Distribution

Slitting is a technique utilized on the metallic portion of the patch that lengthens the current path for a fixed dimension while also decreasing the patch's overall size [14] Subsequently, the patch surface current route is bent lowering the resonance frequency along the antenna excitation.

In this work, three band characteristics are obtained by cropping orthogonal V-shaped slits at the boundary of the circular patch antenna as shown in Figure 3. The circular patch's current route lengthens in the presence of slits, resulting in the acquisition of two more resonances. Additional resonance bands can be estimated and are expressed as follows:

$$f_{ri} = 1.841 * \frac{c}{P_e * \sqrt{\epsilon_{eff}}} \tag{7}$$

$$P_e = P_i \sqrt{1 + \left(\frac{2h}{\pi R \epsilon_{re}}\right) * \left(\ln\left(\frac{\pi R}{2h}\right)\right) + 1.77} \tag{8}$$

where  $i=1, 2, 3$ . Additionally:

$$P_1 = 2\pi r + 4r_1' \tag{9}$$

$$P_2 = 2\pi r + 2r_1' + 2r_1 \tag{10}$$

$$P_3 = 2\pi r - 3a - a' \tag{11}$$

where  $P_1$  is due to the slits in y-axis,  $P_2$  is due slits in x-axis and  $P_3$  is due to the remaining part of the sectors of circular patch after slits removal, and  $r_1'$  and  $r_1$  are shown in Table I. The antenna resonates at three frequencies, i.e., 5.3, 7.9 and 11.1 GHz, and its current distribution is visualized in Figure 3. It shows the surface distribution is split from one resonant frequency to the other due to the V-shaped slit perturbation in the circular patch.

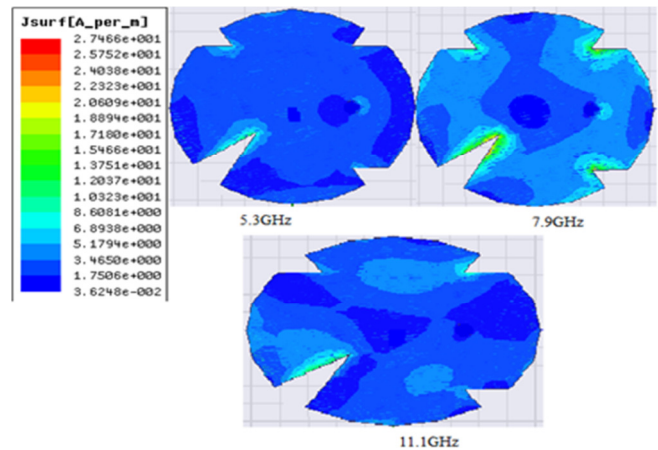


Fig. 3. Proposed antenna surface current distribution at 5.3 GHz, 7.9 and 11.1 GHz.

Figure 4 illustrates the return loss and gain of the proposed antenna with and without superstrate. The return loss of the antenna with superstrate is improved from 15 dB to 32 dB. The

gain (dBi) of the proposed triple-band CP antenna with superstrate is improved by 3 dBi when compared to the one without superstrate. Observing the performance characteristics of the antenna a variation in resonance frequencies with deep dip for all the bands. This variation is attributed to the addition of superstrate.

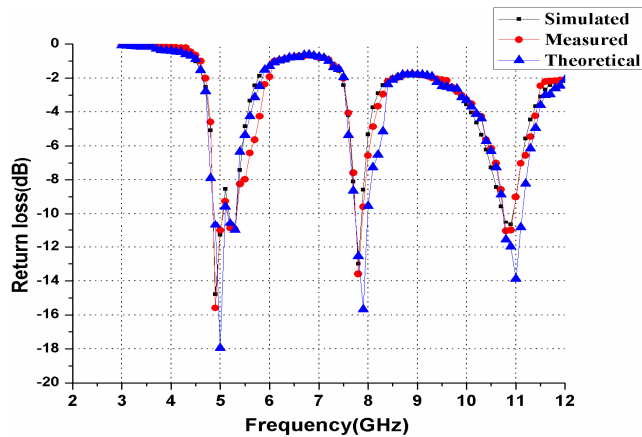


Fig. 4. Comparison of return loss of the proposed triple-band compact CP micro strip antenna with and without superstrate for three cases simulated (black square), theoretical (blue triangle), and practical (red circle).

### III. MEASURED AND SIMULATED RESULTS

It demonstrates that for resonance frequencies of 5.3 GHz, 7.9 GHz, and 12.1 GHz, the observed return loss is 32.2 dB, 18.9 dB, and 12.1 dB. The Measured 10dB impedance bandwidths for the resonant frequencies are 700MHz (4.9-5.6GHz), 260MHz (7.74-8GHz), and 300MHz (10.9-11.2GHz). Figure 5 presents the built-in antenna.

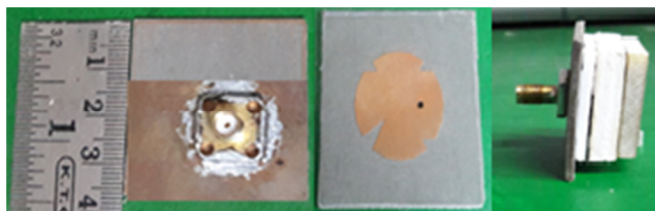


Fig. 5. Triple-band prototype, a small and CP microstrip antenna.

The suggested configurations and the measured return loss are illustrated in Figure 6(a). The antenna exhibits resonance at three frequencies: 5.3 GHz, 7.9 GHz, and 11.1 GHz, in which the observed return loss is 32.2 dB, 18.9 dB, and 12.1 dB respectively. In addition, the measured 10 dB impedance bandwidths for the resonant frequencies are 700 MHz, 260 MHz, and 300 MHz for the ranges 4.9-5.6 GHz, 7.74-8 GHz, and 10.9-11.2 GHz. As shown in Figure 6(b), the measured gains at 5.3 GHz, 7.9 GHz, and 11.1 GHz are 8 dBi, 6.89 dBi, and 8 dBi, respectively. The axial ratio, depicted in Figure 6(c), is a quantity that reveals the circular polarization of an antenna. The measured axial ratio for the suggested antenna is also presented in Table II. In the 5.1-5.8 GHz frequency range, the attenuation values are 0.47 dB, 0.925 dB, and 1.55 dB, with a bandwidth of 700 MHz achieved.

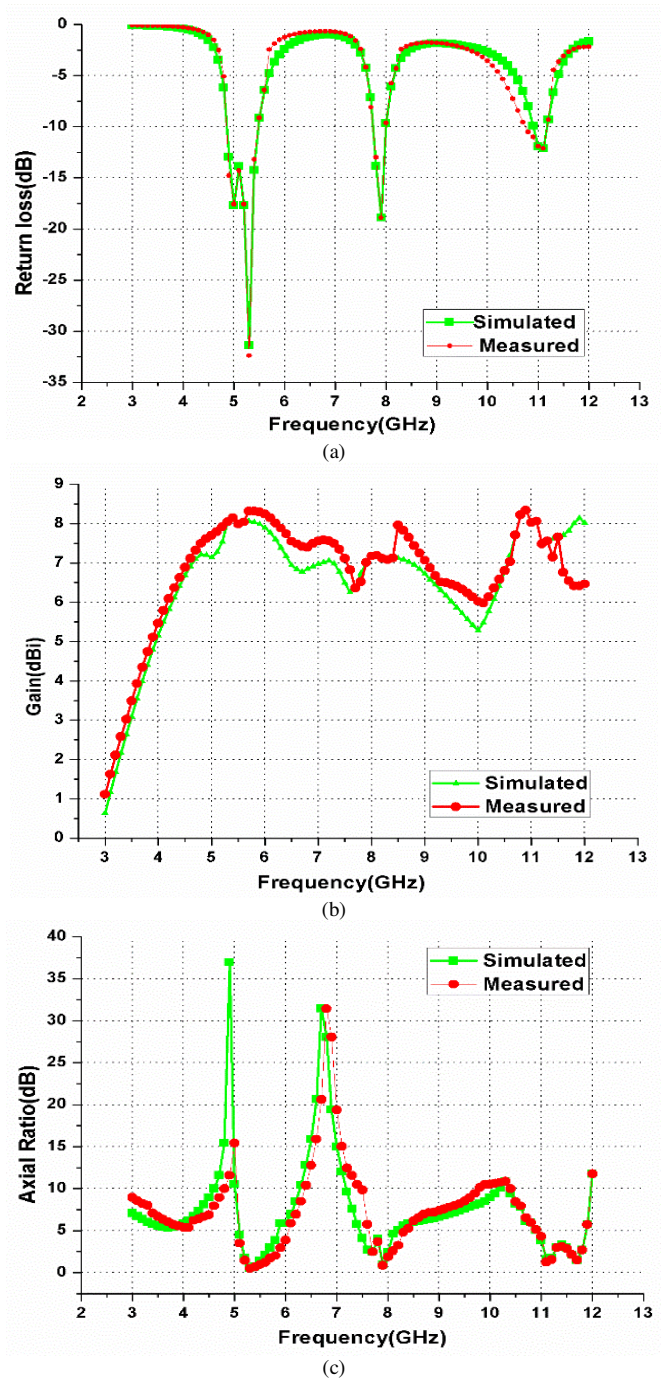


Fig. 6. (a) Return loss, (b) gain (c) axial ratio results of the proposed antenna.

Elevation and azimuth patterns in two dimensional are shown for various resonant frequencies, i.e., 5.3, 7.9, and 11.1ghz. Figure 7 indicates that the patterns are directional in elevation plane. Figure 7(a) describes they are omnidirectional in the azimuth plane. Table II gives the comparison of the proposed prototype with the existing designs.

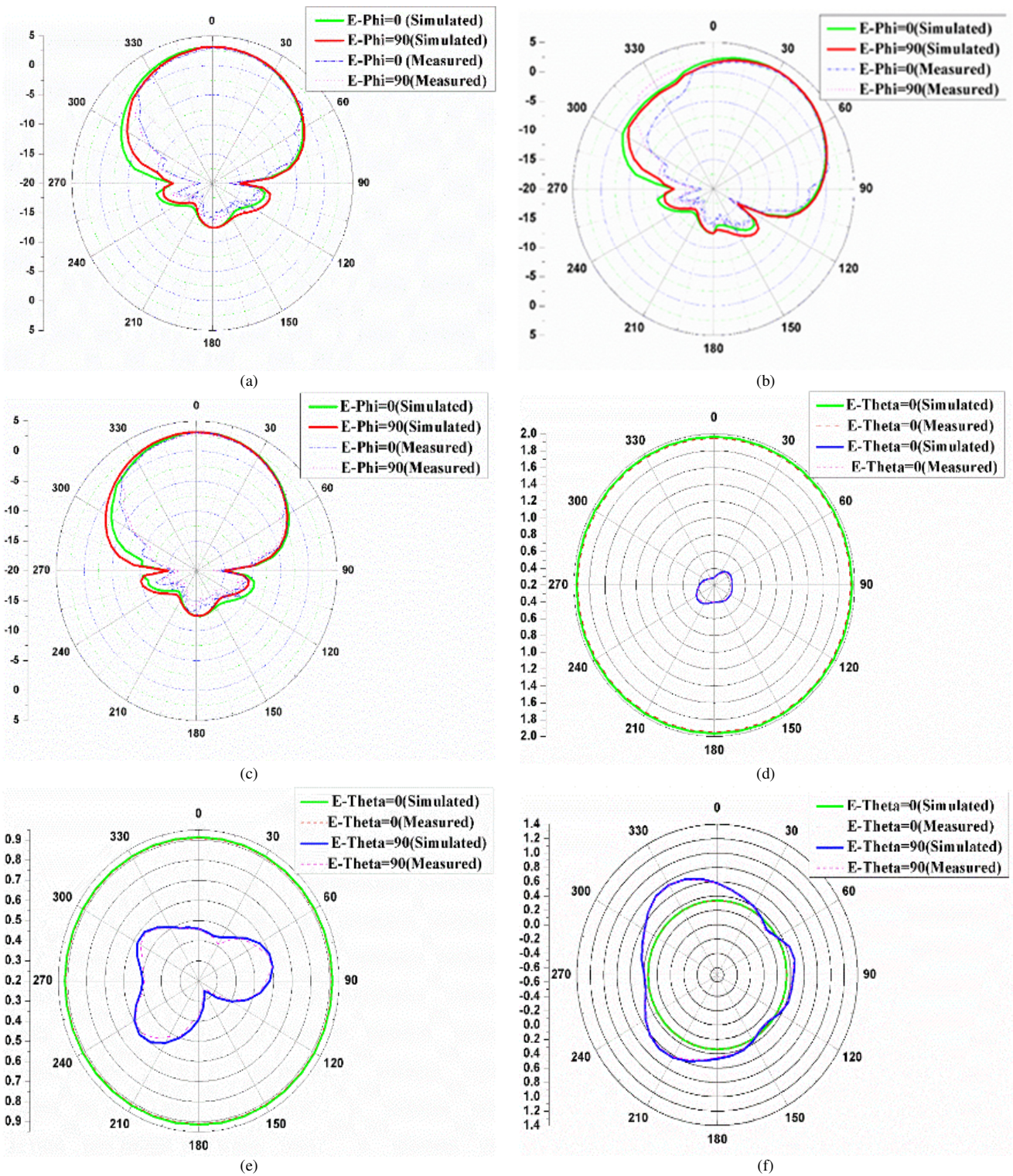


Fig. 7. Elevation patterns of the simulated and measured findings for a compact CP microstrip antenna at resonant frequencies of (a) 5.3 GHz, (b) 7.9 GHz, and (c) 11.1 GHz. Azimuth patterns for (d) 5.3 GHz, (e) 7.9 GHz, and (f) 11.1 GHz.

TABLE II. ASSESSMENT OF THE DESIGNED PROTOTYPE ANTENNA AGAINST THE PUBLISHED LITERATURE

References	Resonant Frequency (GHz)/ Operating Frequency Range	Impedance Bandwidth (MHz)	Gain (dBi)	Axial ratio Bandwidth (MHz)	Size of the antenna
[12]	8.6	980	3.4	-	50 mm×30 mm
[15]	9 and 11.35	612 and 351	8.2 and 10.1	-	30.26 mm×33.06 mm
[16]	5.8 (5.725 GHz –5.875 GHz)	150	17.5	-	-
[17]	2, 2.1	54	5.0	26 and 23	20 mm×20 mm
[18]	1.625 and 1.75	100	7.0	19 and 21	30 mm×30 mm
[19]	3, 3.6, 3.7, and 4.5	100-180	2-4	-	30 mm×40 mm
[20]	2.27	265	6.8	56	-
[21]	10.8 (10.1 GHz –12.9 GHz)	2800	13.7	1.5	40 mm×40 mm×17.45 mm
[22]	4.1, 5.8, and 6.7 GHz	450, 560, and 830	1-2	200, 370 and 230	29 mm×26 mm×1.6 mm
[23]	3.1 (2.84 GHz-3.24 GHz) 4.7 ( 4.44 GHz -4.92 GH)	400 and 480	5-6 at both frequencies	100 and 200	70 mm×70 mm×12 mm
[24]	2.42, 5, and 5.3	-	5.5, 4.6, and 4	-	120 mm×120 mm×1.6 mm
[25]	2.4, 3.5, and 4.9	870, 1170, and 400	2.73, 2.08, and 3.04	300, 100 and 200	40 mm×40 mm×1.6 mm
[26]	6.95, 7.93, and 8.9	5637	5.6 and 4.4	95, 186 and 149	63 mm×75 mm×1.6 mm
[27]	7.5, 10.2, and 12.2	540 and 8000	1, 1, and 4	152, 161, and 112.5	35 mm×30 mm×1.6 mm
[28]	5.35–5.56	3.9	6.67	1.1	36 mm×36 mm×0.787 mm
Proposed antenna	5.3, 7.9, and 11.1	700, 260, and 300	8.04, 6.89, and 8.06	700, 250, and 300	36 mm×36 mm×12.25 mm

#### IV. CONCLUSION

This research simulates and analyzes a compact Circularly Polarized (CP) antenna with V-shaped slit and a superstrate for 5G Wireless Local Area Network (WLAN) and X-band applications. By modifying the length  $r_1$  at one corner of the circular patch, an asymmetric V-shaped slit is formed to achieve the desired frequencies. Microstrip antennas are flexible, compatible to multiple circuitry and require protection from environmental risks, since it can affect the antenna's performance characteristics.

Superstrate can improve the antenna's performance and protect it from environmental hazards. The superstrate is positioned at a height of  $\lambda_0/4$  from the surface of the ground. When the patch is radiated, electric field waves get reflected and transmitted towards the superstrate's surface and it acts as partial reflecting surface. Subsequently, the wave gets reflected towards the propagating wave and thereby enhancing the phase and the amplitude of the wave. Although, the superstrate technique strengthens the antenna's performance characteristics it lowers its resonant frequency, lower impedance matching, and affect the effective dielectric constant. These characteristics can be improved by selecting the appropriate thickness of the superstrate. The effects of the effective dielectric constant on lowering the resonant frequencies are briefly explained, with a comparison of simulated, measured, and theoretical results.

The proposed antenna at lab scale design reveals superior return loss, axial ratio, gain, directional pattern, and size of the CP antenna. The simulated 10-dB impedance bandwidths are 13.2%, 3.16%, and 2.7% at 4.9-5.6 GHz, 7.74-8 GHz, and 10.9-11.2 GHz respectively. Furthermore the gains of 8 dBi, 6.89 dBi, 8 dBi at resonant frequencies of 5.3 GHz, 7.9 GHz, and 11.1 GHz. The proposed CP compact antenna with superstrate dimensions of 36 mm×36 mm×12.25 mm triple-band characteristics and is suitable for the 5G WLAN and X-band application.

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