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A Novel and Compact Circularly Polarized Antenna for 5G Wireless Local Area Network Application

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Abstract **– The research paper presents a novel and compact circularly polarized (CP) antenna for a 5G wireless local area network (WLAN) application. It consists of a circular patch and a coaxial probe feed radiator. Circular polarization (CP) is attained by symmetric semi-circular slits of radius r_1 at three edges of a circular path with 90° in direction, and the other semicircular slit is of different radius r_2. To improve the impedance bandwidth and axial ratio, the radius of the fourth semicircular slit on circular patch antenna is varied. The design is verified by fabricating a compact antenna of $0.65\lambda_0 \times 0.65\lambda_0 \times 0.01\lambda_0$. The measured 10 dB impedance bandwidth is 3.9 % (5.36–5.56 GHz), 3-dB axial ratio bandwidth is 1.1 % (5.43–5.49 GHz) and gain of 6.6 dBi at resonant frequency of 5.37 GHz is obtained. The authors also describe two-dimensional radiation patterns of azimuth and elevation plane surface current distribution of the CP patch, VSWR < 2. The proposed CP antenna is suitable for the 5G WLAN application. The proposed design is compared with various techniques in literature and tabulated. The measured results are also discussed and they are in good agreement with simulated results.**

Keywords **– 5G WLAN application; Circular polarization; Microstrip antenna; Microwave communication; Semi-circular slits.**

I. Introduction

As the days pass on, people's usage of wireless handheld devices is increasing along with the requirement for high-speed networks, i.e., 5G wireless communication. In 1G, 2G & 3G, voice is transmitted in analogue form, digital form and then brought to the mobile data. 4G introduced the era of portable broadband. 5G wireless networks provide high-speed, ultra-low latency, more reliable and increased capacity. The compact microstrip circularly polarized antenna for 5G wireless communication is in high demand since the advances in semiconductor technology for wireless technology have led to a reduction in cost. Federal Communications Commission (FCC) adopted a new regulation in the 5GHz band, with an additional 400 MHz band, which resulted in a standard IEEE 802.11ac for 5G WLAN application [1]–[3].

Microstrip antenna is of lightweight, low volume, thin profile configuration at low fabrication cost, as well as it is easily integrated with microwave circuits. Circular polarization is opted due to low polarization losses, low multipath interferences, polarization mismatch, and reduced Faraday rotation effects. The single probe feed structure reduces complexity, size, and it is characterised by ease of installation onto the microstrip patch [4], [5].

There is circular polarization (CP) due to the orthogonal field components of electric fields [6]. Various techniques are used to enhance the bandwidth of CP antennas such as folding the edge of the radiating patch antenna with slots loaded; with these techniques, the size of the antenna reduces to 44.8 %, so that the antenna appropriatness for the 5G mobile phone is discussed in [7]. On the microstrip patch embedding, the substrate integrates a meandering probe feed for 5G wireless fidelity (Wi-Fi) to improve the CP antenna bandwidth [8].

Enhancement of bandwidth with CP can also be obtained by truncating the corners [9], [10], virtual shorting [11], slit formation at the edges [12]. Slot antenna is backed in substrate integrated waveguide cavity, an antenna can produce CP, but the size is large [13]. Shorting the patch in the quasi magnetic-electric region is studied in [14]. Slotted patch is created symmetrical on the patch [15]. Loading the CP antenna with substrate integrated waveguide cavity is discussed in [16]. Cross-slot with unequal lengths on the circular patch results in CP [17]. Directive triangular EBG antenna is designed to obtain high directivity and bandwidth [18]. Other forms of CP antennas are reported in [19]–[21].

A novel and compact circularly polarized antenna with a single probe feed is proposed for WLAN use. The antenna geometry is given in Section II. In Section III, interpretations of the simulated results and parametric analysis are discussed. Measured results and surface current distribution of the design are discussed in Section IV, and conclusions are given in Section V.

II. Antenna Geometry

The structure of the antenna is displayed in Fig. 1 (a), and Fig. 1 (b) shows the cross-sectional view. The proposed circular patch antenna is aimed at a resonant frequency of 5.37 GHz, with radius '*r*' on a square substrate of thickness '*t*.' Rogers RT Duroid 5880 is used as a substrate ($t = 0.787$ mm, $\varepsilon_r = 2.2$, $\tan\delta = 0.005$) and the fabricated antenna is shown in Fig. 2. The antenna is fed through the coaxial feed for proper impedance matching.

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In antenna geometry, a circular sector portion is removed at θ = 90° edges of the four quadrants to surge the electrical length of the patch, which results in better radiation characteristics. The radius (r_1) of the circular sector is equal at the three quadrants, but at the fourth quadrant, the radius (r_2) is increased to create asymmetry, which results in circular polarization.

Microstrip antennas resemble dielectric-loaded cavities, and they parade higher-order resonances. The normalized fields inside the dielectric substrate can originate more precisely by considering that region is a cavity bounded by electric conductors and magnetic walls beside the perimeter of the patch. Based on the cavity model formulation, a design technique is outlined, as shown below. The process adopts that the identified information includes the dielectric constant of the substrate (ε_r), the resonant frequency (f_r), and the height of the substrate h. The radius r of the circular patch as a function of h and ε is given by [22].

$$r = \frac{F}{\sqrt{1+\frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]}}, \quad (1)$$

where F is given below:

$$F = \frac{8.791\times 10^9}{f_r\sqrt{\varepsilon_r}}. \quad (2)$$

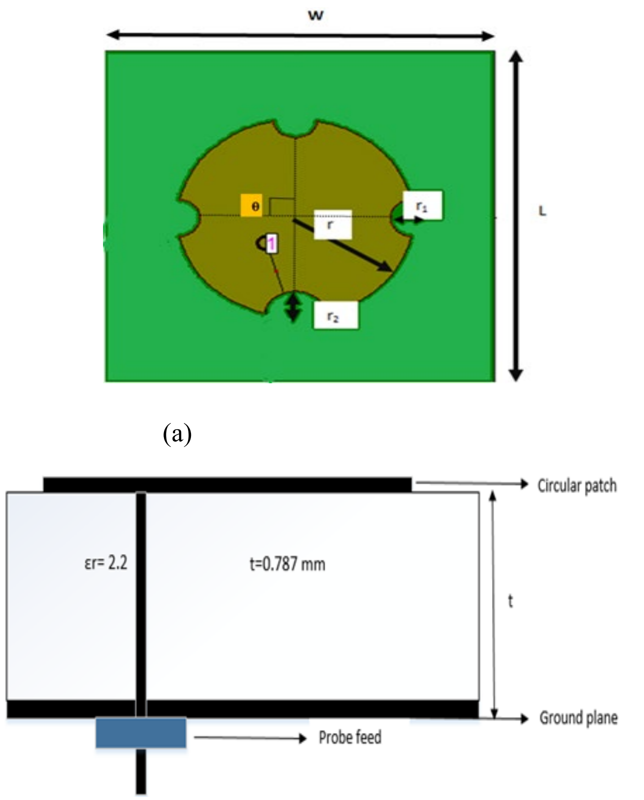

Fig. 1. The layout of the proposed antenna: (a) top view; (b) cross-sectional view.

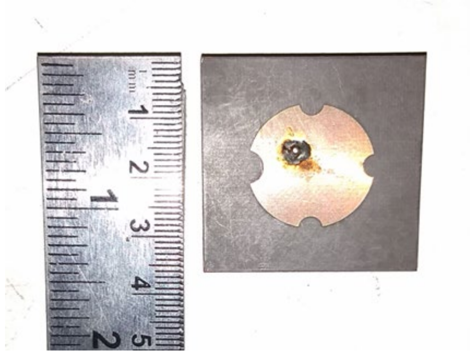

Fig. 2. The fabricated antenna.

III. Interpretation of the Simulated Results

On the circular patch, asymmetry is generated by perturbing the structure with semi-circular slits at four sides of the patch, which results in circular polarization. The feed position is optimized at (−2.7, −2.7) with reverence to the centre of the patch. The value of r_2 is optimized to give better performance. The designed parameters of antenna are shown in Table I.

Parametric Analysis

The effect of radius r_2 of the semi-circular slit on the return loss, impedance bandwidth, gain, etc. is evaluated by varying its value. Table II shows the performance parameters of the proposed antenna for altered values of r_2 and the corresponding return loss, and axial ratio curves are shown in Figs. 3, 4. By several iterations, the value of r_2 is fixed at 2.9 mm for the WLAN application band. Change in radius r_2 results in the shift of resonant frequency, and gradually bandwidth decreases.

TABLE I
Antenna Design Parameters

Parameter	Value	Parameter	Value
L	36 mm	r_1	2 mm
w	36 mm	r_2	2.9 mm
r	10.6 mm	t	0.787 mm

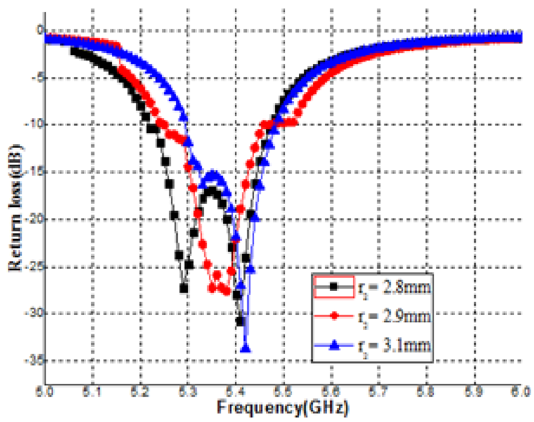

Fig. 3. Return loss for various values of radius r_2.

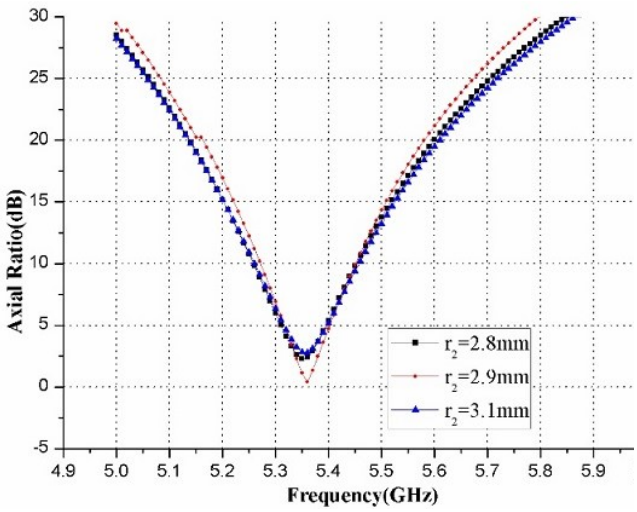

Fig. 4. Return loss for various values of radius r_2.

IV. Measured Results

A. Return Loss

The antenna is radiated by feeding on the ground plane; here its coaxial probe feed. When these are in contact with each other, there is an impedance mismatch, which gives a measure of return loss. To check the performance of the proposed design, the return loss is shown in Fig. 5. For the fabricated antenna, the measured return loss is −28.45 dB at resonant frequency of 5.37 GHz with 10 dB impedance bandwidth of 210 MHz in the range of 5.25–5.45 GHz. It clearly shows that the designed antenna is suitable for WLAN application.

TABLE II

Effect of the Radius of R_2 of Semi-Circular Slit on Impedance Bandwidth, Axial Ratio, and Gain

r_2 value, mm	Resonant frequency, GHz	10 dB impedance bandwidth, GHz	3 dB axial ratio bandwidth, GHz	Gain, dBi
3.1	5.51	4.71 (5.33–5.59 GHz)	0.5 (5.34–5.37 GHz)	6.681
2.9	5.37	3.9 (5.251–5.45 GHz)	1.1 (5.33–5.39 GHz)	6.638
2.8	5.50	4.53 (5.33–5.58 GHz)	0.7 (5.34–5.37 GHz)	6.670

B. Gain

It is the measure of the power of antenna radiation in broadside direction with reference to a reference antenna. The measured gain at resonant frequency of 5.37 GHz is 6.63 dBi and is shown in Fig. 6.

C. Axial Ratio

Axial ratio is a factor that indicates the CP of an antenna and is shown in Fig. 7. For the proposed antenna, the measured axial ratio is 0.34 dB, and bandwidth of 60 MHz in the frequency range of 5.33–5.39 GHz is obtained.

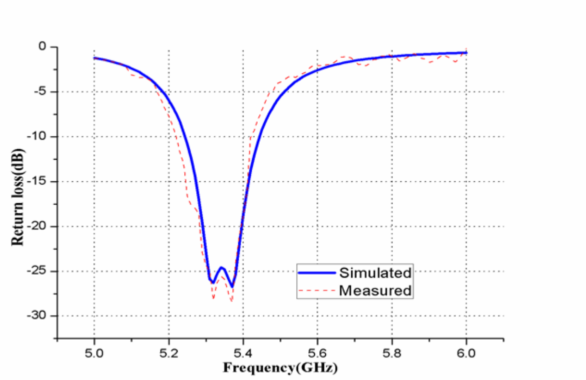

Fig. 5. The return loss of the antenna.

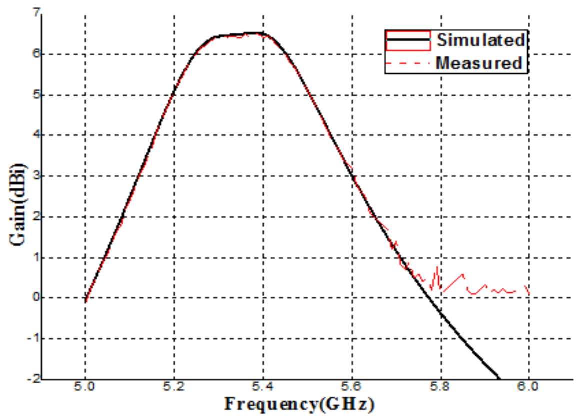

Fig. 6. The gain of the proposed antenna.

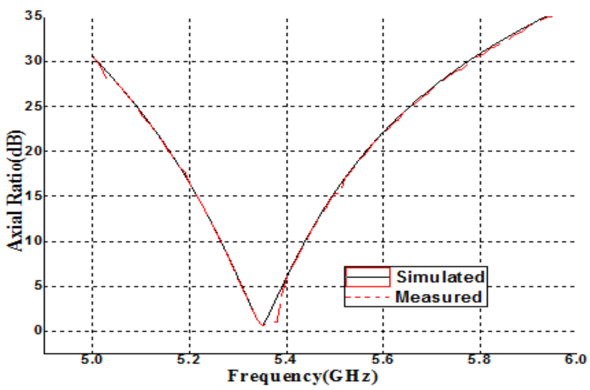

Fig. 7. The axial ratio of the proposed antenna.

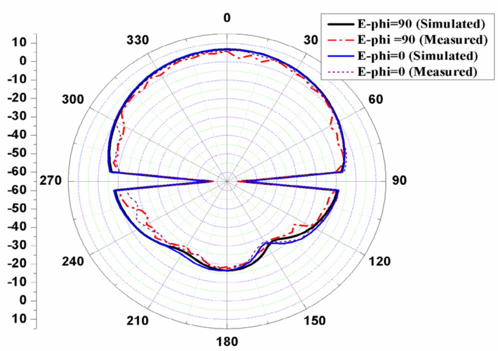

Fig. 8. 2D elevation pattern at the resonant frequency of 5.37 GHz.

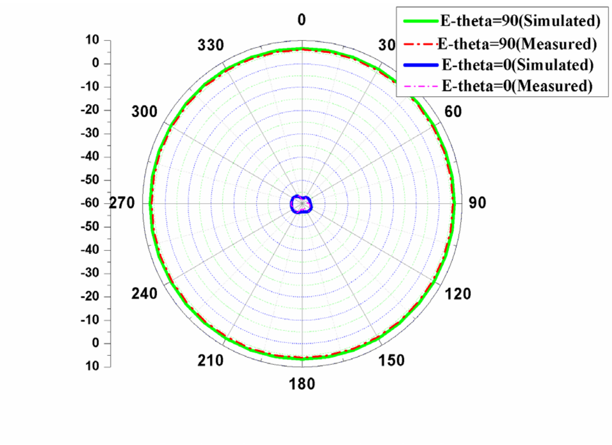

Fig. 9. 2D azimuth pattern at the resonant frequency of 5.37 GHz.

D. Radiation Pattern

It signifies the orientation of the electric field radiated by the antenna with respect to spatial coordinates. It has two patterns: azimuth and elevation plane, and in the anechoic chamber, measurement setup is made to take the patterns. Figs. 8 and 9 show the simulated, measured azimuth, and elevation planes at the resonant frequency of 5.37 GHz. VSWR (Voltage Standing Wave Ratio) is shown in Fig. 10. The radiation efficiency of 74 % is obtained for the proposed antenna (see Fig. 11).

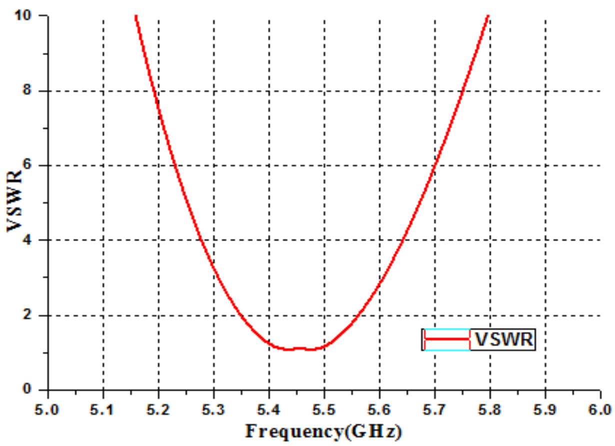

Fig. 10. VSWR of the proposed antenna.

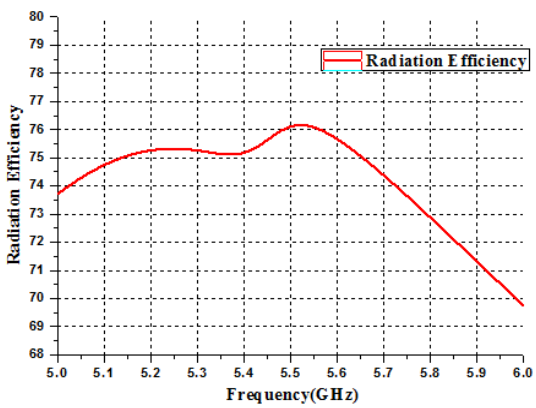

Fig. 11. The radiation efficiency of the proposed antenna.

E. Surface Current Distribution

To create radiation in antenna, there must be charge acceleration and deceleration, i.e., time-varying current. Usually, the microstrip antenna is excited by a conductor in the centre of the coax serving as the feed probe to couple electromagnetic energy in or out of the patch; charges get accumulated on it. The charge constitutes a current. When a current starts flowing from ground to the patch, parallel to its charge distribution is present at the microstrip surface and ground plane.

Accumulation of charges on to the patch results in the surface current distribution. Figure 12 shows that most of the current resides on the top surface of the patch at the resonant frequency and high current magnitudes at the edges. Consequently, the constituent of the magnetic field, which is oblique to the patch edge, is small. Reactive and resistive components are present at the input impedance of the microstrip antenna. The power radiated by the antenna is due to the resistive elements in antenna power loss by radiation and dielectric mainly due to the presence of imaginary poles and even conduction losses. Current distribution on the microstrip patch surface with the addition of deep semi-circular slit changes current density in magnitude as well as the direction along with the various time intervals. It can be observed in Fig. 12, which in turn creates CP at the respective resonant frequency.

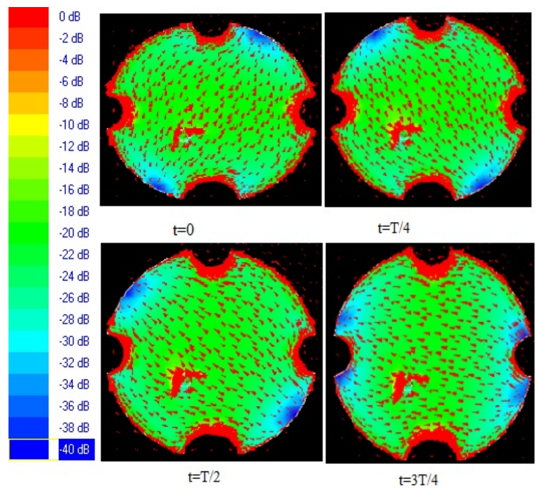

Fig. 12. The surface current distribution of the antenna at the resonant frequency of 5.37 GHz.

Now, each vector characterises a major current component in the microstrip radiating patch. The simulated normalized current distributions are illustrated at various time intervals $t = 0$, $T/4$, $T/2$, and $3T/4$. It is perceived that the vector sum of the significant components at $t = 0$ is orthogonal to that of $t = T/4$. Thus, a CP mode is generated. In a microstrip patch antenna, the performance parameters like radiation pattern, input impedance, bandwidth, and resonant frequency are controlled by the surface current, which is induced on the microstrip patch. Table III shows the performance comparison of the proposed antenna with some of the existing designs.

TABLE III

PERFORMANCE COMPARISON OF THE PROPOSED ANTENNA WITH SOME OF THE EXISTING DESIGNS

References	Frequency, GHz	10 dB impedance bandwidth, % (MHz)	3 dB axial ratio bandwidth, % (MHz)	Gain, dBi	Size of the antenna
[11]	2.487–2.501	3.25	0.62	3.8	$0.174\ \lambda_0 \times 0.174\ \lambda_0 \times 0.026\ \lambda_0$
[12]	2.404–2.416	2.10	0.5	4.35	$0.288\ \lambda_0 \times 0.288\ \lambda_0 \times 0.0118\ \lambda_0$
[13]	14.38–14.94	4	0.83	7.1–7.4	$1.03\ \lambda_0 \times 0.56\ \lambda_0 \times 0.0372\ \lambda_0$
[14]	5.84–6.00	2	0.33	8.5	$0.5\ \lambda_0 \times 0.5\ \lambda_0 \times 0.03\ \lambda_0$
[15]	2.138–2.230	4.2	0.8	–	$0.436\ \lambda_0 \times 0.436\ \lambda_0 \times 0.0116\ \lambda_0$
[16]	5.7–5.8	4.3	–	2.3–3.3	$1.74\ \lambda_0 \times 0.313\ \lambda_0 \times 0.0386\ \lambda_0$
[17]	2.45–2.55	4	–	24 dB (directivity)	–
Proposed antenna	5.35–5.56	3.9	1.1	6.67	$0.65\ \lambda_0 \times 0.65\ \lambda_0 \times 0.01\lambda_0$

F. Measurement Setup

When an antenna is fabricated with a finalized design on aperformance by measuring its performance parameters like return loss, axial ratio, gain, radiation efficiency, and radiation characteristics using the Network Analyser and antenna measurement setup. Here are mostly two types of network analyzers available: scalar and vector network analyzers. Scalar network analyzer measures the magnitudes of transmission and reflection coefficients; however, both the magnitude and phase of the S-parameters are measured by the vector network analyzer. In general, the network analyzer consists of a signal processor, calibration kit, display unit, and microwave source. To evaluate the performance, parameters of the antenna using a vector network analyzer are calibrated once the ports are matched, as shown in Fig. 13. After the matching is done, the antenna is connected to port 1 and matched load to port 2, as shown in Fig. 14, and Fig. 15 illustrates the measured return loss for the proposed antenna.

Fig. 13. Ports are connected via a coaxial cable for matching.

G. Discussion of Results

The performance and radiation characteristics of the proposed design are evaluated by the method of moment technique embedded in a solver called integral equation 3-dimensional. Inductive and capacitive loading technique is employed to generate circular polarization, but low return loss is obtained and not compact. Loading of shorting pins creates short from the ground to the patch to get impedance match and high gain but low impedance – bandwidth. Formation of slits and slots on to the patch varies the results a lot since these depend on the shape of the patch; the position of the slit or slot formed will increase the electrical length of the patch to increase the impedance bandwidth. Axial ratio and gain are moderate.

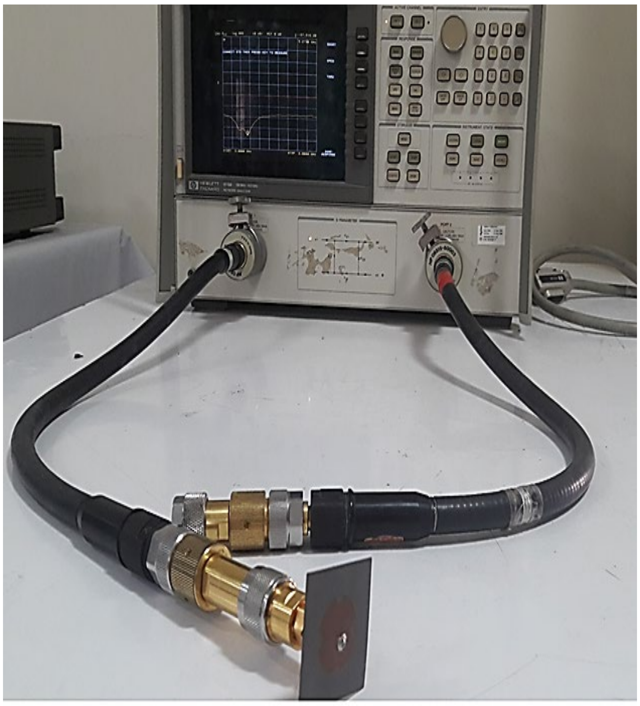

Fig. 14. An antenna connected to one port and matched load with other port.

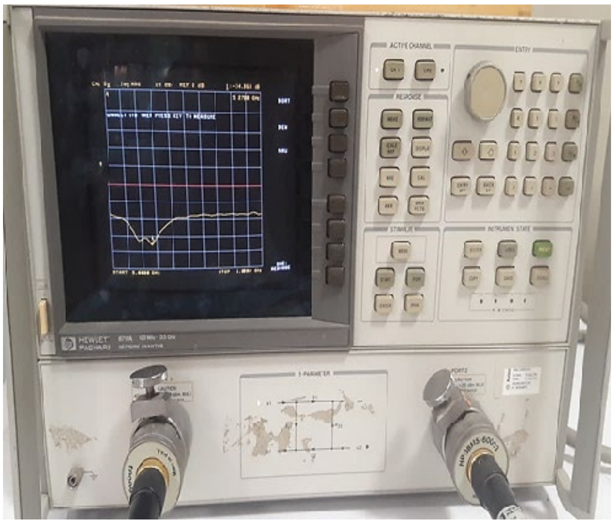

Fig. 15. Measured return loss for the CP antenna for 5G WLAN.

The proposed circularly polarized antenna is compared with similar antennas updated in the literature with respect to various design parameters, as shown in Table III. The measured results of the proposed antenna are in agreement with the simulated ones.

V. Conclusion

In the research, a compact semicircular microstrip patch CP antenna for 5G WLAN application has been reported. The size of the compact microstrip patch antenna is 36 mm × 36 mm × 0.787 mm. By changing the radius r_2 at one corner of the semicircular slit, the desired resonant frequency band with circular polarization is achieved. A detailed description of how CP is obtained with slit formation at the corners is illustrated using surface current distribution at various time intervals. The specified fabricated design has been illustrated and compared with multiple existing models in terms of different performance parameters. A detailed description of techniques has been discussed and compared with the novelty of the design. The measurement setup has been described, and an antenna has been connected after matching the ports. A detailed picture of the fabricated microstrip patch antenna with a semi-circular slit connected to the network analyzer has been shown. The proposed structure gives better return loss, axial ratio, gain, and omnidirectional pattern. The resonant peak at 5.37 GHz falls in 5G WLAN (5.1–5.725 GHz) and suitable for 5G WLAN applications.

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