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A Wideband and Wide Axial Ratio Bandwidth Circularly Polarized Antenna Loaded with Circular Ring Slot

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***Abstract*— The presented model for wideband circularly polarized microstrip antenna is an improved version of the previous models which is widely applicable to satellite, microwave relay and radar. The designed circularly polarized antenna having overall volume of 20× 20 × 1.6 mm^3 actively works at the impedance bandwidth of 9000 MHz (4.0–12.9 GHz) having 105%(with 8900 MHz taken as center frequency). The 3-dB axial ratio bandwidth is obtained as 5500 MHz (5.4–10.9 GHz) depicting 67.5% (with 8150 MHz taken as the center frequency). Measured results of impedance bandwidth, axial ratio, gain and VSWR agrees to the simulation results.**

***Index Terms*—** Bandwidth, Compact Antenna, Ring Slot, Wideband.

I. INTRODUCTION

In present scenario, printed antennas in wireless communication system are demanding wider bandwidths followed by controlling the polarization properties of such antennas. Controlling the polarization properties of printed antennas is in demand due to the fact that making more use of polarization properties of waves results in physically small and broad impedance bandwidth of such antennas.

Among the various polarization types utilized in recent wireless communication systems is the Circular Polarization. Antenna generating circularly polarized waves are known as Circularly polarized antennas. Such antennas have attractive feature of avoiding multi-path interferences, fading and reduction of Faraday rotation in ionosphere which makes such antenna find application in the field of wireless communication. Several applications additionally would prefer compact CP microstrip antennas wherever its dimensions might be a major thought, such as satellite, microwave relay, radar, wireless mobile along with transportable wireless equipment's. Various applications such as mapping, positioning, atmospheric information, geographic surveys, navigation, time standards,

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weather, public safety and surveillance required compact systems with strong signal strength. Thus, a small size antenna with CP wave and medium gain is a great challenge, mainly for transportable terminals. Due to aligned property of polarization of CP antennas, they are suitable to establish a consistent system connection.

In subsequent years, emerging research works were done in the field of wide-slot printed antennas [1], [2] owing to their promising impedance characteristics. The fundamental principle of operation of an antenna for radiation of CP waves is generation of two in-phase quadrature orthogonal modes with equal magnitude. The circular polarizations are often obtained by accepting methodology of truncated microstrip antenna of square shape having single feed four slits [3]. The foremost good thing about single feed CP microstrip antennas [4]-[6] is its conventional structure that does not need an external polarizer. To analyze it concisely, lesser board area is required than that in case of dual feed CP microstrip antennas. CP waves can be obtained by designing totally different shapes and structures of microstrip antennas. To obtain CP radiation, perturbations of slotted antenna are done by creating some asymmetric slots into it. Different properties of printed slotted antennas which are fed by microstrip line having different tuning stubs are also widely studied, and radiation properties have been reported in [7]-[19]. Different multiband slot antennas have been proposed [23-26] by using various slot shapes into the ground.

In an effort to achieve a broad axial ratio (AR) in case of wide CP slot antenna, many structures [7]-[16] were designed. It was observed that on insertion of a two grounded strips [7], [8] or by using L-shaped grounded strips [10], the AR bandwidth was improved significantly. Also, to enhance AR bandwidth and impedance bandwidth, several other methods have been proposed which includes employing a slot comprised of many circular sectors [12],by using two different L grounded strips which are inverted round two opposite corners of slot [14], embedding three inverted-L grounded strips [15], implementing asymmetric inverted T-strip on a ground plane followed by a metal strip of halberd-shaped on the slotted ground[16], by employing a slot composed lightning-shaped feedline and grounded strips of inverted L shaped [17].The above methods though achieved the target of wide AR bandwidth but difficulty in designing and fabrication of antenna was observed. It was also observed that use of metasurfaces [18]-[20] on CP antenna not only led to improvement in Axial Ratio bandwidth (ARBW), but it also led to increase in physical height of antenna.

This work encompasses a simple slot antenna showing circular polarization for wideband system with strategies added in [19]. In this proposed work, a simple structure of printed circular ring slot antenna fed by microstrip line using a horizontal line strip for the enhancement in operating bandwidth is projected and examined. The designed antenna depicts impedance bandwidth of 9000 MHz (4.0–12.9 GHz) showing 105% (having center frequency of 8900 MHz). A 3-dB AR Bandwidth of 5500 MHz (5.4–10.9 GHz) corresponding to 67.5%. The attained wide AR bandwidth is applicable for wideband wireless systems. The designed antenna is simulated by using commercially available Ansoft High Frequency Structure Simulator (HFSS-version 15).

II. CONFIGURATION OF ANTENNA

A. *Structure of Designed Antenna*

One of the techniques used by researchers to design Antennas generating circularly polarized waves is asymmetric perturbation, which resultes in two orthogonal modes having phase difference of 90^0. In this proposed work, a physically small and easier CP circular ring slot antenna has been presented. An asymmetric perturbation is done on the antenna comprising of a circular ring slot with horizontal strip on which a small circular segment is cut, which leads to CP waves being generated followed by wide impedance bandwidth.

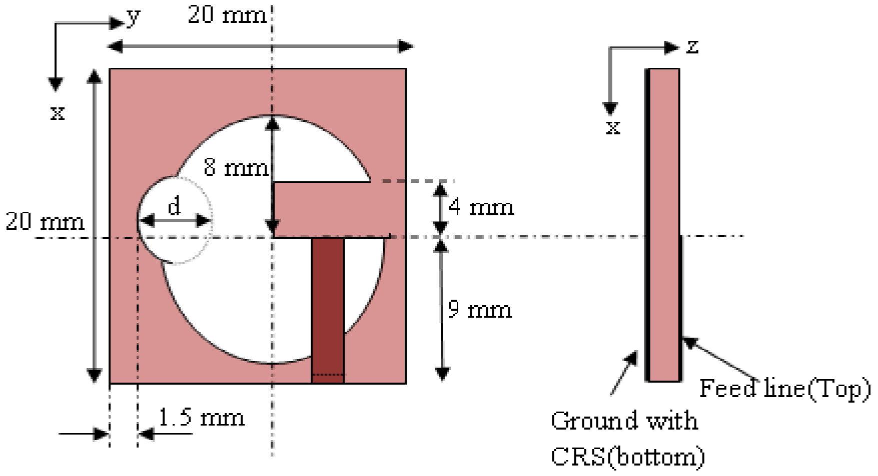

Fig.1. Structure of the suggested antenna.

Fig. 1 illustrates the desired structure of the wideband CP antenna. A wide slot of circular shaped with radius of 8 mm is engraved into the ground plane. The desired antenna with FR4 as substrate with height (h) of 1.6 mm and having relative permittivity (ε_r) of 4.4. A horizontal strip of dimensions 8mm × 4mm is fabricated, which is placed at other extreme to a small circular segment cut having diameter (d) of dimension 5 mm on the circular slot. The designed antenna achieves an overall compactness having dimensions of 20 mm × 20 mm fed by 50 ohm microstrip feed line, placed just below the strip on the top side of the substrate. For the designed antenna to attain wideband CP radiation, the microstrip feed line is printed on the right edge of it [26]. Between the ground plane and feed line the coupling effect is minimized by etching small gap on the ground plane.

B. *Evolution stages of proposed antenna configuration*

Fig.2 depicts the evaluation stages of the planned Antenna. The reference antenna I comprising of the ground plane having a circular slot generates two orthogonal modes and thus showing circular polarization in the range 10.9 GHz-11.5 GHz and attaining an impedance bandwidth of 4600 MHz (8.1 GHz-12.7 GHz), with AR bandwidth of 600 MHz, as illustrated in Fig.3. Antenna I performance is improved by a horizontal strip of dimensions 8 mm × 4 mm placed opposite to a minor circular cut of 5 mm as diameter on the circular slot giving rise to antenna II. Ass depicted in Fig. 3(b), the return loss bandwidth of antenna II is about 6.50–13.5 GHz (7000 GHz). The horizontal strip increases the bandwidth as the current is strengthened around the strip, which leads to improvement of the electric field distribution, but the AR bandwidth was found to be greater than 3dB in most frequencies within the bandwidth indicating that Antenna II is linearly polarized. To further enhance the overall performance process, a small circular segment is cut over the circular ring slot having a horizontal strip which causes other resonant modes to be created that leads to a wide axial ratio bandwidth and return loss bandwidth. The proposed antenna is having wide impedance bandwidth from 4.1–13.1 GHz (9000 MHz) followed by a wide axial ratio bandwidth of 4960 MHz (5.69–10.65 GHz). Fig. 3(a) and (b) respectively, shows the effect on return loss bandwidth and ARBW of antenna II and of proposed antenna. Fig.1 shows the proposed antenna's design generating left-hand circular polarization (LHCP) waves. Table 1 depicts, parameters of the different evolution steps of the suggested antenna.

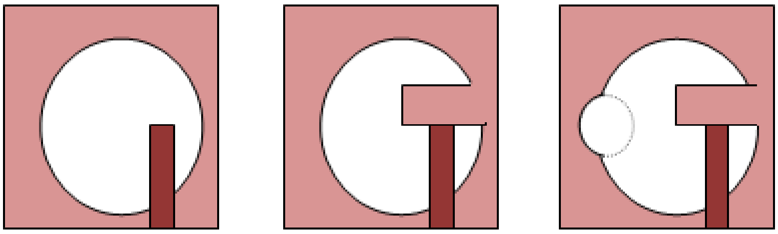
Antenna I Antenna II Proposed Antenna

Fig. 2. Antenna prototypes.

TABLE I. PARAMETERS OF DIFFERENT DESIGNS OF ANTENNA'S EVOLUTION STAGES

Parameters	**Antenna** I	**Antenna II**	**Proposed Antenna**
Impedance Bandwidth(MHz)	4600	7000	9000
Axial Ratio Bandwidth(MHz)	600	-	4960

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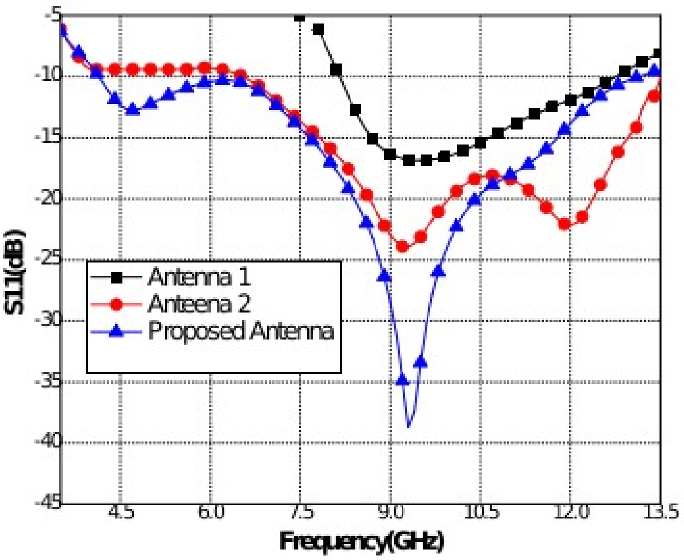
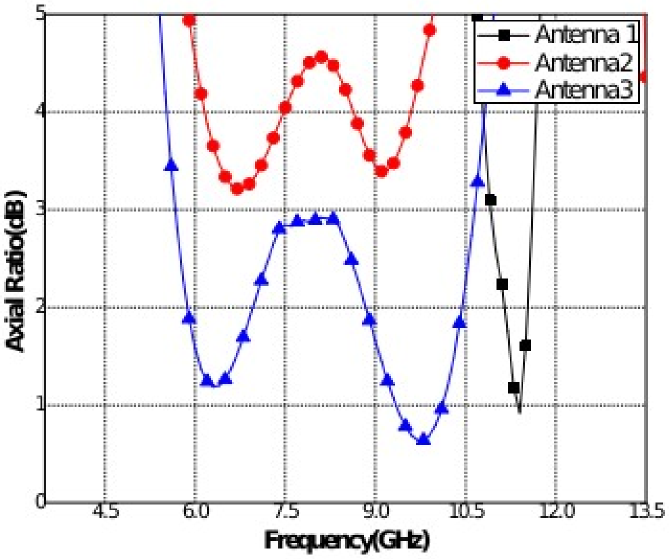


(a)



(b)

Fig. 3. Simulated results (a) S11 and (b) AR for Antenna I, Antenna II and Proposed Antenna.

III. RESULT ANALYSIS

To obtained measured result of suggested antenna, the implementation of Agilent TM vector network analyzer (PNA-L series) is done. The fabricated antenna is connected with 50-Ω SMA connector located laterally to the microstrip line. Fig. 4(a) depicts the front view and back view of the fabricated proposed antenna. Any mismatch with the simulated results may be due fabrication tolerances.

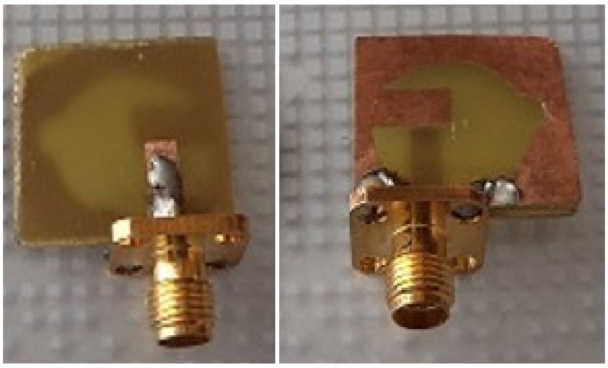


Fig.4. Fabricated model of the suggested compact CP antenna.

Fig. 5 depicts at different time phase simulated results of surface current distributions of suggested antenna. It illustrates simulated surface current distribution of the suggested antenna at different phases of ωt=0º, ωt=90º, ωt=180º and ωt =270º at frequency 8.2 GHz. It is observed with changes in phase, the simulated surface current vector turns counterclockwise. As depicted in Fig. 5 the surface current vectors direction is in –y and -x direction, respectively, at 0-degree and 90-degree time phase, Overall observation from the surface current distributions is the current vectors in 180º and 270º are in same magnitude and opposite phase to 0º and 90º, respectively. LHCP radiation are observed to be within the far field boresight (+z) direction.

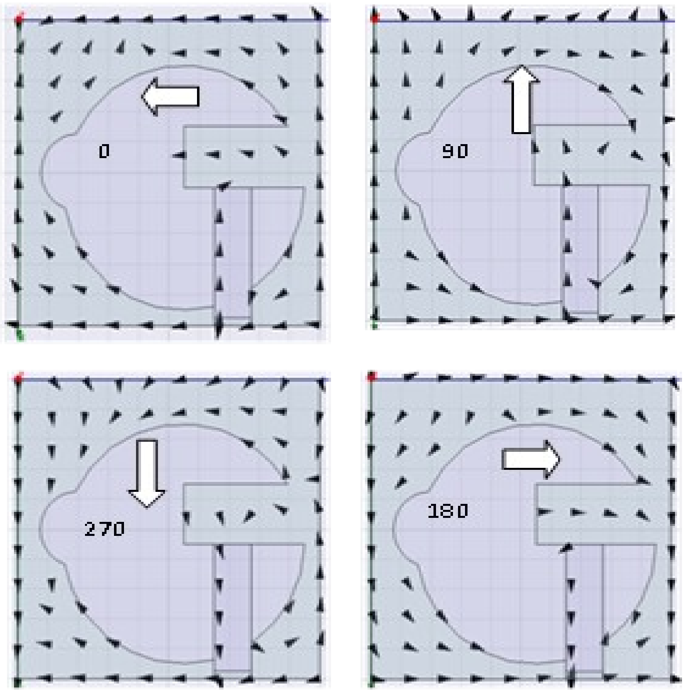
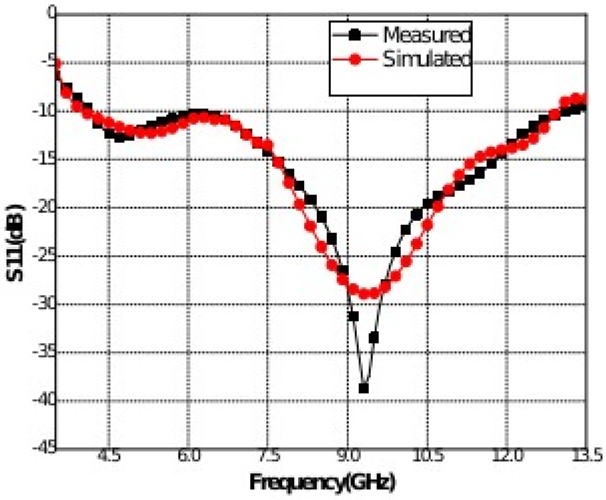
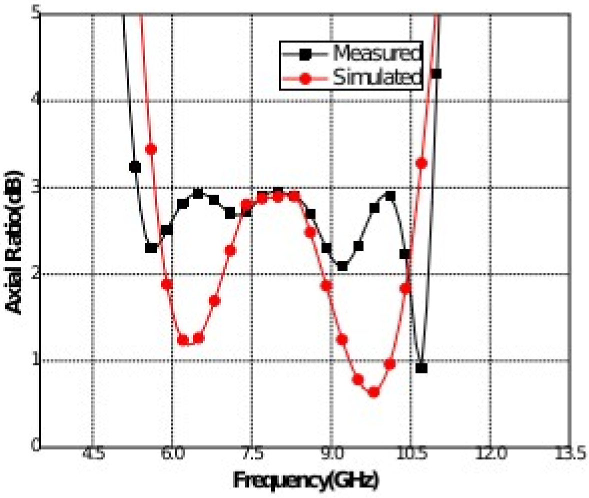


Fig. 5. Simulated surface current distributions of proposed Antenna at 8.2 GHz by the simulator Ansoft HFSS

As observed in Fig. 6 the simulated return loss bandwidth is appropriate with the measured impedance bandwidth. On inclusion of minor slot, more resonant modes are created which leads to enhanced impedance bandwidth of 8900 MHz (4.00–12.9 GHz) which matches with the simulated impedance bandwidth of 9000 MHz (4.1–13.1 GHz). By optimizing the dimensions of minor slot the modes are tuned to get orthogonal modes resulting in CP waves. The simulated 3dB AR of 4960 MHz (5.69–10.65 GHz) corresponding to 60.7% which is close to measured 3dB AR bandwidth of 5500 MHz (5.4–10.9 GHz) corresponding to 67.5%. The suggested antenna shows simulated 3-dB AR which is greater than the AR bandwidth of other ring slot antennas [11]-[13] and [18].



(a)



(b)

Fig. 6. Simulated and measured (a) S11 (b) AR results of proposed antenna.

Fig. 7 depicts the experimental results of normalized far field radiation at 8600 MHz at the two orthogonal planes (ϕ=0° and ϕ=90°). At frequency of 8.2 GHz, the radiation patterns are obtained in both the xz-plane and yz-plane. Experimental outcomes along with the simulated ones, are with affordable agreements, having a moderate tilt inside the direction of the radiation. This is especially because of the uneven designing of the desired antenna which reasons the direction of maximum

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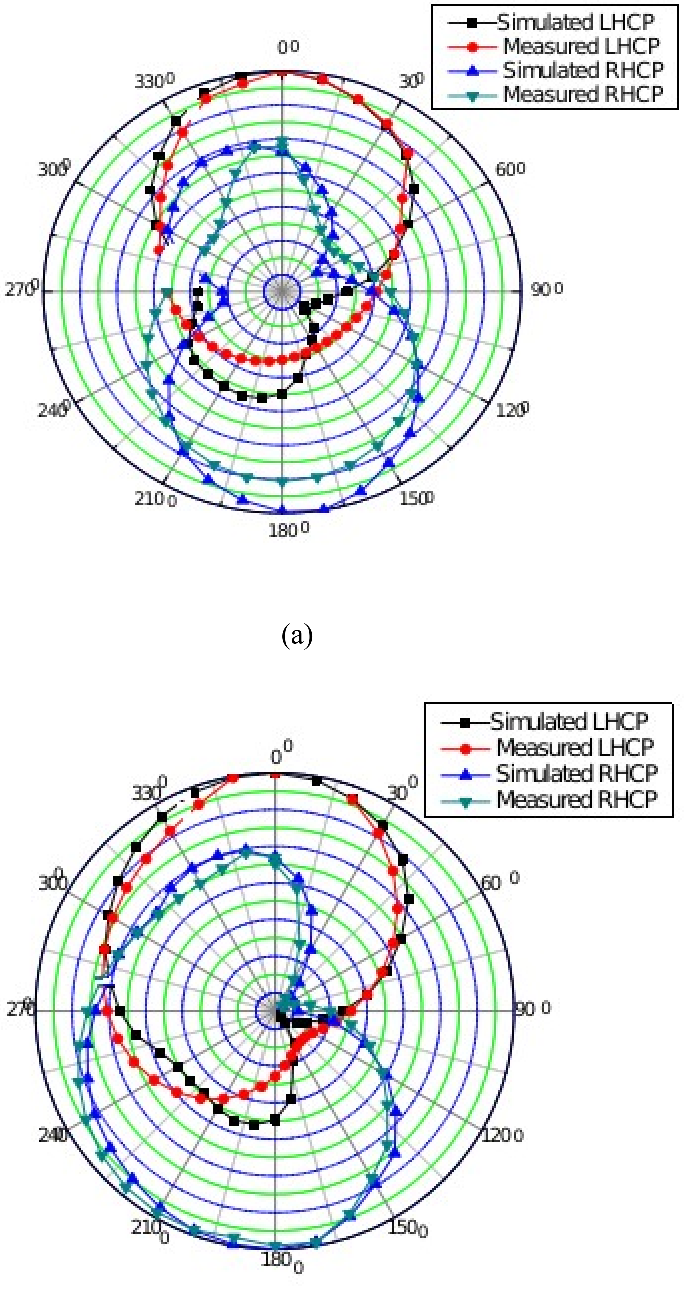
radiation to slightly shift towards the +x and +y directions in the planes of E and H respectively. It is also observed that bidirectional radiation patterns is achieved which concludes that LHCP characteristics are within the higher-half area and RHCP waves in the decrease-half of the area.



(a)

(b)

Fig. 7. At (a) ϕ=0° and (b) ϕ=90° simulated and measured radiation pattern of suggested antenna at 8.2 GHz.

The performance of suggested desired antenna is validated by the experimental results of the gain and VSWR of the antenna. Fig. 8(a) depicts the peak gain versus frequencies, which represents a stable gain varying around 2.32 dB to 5.88 dB, across the AR bandwidth. Fig. 8(b) illustrate the experimental results of VSWR of the designed antenna also depicting that the measured VSWR is in a suitable settlement with the simulated one. A VSWR of less than two in the impedance bandwidth

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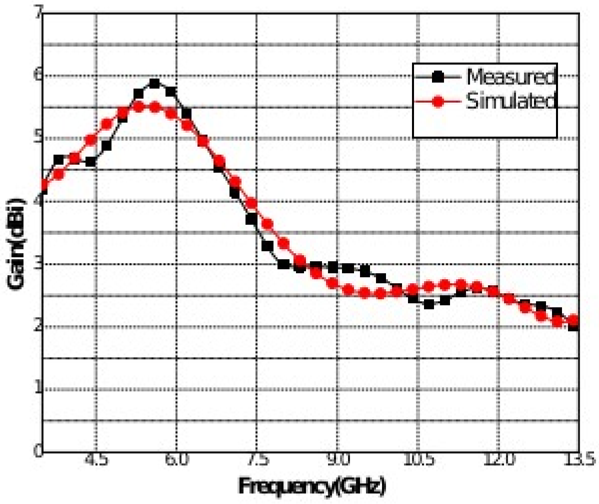
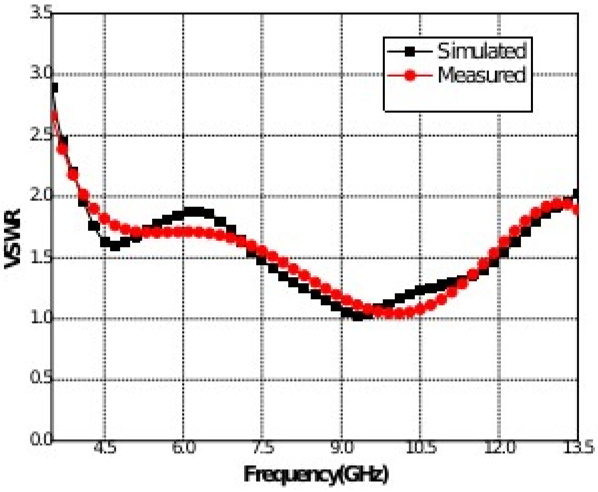
of 9000 MHz (4.1–13.1 GHz) is depicted. It has been observed that the simulated results matches with the experimental results. The little distinction between experimental and simulated outcomes is because of the effect of measurement environment and the tolerances within the producing method.



(a)



(b)

Fig. 8. Simulated and measured results for (a) Gain (b) VSWR for proposed antenna.

Table II lists a brief comparison between various shaped wide slot antennas presented in past years and proposed antenna. In Table II, fc shows 3-dB AR bandwidths center frequency and λ_o is the agreeing to free- space wavelength. The Table II outcomes depicts a wider AR bandwidth with a small size of the suggested antenna, as related to the other listed works.

TABLE II. DIMENSIONS AND PERFORMANCES OF CERTAIN EXITING RING AND WIDE-SLOT ANTENNAS

Ref.	**Antenna Type**	f_c **(MHz)**	**3-db Axial ratio Bandwidth (%)**	**Antenna size (mm × mm),** λ_o^2
[7]	WS	2220	30.6	60 × 60, 0.197
[8]	WS	2413	28.8	60 × 60, 0.233
[9]	WS	2500	16.0	30 × 46, 0.096
[11]	RS	2165	32.8	60 × 60, 0.187
[12]	RS	3030	57.4	106.5 × 106.5, 1.157
[13]	RS	3000	46.7	65 × 35, 0.228
[14]	WS	5790	32.2	60 × 60, 1.341
[15]	WS	3575	85.0	60 × 60, 0.511
[16]	WS	1575	3.81	60 × 60, 0.099
[18]	RS	3700	27	50 × 50, 0.381
[19]	WS	5750	40	25 × 25, 0.230
Proposed	**RS**	**8150**	**67.5**	**20 × 20, 0.122**

IV. CONCLUSION

A wide circular slot compact antenna with simple configuration has been presented in this paper to obtain wide-ranging impedance bandwidth and axial ratio bandwidth. In the designed antenna, a circular shaped slot having a minor circular segment is cut into the ground plane followed by a horizontal strip for CP radiation has been proposed. Despite the fact that the antenna design systems are based totally on the cheaper FR4 substrate. The achieved AR bandwidth is up to 67.5%, covering the frequency range 5.4-10.9 GHz. The designed antenna presents a wide impedance bandwidth of about 9 GHz/9000 MHz (4.1–13.1 GHz) corresponding to 104%. The antenna is compared with previously reported different wideband CP antennas, demonstrating its wide operating bandwidth with CP characteristics and antenna size with reference to the cross-sectional area.

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