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Circularly Polarized Antenna with Metallic Reflector for High-Gain Satellite Communication

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Abstract— This paper describes the design and performance of a circularly polarized antenna for satellite communication applications. The antenna design includes a monopole patch antenna, split ring resonator, defective ground surface and a metallic reflector. The antenna is designed to operate in multiple frequency bands and to have high gain. The metallic reflector is used to enhance the antenna gain by reflecting the signal in the same phase as the transmitted signal, thereby strengthening the signal. The antenna resonates in 4.4 GHz and 7.6 GHz frequency bands, making it suitable for satellite communication applications. The paper presents both simulated and measured results of the antenna's performance, including return loss, gain, VSWR and polarization characteristics. The paper provides a detailed analysis of antenna's performance, demonstrating its suitability for satellite communication applications. The use of a metallic reflector, the split ring resonator and defective ground surface design results into antenna's high gain and multiband operation.

Keywords-Microstrip patch antenna, circular polarization, ring resonator, defective ground, reflector.

I. INTRODUCTION

The demand for microstrip antennas (MSAs) is increasing due to their small size, low cost, and low power consumption, making them ideal for wireless devices like cellular systems, wireless network switches, and industrial automation devices. Broadband antennas are also gaining popularity since they can be used in several practical applications including in wireless communication application. By literature survey indicates that researchers have developed various techniques to improve the bandwidth of MSAs, such as creating resonant structures by removing various shapes from patch or ground surface [1,2].

Microstrip antennas (MSAs) have gained immense popularity in recent years due to their compact size, low cost, and low power consumption. These features make MSAs ideal for use in small handheld devices such as cellular systems, smart watches, and home automation devices. The increasing demand for these wireless devices has led to a growing demand for MSAs. Broadband antennas are another type of antennas that have gained significant attention due to their ability to operate over a wide frequency range, making them a practical solution for many scenarios. To improve the bandwidth of MSAs, researchers have utilized various techniques. One approach is to create resonant geometry through etching of various shapes into the MSA, such as various English alphabet like E, V, F or geometrical slots [3,4]. Another approach is to add multiple patches to the antenna design. These techniques help to enhance the bandwidth of the MSA, making it more versatile and suitable for a broader range of applications.

Circularly polarized (CP) radiations are becoming increasingly popular in wireless communication systems due to their ability to overcome multipath distortion and the Faraday effect. RHCP and LHCP antennas can be used to generate waves with the respective polarization. One common design for a circularly polarized microstrip antenna involves placing a slit and a stub on the ground plane of the antenna, along with an asymmetrical feed that provides an orthogonal component to the design [5]. The slit and stub help in creating the necessary phase shift between the two orthogonal components of the wave, while the asymmetrical feed helps in exciting the two components with the correct phase relationship to generate circular polarization. Circularly

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polarized microstrip antenna designs may use different design techniques, such as introducing a phase delay through the use of a quarter-wave transformer or using a crossed-dipole configuration [6]. The specific design used will depend on the desired frequency range and performance requirements of the antenna. Another method is to use a 2x2 single-fed CP corner-cut MSA, which consists of four patches arranged in a square pattern [7]. A third approach involves using a 4x4 substrate-integrated waveguide feed to a slit-joined switched strip with a copper topped through boundary made-up using Low-Temperature Co-Fired Ceramic technology [8].

High gain antennas offer numerous benefits such as increased efficiency, enhanced transmission range, and reduced transmission power. These advantages make them well-suited for various practical applications such as wireless communication, satellite communication, and radar systems. A variety of techniques can be used to improve the gain of antennas [9], including the use of antenna arrays, superstrates, and frequency selective surfaces (FSS) [10]. These methods aid in enhancing the effectiveness and efficiency of antennas by boosting gain and bandwidth, minimizing radar cross-section, and generating circularly polarized waves to avoid the effects of multipath distortion and the Faraday effect.

II. Antenna Design

This paper provides technical details for the design of a high gain circularly polarized microstrip antenna. The substrate of the antenna is a square FR4 with specific dimensions and properties, including reflection coefficient 4.4 and loss tangent value tanδ 0.02. In the antenna geometry; monopole is placed on the one side of substrate, which is covered partially by a ground on the other side with its own dimensions. To make the multiband antenna, a rectangular split ring with a slot is positioned near by the monopole so that electric field of antenna can be coupled with split ring. The antenna is suspended at an optimal height from a square metallic reflector surface with specific dimensions, and both structures are aligned precisely. The metallic reflector reflects backward radiation at an angle of 180°, thus boosting the antenna's gain. The proposed design generates RHCP waves for a frequency band of 4.6 GHz and 7.01 GHz by exciting a reflector with an SRR and a rotating current. The proposed antenna structure is optimized by using Ansys High-Frequency Structure Simulator (HFSS) Version 15, and its optimized dimensions are listed in Table 1. The antenna is fabricated by using the data given in Table 1 to validate the simulation and measured results.

III. Operating Mechanism Of The Antenna Design

The proposed antenna design exhibits circular polarization and high gain characteristics. The gain is increased, and circular polarization is generated by placing the metallic reflector beneath the patch radiator and feed position on the antenna. There are two factors responsible for this. Firstly, the placement of the metallic reflector under the patch radiator results in the reflected waves being in the same phase as the main lobe radiation, leading to enhanced gain. Secondly, the waves transmitted by the reflector are circularly polarized waves because the reflector is energized by a source that exhibits characteristics that are like circularly polarized. Due to the monopole nature of the antenna, the radiated waves from the upper plane are divided into two parts E1 and E2, as shown in Figure. 2. Wave E2 undergoes a 180° phase shift from the reflecting surface and an additional 180° phase shift due to path difference. Therefore, the total phase difference between the direct radiating wave and the reflected wave achieves 360°, which is a necessary requirement for gain enhancement.

As shown in Figure 2, when a backward electromagnetic wave is incident on a metallic reflector, the wave is reflected back at an angle of 180° toward the main lobe in the same phase as the main lobe radiation, resulting in gain enhancement of the proposed design. The total path difference can be calculated by evaluating the effective dielectric constant of the medium consisting of the substrate and the air above it.

The step-by-step process of designing the antenna is shown in Figure 3. We first designed a monopole circularly polarized patch antenna, then we added a split ring resonator near the patch antenna, then another split ring resonator, and finally some patches on the back side of the antenna i.e.in the ground plane. In all designs, we applied the defective ground plane.

TABLE I. ANTENNA PARAMETERS AND THEIR VALUES

Label	L_1	W_1	L_2	W_2	L_3	*W3*	*L4*	*W4*
Value (mm)	21	21	2.5	14.7	21	5	4	4
Label	*L5*	*W5*	*l1*	*w1*	*l2*	*w2*	*w3*	*L5*
Value (mm)	50	50	9	9.2	6	6.4	3.8	50
Label	*b*	*l4*	*w4*	*l5*	*w5*	*b*	*l4*	*w4*
Value (mm)	0.8	4	4	14.7	21	0.8	4	4

IV. Results and Discussion

The simulated reflection coefficient S11 vs frequency curve shown in figure 4 for design 1 shown in figure 3 typically shows that a good matching between antenna and feed line may be achieved at frequency 4.35 GHz. For design 2 good matching is realized at frequency 4.5 GHz but an additional dip at frequency 7.8 GHz is obtained due to variation in geometry. On further improvement in the geometry as shown in design 3, good matching at three

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frequencies viz. 4.3 GHz, 6.4 GHz and 7.7 GHz are realized. However, with finally considered modifications in the structure of antenna, amount of matching between antenna and feed is reduced. The finally considered design 4 provides good matching at frequencies 4.4 GHz and 7.6 GHz. A comparison between simulated and measured reflection coefficient values and VSWR values for design 4 as a function of frequency is shown in figures 5(a) and 5(b) respectively. A nice agreement between simulated and measured results for design 4 may be realized from these figures. The measured 3dB bandwidth for design 4 corresponding to frequency 4.4 GHz is close to 0.9 GHz while corresponding to frequency 7.6 GHz it is close to 1.1 GHz.

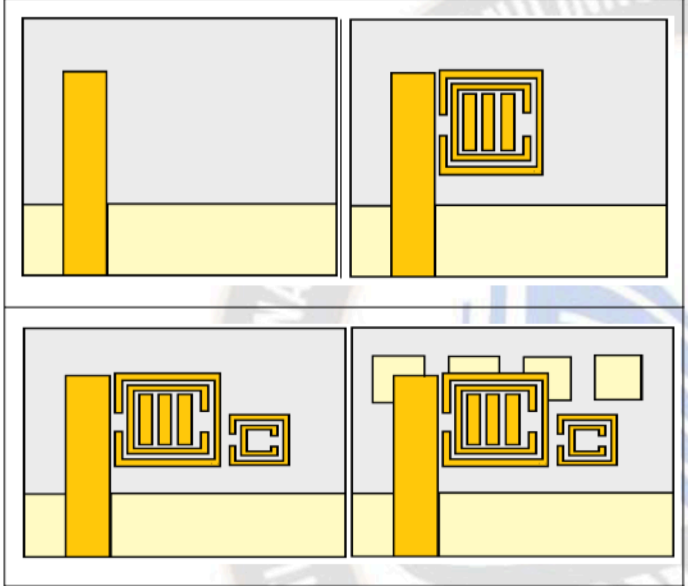


Figure 3: Design 1 to Design 4 schematic diagram

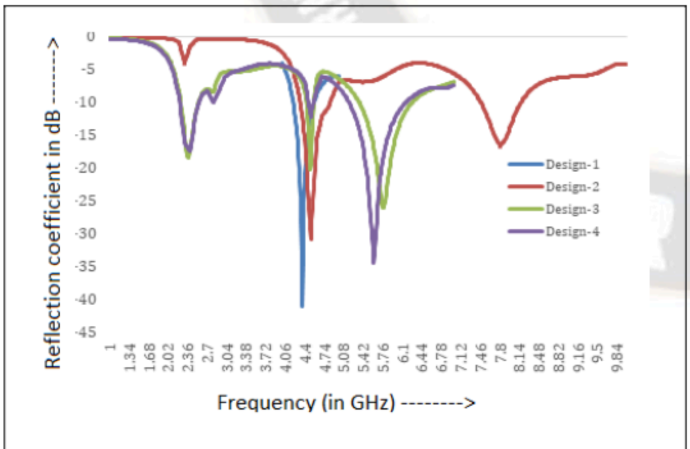
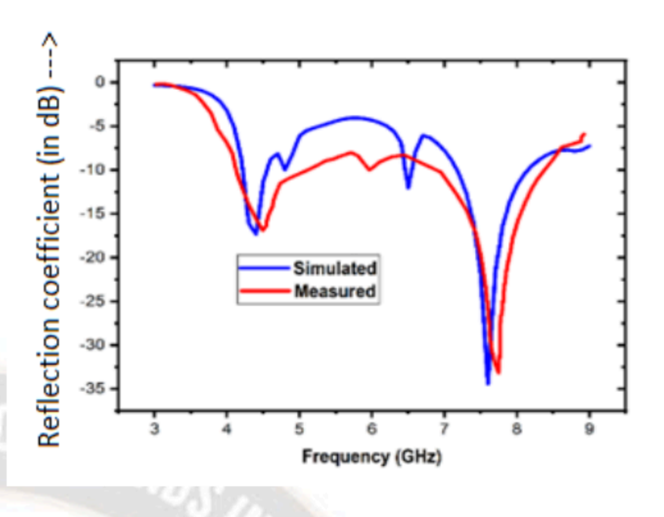
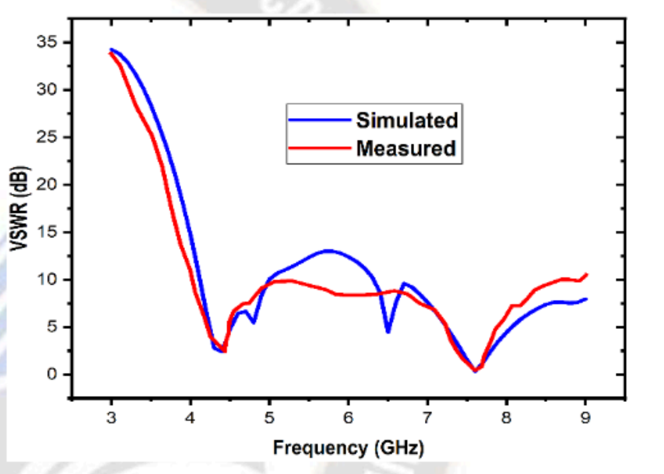


Figure 4: Variation of Reflection coefficient as a function of frequency for various designs



(a)



(b)

Figure 5: Comparison of simulated and measured Reflection coefficient and VSWR as a function of frequency for design 4

Figure 6 shows the variation in simulate gain of antenna as a function of frequency. These variations are obtained for all the four designs. For design 1, the realized maximum gain is close to 6.35 dB at frequency 4.35 GHz. For design 2, the realized simulated gain of antenna at frequencies 4.5 GHz and 7.8 GHz are close to 7.97dB and 2.3dB. For design 3 at frequencies 4.3 GHz, 6.4 GHz and 7.7 GHz, the simulated gain of antenna is close to 7.8, 5.8, and 2.6 dB, respectively while for design 4, corresponding to the frequencies 4.4 GHz and 7.6 GHz, the gain values are close to 7.65 and 5.6 dB respectively. A comparison between simulated and measured gain values as a function of frequency for the design 4 is presented in Figure-7 which provides good agreement between two results.

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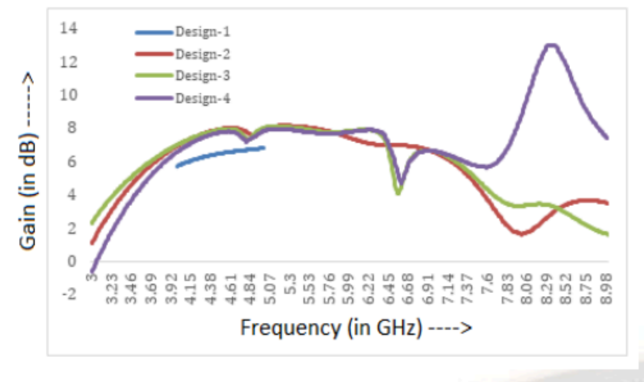

Figure 6: Simulated gain variations of four designs with frequency

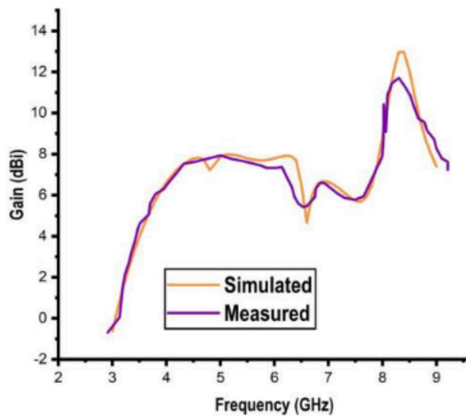

Figure 7: Comparison between simulated and measured gain variations of design 4 with frequency

Figure 8 shows the simulated axial ratio variation of all four designs as a function of frequency. In Design 1, the value of the axial ratio at frequency 4.35 GHz is 2.72 dB which indicates that antenna is displaying circular polarization at this frequency. Design 2 indicates that at the two considered frequencies 4.5 GHz and 7.8 GHz, the axial ratio values are significantly higher than 3dB desired value and hence the behavior of the antenna is not circularly polarized at these frequencies. In Design 3, antenna is displaying circular polarization at frequency 7.77 GHz. Design 4 is designed to obtain circular polarization at both the desired frequencies (4.4 GHz and 7.6 GHz) and the axial ratio values at both these frequencies are less than 3dB (2.4 dB and 1.4 dB). Figure 9 provides a comparison between measured and simulated axial ratio variations for design 4. Both simulated and measured results are indicating that design 4 is providing circularly polarized radiations at frequencies 4.4 GHz and 7.6 GHz.

A comparison between simulated gain and axial ratio variations as a function of frequency is presented in table – II for all he four designs.

Figure 10 (a) and 10(b) provide the comparison between measured and simulated LHCP and RHCP gain values at two desired frequencies 4.4 GHz and 7.6 GHz for design 4. A nice agreement between simulated and measured results at both the frequencies is achieved.

TABLE- II: COMPARISON BETWEEN VARIOUS DESIGNS

Design	**1**	**2**		**3**			**4**	
Frequency	4.35	4.5	7.8	4.3	6.5	7.7	4.4	7.6
Gain	6.35	7.97	2.3	7.8	5.8	2.6	7.6	5.6
AR	2.72	15.5	6.5	16.7	23	3.0	2.4	1.4

V. CONCLUSION

This paper presents the design and performance of a circularly polarized patch antenna with metallic reflector high gain satellite communication systems. For operation in multiple bands, split rings near the monopole antenna are arranged while defective ground plane is considered to obtain wide bandwidth. For enhancing the gain of antenna, a reflector is placed at an optimal distance from the radiating structure. Desired antenna is realized in four steps and performance of antenna in every stage of development is checked. The final design is a successive progression from design 1 to design 4. An excellent agreement in simulated and measure gain and axial ratio variations for design 4 indicates that antenna is very carefully designed.

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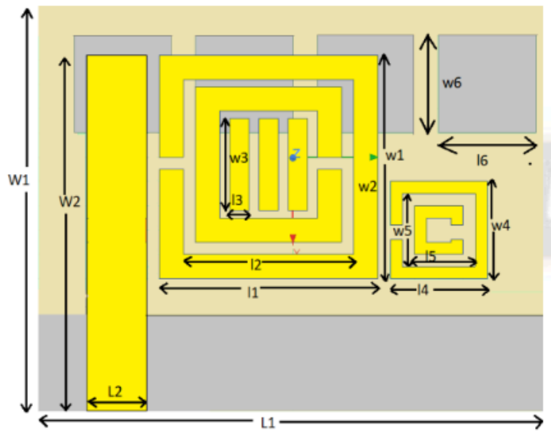

Figure 1(a): Geometry of upper side of antenna in yellow colour while back side in blue colour

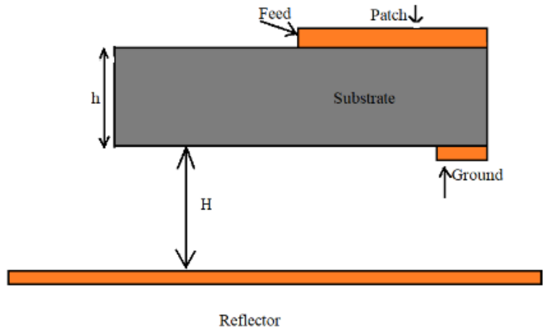

Figure 1(b): Side view of antenna geometry

Figure 1 (c): Dimensions of reflector used

Figure 1(d): Different views of fabricated antenna structure

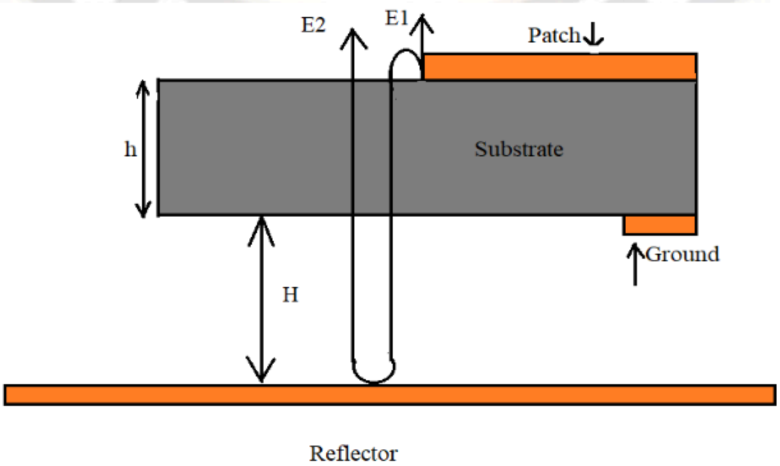

Figure 2: Working of antenna with reflector

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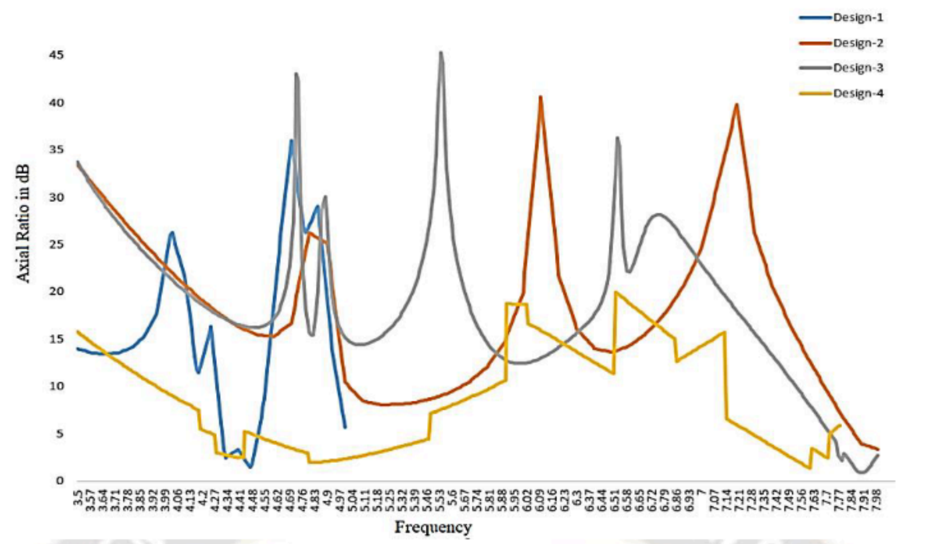

Figure 8: Simulated axial ratio variations of four designs with frequency

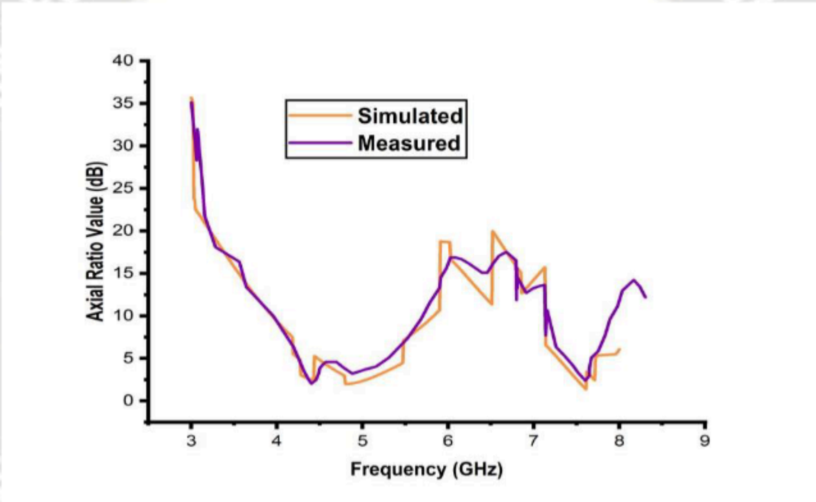

Figure 9: Comparison between simulated and measured axial ratio variations of design 4 with frequency

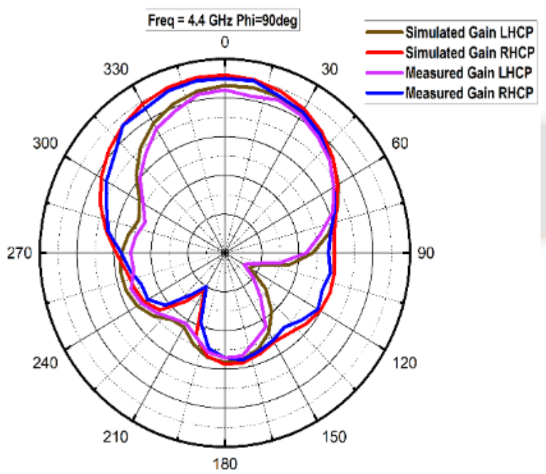

Figure 10(a): Comparison between measured and simulated LHCP and RHCP gain values at frequency 4.4 GHz for design 4

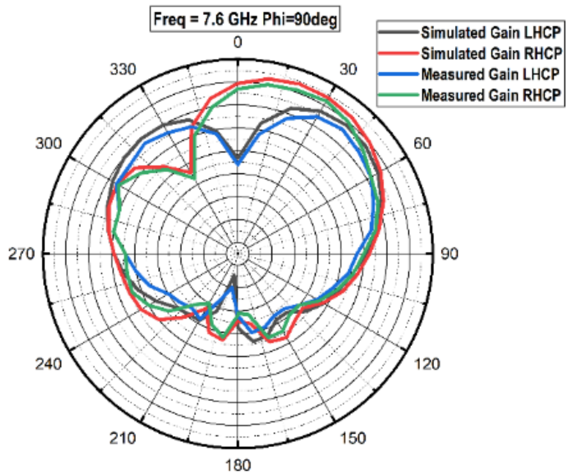

Figure 10(b): Comparison between measured and simulated LHCP and RHCP gain values at frequency 7.6 GHz for design 4

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