

Designing, developing and analyzing of a rectangular-shaped patch antenna at 3.5 GHz for 5G applications at S band

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ABSTRACT

This research study focuses on the design and analysis of two distinct patch antennas for 5G applications at 3.5 GHz. Rogers RT5880 served as the foundational material for antenna designs I and II. A 50 Ω feed line is utilized to supply both antennas. According to the calculations, Design I exhibits a reflection coefficient (S_{11}) of -32.98 dB, a voltage standing wave ratio of 1.045, a gain of 7.81 dBi, an efficiency of 89.2%, and a surface current of 66.82 A/V. Design II has a reflection coefficient (S_{11}) of 34.98 dB, voltage standing wave ratio (VSWR) of 1.036, gain of 8.78 dBi, efficiency of 89.87%, and surface current of 62.7 A/V. Among the two antenna designs, design II outperformed design I, and the results indicate that the antenna fulfilled the designated purpose. The novelties of the proposed paper are to design two different patch antennas using same materials and highlight the performance of the design parameters. Design II is proficient in supporting 5G services owing to its advantageous performance. In addition, S_{11} of the antenna is reduced to bring the VSWR value is close to 1. Also, improve gain, directivity and efficiency by bringing the antenna impedance matching close to 50 Ω .

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1. INTRODUCTION

Antennas play a crucial role in both the reception and transmission of waves. The growing demand in social networking, cloud computing, e-commerce, and online video streaming necessitates increased data rates. The existing 4G wireless network is encountering a capacity limitation. The increasing data demand may exceed its capacity, prompting a change in focus towards S-band frequencies [1], [2]. The Ericsson mobility report data from June 2024 confirms the rapid increase of data traffic in the 5G mid-band (1-6 GHz). As a result, modern wireless communications seek unlimited power, bandwidth, and spatial efficiency [3]. End-to-end communication and the performance of wireless networks will both be improved by 5G Advanced, which will also provide new efficiencies and lay the technical groundwork for mobile technology. Over the past few years, there have been tremendous developments in the wireless communication components used in 1G, 2G, 3G, and 4G networks. Extremely rapid progress is being made in their applications, which include GPS, Wi-Fi, infrared, and several other [4]. Wireless communication technologies have rapidly progressed to meet the demands of high data volume in electronic products. 5G technologies make use of larger frequency bands to transmit data with large capacities that allow data transfer

speeds of Gbps. Additionally, 5G technologies are capable of gathering and broadcasting an endless amount of data in the most recent mobile technology. 5G is now regarded as one of the most revolutionary technologies in wireless communication. This technique aims to enhance the performance of wireless networks by increasing transmission speeds, enhancing network responsiveness, and expanding coverage. Moreover, 5G technology is recognized for its capability to support numerous linked devices, including autonomous vehicles, smart devices, medical apparatus, and others [5], [6]. Microstrip antennas are optimal choices for applications such as 5G wireless systems due to their compact size, lightweight nature, cost-effectiveness, and ease of fabrication and integration into circuits. Patch antennas have garnered research attention owing to their compact dimensions, adaptability, low profile, and integration potential [7], [8]. Figure 1 illustrates the physical configuration of the patch antenna [9].

This article is organized into five sections for clarity and coherence. The initial portion functions as an introduction. The second section examines the pertinent literature, while the third delineates the materials and procedures employed in the study. The fourth segment assesses the efficacy of the suggested design. The fifth section delineates the conclusion.

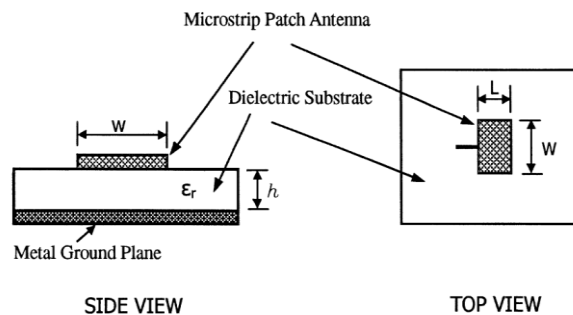


Figure 1. Side and top view of the patch antenna [9]

2. LITERATURE REVIEW

The field of wireless communication, which is the most prolific sector for technological innovation, has seen major developments in recent years. These technological improvements have improved the performance of wireless devices. The subject of wireless communication has witnessed the most significant technological improvement in recent times [10]. The design of antennas is significantly impacted by the increasing number of wireless applications that are becoming available. Microstrip patch antennas are a common choice for wireless antennas due to their inexpensive cost and the ease with which they can be designed. Numerous research papers on 3.5 GHz have been published in reputed journals and publications, and conferences have also featured presentations of these papers with their respective topics. Understanding the design and performance of microstrip patch antennas in applications that take place in the real world is essential, and the explanations that follow provide invaluable insights into these aspects.

This study showcases [4] a patch antenna suitable for WLAN applications. The results of the far-field observations and the input reflection coefficient of the simulated antenna show strong concordance. For the purpose of ensuring that the design is consistent, a comparison analysis with other recent publications is carried out. This study offers [11], a patch antenna that is small and designed for use in 5G applications operating at 3.5 GHz. Both the results of the simulation and the design of the proposed antenna are validated by means of an analogous circuit model to achieve the best possible bandwidth, S_{11} , gain, and efficiency.

In this article [12], various designs of patch antenna arrays for use in wireless applications in the S-band are discussed. All of the parameters for the antenna, including gain, voltage standing wave ratio (VSWR), S_{11} , and bandwidth, have been achieved, according to the findings of the simulation. This study presents [13], a compact and wideband patch antenna design for 5G communication. The antenna arrangement consists of end-fire directing elements and a microstrip folded dipole resonator. This study introduces [14], a small printed antenna utilizing two folded U-shaped arm radiators for 5G applications. The suggested antenna is simulated with the HFSS simulator, constructed, and subjected to experimental testing. The antenna measurements have demonstrated favorable properties that align well with the simulation findings produced. This research examines [15], a circular patch antenna design for 5G wireless network at 3.5 GHz. The incorporation of nanoparticles into the substrate enhanced the antenna's performance and resolved issues concerning dielectric constants, potentially obviating the necessity for several board kinds. This research underscores the promise of integrating nanotechnology with rapid prototyping in antenna design, providing an economical alternative for small-scale facilities. This study shows [16], a new type of

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high-gain polarization reconfigurable fractal antenna that can be used in wideband situations. The proposed antenna is capable of achieving a significant impedance bandwidth and gain, respectively. The performance of the prototype, which was created for both linear and circular polarization, was validated through measurements. This research study presents [17], design a slotted S-shaped patch antenna for wireless applications. The proposed antenna demonstrates an outstanding reflection coefficient, a satisfactory VSWR, and a good gain. In this paper [18], design a hexagonal ring-shaped antenna for 5G applications. The proposed antenna exhibits a compact design, advantageous return loss, uniform omnidirectional pattern, enough gain, and bandwidth throughout all specified bands. This research presents [19] a gap-coupled, ring-shaped patch antenna with quad-band characteristics. The proposed quad-band antenna is an economical and effective solution for wireless communication equipment. This work presents [20] a small coplanar-waveguide-fed rectangular patch antenna with a semicircular ground plane. The antenna's performance was analyzed in two distinct configurations: linear and curved. To achieved S_{11} , directivity, gain, and bandwidth from the design. This work presents [21] a slotted patch antenna for 5G wireless applications. It has achieved a favorable reflection coefficient, superior impedance matching, efficiency, and gain. For 5G applications [22], a slotted plus-shaped patch antenna and a defective ground structure (DGS) have been created and proposed. To achieve return loss, gain, directivity, VSWR, and efficiency from the simulation results. This research presents [23], a downsized antenna design for a tiny patch antenna operating at 3.5 GHz. This antenna conceived attained improved bandwidth and a strong gain.

In order to provide the best possible balance between coverage and high data speeds, the 3.5 GHz frequency band has been widely designated for mid-band 5G services all across the world. It is an essential standard for antenna design due to the fact that it is widely used in regional 5G installations. The proposed design's outcomes are comparatively favorable compared to previously published results, which may be applicable to future 5G wireless applications.

3. DESIGN METHODOLOGY

In contemporary wireless communication systems, antennas are critical components that facilitate reception. A considerable volume of research has been conducted over the past four to five decades to develop antenna designs that are compact, modest in size, efficient, and robust. While wideband antennas exhibiting uniform radiation patterns and high-gain configurations have been recorded, their sizes are considerable. Consequently, there is a demand for antennas that are compact and lightweight, suitable for wireless applications. The reduction in size of the patch antenna may diminish certain advantages, thus impairing its performance [24]. Figure 2 depicts the flowchart of the proposed antenna design.

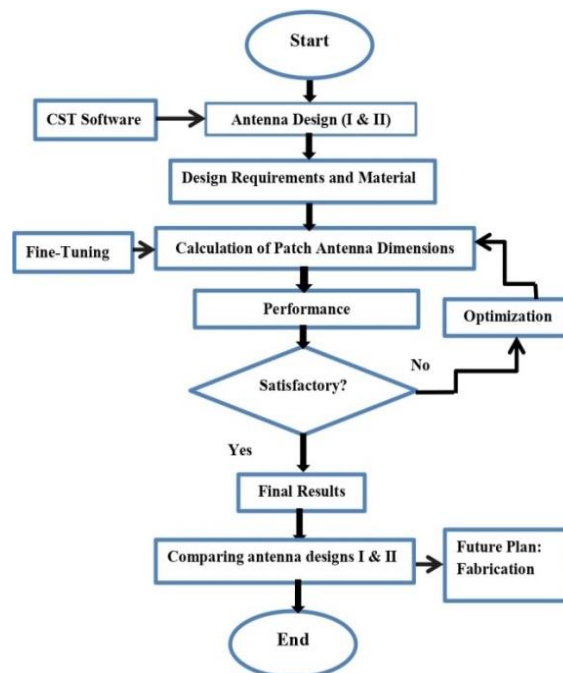


Figure 2. Flow chart of the proposed antennas

When designing a patch antenna for use in wireless applications, the substratum dielectric constant, the thickness, and the resonant frequency must be carefully considered. Figure 3 presents the physical dimensions of design I in Figure 3(a) and design II in Figure 3(b), respectively. The structure being presented is created and constructed on a Rogers RT5880 dielectric material. The material has a loss tangent (δ) of 0.0009, a dielectric constant (ϵ_r) of 2.2, a substrate thickness (H_s) of 0.6 millimeters, and a patch thickness (t_s) of 0.035 millimeters. The proposed antenna design and simulation were both carried out with the assistance of CST software. The dimensions of the antennas above are presented in Table 1.

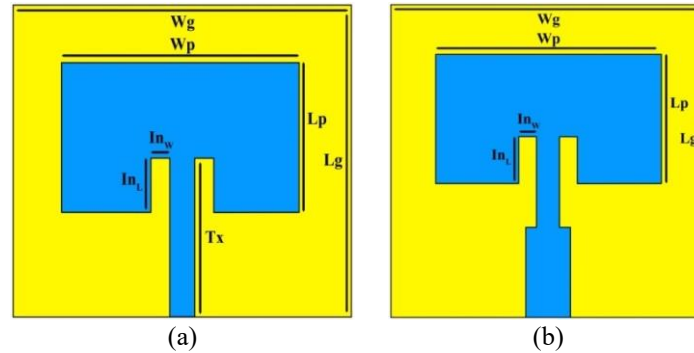


Figure 3. Proposed antenna was designed utilizing CST: (a) design I and (b) design II

Table 1. The suggested antennas have been subjected to improved measurements

Parameter	Wg	Lg	Wp	Lp	Hs	Wf	Wi	Li	Lf	WxF
Design I (mm)	100	70	52.45	27.97	06	1.76	1.5	4	-	-
Design II (mm)	100	70	48	27.78	0.6	1.8	0.8	5	1.5	0.5

4. RESULTS AND DISCUSSION

The findings of the suggested antenna design are discussed in this part. These results include the reflection coefficient, the voltage standing wave ratio (VSWR), gain, directivity, efficiency, surface current, and impedance matching of the antenna. The findings of the suggested antenna are presented in Table 2, and they are also compared with the results that were announced in Table 3 before. Noting that the results of the proposed antenna are superior to those of previously published studies is something that should be taken into consideration. This may make it a good contender for future wireless applications that utilize 5G technology.

Table 2. Delivers a summary of the proposed simulation outcomes

Model	Materials	S ₁₁ (dB)	VSWR	Gain (dBi)	Directivity (dBi)	Efficiency (%)	Impedance matching (Ω)	Surface current (A/m)
Design-I	Rogers RT5880	-32.98	1.045	7.81	8.75	89.25	50.15	66.8
Design-II		-34.98	1.036	7.89	8.78	89.87	49.89	62.7

Table 3. Comparison of the proposed study with several previously published research

Ref	Fr (GHz)	S ₁₁ (dB)	VSWR	Gain (dBi)	Efficiency (%)
[11]	3.5	-23.62	1.19	3.39	-
[20]	3.2	-33	≤ 2	-	-
[21]	3.5	-26.5	below -2	4.2	82
[25]	3.5	-14.13	1.48	4.66	61.51
[26]	3.5	-19.96	1.22	3.8	-
[27]	3.5	-	-	7.5	80
This works	3.5	-34.98	1.036	8.78	89.87

4.1. Reflection coefficient

The reflection coefficient quantifies the proportion of an electromagnetic wave reflected at antenna terminals within the transmission medium and it has the symbol S_{11} . According to equation 8, an S_{11} value is a negative value measured in decibels that reflects the ratio of the reflected power (P_{ref}) to the incident power (P_{in}) at port 1. If S_{11} is less than -10 dB, then 90% of the power that is excited is communicated [28]. Figure 4

illustrates the predicted return loss of the proposed Antenna design I and design II. At 3.5 GHz, the reflection coefficient (S_{11}) of design I is -32.98 dB, while design II is -34.98 dB.

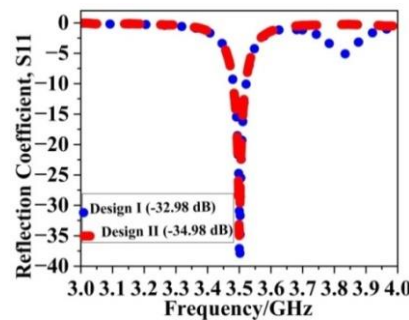


Figure 4. Graph of frequency versus return loss of gap inset feed

4.2. Voltage standing ratio

The voltage standing wave ratio (VSWR) quantitatively assesses the degree of impedance matching between the antenna feed and the transmission line during transmission. It is characterized as a quantification of the discrepancy between the load and the transmission line. Also, it indicates the antenna radiation when it is less than or almost equal to 2. In an ideal world, this value would be equal to 1. The antenna is emitting radiation [24], [29]. Figures 5(a) and 5(b) illustrates that for each resonant frequency of the proposed designs I and II, the VSWR values are at or below 2. Both antenna I and antenna II have a VSWR value of 1.0458 at 3.5 GHz.

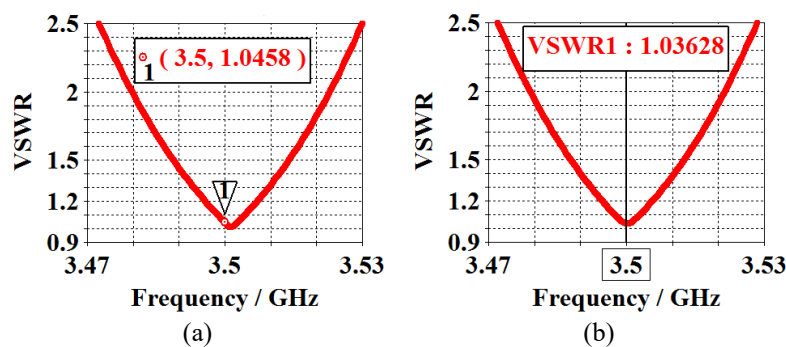


Figure 5. Graph frequency versus VSWR of simulation result: (a) design I and (b) design II

4.3. Radiation pattern

Radiation patterns are graphical representations of the dispersion of electromagnetic power in free space. Figures 6(a) and 6(b) and Figures 7(a) and 7(b) illustrate the two-dimensional and three-dimensional radiation patterns. The E-plane radiation patterns of the proposed antenna in three configurations: straight, horizontally bent, and vertically bent, along with the H-plane radiation pattern. The E-plane radiation pattern demonstrates that the antenna displays bi-directional radiation across all three circumstances. In contrast, the H-plane pattern indicates that the antenna radiates bi-directionally when aligned straight, quasi-omnidirectionally when bent vertically and almost omnidirectionally when curved horizontally. The E-plane far-field patterns of the two models are strongly correlated. The parameters of the radiation pattern are also displayed in Table 4.

4.4. Gain and directivity

Gain refers to an augmentation in power level [9]. Antenna gain is typically referenced to an isotropic antenna and is represented in dBi. An antenna's energy gain is contingent upon its directivity and energy dissipation [29]. At a frequency of 3.5 GHz, designs I and II exhibit gain of 7.81 and 7.89 dBi, respectively as shown in Figures 8(a) and 8(b). Directivity is a performance metric for an antenna. In the

direction of the antenna's maximum emission, it measures the power density of the antenna as it radiates. It can be shown in Figures 9(a) and 9(b) that designs I and II have a directivity of 8.75 and 8.78 dBi, respectively.

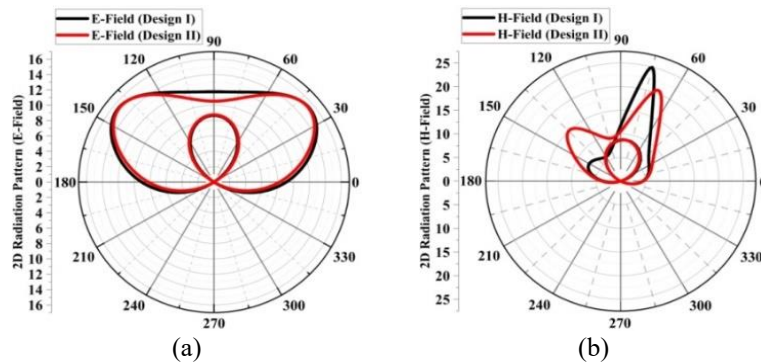


Figure 6. Perspective of 2D radiation pattern design I and II: (a) E-Field and (b) H-Field

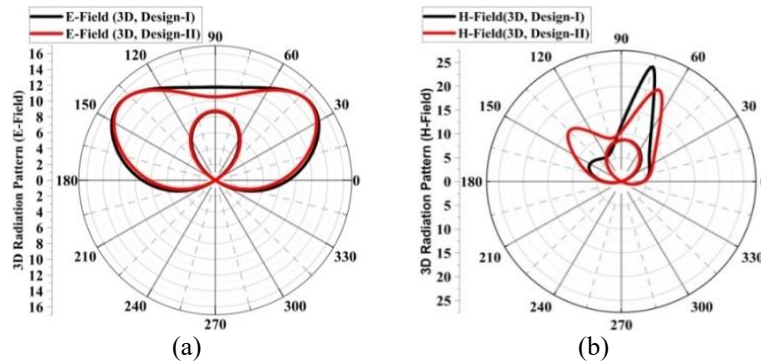


Figure 7. View of 3D radiation pattern design I and II: (a) E-Field and (b) H-Field

Table 4. The determinants that affect the radiation pattern of an antenna

Parameter	Design I	Design II
Main lobe magnitude (E-plane)	0.0 Deg.	0.0 Deg.
3 dB Beamwidth (E-plane)	63.0 Deg.	65.2 Deg.
Side lobe label (E-plane)	-20.4 dB	-19.3 dB
Main lobe magnitude (H-plane)	6.0 Deg.	4.0 Deg.
3 dB Beamwidth (H-plane)	75.1 Deg.	72.8 Deg.
Side lobe label (H-plane)	-14.7 dB	-18.1 dB

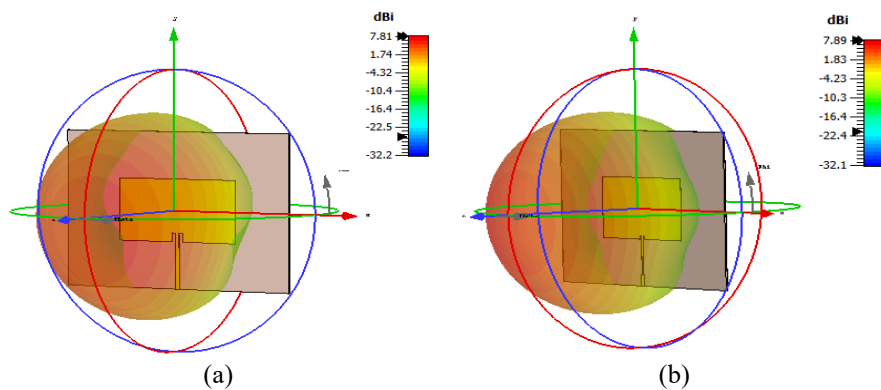


Figure 8. Depiction of the 3D gain pattern of: (a) design I and (b) design II

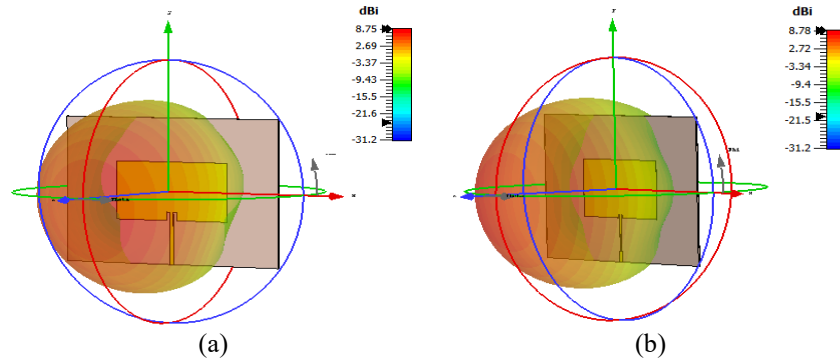


Figure 9. Illustrations of the 3D directivity pattern of: (a) design I and (b) design II

4.5. Efficiency, radiation efficiency and surface current

In accordance with the property of the transmission line, the gain and the directivity are precisely proportional to one another, then is called efficiency [30]. An electric field has been assigned to the antenna to observe the current distribution over the patch and the ground. The blue parts have a current that is zero, whereas the red areas symbolize the intense current. Additionally depicted in the graphic is the effective area that is responsible for the resonance of the proposed antenna at a particular frequency. Figures 10(a) and 10(b) illustrate the radiation efficiency of the proposed antenna. Figure 11(a) and 11(b) depicts the surface current which is measured at the resonant frequency.

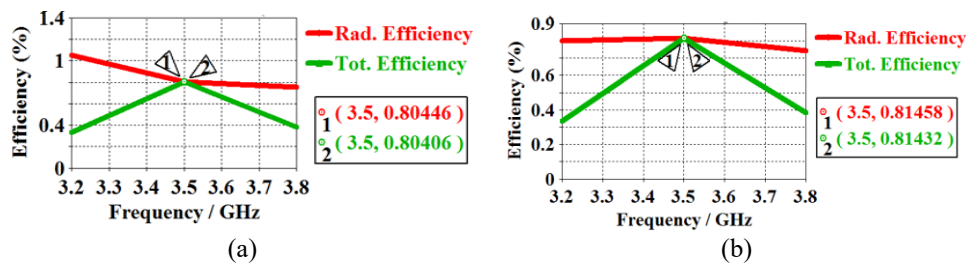


Figure 10. Visual representation of the efficiency of antenna: (a) design I and (b) design II

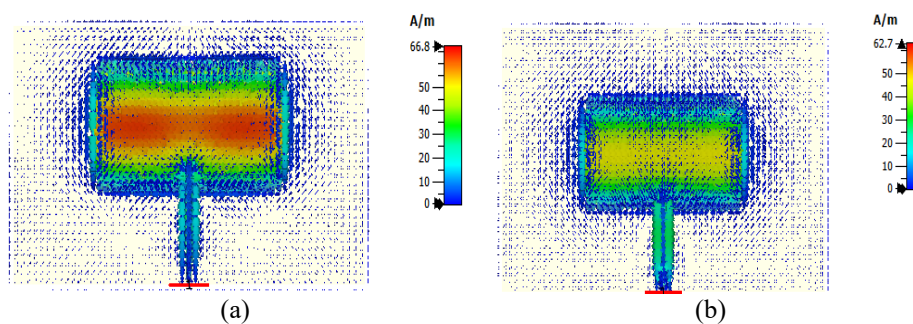


Figure 11. Observation of the surface current in antenna: (a) design I and (b) design II

4.6. Impedance matching and Smith chart

Assuming that the impedance of the power line should be fifty ohms, the design of the antenna is constructed. A matching system can be used in situations where there are significant differences [29]. Figure 12 illustrates the specific input impedance values for antennas I and II as a function of frequency. The impedance plot graphically illustrates the complicated impedance characteristics of a device or system across a range of frequencies. The antenna's impedance is calculated in a complex form by simulation [30]. Figures 13(a) and 13(b) displays the smith chart for antenna designs I and II.

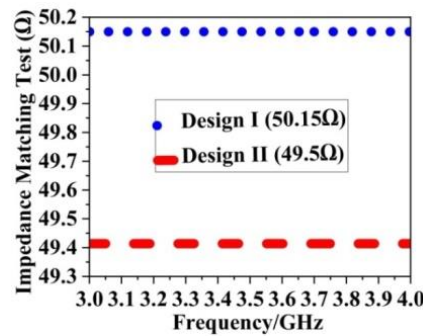


Figure 12. View of impedance matching test

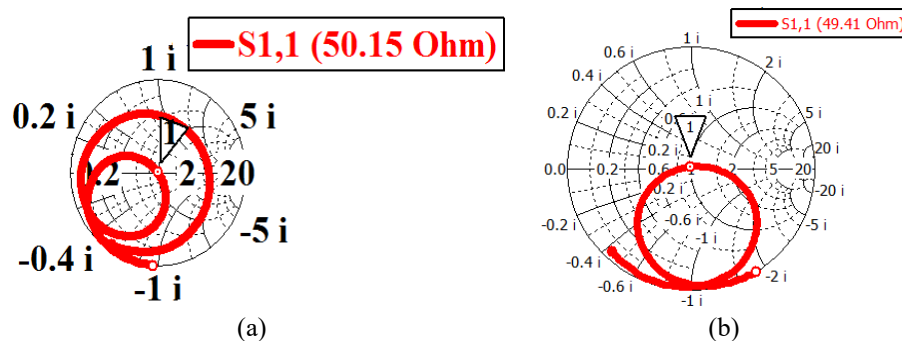


Figure 13. Illustrates the Smith chart for antenna: (a) design I and (b) design II

5. CONCLUSION

This research examines and provides two designs (design I & II) for rectangular microstrip patch antennas appropriate for 5G applications at 3.5 GHz. The design methodology can be employed to create antennas that fulfill the specifications for 5G wireless and cellular networks. This encompasses a low VSWR, a minimal S_{11} , and enhanced gain and efficiency at the selected 3.5 GHz. Moreover, these findings offer substantial insights into the antenna's efficacy and applicability for 5G wireless network applications. The proposed antennas are advantageous for integration into mobile devices due to their operational frequency and compact size. Many methods will be utilized to acquire an additional 5G band, including sub-6 GHz. The antenna's structure could be improved to reach the target band. This could involve increasing the parametric variations or using a different antenna arrangement and dielectric material. Due to physical limitations such as substrate characteristics, geometry, and fabrication tolerances, it is challenging to achieve antenna performance equivalent to that of industry-standard antennas at this particular frequency. The design's manufacturing procedure, on the other hand, is the most significant difficulty. It will be possible to manufacture this antenna in the not-too-distant future and then evaluate the simulation results in comparison to the actual results.

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