Design and Analysis of Microstrip Rectangular Patch Antenna for 5G Applications

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Abstract: The rectangular Microstrip patch antenna is a popular choice for 5G applications due to its integrated design and wideband capabilities. Operating in the 1 GHz to 3 GHz range, this antenna boasts a gain of 4 dBi. In a recent study, researchers utilized the 5G mm-wave bands at a resonance frequency of 39 GHz to create a high-definition video antenna for various 5G applications. The proposed design incorporates a dielectric constant of 4.4 and was analyzed and simulated using HFSS software. Results from the simulation demonstrated a good bandwidth of 3.5 GHz, return loss of -31.87 dB, and a voltage standing wave ratio (VSWR) of 1.
Keywords — rectangular patch, Integrated, high return loss, wireless, 5G applications.

1. INTRODUCTION

Smart home gadgets and appliances are becoming increasingly popular, and a 5G network is necessary to ensure device connectivity and application monitoring. In addition, 5G wireless networks are critical for the development of self-driving cars, as they require high throughput and low latency for autonomous driving. With intelligent traffic lights, environment-based items, and other moving vehicles interacting with automobiles, every millisecond counts to prevent accidents and ensure passenger safety[1]. To achieve this, a high-speed data rate and ample bandwidth are needed, which cannot be provided by the present 4G data rate. Therefore, 5G millimeter waves are being utilized to increase the bandwidth[3]. In this context, a rectangular Microstrip Patch Antenna with good reflection coefficient, high gain, and bandwidth was developed.

The microstrip patch antenna is an essential component of wireless communication and consists of a ground plane, dielectric substrate, and a thin copper metallic patch[2]. The rectangular and circular shapes are the most frequently employed shapes for microstrip patch antennas, and in this project, a rectangular shape was chosen.

The proposed antenna has a high bandwidth of 3.5 GHz resonating at 39 GHz, achieved by

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selecting a dielectric material with low permittivity to ensure high efficiency[4-5]. Microstrip patch antennas are widely used in wireless communication applications. Due to their low profile, simplicity in production, and compatibility with planar circuits. Rectangular microstrip patch antennas, in particular, are frequently used in 5G applications due to their high gain, efficiency, and compatibility with high-frequency bands[6-8].

2. DESIGNING

In the suggested design, the microstrip patch antenna was created using the High Frequency Structure Simulator (HFSS).Due to their flexibility for feed line multiple frequency operations, circular and rectangular patch antennas are frequently utilized for a variety of applications.To improve the return loss and bandwidth we increased the design parameters of the microstrip rectangular patch antenna such as the width and length of the substrate.In the proposed microstrip rectangular patch antenna we have removed the e-shaped patch and used a rectangular patch to increase the directivity and also to change the omni-direction antenna into the directional antenna.Therefore the directivity of the microstrip rectangular patch antenna is increased.

3. PARAMETER ANALYSIS

The most optimal combinations are found in the rectangular patch antenna.When developing an antenna, the best electric substrate with a low dielectric constant must be used, and FR4 substrate materials with a 2 mm substrate height are used. Finding the antenna's length and width is the next crucial step. Here we are using equations (1) and (2) respectively and lastly selecting the resonant frequency the authors used the 39 GHz frequency. The parameters used in the design are shown in the below table:

Table 1: PARAMETERS USED FOR DESIGNING ANTENNA

Parameters Symbols	Details of parameters	Value(mm)
Ws	Width of the substrate	7.4
Ls	Length of the substrate	6.25
W	Width of the patch	2.5
L	Length of the patch	3.5
Wf	Width of the feed	0.3
Lf	Length of the feed	1.3
H	Height of the substrate	0.035

3.1 The Calculation Process for Microstrip Patch Antennas:

3.1.1: Finding the Width ()

The input impedance is regulated by width W. By increasing the width of antenna, we can increase the bandwidth and also at the same time reduce the impedance.

$$W = \frac{c}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \quad (1)$$

3.1.2: Finding the Effective Dielectric Constant (εreff)

It is dependent on calculated width and height as well as the dielectric material's dielectric constant. In the case of patch
antennas, the air above the substrate will result in

$$1 < \varepsilon_{reff} < \varepsilon_r \ .$$

εreff comes closer to the true value of the substrate's dielectric constant ε_r for ε_r >> 1.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{W} + \frac{\varepsilon_r-1}{W}(1+\frac{12h}{W})^{-\frac{1}{2}} \quad (2)$$

3.1.3: Effective length calculation (L_{eff})

Adding the length L to the extension of the length ΔL yields the effective length, which is then calculated.

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (3)$$

3.1.4: Calculating the ΔL-length extensions

Because of the effect of fringe, the microstrip patch antenna seems longer than its actual length. As a result, the effective length is ΔL shorter than the actual length. An extremely common approach for determining the extension of the patch's length is

$$\Delta L = 0.412h\frac{(\varepsilon_r+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

3.1.5: Measurement of patch actual length (L_{eff})

By deducting effective length from the length of Δ L's extension, we may determine the real length.

$$L = L_{eff} - \Delta L \quad (5)$$

When using the aforementioned variables, the resonance frequency is f_0, W is the patch's width, L is the length, h is the thickness, r is relative permittivity, and c is the speed of light which is 3 x 10^8.

4. STIMULATION ON HFSS

The parameters are shown in Table.2 helps us in designing the antenna in High Frequency Structure Simulator(HFSS). Fig.1 shows how the finished antenna would look after designing using the parameters in Table.2 in the HFSS software. After simulating the antenna in HFSS, we get the results of the antenna, which gives us different mathematical values like VSWR, S-parameters, etc.

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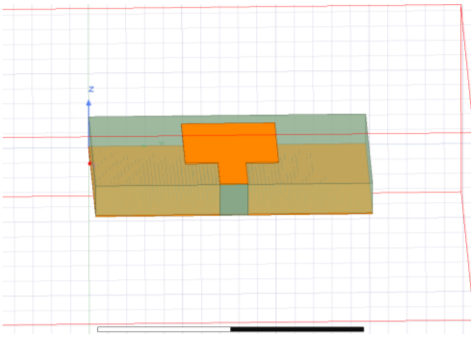

Figure 1. Perspective View of Rectangular antenna

Table 2: ACTUAL PARAMETERS USED IN HFSS

Max U	1.7244 mW/sr
Peak Gain	4.2345
Peak Directivity	3.0423
Peak Realized	2.167
Peak System	2.167
Radiated Power	7.1231 mW
Accepted Power	9.2751 mW
Incident Power	10 mW
System Power	10 mW
Radiation Efficiency	0.76798
Total Efficiency	0.71231
System Efficiency	0.71231
Decay Factor	0
rE Field Total	1.1403 V
X	895.28 mV
Y	631.94 mV
Z	1.1033 mV
Phi	-58deg, 140deg
Theta	70deg, 0deg

5. RESULTS

Other names for it include voltage standing wave ratio and standing wave ratio or standing wave ratio. The magnitude of the mismatch increases with increasing VSWR. As a result, the authors suggested the microstrip patch antenna in Figure 2, which has a 1.04 VSWR at 39 GHz.To get a good quality the VSWR should be in the range of 1≤VSWR≤2. (s11) depicts the reflection coefficient, sometimes referred to as return loss. The performance of an antenna normally depends on a good reflection coefficient or return loss of at least -10 dB or better than -15 dB since the return loss of an antenna is a ratio of incoming power to reflected power. The antenna radiates no power if the reflection coefficient is 0 dB.
since the antenna has reflected all of the power. The return loss is -31.02 and the bandwidth is 3.45 GHz, as indicated in the figure. We can transmit high-quality video and other 5G apps using this high bandwidth**.**

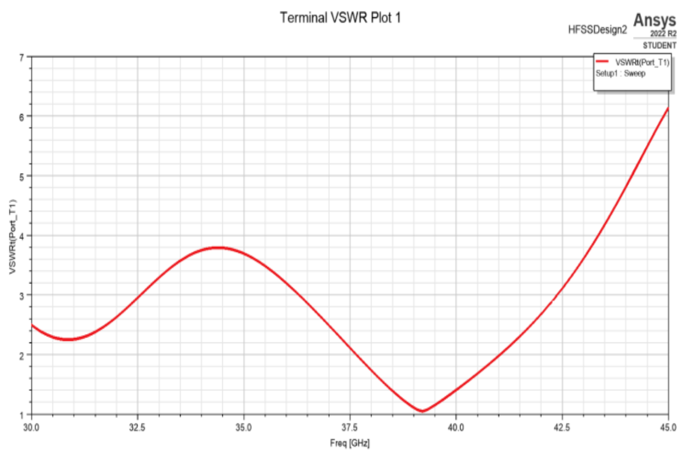

Figure 2. Voltage Standing Wave Ratio

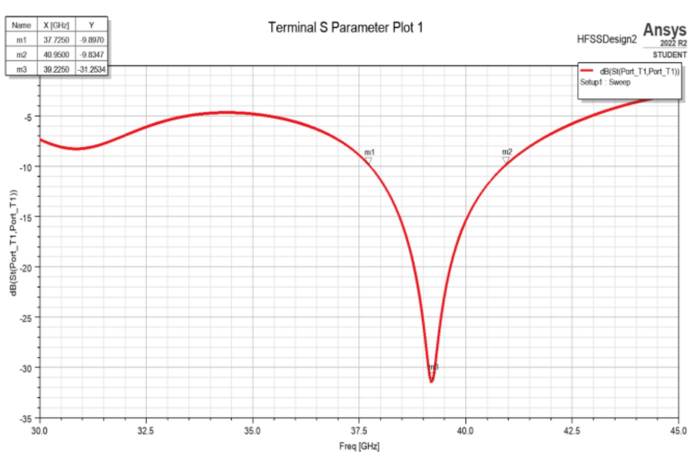

Figure 3. S-Parameters

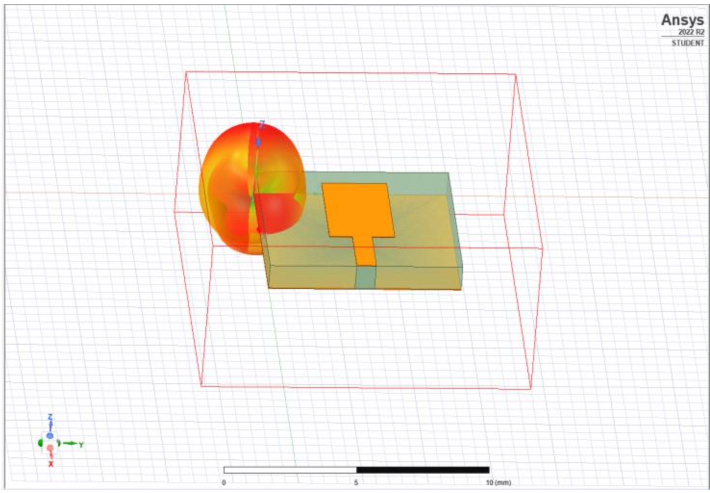

Figure 4. Radiation Plot of Microstrip Patch Antenna

A radiation pattern is a graphical representation of how an antenna radiates electromagnetic waves into the surrounding space. The radiation pattern of a microstrip antenna depends on its physical dimensions, the dielectric constant of the substrate, and the frequency of operation. In general, microstrip antennas have a directional radiation pattern with maximum radiation in the direction perpendicular to the patch

The radiation pattern defines the variation of the power radiated by an antenna. Antenna gain is the ability to emit more or less in any direction as compared to a theoretical antenna.

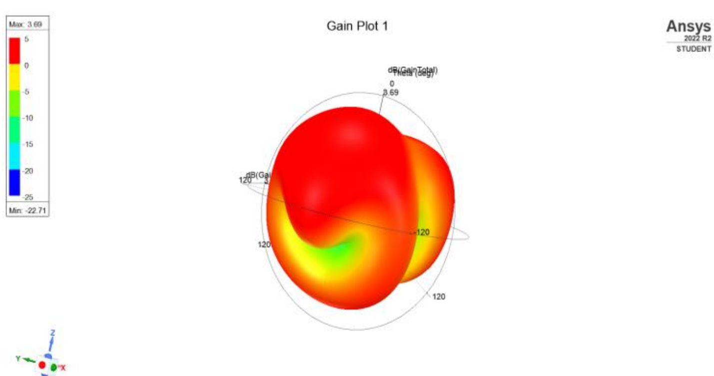

Figure 5. Gain of the Microstrip Patch Antenna

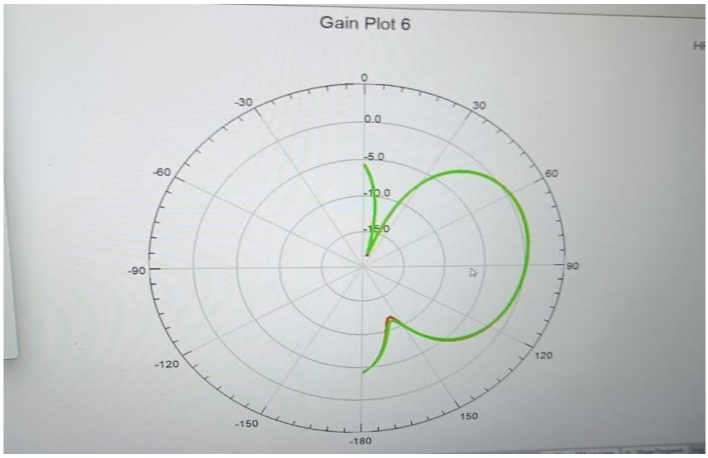

Figure 6. Gain Plot

The microstrip patch antenna's gain is an indicator of how well it can concentrate and point radio waves in a certain direction. According to its definition, it is the ratio of the radiation coming from a source in one direction to the radiation an isotropic radiator would produce a gain of the microstrip patch antenna may be determined using a number of different methods, including simulation software like HFSS or CST, or analytical models like the cavity model or the transmission line model. The precise design parameters and operational circumstances will determine the actual gain of a microstrip patch antenna, which may require optimization through iterative design and testing.

Table 3. COMPARISON WITH THE EXISTING MICROSTRIP PATCH ANTENNAS

Reference	Resonant frequency	Return loss (dB)	Bandwidth (GHZ)	Gain (dB)	Antenna Radiation Efficiency (%)
1	28	-18.25	1.1	6.83	-
2	38	-15.5	1.92	6.9	93.5
3	54	-12	2	7.4	82.7
4	28	-25	1.26	9.75	98
5	38	-17.09	1.05	8.28	-
6	39	-31	3.5	4	79

6. CONCLUSION

The proposed microstrip rectangular patch antenna has been designed and analyzed using High-Frequency Simulation Software. It is successfully implemented using the resonant frequency of 39GHz.The proposed microstrip rectangular patch antenna has higher bandwidth of 3.5 GHZ compared to the previous one. This type of microstrip patch antennas are used in mobile phones for high quality videos, used in cars for speed traffic signals and also used in base station antennas etc., The antenna has a 4 dB gain. The authors have also increased the return loss to -31.9, Voltage Standing Wave Ratio to 1.03 the higher the SWR the greater the mismatch. for quality video and other 5G applications, the VSWR should be $1 \leq vswr \leq 2$.

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