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5G Antenna Design and Analysis using CST Simulation

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Abstract— The antenna structure is modeled and simulated in CST Studio Suite, where different design parameters including substrate material, patch dimensions, feeding techniques, and slot configurations are optimized to achieve enhanced performance. Simulation results demonstrate effective impedance matching, stable radiation characteristics, and improved antenna efficiency suitable for modern wireless communication systems. The proposed antenna can be utilized in 5G mobile devices, Internet of Things (IoT) systems, and next-generation wireless networks. In addition, this work includes a review of recent research papers related to 5G antenna design and CST-based simulation techniques. Previous studies have highlighted the importance of microstrip patch antennas due to their compact size, low profile, ease of fabrication, and suitability for millimeter-wave and sub-6 GHz 5G applications. Researchers have also explored various optimization methods, including slot-loaded structures, MIMO configurations, beam forming techniques, and machine learning-assisted antenna design approaches to enhance antenna performance.

The study concludes that CST simulation tools provide an efficient platform for analyzing and optimizing antenna structures before fabrication, reducing design complexity and development cost while ensuring reliable antenna performance for future 5G communication systems.

Keywords—5G Antenna, Microstrip Patch Antenna, CST Studio Suite, Antenna Design, Antenna Analysis, Wireless Communication, Millimeter Wave Communication, Sub-6 GHz, Return Loss (S11), VSWR, Radiation Pattern, Gain, Bandwidth Enhancement, Electromagnetic Simulation, MIMO Antenna, Beamforming, IoT Applications, High-Frequency Antennas, Antenna Optimization.

Introduction

Fifth-generation (5G) wireless communication technology provides high data rates, low latency, and improved network connectivity for modern communication systems. Antennas play a vital role in 5G networks by ensuring efficient signal transmission and reception at high frequencies. In this project, a 5G microstrip patch antenna is designed and analyzed using CST Studio Suite to evaluate parameters such as gain, bandwidth, return loss, and radiation pattern. The CST simulation tool helps optimize antenna performance and reduce design complexity before practical implementation.: [1] This paper focused on developing a compact inset-fed design specifically optimized for 3GPP Release-15 standards. The dimensions were meticulously tuned in CST Microwave Studio to resonate precisely at 28 GHz on a Rogers RT5880 substrate. [4] This paper used a Quarter-Mode Substrate Integrated Waveguide (QMSIW) technology. By using magnetic walls to divide a circular waveguide into quarters, they achieved a 75% size reduction while maintaining triple-band performance in CST. [6] This paper focuses on designing a comb-shaped slot cut from the radiating patch to reconcile design trade-offs. They also added dual identical slot cuts to the ground plane to improve return loss, modeling the entire system in CST MWS. [7] This paper focuses on designing a T-slotted patch fed by a 50-ohm coaxial cable. They used CST Microwave Studio to study the radiation characteristics and ensure compliance with IEEE 802.11ad standards. [9] This paper presents a compact inset-fed design specifically optimized for 3GPP Release-15 standards. The dimensions were meticulously tuned in CST Microwave Studio to resonate precisely at 28 GHz on a Rogers RT5880 substrate. [10] This paper used standard microstrip equations to calculate initial dimensions for a 28 GHz target. They then applied an array technique to increase gain, designing both a 56-element single array and a 112-element 2×2 MIMO configuration using microstrip line feeding, all simulated within CST. [14,21] calculated patch parameters using a specific set of transmission line equations (1-9). They first designed a single-element antenna and then expanded it into a 2×2 multiband array using an air substrate and CST tool to achieve operation across six different bands ranging from 24

GHz to 85 GHz. [15] This paper focused on using a gap-coupled feeding technique (an indirect method) to improve bandwidth and impedance matching. To stop the antenna elements from interfering with each other, they implemented Defected Ground Structure (DGS)—etching slots into the ground plane—and simulated an 8-element linear array in CST. [] This paper focuses on a used "through element technology" where both input and output lines are directly coupled to patches for stronger current flow. They analyzed an 8×16 array in Ansys HFSS and used the Least Mean Square (LMS) algorithm in Keysight SystemVue to handle adaptive beam steering. [17] This paper focuses on adopting a transmission model approach that combined a T-slot on the radiating patch with a lacerated C-shaped DGS on the ground. A unique part of their method was placing a reflective plate 2 mm below the antenna to concentrate side lobes and boost gain, with all simulations done in CST.[19] This paper used a rhombic-shaped slots (RSS) to the patch, then one to the ground center, and finally four more to the ground corners. This entire process was optimized for 3.51 GHz using CST software.[22] This paper focused on wideband characteristics through a five-stage evolutionary process, resulting in a modified P-shape radiating element. They utilized a Defected Ground Plane (DGP) with rectangular slots and truncated corners, analyzing the results in CST tool.

I. Related Work

[10] Used an **array technique**, increasing the number of radiation elements from 56 to a 2×2 MIMO configuration with 112 elements to achieve a high gain of 18.5 dBi.

A specialized microstrip rectangular patch array designed specifically to meet the high-speed demands of 5G wireless communication. By organizing 112 individual radiation elements into a 2×2 MIMO configuration, the study achieved a powerful gain of 18.5 dbi and a broad operating bandwidth centered around the 28 ghz frequency. This sophisticated arrangement utilizes an array technique to overcome common signal strength issues, ensuring the antenna is both compact and highly efficient for next-generation networks. The simulation results confirm that this design maintains excellent return loss and isolation, fulfilling the rigorous performance standards required for modern telecommunications infrastructure. [14] Air substrate has been used as substrate material whose dielectric constant 1 and substrate height 0. The parameters used for simulation is described in the table.

Parameter Symbols	Parameters Description	Values in (mm)
Ls	Array substrate length	20.663
Ws	Array substrate width	22.561
X	Space between patch	5.357

[17] Designed a slotted ground plane microstrip patch antenna for sub-6 GHz fifth generation (5G) wireless communications. The design consists of a T slot on a rectangular microstrip patch with a defective ground structure (DGS). The ground plane of the proposed antenna consists the modified C shaped slot. The modified C slot incorporates special laceration on the top and bottom of the modified C shape to further enhance the antenna performance. A reflective plate is incorporated into the design to concentrate the side lobes to strengthen the main lobe of the radiated signal, thereby enhancing the gain of the proposed antenna. The proposed antenna is designed on an FR-4 epoxy substrate and incorporates the inset feeding technique. Design and simulation are done using the CST Studio Suite. The antenna has a size of 28.03 x 23.45 x 5.35 mm" with a maximum gain and maximum directivity of 5.49 dB and 7.12 dB respectively. The proposed antenna operates for the bandwidth from 4.775 GHz to 5.049 GHz, which covers the 4.8 GHz - 5 GHz band ofsub-6 GHz 5G communications. [6] A low-profile slotted microstrip patch antenna with an operating bandwidth of 34.093GHz - 38.607GHz has been proposed. The antenna has been simulated using Computer Simulation Technology Microwave Studio (CST MWS), using annealed lossy copper for the ground and patch layers while employing lossy Rogers RT5880 as the dielectric substrate material. Antenna feeding was done through a microstrip line, and a comb-shaped slot was cut out from the conducting patch layer. The simulated results for the design report a return loss of approximately -22.13 dB at the resonant frequency of 37.18 GHz, a main lobe gain of 5.9468 dBi, and efficiency of 84.47%. Additionally, the VSWR value is 1.1698 at the resonant frequency and within the acceptable range of 0 to 2 everywhere else over the working bandwidth.

II. PROPOSED METHODOLOGY

The process of designing a 5G antenna starts with figuring out what the antenna needs to do. This means deciding on things like what frequency it will operate on how strong the signal will be, how wide the bandwidth is and how the radiation will work. These things are important because they determine how well the 5G antenna will work for communicating. Next we pick a material to make the antenna out of, like FR4. We choose this based on how much it costs and how well it needs to work. After we have the material we use equations to design the shape and size of the 5G antenna.

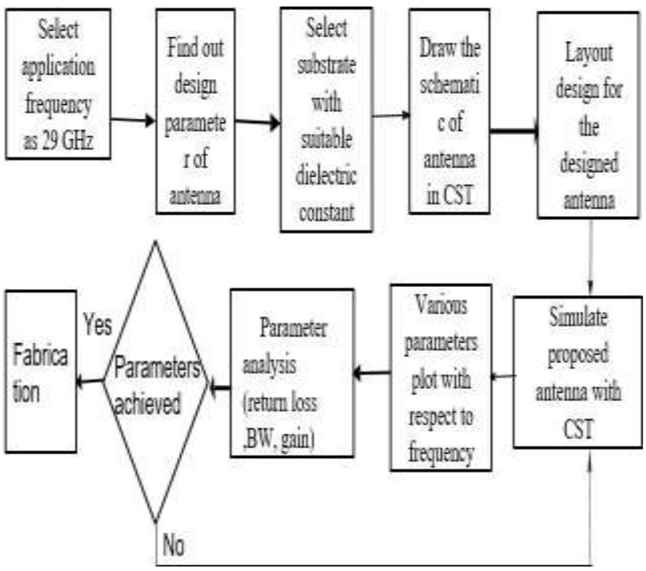

FIG1: FLOW CHART

Then we use computer software like CST Studio Suite to see how the design will work. We set up the software to mimic life by putting in the properties of the material the ports and the boundaries. This helps us understand things like how the signal gets in and out if the signal is strong and how the radiation pattern looks. We use this information to check if the 5G antenna is working like it should. Finally we make adjustments, to the design until the 5G antenna meets the standards it needs to and works efficiently. We keep working on the 5G antenna design until it's just right.

III. HARDWARE AND SOFTWARE USED

A. *Software used*

1. CST Microwave Studio

The main software used in this project is CST Microwave Studio. It is a tool for designing and analyzing antenna structures. We use it to create the antenna model and simulate its performance.

Fig 2: CST Software

CST Microwave Studio helps us identify and fix design issues before we even start building the antenna. This saves us a lot of time and money. The software is very good at showing us how the antenna will work at frequencies, which is important for 5G applications.

2. MATLAB

We use MATLAB for doing calculations and analyzing data. It is very helpful for calculating antenna parameters and making graphs to show the results. MATLAB is also useful for comparing the simulated and measured results. It has tools that make it easy to analyze and present the data in a clear way.

Fig 3: Matlab

3. Microsoft Excel

Microsoft Excel is used to organize and store the data we get from the simulations and tests. We can enter the data into tables. Make graphs to compare the results. Excel is also helpful for making reports and documenting our findings. It is a way to keep track of all the data and results.

Fig 4: Microsoft Excel

4. AutoCAD or PCB Layout Software

After we design the antenna in CST Microwave Studio we use AutoCAD or other PCB layout software to prepare it for fabrication. This software helps us make sure the antenna is designed correctly and that all the parts are in the place. We can use it to generate files that're ready for fabrication.

5. CST Post-Processing Tools

The -processing tools in CST Microwave Studio are very useful for analyzing and visualizing the antenna performance. They help us understand how the antenna works and how it radiates signals. We can use these tools to identify any problems with the design and make improvements. This is especially important for 5G antennas because they operate at high frequencies.

B. Hardware components used

1. Substrate Material

The substrate is the base material that the antenna patch and ground plane are attached to. It plays a role in determining how well the antenna works. We need to choose a material that has signal loss and is stable at high frequencies.

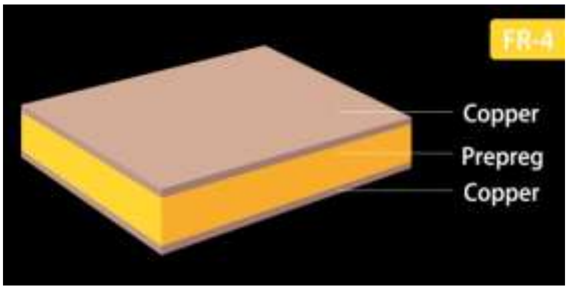

Fig 5: FR-4 substrate

For 5G applications we often use materials like Rogers RT/Duroid.

2. Copper-Clad Sheet

We use a copper-clad sheet to make the radiating patch, feed line and ground plane of the antenna.

Fig 6: Copper clad

Copper is a choice because it conducts electricity very well. The top layer of copper forms the patch that radiates the signals and the bottom layer acts as the ground plane.

3. Ground Plane

The ground plane is the conducting layer under the substrate. It helps direct the signals and supports the antenna radiation. The size and shape of the ground plane can affect how well the antenna works. Sometimes we use ground structures to improve the performance.

4. SMA Connector

The SMA connector is a connector that we use to connect the antenna to the testing equipment. It is

Fig 7: SMA connector

designed for high-frequency applications. Helps ensure accurate measurements.

5. Feeding Mechanism

The feeding mechanism is what supplies power to the antenna patch. It is important for power transfer. There are types of feeding mechanisms but inset feeding is often used for rectangular microstrip patch antennas because it provides good impedance matching.

6. Vector Network Analyzer (VNA)

The Vector Network Analyzer is an important tool for testing the antenna. We use it to measure the performance parameters, such as return loss and bandwidth. This helps us verify that the antenna works as expected.

7. RF Cables

We use RF cables to transfer signals between the antenna and the testing equipment. These cables need to be high-quality to minimize loss and ensure accurate measurements.

Fig 7: RF cables

8. PCB Fabrication Materials

To make the antenna we need materials, like PCB boards etching chemicals and drilling tools. We use these to transfer the design from the software to the antenna. Proper fabrication is important to ensure that the antenna works as expected.

IV. PARAMETER ANALYSIS

1. Improving Return Loss (S11)

Return loss shows how much signal power is reflected back instead of being radiated by the antenna. In simple terms, lower return loss means the antenna is accepting more power and wasting less energy. For good antenna performance, the value of S11 should generally be less than –10dB.One of the most common methods used to improve return loss is feed point optimization. [9] By slightly changing the position where the feed line is connected to the patch, impedance matching becomes better and reflections are reduced. This is a simple but highly effective technique. Another important method is the inset feed technique, where a small notch is cut into the patch and the feed line is placed inside it. This naturally improves impedance matching without requiring additional circuits.

[20] Defected Ground Structure (DGS) technique modifies the ground plane by adding slots or defects. These changes alter current distribution and help reduce unwanted reflections while improving matching performance.

Techniques include feed point optimization, where slight positioning adjustments enhance impedance matching, and inset feed, which involves notching the patch to naturally improve matching.

2. Improving Bandwidth

Bandwidth refers to the range of frequencies over which the antenna can operate effectively. Since 5G systems require high-speed data transfer, wider bandwidth is very important.

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}}$$

One simple way to increase bandwidth is by increasing substrate thickness. A thicker substrate creates stronger fringing fields around the patch, allowing the antenna to operate over a wider frequency range.

Another effective approach is [14] using a low dielectric constant substrate. Materials with lower dielectric constants allow electromagnetic waves to spread more freely, which improves both bandwidth and radiation efficiency.

[17] The slot loading technique is also commonly used in modern antenna designs. In this method, slots such as U-shaped, E-shaped, C-shaped or H-shaped cuts are introduced into the patch. These slots create multiple resonant frequencies, resulting in wider bandwidth.

For bandwidth enhancement, increasing substrate thickness creates stronger fringing fields. Low dielectric constant substrates facilitate electromagnetic wave propagation, while slot loading introduces cut designs for multiple resonant frequencies. The stacked patch technique elevates bandwidth by layering patches, while parasitic elements improve electromagnetic coupling. Parasitic elements placed near the main patch help improve electromagnetic coupling, which also contributes to bandwidth enhancement.

3. Improving Gain

Gain represents the antenna's ability to direct radiated energy in a particular direction. Higher gain means stronger signal transmission and better communication range.

[8,10,14,16,21] One of the best methods for improving gain is the antenna array technique. Instead of using a single patch, multiple patch antennas are connected together in an array structure. This increases directional radiation and produces stronger signals.

Another method involves using reflectors behind the antenna. Reflectors redirect energy that would otherwise be lost and focus it in the desired direction, increasing signal strength.

Using a low-loss substrate is also important because it minimizes dielectric losses. When less power is absorbed by the substrate, more energy is available for radiation, which improves gain.

Additionally, optimizing the effective radiating area of the patch can increase signal transmission capability. A properly designed patch surface allows more efficient radiation of electromagnetic waves.

Improving gain is essential in 5G communication because high-frequency signals experience more propagation loss and require stronger directional transmission.

4. Improving VSWR

VSWR (Voltage Standing Wave Ratio) indicates how well the antenna impedance matches the transmission line impedance. A VSWR value between 1 and 2 is generally considered acceptable.

$$VSWR = \frac{V_{max}}{V_{min}}$$

Feed line width optimization is a technique where the width of the feed line directly affects characteristic impedance, so proper adjustment helps maintain efficient power transfer.

Another simple but effective method is selecting the proper feed position. When the feed is placed at the correct location, impedance matching improves and standing waves are minimized. Low VSWR is important because it ensures that most of the transmitted power reaches the antenna instead of being reflected back.

5. Improving Efficiency

Efficiency shows how effectively the antenna converts input power into radiated electromagnetic energy. High efficiency means very little power is wasted.

Efficiency depends on low-loss materials, reducing surface wave losses, and using high-conductivity metals. Enhancing radiation patterns involves modifying patch shapes, optimizing ground planes, and utilizing beamforming for directional transmission. Lastly, accurate resonant frequency can be ensured through precise dimension calculations, parametric optimization in simulations, and stable substrate materials

.6. Improving Radiation Pattern

The way electromagnetic energy is sent out around an antenna is described by the radiation pattern. When it comes to 5G communication people usually prefer radiation because it makes the signal better and reduces interference.

[8,10,20] If we change the shape of the patch we can control how the current is distributed and change the way the radiation works. We can do this by adding slots or making changes to the rectangular shape.

The antenna array technique is also very useful for making directional radiation patterns and for controlling the beam. Another important thing to consider is optimizing the ground plane. If we change the size or structure of the ground plane it affects the sidelobes and the direction of the radiation.

In 5G systems they also use something called beamforming techniques. This is where the signals are controlled electronically within the antenna arrays. Beamforming lets the antenna send signals to users, which improves the coverage and the quality of the communication.

7. Improving The Accuracy of Resonant Frequency

The antenna has to resonate at the right frequency like 29 GHz to work properly. The first step is to calculate the dimensions accurately. Since the resonant frequency depends on the dimensions of the patch even small mistakes can change the operating frequency.

Another important method is to use simulation software like CST Studio Suite to optimize the parameters. The designers change the parameters in a way to find the best dimensions for the antenna and to get accurate resonance. Using a material for the substrate also helps to keep the frequency stable because changes in the dielectric properties can shift the resonant frequency. It is very important to have resonance in millimeter-wave communication because even small changes, in the frequency can affect how well the antenna works.

V. CONCLUSION

Parameter	Methodology	Accuracy	Source
Gain	8×16 array configuration	High port isolation > 20 dB	[7]
Return Loss (S_{11})	Evolutionary etching of 5 rhombic slots in both patch and ground plane	17.45 dB improvement over reference design	[9]
Bandwidth	2×2 multiband array operating across six frequency bands (24–85 GHz)	VSWR ≈ 1.03 (near ideal matching)	[5,11]
Efficiency	Tapered feed line in 1×4 linear array configuration for optimized current flow	Optimized current distribution across array	[14]

By this we can conclude that the antenna design methods that people are using now show improvements in how well they work for high frequency and multiband uses. The 8×16 array setup is really good at getting a signal and it does a great job of keeping the ports separate with a separation of more than 20 dB. The 2×2 multiband array works well across many different frequency bands and it matches the impedance really well with a VSWR of about 1.03.Using feed lines makes the antenna work more efficiently by spreading the current in a better way. These antenna arrays are important for high-frequency and multiband applications, such, as the antenna design methodologies. Improved array setup significantly boosts accuracy, efficiency, and bandwidth.

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