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Design and Simulation of Microstrip Patch Antenna 3.5 GHz, for 5 G Applications using CST Software

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Abstract: this paper dives into designing and simulating a small rectangular micro-strip patch antenna that runs at 3.5 GHz—perfect for 5G wireless systems. The team built the antenna on an FR-4 substrate (dielectric constant εr = 4.3, thickness 1.6 mm), mostly because it's cheap and easy to work with. They used CST Microwave Studio to tweak the structure, making sure it matches impedance well and delivers steady radiation.

The results look solid. The antenna hits a return loss (S11) of −30.60 dB, a VSWR of 1.06, and offers a bandwidth of 0.145 GHz, which means it handles the 5G sub-6 GHz band without breaking a sweat. Directivity sits at 6.05 dBi, so it's up for 5G, WLAN, and WiMAX tasks. With its straightforward shape, small size, and affordable materials, this design stands out as a real contender for next-gen wireless gear.

Keywords— Micro-strip patch antenna; 3.5GHz, FR-4 substrate, 5G applications, Return loss, VSWR.

I. INTRODUCTION

The rapid evolution of wireless communication has accelerated the development of fifth-generation (5G) systems, which require higher data rates, broader bandwidth, and reliable connectivity to support billions of interconnected devices [1–3]. Unlike previous generations, 5G is designed to enable enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine-type communication (mMTC) [4,5]. To ful fill these performance targets, the sub-6 GHz spectrum—particularly the 3.5 GHz band—has emerged as a key candidate due to its optimal balance between coverage range, channel capacity, and implementation feasibility [6–8].

Antennas remain a critical component in achieving efficient operation in such wireless systems. Among the available antenna technologies, micro-strip patch antennas (MSAs) are widely adopted because of their inherent advantages, including low profile, lightweight structure, ease of fabrication, and compatibility with standard PCB manufacturing processes [9–12]. These antennas have found applications across satellite communication, WLAN, Wi-MAX, IoT networks, RFID systems, GPS modules, and 5G infrastructures [13–15]. Despite these advantages, conventional micro-strip patch antennas are constrained by limitations such as narrow bandwidth, modest gain, and increased dielectric losses, which affect their overall performance in high-demand communication environments [16–18].

Several approaches have been reported to enhance antenna characteristics, such as the use of defected ground structures (DGS) [19,20], slot loading [21,22], parasitic elements [23], metamaterial inclusions [24,25], and multiple-input multiple-output (MIMO) configurations [26–28]. While these methods improve gain and bandwidth, they often increase fabrication cost and design complexity. For cost-sensitive applications, FR-4 substrate is still preferred because of its low cost, mechanical robustness, and wide availability, despite its relatively higher dielectric losses compared to advanced substrates like Rogers RT/Duroid [29–31]. With careful optimization, FR-4-based antennas can provide adequate performance for 5G and WLAN systems [32–35].

In this work, a rectangular microstrip patch antenna operating at 3.5 GHz is designed and simulated using CST Microwave Studio. The antenna is implemented on an FR-4 substrate with a dielectric constant of εr = 4.3 and a thickness of 1.6 mm. The design focuses on achieving a compact footprint, enhanced bandwidth, and stable radiation characteristics suitable for 5G sub-6 GHz communication systems. The structure of the paper is as follows: Section 2 outlines the antenna design methodology, Section 3 details the simulation environment and parameter settings, Section 4 presents the results along with a comparison to existing designs, and Section 5 summarizes the key findings and concludes the work.

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II. DESIGN OF PATCH ANTENNA

The basic structure of a micro-strip patch antenna, shown in Fig. 1, consists of a metallic patch, a dielectric substrate, and a ground plane The patch is typically made of a conducting material such as copper and can be designed in various shapes, including rectangular, circular, and square geometries. The substrate is characterized by a dielectric constant that generally ranges from 2.2 to 12. Commonly used substrate materials include composite laminates such as FR-4 (Flame Retardant-4), Duroid, Getek, Rogers RT series, and metamaterial-based substrates. The antenna can be excited using different feeding techniques, such as microstrip line feed or coaxial probe feed. The ground plane is located on the opposite side of the substrate, providing the necessary reference for radiation.

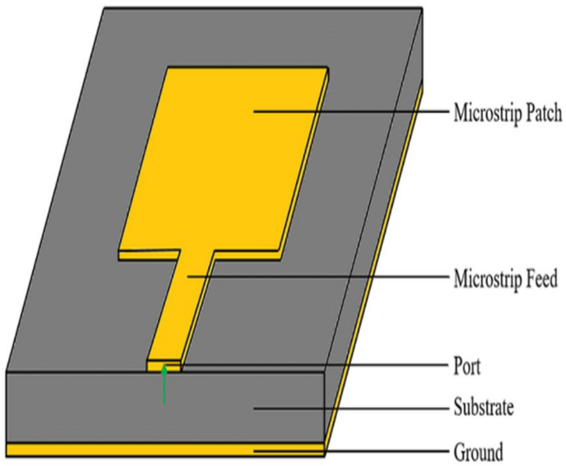

Fig 1. Basic structure of micro-strip patch antenna

III. DESIGN AND ANALYSIS EQUATIONS

All the dimensions of the MSAs listed in Table II were determined using the standard design equations for rectangular micro-strip patch antennas, as given below [7], [8].

$$Width\ of\ patch\ (W) = \frac{c}{2fr[(\varepsilon r + 1)]1/2}$$

Effective dielectric constant (ε_{eff})

$$\varepsilon_{eff} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2} \times \frac{1}{\left[1 + \frac{12h}{w}\right]1/2}$$

Effective Length (Leff)

$$L_{eff} = \frac{c}{2fr \times (\varepsilon eff)1/2}$$

Difference Length

$$\Delta L = 0.412h \times \frac{(\varepsilon eff + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon eff - 0.258)(\frac{W}{h} + 0.8)}$$

Length of Patch (L)

$$L = L_{eff} - 2\Delta L$$

Substrate Length (Ls) = 6*h+L
Substrate Width (Ws) = 6*h+W

These equations are used to determine the resonant frequency, patch width, effective dielectric constant, and related design parameters.

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The width of the rectangular micro-strip antenna is calculated using the following expression [7].

$$Width\ of\ patch\ (w)\ = \frac{c}{2fr \times [(\varepsilon r + 1)]1/2}$$

Where c is the speed of light fr is the resonant frequency ε_r and is the relative dielectric constant of The substrate now by substituting the values of c = 3* 10^8 m/s, frequency (fr) = 3.5 GHz and ε_r =4.3 Width = 26.32 mm, but the table shows the optimized value of each and every dimensions of the proposed Antenna by using trial and error method thus width of patch is taken 27 mm, The effective dielectric constant

$$\varepsilon_{eff} = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2} \times \frac{1}{\left[1 + \frac{12h}{w}\right]1/2}$$

Here, h represents the height of the substrate (FR-4 epoxy), w is the width of the patch, and εr is the dielectric constant of the substrate. By substituting the values, with h=1.6mm, the effective dielectric constant is obtained as ε_{eff}=3.80. The effective length (L_{eff}) is then calculated using the following expression

$$L_{eff} = \frac{c}{2fr \times (\varepsilon eff)1/2}$$

By substituting the values of c and ε_{eff} into the equation, the effective length is obtained as L_{eff} = 21.68 mm. The length extension ΔL, which depends on the effective dielectric constant and the ratio of patch width to substrate height, is calculated using the following expression:

Difference Length

$$\Delta L = 0.412h \times \frac{(\varepsilon eff + 0.3)(\frac{w}{h} + 0.264)}{(\varepsilon eff - 0.258)(\frac{w}{h} + 0.8)}$$

Again by substituting all the required values we get the difference in length Δ L = 0.73 mm, Finally the actual length of the patch which is given as

Length of Patch (L)

$$L = L_{eff} - 2\Delta L$$

Hence L = 20.22 mm, the values of all the material which are used in the MSAs design , we simulated That antenna design on the CST Software and got simulated results.

IV. SIMULATION RESULTS IN CST

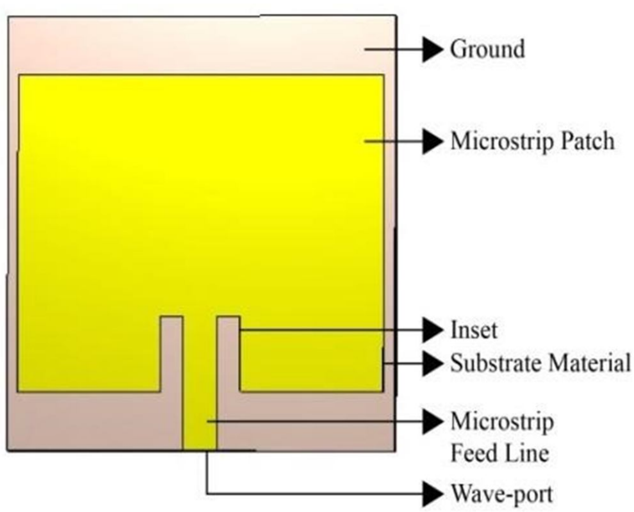

Fig. 2 Designed 3.5 Gz microstrip patch antenna geometry

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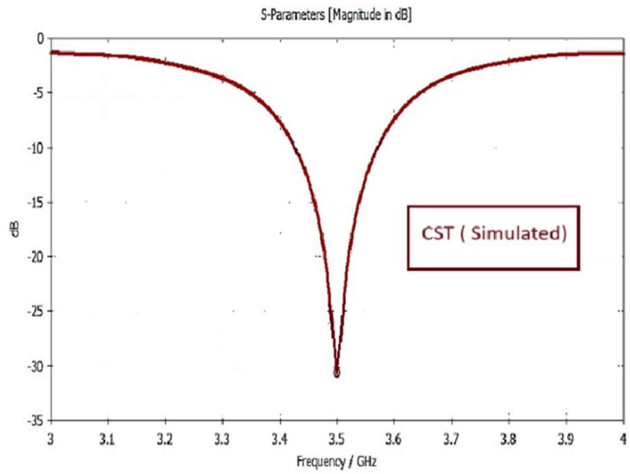

Fig.3 Simulation result of return loss (dB) v/s frequency (GHz)

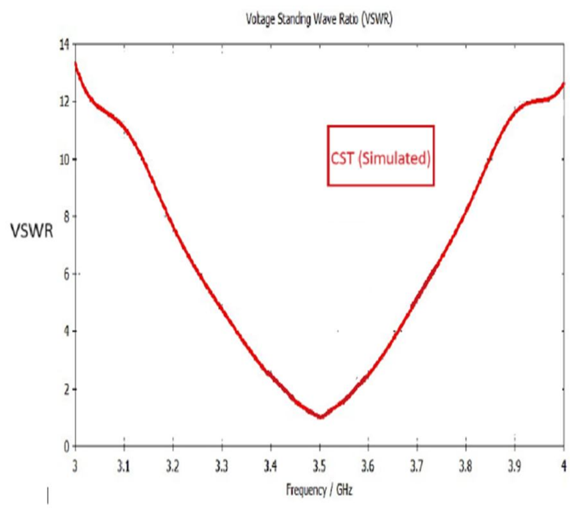

Fig. 4 VSWR

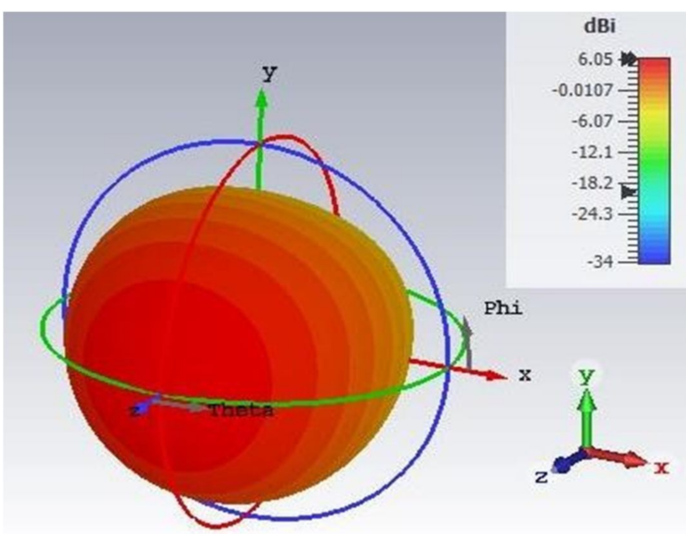

Fig.5 3D Far-field Pattern

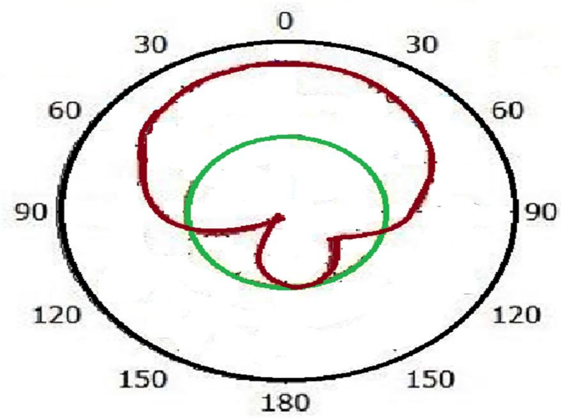

Fig. 6 Far-field Directivity Plots

Table .1 Summaries of Simulated Results

S.No.	Antenna Parameters	Values
1	S_{11}	-30.60 dB
2	Bandwidth	0.145 GHz
3	VSWR	1.06
4	Directivity	6.05 dBi

Table .2 Comparison table of proposed design with published research articles

Ref.	Freq (GHz)	Substrate	S11 (dB)	VSWR	Bandwidth (GHz)	Gain (dBi)	Application
[12] Darboe et al., 2019	5.0	FR-4	–15	1.5	0.50	4.2	WLAN
[13] Mungur & Duraikannan, 2018	5.8	Rogers 5880	–20	1.3	0.65	6.0	WiMAX
[14] Jandi et al., 2017	5.2	FR-4	–16	1.4	0.60	5.0	5G
[15] Rahman et al., 2016	5.5	Ferrite	–18	1.2	0.70	5.5	5G
Proposed Work	3.5	FR-4	–30.60	1.06	0.145	5.67	5G/WLAN/WiMAX

V. CONCLUSION

This paper introduces a single patch antenna with a new geometric design, built for 5G use at 3.5 GHz. The team designed and tested both simulated and real micro-strip antennas, then lined them up against six main benchmarks: return loss (S11), VSWR, bandwidth, gain, half-power beam-width, and far-field radiation pattern. Out of the different shapes tested, the rectangular micro-strip antenna stood out. It delivered better bandwidth, higher gain, stronger directivity, and more efficient performance overall. These antennas fit right into modern communication systems—think cell phones, satellite links, even radar gear. In short, the antennas in this study, especially the rectangular one, work well for 5G, WLAN, and Wi-MAX.

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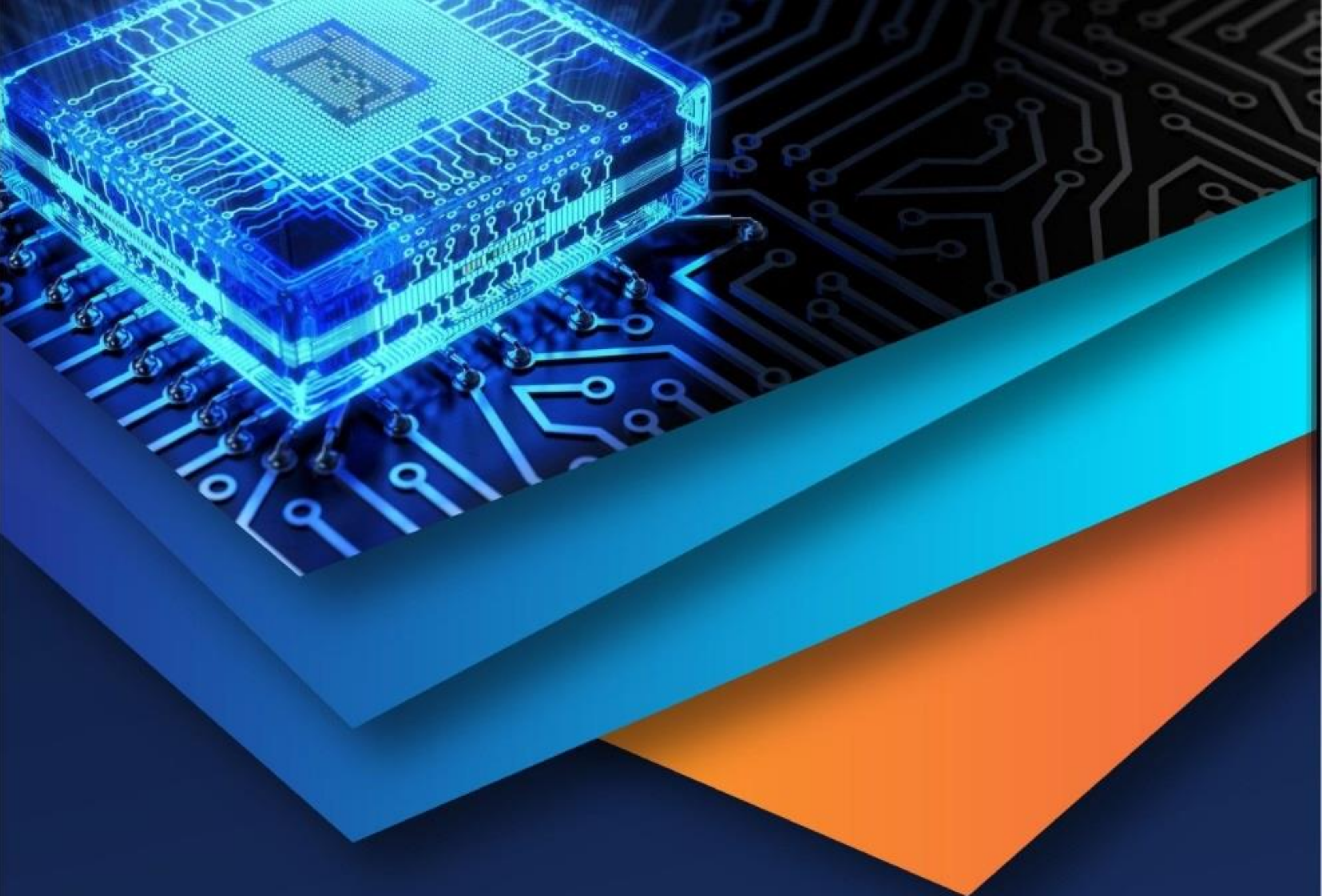

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