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Development and implementation of a microstrip antenna for autonomous vehicles and IoT in 5G communication systems

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Abstract: This research paper presents the design and implementation of a microstrip patch antenna (MPA) that operates at 5.8 GHz and achieves all important characteristics for 5G communication systems and autonomous vehicles. The Roger RT5880 material of 0.8 mm thickness had been employed as a substrate to execute the proposed antenna. The proposed antenna was simulated using the CST Microwave Studio software. The simulated antenna demonstrates directivity and gain of 8.09 dBi, and 7.38 dBi. The antenna was fabricated using the Roger RT5880 material of 0.8 mm thickness. The antenna was evaluated using return losses. It demonstrates -20 dB at the resonance frequency, and this means the proposed antenna has achieved the goal of the work.

Keywords: Microstrip antenna, autonomous vehicles, 5G communication, return loss, directivity, gain IoT

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1. Introduction

With the rapid advancement of wireless communication techniques, the integration of the Internet of Things (IoT) and autonomous vehicles into 5G networks has converted into a prominent area of research (Lyu & Zhang, 2017). These emerging applications require reliable and efficient wireless connectivity to enable seamless communication and data exchange. Microstrip antennas find extensive application in diverse communication systems such as 5G networks, the Internet of Things (IoT), and autonomous vehicles (Al-Rubaye et al., 2023; Mohamed & Ammor, 2019). These antennas offer several advantages, some of the notable characteristics of this antenna include its lightweight design, low profile, ease to fabrication, and suitability for integrated circuits. In the context of autonomous vehicles and IoT in 5G communication systems, microstrip antennas play a crucial role in enabling wireless connectivity (Ndip et al., 2018).

In 5G communication systems, various frequency bands are allocated for different applications. Microstrip antennas can be designed to operate in these frequency bands based on the specific requirements of autonomous vehicles and IoT devices (EL Mashade & Hegazy, 2018). Examples of relevant frequency bands include sub 6 GHz bands (e.g., 3.5 GHz, 5.8 GHz) and millimeter wave bands (e.g., 26 GHz, 28 GHz, 39 GHz) (ALRikabi et al., 2024; EL Mashade & Hegazy, 2018).

Autonomous vehicles and IoT devices often have space constraints. Microstrip antennas (Arizaca-Cusicuna et al., 2018), with their compact and planar structure, are well-suited for integration into these devices. They can be designed to have small form factors while maintaining good performance characteristics (Khabba et al., 2019).

Extensive testing and optimization of microstrip antennas are necessary to ensure their performance meets the specifIoT devices (Yoon & Seo, 2017). Techniques such as computer simulation, prototyping, and field testing can be employed to refine the antenna design and maximize its effectiveness (Gharbi et al., 2017).

It is crucial to emphasize that the advancement of microstrip antennas for self-driving vehicles is of utmost significance. and IoT in 5G communication systems is an active and evolving area of research. Ongoing advancements in antenna design (ALRikabi & Hazim, 2022; Khatun et al., 2017), materials and integration techniques will continue to drive improvements in wireless connectivity for these applications (Arora et al., 2015). The discussion encompasses various aspects, including frequency band selection, beamforming and MIMO techniques, compact design considerations, wideband and multiband operation, integration with other components, antenna placement, radiation patterns (Sawant et al., 2016), environmental considerations, and testing and optimization methodologies (Roy et al., 2016). By addressing these factors, researchers and engineers can develop microstrip antennas that meet the unique challenges and performance requirements of autonomous vehicles and IoT devices in 5G communication systems (jassem Mohamed et al., 2023; Mozaffari et al., 2019). By leveraging the capabilities of microstrip antennas, researchers and practitioners can contribute to the advancement of autonomous and connected systems, leading to safer, more intelligent, and interconnected transportation and IoT infrastructures (Cui et al., 2019).

2. Microstrip antenna design

The decision to use a rectangular patch antenna was made due to its superior performance. The antenna characteristics were determined through the following equation:

$$W = \frac{c}{2\,f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

where, fr = Operating frequency
c =light speed
w = width of the substrate
ε_r = dielectric constant of the substrate
The formula for the length of the antenna is:

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

The effective length L_{eff} can be derived and calculated using the following equations.

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} \tag{3}$$

$$\Delta L = 0.4$$

$$12h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{4}$$

In antenna design, the feeding technique plays a crucial role as it guarantees correct impedance matching within the feed line. preventing any reflections back from the antenna and ultimately enhancing antenna efficiency. The inset feed technique is known for offering Equations (5) and (6) to determine the calculation of the depth of inset feed and notch gap, resulting in the highest gain and the lowest return loss.

$$\mathrm{Fi} \approx = \frac{0.822 \times \mathrm{Lp}}{2} \tag{5}$$

$$\mathrm{Gap} \approx \frac{c}{\sqrt{2\varepsilon_{eff}}} \text{ x } \frac{4.65\times 10^{-12}}{\mathrm{fr}} \tag{6}$$

50Ω feed line width can be determined by equation (7),

$$\mathrm{Wf} \approx \frac{120\pi}{\sqrt{\varepsilon_{eff}}\,\left(1.393+\frac{\mathrm{Wp}}{\mathrm{h}}+\frac{2}{3}\ln\left(\frac{\mathrm{Wp}}{\mathrm{h}}+1.444\right)\right)} \quad (7)$$

The dimensions of the single antenna ground plane can be determined using equations (8) and (9), where the width of the ground is denoted as Wg and the length of the ground is denoted as Lg.

$$W_g \approx 6h + W_p \quad (8)$$

$$L_g \approx 6h + L_p \quad (9)$$

The substrate material, Roger RT5880 (lossy), was selected based on its lower dielectric constant. leading to higher directivity and cost efficiency. The substrate dielectric constant is 2.2, while the loss tangent is 0.0009. The parameters for single antennas operating at a frequency of 5.8 GHz are shown in Table 1, and the proposed design for a single antenna is illustrated in Figure 1. CST Microwave Studio was used to simulate and design the antenna.

Table 1. The list of parameters of single antennas.

Parameters	Value (mm)
W_p	20.432
L_p	17.44
W_g	35
L_g	35
Fi	4
W_f	2.3
Gap	3.85
h_p	0.035
h	0.8

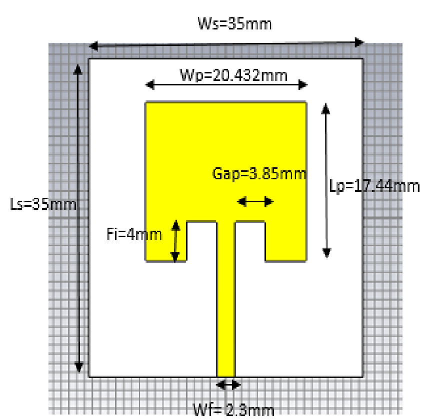


Figure 1. Single patch antenna.

3. Simulation results

The CST electromagnetic simulator was used to show the simulation outcomes for return loss, VSWR, gain, and directivity.

3.1. Return loss (S11)

When waves bounce back and forth between the antenna and the transmission line, some of the power is lost due to these reflections. This loss is referred to as return loss, and it is expressed in dB. Figure 2 displays the return losses for the patch antenna with resonance frequency of 5.8 GHz, S11 of -20 dB, and bandwidth (BW) of 90 MHz.

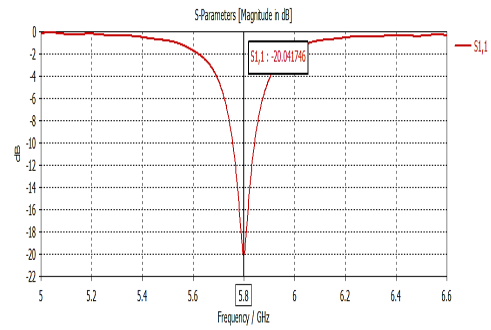


Figure 2. The return loss of the proposed patch antenna.

3.2. Voltage standing wave ratio (VSWR)

When the impedance of the antenna input and the transmission line don't match up, some of the signal gets flipped around. This flipped signal part is referred to as the input-to-reversed signal ratio. A positive number between 1 and 2 is called the VSWR. When the VSWR drops, more power is sent to the antenna, improving its match with the transmission line. The VSWR graphs in experimentation, at 5.8 GHz with VSWR=1.2 are shown in figure 3. The results show that the VSWR value meets the necessary condition (VSWR ≤ 2).

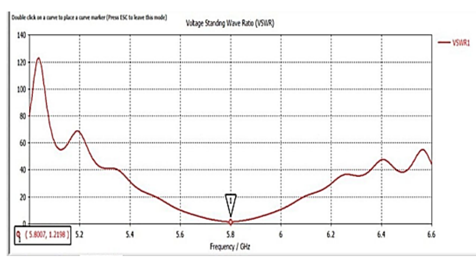


Figure 3. VSWR of the proposed patch antenna.

3.3. Antenna gain

The 2D gain plot shows the radiation pattern of the antenna in a 2-dimensional view. It represents the directional properties of the antenna's gain, indicating how much power the antenna radiates in a specific direction The plot provides information about the maximum gain, beam width, and overall distribution of the antenna's radiated power. Figure 4.a illustrates the radiation pattern of the designed antenna, where its' gain measures at 7.38 dB. This value is considered favorable for a single patch antenna designed for use in 5G communication systems, as it meets the requirements for such systems.

Figure 4.b also shows the gain value in the 1D radiation mode at this frequency at 5.8 GHz, and the gain value at this frequency is 7.38 dB. Figure 5. shows the 3D gain of the proposed patch antenna.

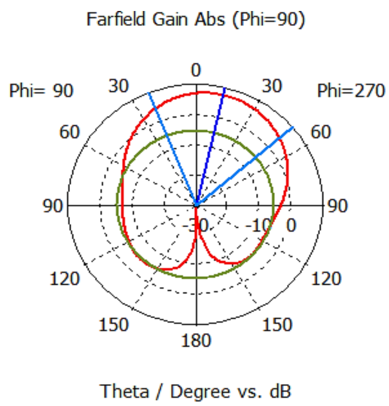


Figure 4a. 2D gain of the proposed patch antenna.

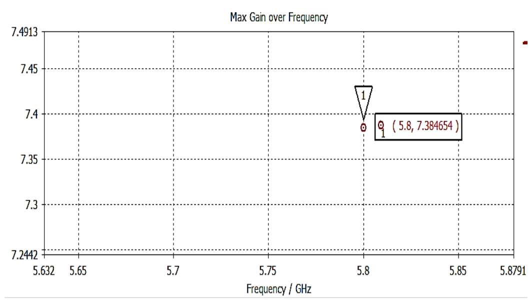


Figure 4b. 1D Gain of the proposed patch antenna.

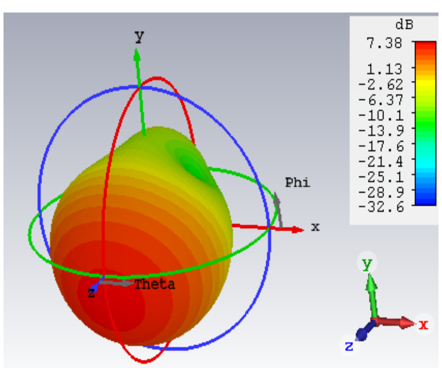


Figure 5. 3D gain of the proposed patch antenna.

3.4. Antenna directivity

An essential antenna parameter is the antenna directivity. It is a measurement of the radiation pattern's degree of "direction" of an antenna. The directivity of an antenna with uniform radiation in all directions would be 1 (or 0 dB), and it would have practically zero directionality. and it equals 8.09 dBi for this design, as shown in Figures 6 and 7. This single-patch antenna offers excellent value. It has an 84 overall efficiency and 85 radiation efficiency.

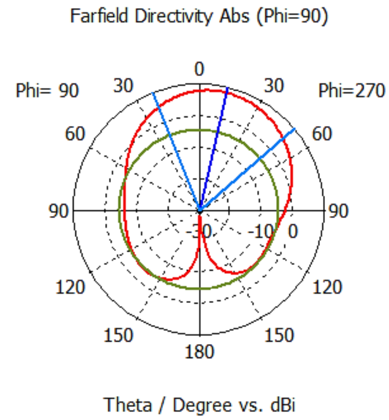


Figure 6. 2D directivity of the proposed patch antenna.

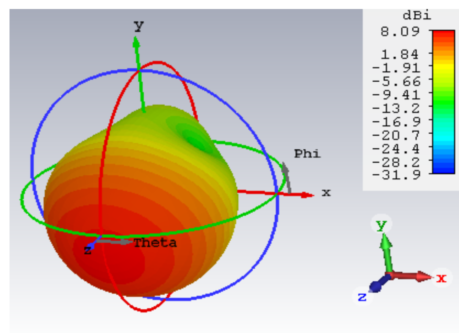


Figure 7. 3D directivity of the proposed patch antenna.

3.5. Reference impedance

The reference impedance is the value of the impedance that the antenna is designed to match with the feeding line. In this case, the reference impedance is about 50 ohms as shown in Figure 8, which is a common impedance value, used in radio frequency (RF) and microwave systems. Matching the antenna's impedance to the reference impedance is crucial for efficient power transfer and minimizing reflections between the antenna and the feeding network.

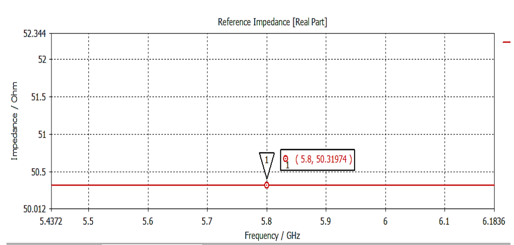


Figure 8. Reference impedance of the proposed patch antenna.

3.6. Surface current distribution

The surface current distribution plot in Figure 9, shows the magnitude and distribution of the electric currents flowing on the surface of the antenna. This information can provide insights into the antenna's operation, such as identifying the current flow patterns, locating the feed point, and understanding the radiation mechanism. The surface current distribution can also help in the optimization of the antenna design.

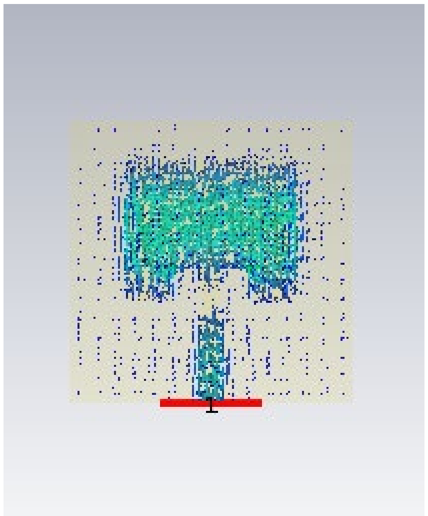
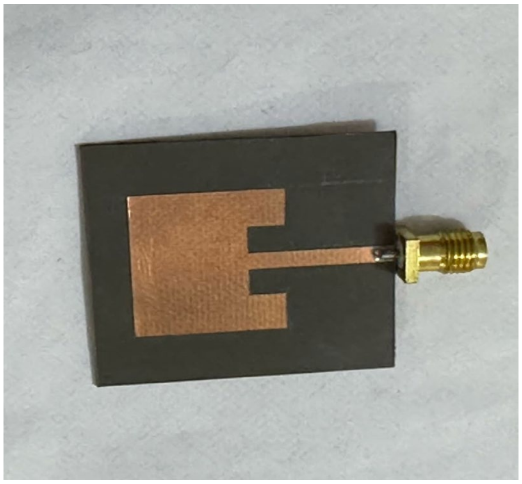


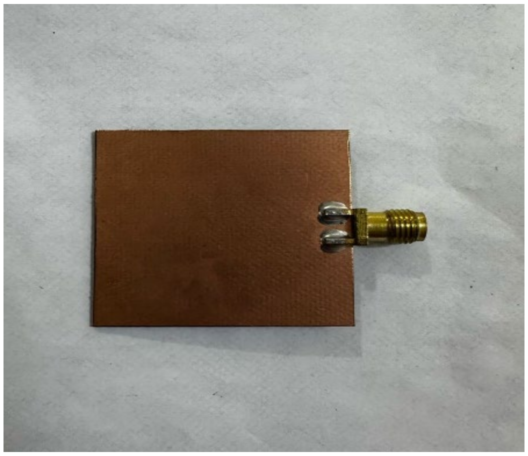
Figure 9. Surface current of the proposed patch antenna.

4. Fabrication and testing of a microstrip patch antenna

A microstrip patch antenna was constructed using the Rogers RT/Duroid 5880 substrate. The substrate antenna has a thickness of 0.8 mm and a tangent loss of 0.0009. The upper and lower views of the manufactured microstrip patch antenna can be seen in Figures 10 (a) and (b), respectively.



(a)



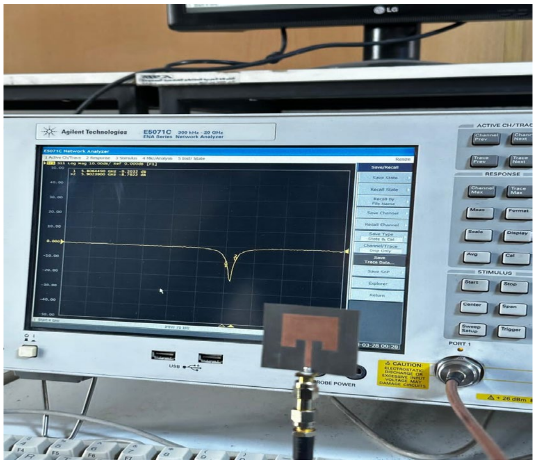
(b)

Figure 10. (a) Upper and (b) lower views of the manufactured microstrip patch antenna.

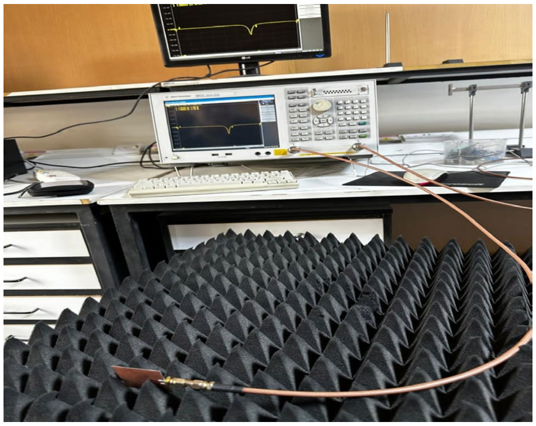
The fabricated microstrip patch antenna is tested using the Keysight Agilent Technologies E5071C Vector Network Analyzer as shown in figure 11(a, b).

Figure 12 displays the return loss result. The measured outcomes of the fabricated antenna are well agreed with the outcomes of the simulation. Where the performance of the proposed antenna exhibits good results for both simulated and fabricated antenna.

The antenna value when manufactured was -20dB.



(a)



(b)

Figure 11. VNA measurement setup for the proposed patch antenna.

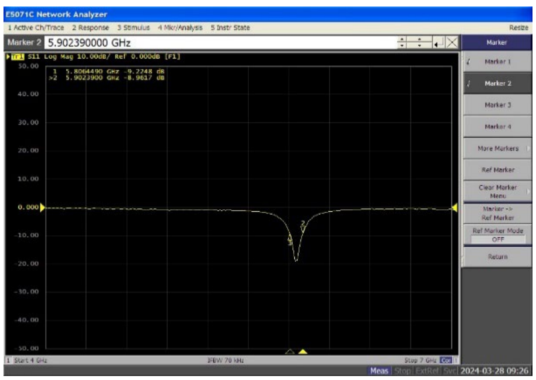


Figure 12. Measured return loss against frequency for the proposed aperture-coupled microstrip antenna.

5. Conclusions

The design and fabrication of a 5.8 GHz microstrip patch antenna are outlined in this paper. The proposed patch antenna was created using CST Microwave Studio for design and simulation purposes. Its directivity, gain, VSWR, and return loss are measured. The suggested antenna was constructed Using a Roger RT5880 substrate. The Network Analyzer was used to test the antenna, where it achieves -20 dB as return losses. The performance of the proposed antenna exhibits good results for both simulated and fabricated antenna.

Conflict of interest

The authors have no conflict of interest to declare.

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