Journal of Electrical Engineering and Automation (ISSN: 2582-3167)
https://irojournals.com/irosws/

Electromagnetic Characterization of a Slotted Microstrip Patch Antenna for 28 GHz Fifth-Generation Wireless Communication

Manjula A.R.[1*], Manjula T.R.[2]

[1]Research Scholar, Department of Electronics and Communication Engineering, Jain University, India.

[2]Associate Professor, Department of Electronics and Communication Engineering, Jain University, Kanakapura Branch, India.

E-mail: [1*]manjulaar@bit-bangalore.edu.in, [2]tr.manjula@jainuniversity.ac.in

Abstract

In this research, the design and electromagnetic analysis of a slotted microstrip rectangular patch antenna for 5G wireless communication at 28 GHz are considered. The antenna design uses Rogers RO4350B dielectric material and a rectangular slot in close vicinity of the patch feed region is used to analyze the effect of this configuration on the antenna's resonance behavior and impedance matching capability. The design performance analysis is carried out at the simulated frequency band of 20-36 GHz using reflection coefficient (S_{11}), VSWR, and radiation pattern. The simulated response shows that there is a resonance frequency of 28.08 GHz, with the lowest value of (S_{11}) being 21.84 dB, resulting in a lowest value of VSWR of 1.164. These results indicate that the antenna has favorable impedance matching in the vicinity of the desired frequency. The radiation pattern simulation gives an insight into the angular distribution of the radiated field.

Keywords: 28 GHz Antenna, Slotted Rectangular Microstrip Patch, Millimeter-Wave Communication, Rogers RO4350B, Reflection Coefficient, Impedance Matching, Voltage Standing-Wave Ratio.

1. Introduction

Fifth generation (5G) wireless communications have contributed to the development of antennas that can operate within the millimeter wavelength range with adequate impedance and

*** Corresponding Author**

IRO Journal on Sustainable Wireless Systems, December 2026, Volume 8, Issue 4, Pages 267-279
DOI: https://doi.org/10.36548/jsws.2026.4.002
Extended version of article received from **6th International Conference on Artificial Intelligence, 6G Communications and Network Technologies 2026**
Received: 10.09.2026, received in revised form: 08.10.2026, accepted: 19.10.2026, published: 05.11.2026
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radiation features. One of the major frequencies that have attracted many researchers' attention is the 28 GHz frequency range since it offers abundant spectrum for wireless communications. However, millimeter-wave antenna design presents several challenges, such as higher propagation loss, geometrical sensitivity, and high impedance matching and radiation criteria. For this reason, it is necessary to design and analyze antennas in order to determine their appropriateness at the desired frequency.

Microstrip patch antennas are widely investigated for millimeter-wave applications with the printed circuit technique, microstrip patch antennas are extensively studied for mm-wave applications. However, the performance of the microstrip patch antenna is determined by many interdependent parameters, such as patch size, substrate, ground plane, and feed. The changes in these parameters at 28 GHz can affect the resonance frequency and impedance. Thus, geometrical design and electromagnetic analysis are significant steps in the design process of the antennas. In previous studies, partially grounded patches, optimized antenna geometry, and slot structures were studied to enhance the electromagnetic behavior of the antennas for mm-wave communication [5], [7], [8].

Slot incorporation provides a means of modifying the current distribution and effective current path within a radiating patch. The electromagnetic behavior that arises from such configurations will depend on the size, position, and interactions of the slots with the feed configuration. Slotting the antenna in a proper way, therefore, can help to shape the resonant characteristics and the input matching properties of a patch antenna. But the performance of any slot must be evaluated in conjunction with the other components of the antenna structure. A complete analysis of the structure is thus needed to ascertain its predicted response at the intended operational frequency.

A design of slotted rectangular microstrip patch antenna for 28 GHz operation using Rogers RO4350B dielectric material is presented in this research. The design includes rectangular slot in the vicinity of the patch-feed location and the antenna design consists of radiating patch, microstrip feed line, and ground plane. Electromagnetic simulation is carried out to study the frequency dependent reflection coefficient, VSWR, and radiation pattern. Reflection coefficient analysis is conducted to determine the resonance point and impedance matching of the structure, whereas VSWR is used to supplement the analysis of the reflection coefficient in determining the

ratio between incident and reflected wave.

2. Related Works

Recent investigations on microstrip patch antennas for 5G communications have focused on the aspects of impedance matching, bandwidth improvement, isolation and radiation. Isolation using parasitic elements in MIMO antennas [1], four element ultra-wideband MIMO structure [2], reconfigurable antennas for fifth generation wireless networks [3] have been investigated.

Optimization of antenna geometries has been well-researched in the context of millimeter-waves. The application of particle swarm optimization using AI has been explored for low-profile 5G antennas [5], whereas slot-cuts in rectangular patches have been considered for use in the V-band range [7]. Literature surveys have also explored the principles of 28 GHz MIMO antenna configurations [6].

Further researches include patch antennas at 28 GHz frequency with partial ground plane [8], compact wideband antennas with reduced mutual coupling [10] and array antennas for massive MIMO communications [12]. Dual band end fire MIMO array antennas using split ring resonator technique have been studied for millimeter wave 5G technology applications [9]. In addition, slot configuration is explored for self-isolated wideband MIMO system and circular patch antennas at 28 GHz frequency [13], [14].

2.1 Research Gap

Despite these developments, the current research work involves only the analysis of a rectangular microstrip patch antenna having a rectangular slot fabricated on the Rogers RO4350B substrate for the frequency range of 28 GHz. This analysis is based on the measurement of the reflection coefficient, Voltage Standing Wave Ratio (VSWR), and the radiation pattern. Impedance matching and radiation properties are considered here only without applying the obtained results to MIMO performance, gain, or radiation efficiency.

3. Proposed Design and Methodology

The design of the proposed antenna is executed based on a sequential design approach that includes parameter specification, geometrical design, electromagnetic analysis, and finally performance evaluation. The antenna is designed based on a slotted rectangular microstrip patch

antenna operating at a frequency range of 28 GHz on a dielectric substrate of Rogers RO4350B. The overall design and evaluation procedure are illustrated in Figure 1.

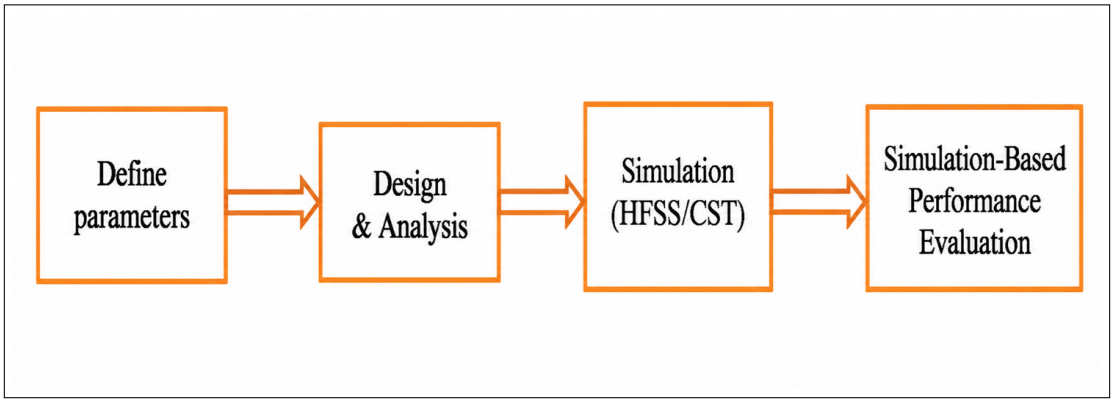


Figure 1. Workflow of the proposed antenna design and electromagnetic evaluation

3.1 Parameter Definition

The geometrical and physical parameters define the structure and electromagnetic properties of the antenna to be designed. These parameters include the radiating patch, ground plane, microstrip feed, dielectric substrate, and the rectangular slot. The dielectric properties like relative dielectric constant and loss tangent of the substrate will affect the effective permittivity, resonance behavior, and dielectric losses, while other parameters define the current flow and input impedance. The principal geometrical parameters are summarized in Table 1.

Table 1. Design parameters of the proposed antenna

Parameter	**Symbol**	**Value**
Substrate material	–	Rogers RO4350B
Relative dielectric constant	ε_r	3.66
Dielectric loss tangent	$\tan\delta$	0.0037
Substrate thickness	h	0.254 mm
Ground-plane length	L_g	5.4 mm
Ground-plane width	W_g	7.6 mm
Patch length	L_p	3.05 mm

Patch width	W_p	4.4 mm
Feed-line length	L_f	1.0 mm
Feed-line width	W_f	0.2 mm
Rectangular slot length	L_s	0.8 mm
Rectangular slot width	W_s	0.2 mm
Slot position	–	Near the patch-feed junction
Conductor material	–	Copper
Conductor thickness	t_c	0.035 mm
Target operating frequency	f_0	28 GHz

3.2 Antenna Geometry and Slot Configuration

The design of the antenna involves the use of rectangular metallic radiating patch fabricated on the Rogers RO4350B dielectric substrate, below which there is a conducting ground plane. The dimensions of the ground plane are 5.4 mm × 7.6 mm, whereas the dimensions of the radiating patch are 3.05 mm × 4.4 mm. Dimensions of the feed line are specified as 1.0 mm in length and 0.2 mm in width.

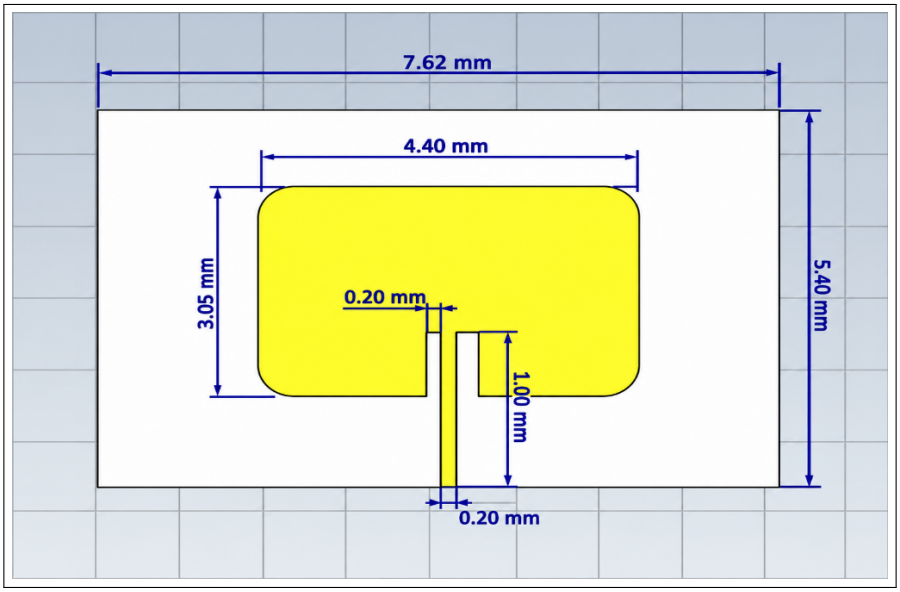


Figure 2. Geometrical configuration of the slotted rectangular microstrip patch antenna

The slot is provided near the patch-feed region to produce a discontinuity on the conducting surface that affects the surface-current distribution pattern. The impact of the slot will vary depending on its size, shape, direction, and location near the feed line. The specifications for the size, shape, and location of the slot must be considered based on the real geometry shown in Figure 2.

3.3 Electromagnetic Simulation and Performance Evaluation

The performance characteristics of the designed antenna are determined by analyzing the S-parameter (S_{11}), VSWR, and radiation pattern of the antenna. The frequency characteristics of the antenna are investigated over the given range of 20 – 36 GHz. The focus of the analysis will be on the design frequency of 28 GHz. The simulation setup must include the electromagnetic solver used in the simulation process, excitation port setup, boundary condition settings, and frequency sweep setup. Table 2 provides a structured record of the simulation parameters.

Table 2. Electromagnetic simulation parameters

Parameter	**Symbol**	**Value**
Substrate material	-	Rogers RO4350B
Relative dielectric constant	ε_r	3.66
Dielectric loss tangent	$\tan\delta$	0.0037
Substrate thickness	h	0.254 mm
Ground-plane length	L_g	5.4 mm
Ground-plane width	W_g	7.6 mm
Patch length	L_p	3.05 mm
Patch width	W_p	4.4 mm
Feed-line length	L_f	1.0 mm
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Conductor thickness	t_c	0.035 mm
Target operating frequency	f_0	28 GHz

The reflection coefficient represents the level of impedance mismatch that exists between the antenna and the excitation point. This decibel value is represented as

$$S_{11}\ dB = 20\log_{10}|\Gamma|$$

where Γ denotes the complex input reflection coefficient and $|\Gamma|$ represents its magnitude. A negative S_{11} value shows that there is a lower magnitude of the reflected wave for that particular frequency.

The VSWR is calculated by taking the magnitude of the reflection coefficient through

$$VSWR = \frac{1\ |\Gamma|}{1 - |\Gamma|}$$

VSWR that approaches unity implies better matching. The S_{11} and the VSWR characteristics that are analyzed together to examine the antenna's input matching. The radiation pattern is analyzed to describe the angle dependence of the radiated field.

The impedance bandwidth should be determined from the frequency interval satisfying a defined matching criterion, commonly $S_{11} \leq -10\ dB$.

Simulation performance analysis of the suggested antenna is presented in Table 3. The obtained findings prove that impedance matching is achieved effectively at the targeted frequency, which validates the use of the suggested antenna for the 5G mm-wave application.

Table 3. Simulated performance of the proposed antenna

Performance parameter	**Symbol**	**Value**
Target operating frequency	f_0	28 GHz
Resonant frequency	f_r	28.08 GHz
Minimum reflection coefficient	$S_{11,\text{min}}$	-21.84 dB
Minimum VSWR	VSWR_{min}	1.164

4. Results and Discussion

Electromagnetic analysis of the design of the slotted rectangular microstrip patch antenna will be based on the reflection coefficient, VSWR and radiation pattern. These parameters will be studied to determine the impedance matching properties and radiation properties of the designed antenna at the designated operating frequency. The reflection coefficient and VSWR will be studied together to determine the consistency of input matching characteristics, whereas the radiation pattern will be examined to determine the direction of radiated energy.

4.1 Reflection Coefficient Analysis

The reflection coefficient shows that the behavior of the antenna has a resonating nature close to the designed frequency. The minimum S_{11} is approximately -21 dB, which means that the amount of reflection is quite low compared to the amount of incident waves. The reflection coefficient reflects the level of impedance mismatch at the point where the antenna input meets the excitation port. A decrease in S_{11} in decibels shows that the percentage of reflection power decreases, meaning that a higher percentage of incident power is absorbed by the antenna. Resonance observed, therefore, implies favorable matching of impedances around the desired frequency. This feature is important in designing millimeter wave antennas, where input response may depend on changes in radiating elements, substrates, and feed system, as depicted in Figure 3.

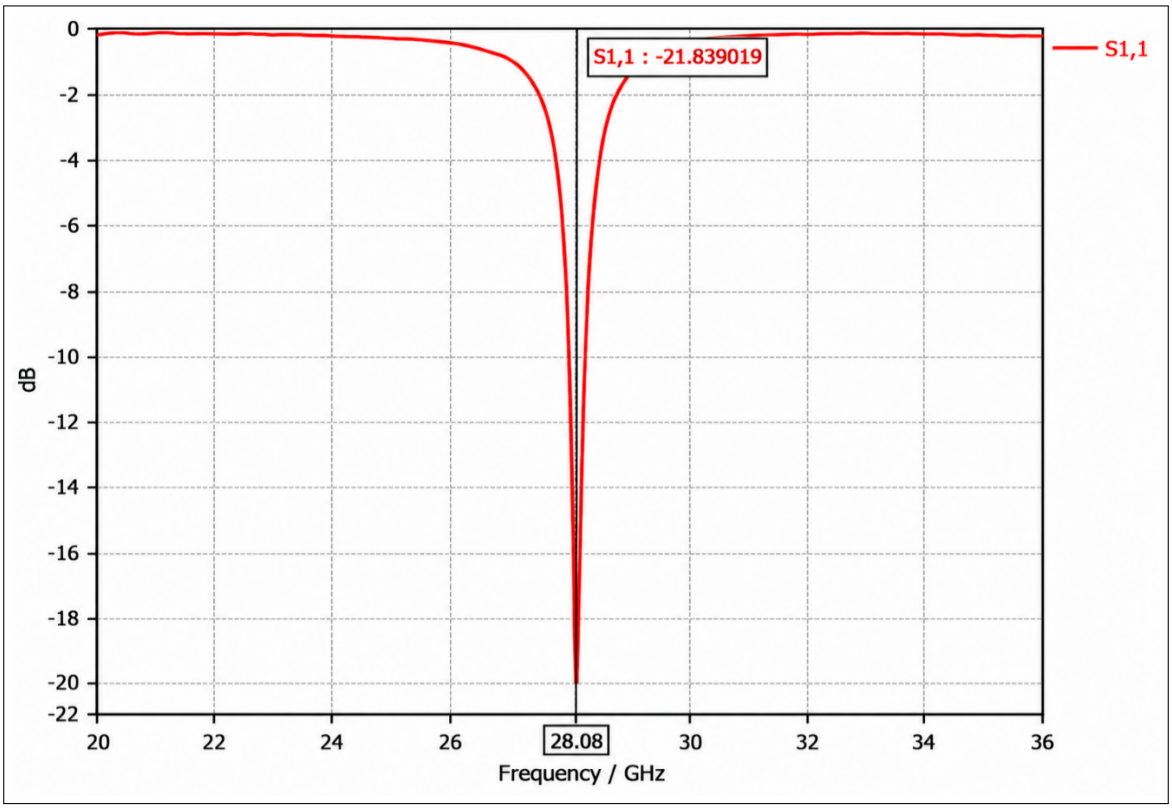


Figure 3. S_{11} response of the proposed single-element patch antenna.

The behavior of the S_{11} parameter in terms of frequency also gives details of the impedance bandwidth of the antenna. The resonant frequency is the frequency where the reflection coefficient is minimized, while the bandwidth is based on the frequency band where the response meets certain criteria, such as $S_{11} \leq -10$ dB.

4.2 Voltage Standing Wave Ratio (VSWR) Analysis

The VSWR describes the impedance matching behavior of the designed antenna by stating the ratio of incident and reflected waves at the input. From the simulation results, a VSWR of about 1.164 is observed at 28.08 GHz, implying good impedance matching at the required frequency. A low VSWR near unity means that there is minimal mismatch in impedance and low reflected waves. These results are similar to those shown in the reflection coefficient response which demonstrate the resonance behavior of the designed antenna near 28 GHz, as shown in Figure 4.

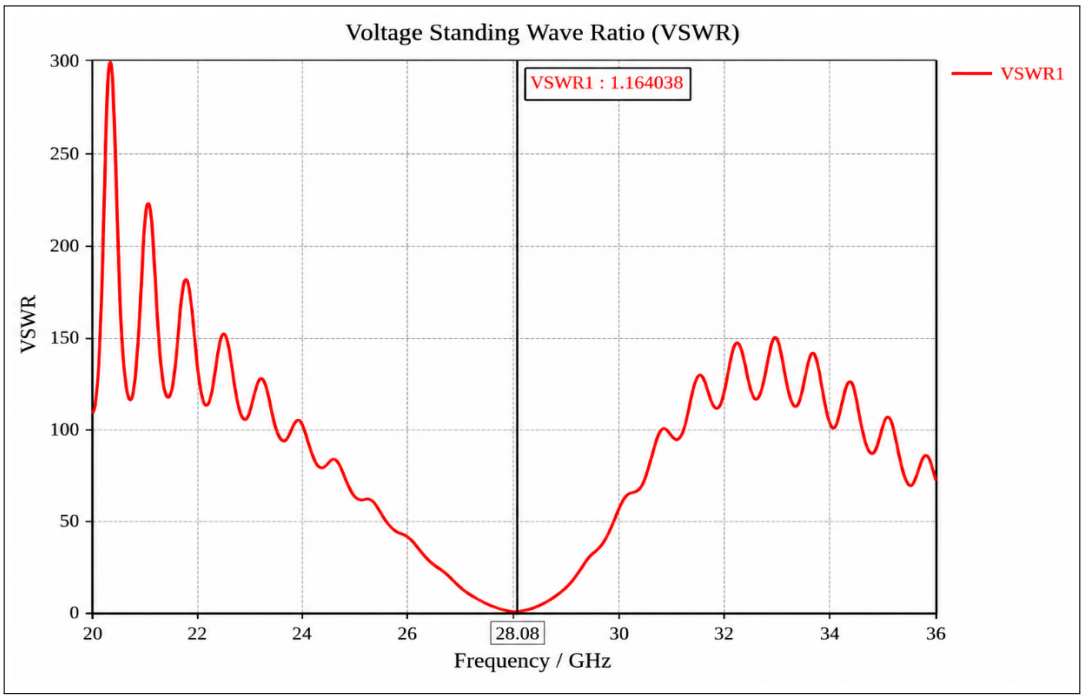


Figure 4. VSWR response of the proposed antenna at 28 GHz

However, the response of the VSWR shows significant increase away from the point of resonance. This implies that impedance matching worsens as the frequency moves further away from the point of operation.

4.3 Radiation Pattern Analysis

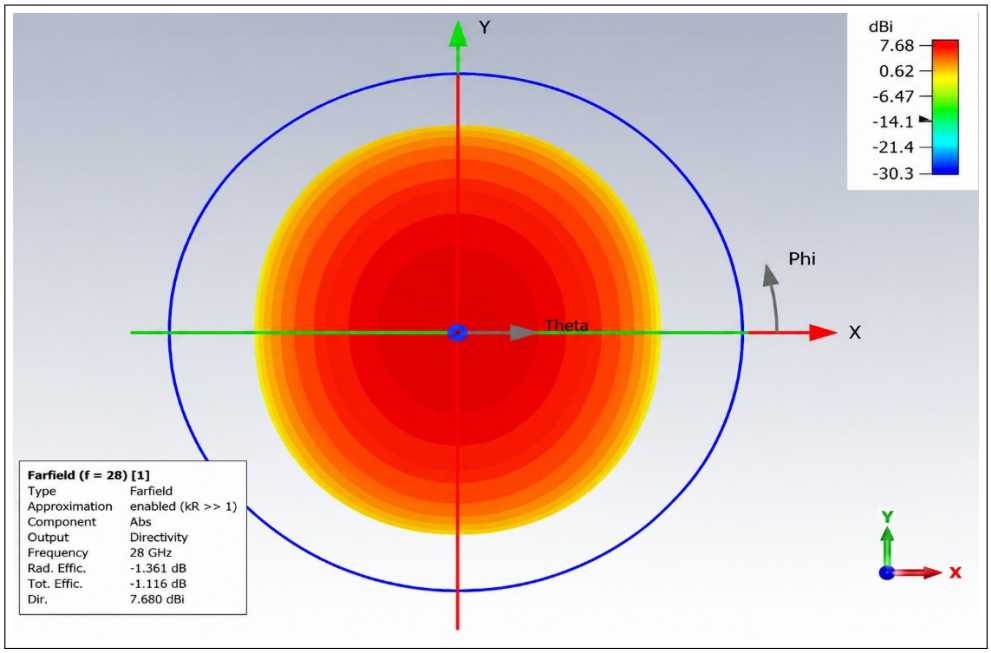


Figure 5. Simulated radiation pattern at 28 GHz

The simulated pattern represents the angle-dependent radiation of the electromagnetic field at the desired operating frequency of 28 GHz. As depicted in Figure 5, the graph reveals a concentration of the central part, followed by color gradients showing variations of the radiation pattern in the plot. The simulated pattern gives qualitative insights into the radiation properties of the antenna, complementing the results of the matching analysis carried out using the reflection coefficient and VSWR response. The simulation should be analyzed in the context of the far-field parameter used in the simulation, such as gain or directivity, and the corresponding observation plane.

5. Conclusion and Future Work

A slotted rectangular microstrip patch antenna design was investigated through electromagnetic simulation for 5G mm wave band. The design analysis of slotted rectangular microstrip patch antenna on Rogers RO4350B substrate, which consists of a rectangular slot located at the patch–feed region of the antenna, is carried out by analyzing its reflection coefficient, VSWR and radiation pattern. This combination of analysis helps understand the resonant frequency, impedance matching, and angular radiation properties of the proposed slotted patch antenna. The future works will include the optimization of slot geometry, feed arrangement, and substrate properties with an aim of improving the performance of the antennas. The research will further explore the impedance bandwidth, peak gain, radiation efficiency, and principal plane radiation pattern of the antennas.

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