

A Multi-Slotted Multi-Band Microstrip Patch Antenna Design for 5G Communication Devices

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ABSTRACT

This study presents a triple-band microstrip patch antenna designed to operate at 28 GHz, 32 GHz, and 38 GHz within the millimeter-wave spectrum. The primary objective is to develop a compact, low-profile antenna that meets the performance demands of high frequency 5G systems. By incorporating multiple slots of various shapes and sizes into a rectangular patch, the design significantly enhances gain and directivity, resulting in stronger signal transmission, wider coverage, and reduced interference. The antenna achieves gain values of 9.153 dBi, 7.48 dBi, and 12.08 dBi at the respective frequency bands. Additional key parameters, such as return loss, Voltage Standing Wave Ratio (VSWR), bandwidth, and efficiency, also indicate strong radiation performance. The design is optimized using the CST Studio Suite simulator. A comparative analysis demonstrates that the proposed antenna outperforms several existing designs, making it a strong candidate for integration into modern 5G mobile devices.

Keywords-5G mobile communication; antennas; gain; microstrip patch antenna; slots

I. INTRODUCTION

Microstrip patch antennas are widely used in mobile communication systems, such as mobile phones, RFID, GPS, and radar, due to their low profile, compact size, cost-effectiveness, ease of fabrication, and design flexibility [1–5]. They are also well-suited for 5G wireless communication systems [6, 7]. A key feature of 5G networks is their use of the millimeter-wave (mmWave) band, which offers a broad spectrum but also introduces challenges, such as high path loss, atmospheric absorption, rain attenuation, and signal blockage by obstacles, like buildings or the human body [8–13]. These issues can be mitigated using antennas with high gain and wide bandwidth [14]. As a result, researchers have focused on improving the gain and bandwidth of microstrip patch antennas for 5G applications, along with other critical radiation characteristics. Traditional microstrip designs often suffer from narrow bandwidth, but this limitation can be addressed through techniques, such as adding slots to the patch, increasing substrate thickness, lowering the substrate's effective permittivity, incorporating multiple resonances, and improving impedance matching [15, 16]. Among these, slotting the patch not only helps widen the bandwidth, but also enhances gain, directivity, and other performance metrics, such as return loss (S11), VSWR, and efficiency. Although bandwidth is a major concern for lower-frequency wireless systems, in 5G mmWave systems, achieving high gain is often a higher priority—as long as the bandwidth remains adequate for large data throughput [17, 18]. Accordingly, this study focuses on designing a high-

gain microstrip patch antenna that operates at 28 GHz, 32 GHz, and 38 GHz, all within the Ka-band spectrum of 5G.

Several studies have explored microstrip patch antenna designs for 5G applications, particularly in the mmWave band. For instance, a compact inset-fed microstrip antenna operating at 28 GHz achieved a gain of 6.83 dBi [19]. A broadband elliptical-slot antenna covering the 20 GHz–40 GHz range reached a maximum gain of 5 dBi [20]. Another design combined a microstrip patch radiator with a waveguide aperture to produce a tilted beam and achieved 7.41 dBi at 28 GHz [21]. A slotted microstrip patch antenna at 28 GHz reported a gain of 6.37 dBi [22], while a dual-band elliptical-slotted circular patch antenna (28/45 GHz) achieved 7.6 dBi at 28 GHz [23]. Similarly, a dual-band antenna with a Defected Ground Structure (DGS) and stub-slot configuration reached a gain of 8.31 dBi [24]. Other designs achieved gains of 7.43 dBi and 9.82 dBi at 28 GHz through various optimizations [25, 26]. In dual-band designs using a Coplanar Waveguide (CPW), gains of 6.6 dBi at 28 GHz and 5.6 dBi at 38 GHz were reported [27]. A Planar Inverted-F Antenna (PIFA) with CPW feeding reached 3.75 dBi and 5.06 dBi at 28 GHz and 38 GHz, respectively, with bandwidths of 3.34 GHz and 1.4 GHz [28]. A triple-band microstrip patch antenna covering 24.4 GHz, 28 GHz, and 38 GHz showed gains of 6.65 dBi, 7.02 dBi, and 5.05 dBi, respectively [7]. At 38 GHz, a compact patch antenna achieved a gain of only 1.27 dBi but had a good return loss of -24.35 dB and a 1.021 GHz bandwidth [29]. Another compact design (12 mm³ × 15 mm³ × 0.79 mm³) offered a wide 6.2 GHz

bandwidth and a peak gain of 8.2 dBi at 39 GHz [30]. For satellite applications, a miniaturized dual-band antenna at 36.944 GHz achieved a return loss of -55.03 dB, 3.028 GHz bandwidth, and 4.83 dBi gain [31]. A dual band microstrip antenna for 5G handsets at 38 and 60 GHz reported a gain of 6.2 dBi at 38 GHz with excellent impedance matching [32]. A compact MIMO antenna for 28 and 38 GHz offered 7 dBi gain and 94.5% efficiency, while keeping SAR values within safety limits [33]. Some other designs reported gains of 8.41 dBi and 8.64 dBi [34, 35]. Additionally, various microstrip patch array designs have been developed to improve beamforming and directivity, with many achieving gains over 10 dBi [12, 14, 36–39]. However, such arrays often involve increased size and complexity, which may not be suitable for compact or simple device applications. In contrast, this paper presents a simpler alternative slotted microstrip patch antenna designed to operate at 28 GHz, 32 GHz, and 38 GHz. The design aims to enhance gain and directivity while also maintaining good return loss, VSWR, and efficiency, without significantly sacrificing impedance bandwidth.

II. ANTENNA DESIGN

Given the widespread use of rectangular patches, the proposed antenna features a rectangular patch with various slot structures strategically arranged to obtain a multi-band operation with an enhanced radiation performance. The substrate material used is Rogers RT5880, with dimensions of 20 mm in length, 16.5 mm in width, and 0.508 mm in thickness. The substrate has a relative dielectric permittivity (ϵ_r) of 2.2 and a tangential loss ($\tan \delta$) of 0.0009 [40].

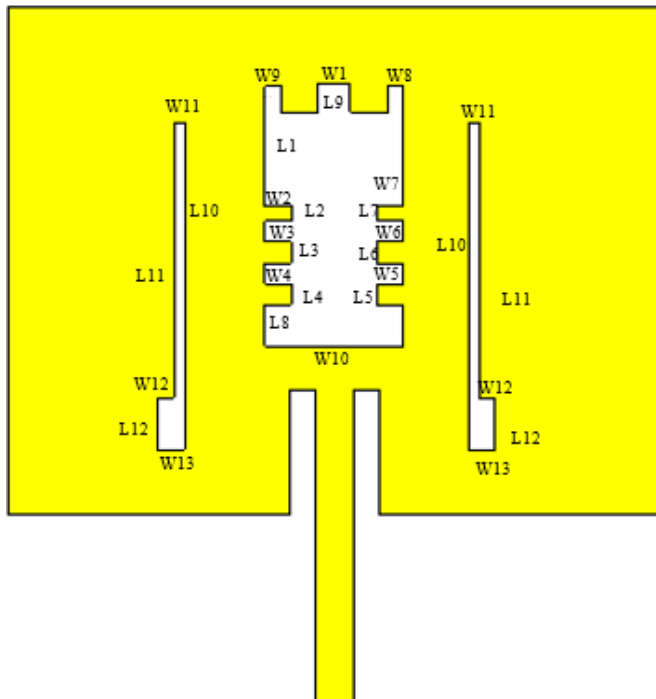


Fig. 1. Geometrical representation of the proposed multi-slotted patch antenna.

TABLE I. OPTIMAL DIMENSIONS OF THE PROPOSED MULTI-SLOTTED PATCH ANTENNA

Parameter	Value (mm)	Parameter	Value (mm)
L1	2.3	L7	0.3
W1	0.6	W7	0.5
L2	0.3	L9	0.5
W2	0.5	W9	0.3
L3	0.35	L10	6.3
W3	0.5	W10	2.6
L4	0.35	L11	5.3
W4	0.5	W11	0.2
L5	0.35	L12	6.27
W5	0.5	W12	1
L6	0.35	L13	0.3
W6	0.5	W13	4.25

TABLE II. SIMULATION RESULTS OF THE PROPOSED ANTENNA AT 28, 32, AND 38 GHz

Frequency (GHz)	S11 (dB)	VSWR	BW (GHz)	Gain (dBi)	Directivity (dB)	Efficiency %
28.05	-19.53	1.23	1	9.153	10.21	89.64%
31.70	-17.92	1.3	0.7	7.48	7.9	94.68%
37.924	-21.34	1.187	1.68	12.08	12.78	94.5%

Among the several feeding techniques available for microstrip patch antennas, the inset feed technique was chosen in the present work to ensure excellent impedance matching between the feed line and the patch. The patch dimensions are $12.2 \text{ mm}^2 \times 9.7 \text{ mm}^2$, fed by a 50Ω microstrip line with a width of 0.7 mm and a length of 4.75 mm. Table I outlines the optimized dimensions of the proposed slotted patch antenna, displayed in Figure 1. All dimensions were optimized through parametric analysis using the sweep option in the CST Studio Suite simulator. This study is primarily empirical, and it does not include a detailed analysis of how each slot contributes to individual resonances.

III. RESULTS

Table II presents the simulation results from the proposed antenna design against key radiation parameters, including S11, VSWR, bandwidth, gain, directivity, and efficiency. The results indicate that the proposed antenna operates across three different mmWave frequency bands: specifically at 28 GHz, 32 GHz, and 38 GHz. The minimum S11 was achieved at 38 GHz, where the highest gain and directivity were also observed. The gain value exceeding 12 dBi at 38 GHz is significantly higher than that found in other designs targeting the same operating frequency.

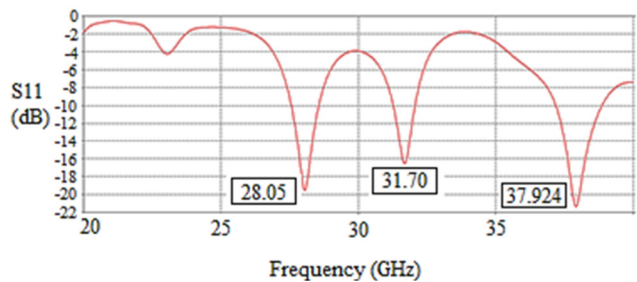


Fig. 2. S11 parameter as a function of frequency for the proposed multi-slotted antenna design.

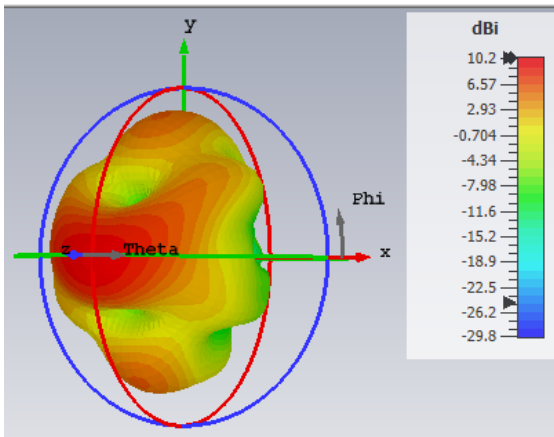


Fig. 3. The 28-GHz 3D directivity polar plot of the proposed design.

particularly at 38 GHz. The total bandwidth across all frequencies is approximately 3.4 GHz.

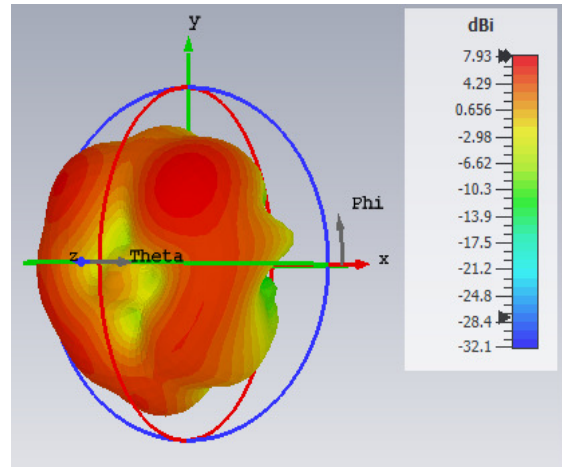


Fig. 5. The 32-GHz 3D directivity polar plot of the proposed design.

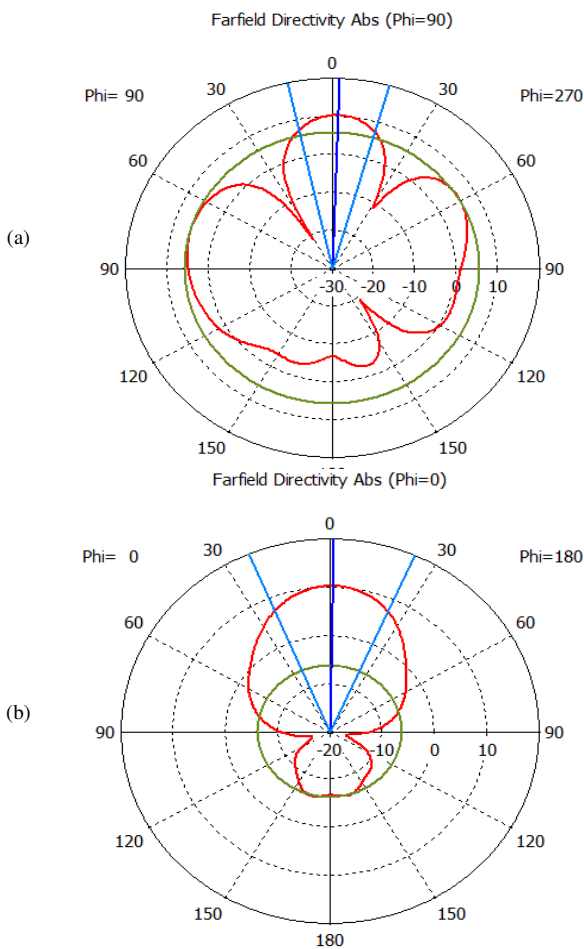


Fig. 4. The 28-GHz E-plane of the proposed design: (a) phase 90, and (b) phase 0.

Nevertheless, the antenna gain remains high at the other two frequencies (i.e., 32 GHz and 28 GHz). All obtained VSWR values were close to 1, demonstrating excellent matching between the antenna and the feed line. The bandwidth of 1.7 GHz across all bands is deemed acceptable,

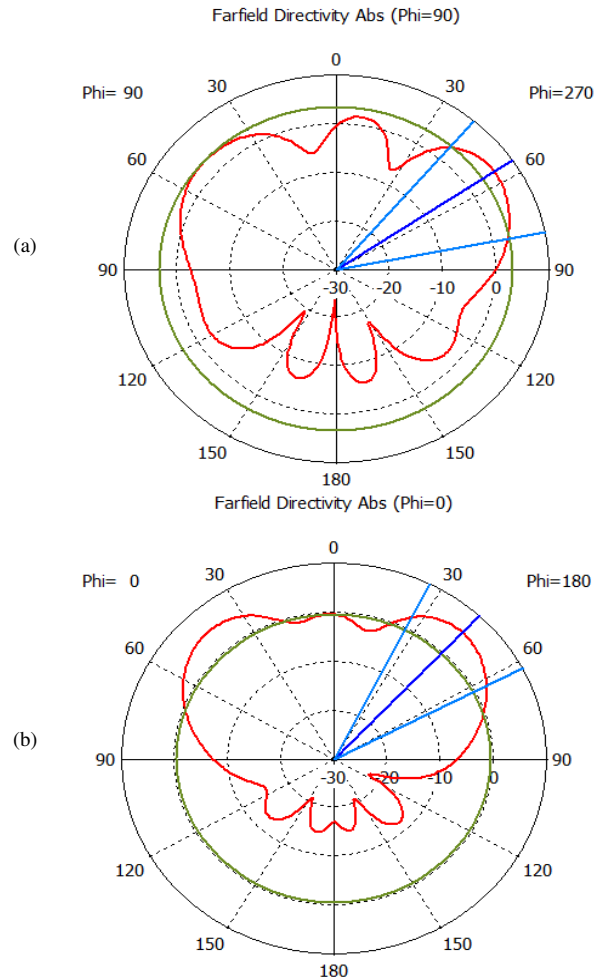


Fig. 6. The 32-GHz E-plane of the proposed design: (a) phase 90, and (b) phase 0.

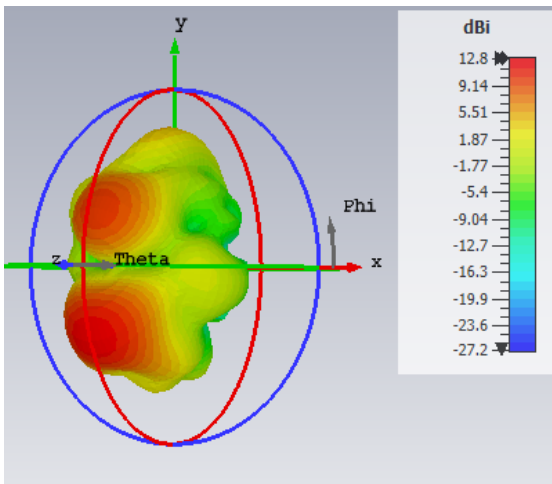


Fig. 7. The 38-GHz 3D directivity polar plot of the proposed design.

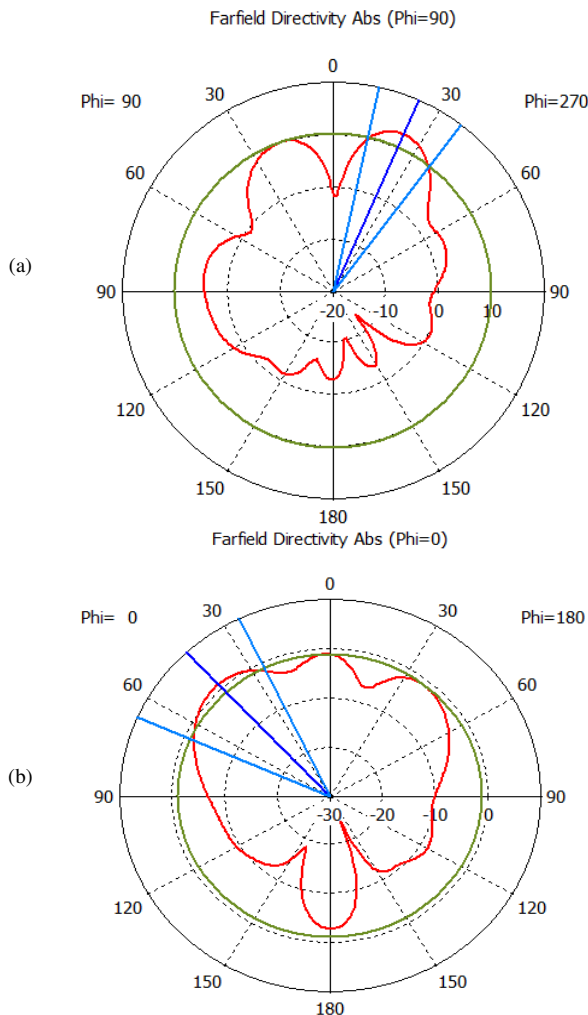


Fig. 8. The 38-GHz E-plane of the proposed design: (a) phase 90, and (b) phase 0.

In this study, the gain and directivity are prioritized over the bandwidth, while there is always a trade-off between these two

parameters. In this design, the compromise made for bandwidth is still insignificant compared to other designs. Regarding efficiency results, the minimum efficiency was nearly 90% at 28 GHz, which is still very high. A detailed comparison with other research works is provided below. Figure 2 illustrates the S11 parameter in dB relative to the operating frequency. The 3D directivity polar plot, followed by the E-plane plot (for phase 90 and phase 0), for the proposed design at 28 GHz, 32 GHz, and 38 GHz bands, is shown in Figures 3-8, respectively.

IV. COMPARISON OF THE MULTISLOTTED ANTENNA WITH OTHER DESIGNS

Table III provides a comparison between the proposed multi-slotted antenna and other designs from the literature, all using a single patch structure and resonating at 38 GHz. This comparative study focuses solely on the 38 GHz design, as it represents the highest frequency among the three selected Ka-band frequencies. This focus is primarily due to the trend of moving to higher bands in the 5G spectrum, which is prevalent in the development of modern communication devices, owing to their distinct advantages over lower frequencies: namely, higher gain, wider bandwidth, and massive data rates [41]. Additionally, while the gain at other frequencies is notably high, it is still surpassed by other designs [17, 18]. However, the introduced design shows improved bandwidth compared to these alternatives. The results demonstrate that the proposed antenna excels over other designs in terms of gain and efficiency. For example, the maximum gain among the other designs is 8.64 dBi [35], and the highest efficiency achieved is 90% [30, 33], both of which are significantly lower than the proposed antenna's. Although some designs provide higher bandwidths, the proposed antenna's bandwidth of 1.68 GHz is offset by its greater gain and efficiency. Moreover, the compact size and straightforward structure of the introduced antenna make it an excellent option for integration into modern communication devices. The smallest design in the performed comparison measures 8 mm² × 5.9 mm² [29], but it offers a considerably lower gain of 1.27 dBi and an efficiency of 77.54%. The proposed antenna's superior gain and efficiency performance, along with its simplicity and cost-effectiveness, render it a candidate for 5G cellular mobile phones, where these parameters are crucial.

TABLE III. COMPARISON WITH OTHER ANTENNAS IN THE LITERATURE FOR 38 GHz

Ref.	Size (mm ²)	Center Frequency (GHz)	Minimum S11 (dB)	VSWR	BW (GHz)	Gain (dBi)	Efficiency %
[29]	8×5.9	38	-24.35	~ 1	1.021	1.27	77.54%
[30]	12×15	38	-34.9	-	6.2	8.2	90%
[31]	10×10	36.94	-55.029	1.0036	3.028	4.83	-
[32]	15×25	37.76	-42	~ 1	2	6.2	89.57%
[33]	28×14	38	-45	-	-	7	~ 90%
[34]	26×20	37.35	-13	1.56	2.35	8.41	68%
[35]	8×8	35.22	-51.96	1.0051	2.54	8.64	-
Proposed	12.2 × 9.77	37.924	-21.34	1.187	1.68	12.08	94.5%

V. DISCUSSION

This study proposes a multi-slotted antenna that offers multiple frequency operations in the Ka-band of the mmWave spectrum. The antenna design evaluation was based on measuring key performance metrics, such as S11, gain, directivity, VSWR, efficiency, and bandwidth. This antenna, with patch dimensions of $12.2 \text{ mm}^2 \times 9.77 \text{ mm}^2$, operates at 28 GHz, 32 GHz, and 38 GHz frequency bands, achieving a high gain and excellent radiation performance at all frequencies. Specifically, at 38 GHz, it obtained an outstanding gain of 12.08 dBi and a great efficiency of 94.5%, which are superior compared to the metrics listed in Table III. However, other parameters were not compromised when compared to the designs listed in Table III, except for the bandwidth. The latter was traded off for the significantly increased gain and directivity values while maintaining a relatively simple compact patch structure. This suggests that the microstrip patch antenna presented in this study could be a strong candidate for 5G cellular mobile phones where simplicity, cost-effectiveness, and reduced antenna size are essential.

VI. CONCLUSIONS

This paper presents a triple-band microstrip patch antenna designed for 5G communication devices, operating at 28 GHz, 32 GHz, and 38 GHz within the millimeter-wave (mmWave) spectrum. The main goal is to develop a compact, low-profile antenna that meets the high-performance requirements of 5G systems. By incorporating multiple slots of different shapes and sizes into a rectangular patch, the design significantly enhances gain and directivity, ensuring strong and reliable communication. The antenna achieves gain values of 9.153 dBi at 28 GHz, 7.48 dBi at 32 GHz, and 12.08 dBi at 38 GHz. It also exhibits low return loss, a Voltage Standing Wave Ratio (VSWR) close to 1, wide enough bandwidth, and high efficiency. At the highest operating frequency (38 GHz), the antenna reaches a gain of 12.08 dBi and an efficiency of 94.5%, outperforming other designs in the literature. While competing antennas may offer wider bandwidth, the proposed design prioritizes gain and efficiency, which are key parameters for 5G applications, making the trade-off worthwhile. Its compact size and simple structure also make it highly suitable for integration into 5G mobile devices, where space, cost, and performance are critical considerations. In summary, the proposed multi-slotted patch antenna combines high gain, strong efficiency, and compactness, making it a promising solution for 5G technologies. Its ability to perform well across multiple Ka-band frequencies further enhances its applicability in modern communication devices. Future work will explore bandwidth enhancement techniques, such as array configurations, while preserving high gain and efficiency. Fabrication and experimental validation are also planned to support the practical viability of this design.

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