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Design and Implementation of Circular Polarized Patched Antenna for 5G Applications

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Abstract

The need for high-performance antennas in 5G technology is discussed in this research. It describes the layout and enhancement of a circular polarized patch antenna, considering feed structure, substrate material, geometry, impedance matching, and gain enhancement. Modern manufacturing techniques are used to construct the antenna, which is designed using sophisticated electromagnetic simulation techniques. The intended antenna can span a wide variety of angles in both vertical and horizontal directions. This study investigates the effects of metallic block addition and dielectric substrate modification on the antenna performance, specifically on the signal strength at low angles and the signal polarization quality. The recommended architecture achieves wideband operation to support the different frequency bands allotted for 5G connectivity. Furthermore, the antenna possesses favorable radiation characteristics, like high gain and low cross-polarization, that ensure efficient signal transmission and reception. Our research aims to optimize the design parameters of the antenna to achieve better performance metrics, such as increased bandwidth, better radiation characteristics, and a small form factor that can be integrated into devices with small footprints, like smartphones and Internet of Things devices. We investigate many methods of improving the antenna bandwidth: substrate-integrated waveguide cavity loading, corner truncation, and slot construction. Furthermore, asymmetrical cross-slots and directional triangular electromagnetic band gap (EBG) structures are examined as unique means of attaining circular polarization. The efficiency of the antenna is demonstrated by simulations on CST Studio Suite, indicating that it is a portable and workable option for 5G networks. Our research aims to optimize the design parameters of the antenna to achieve better performance metrics, such as increased bandwidth, better radiation characteristics, and a small form factor that can be integrated into devices with small footprints, like smartphones and Internet of Things devices. We investigate many methods of improving the antenna bandwidth: substrate-integrated waveguide cavity loading, corner truncation, and slot construction. Furthermore, asymmetrical cross-slots and directional triangular electromagnetic band gap (EBG) structures are examined as unique means of attaining circular polarization.

Keywords: 5G applications, circularly polarized, coplanar waveguide fed, patch antenna, wideband antenna

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INTRODUCTION

The surge in global mobile data usage and the demand for enhanced connectivity are driving the adoption of faster technologies worldwide. One such technology is 5G, which aims to deliver speeds of up to 10 Gbps per user, significantly faster than 4G-LTE, with minimal latency of less than 1 ms. The impact of 5G is expected to be profound across various sectors including automotive, healthcare, defence, and telecommunications, offering substantial benefits.

In modern telecommunications systems, there is a growing need for compact and small antennas. Microstrip patch antennas have gained considerable attention for both military and commercial applications due to their advantages such as low profile, durability, cost-effectiveness, and ease of fabrication [1–4]. In applications like radio frequency identification (RFID), global navigation satellite systems (GNSS), and mobile communication, compact size and circularly polarized (CP) antennas are essential. CP antennas improve the probability of successful transmission and reception by transmitting signals in all planes [5]. Antenna design and implementation capable of satisfying the many demands of this quickly developing technology are being extensively researched due to the increasing need for 5G communication networks. A lot of interest has been focused on circularly polarized (CP) antennas because of their potential to reduce multipath fading, boost spectral efficiency, and increase signal reception in 5G applications [6]. An extensive analysis of the development and deployment of a CP patch antenna especially suited for 5G applications is presented in this research report.

Currently, there is ongoing research aimed at achieving higher security levels and faster data rates in 5G wireless communication systems. In India, research is focusing on 5G bands spanning 3300–3400 MHz, 3400–3600 MHz, 24.25–27.5 GHz, 31.8–33.4 GHz, and 37–40.5 GHz. To achieve these objectives, large bandwidth and high gain antennas are essential [7]. A proposed solution for 5G technologies is a circularly polarized patch antenna with an axial band range of 3.715–3.83 GHz and a measured gain of 5 dBi. Recent studies have explored the use of variable resistors for achieving reconfigurability. For applications in the 23–29 GHz range, a Y-shaped patch antenna has been introduced, while a slotted Y-shaped antenna is proposed for 27 GHz applications. Various techniques are being explored to achieve circular polarization in antennas. The axial ratio (AR) is a critical factor determining the performance of circularly polarized antennas [8]. One approach involves a CPW-fed line with two arms of different lengths, with a slit cut on the ground plane to enhance the AR bandwidth. Additionally, asymmetrical ground planes are utilized to generate CP waves, and rectangular open loops are introduced to achieve broadband circular polarization characteristics. With the maturation of 4G deployment, significant attention is now directed toward the future 5G communication system. While much of the research focus has been on terrestrial communication, particularly with linearly polarized antennas, there's a growing recognition of the potential for 5G mobile phones to integrate satellite communication functionality. While terrestrial cellular systems have effectively provided extensive coverage and high-quality telecommunication services in urban areas, there are still remote regions globally that lack full network coverage. To achieve ubiquitous wireless coverage across the Earth, mobile satellite communication services serve as a complementary solution. The capacity of CP antennas to send and receive electromagnetic waves with circularly polarized polarization has made them popular [9]. Because of its distinct polarization feature, CP antennas may effectively counteract signal distortions brought on by reflections and obstructions in urban settings, resulting in strong and dependable communication links that are essential for 5G networks [10].

The ultimate objective of this research is to provide a CP patch antenna solution that is efficient and dependable, specifically designed to meet the demands of next-generation wireless networks, thus advancing 5G communication systems. We seek to show the viability and efficacy of the suggested antenna design for a variety of 5G applications through meticulous analysis, simulation, and experimentation, thereby easing the smooth transition to the era of incredibly fast, highly capacious, and low-latency wireless connectivity.

The rest of the work is divided as, Section 2 provides detailed information on antenna designing, results are discussed in Section 3, while Section 4 presents the conclusion of the proposed work, along with a comparison with similar works found in the literature. Table 1 shows the comparison of proposed antenna with the previously described one. A comparison between the proposed work and similar studies found in the literature is presented in Table 1.

Table 1. Comparison of the performance of proposed antenna with other reported antenna for 5G applications.

Ref.	**Dimensions (mm)**	**Bandwidth (GHz)**	**Gain (%)**
[2]	10 × 10 × 1.57	20–25	6.5
[4]	8 × 10 × 0.254	34.21–55.57	2–7
Proposed work	22 × 26.5 × 0.8	25–28	7

ANTENNA DESIGN

The proposed antenna structure, as shown in Figure 1, is designed on a rectangular substrate with dimensions L x W mm^2. The substrate material, Rogers RT 5880, has a relative permittivity (εr) of 2.2 and a loss tangent (tan δ) of 0.0009, with a height (hsub) of 0.8 mm. The antenna geometry, depicted in Figure 1, is derived from a rectangular patch by incorporating a Y-shaped slot. CPW feeding is utilized to improve impedance matching with the Y-shaped radiating patch. Simulation and validation of the proposed antenna design are conducted using CST Microwave Studio.

It was observed that the inclusion of a ground adversely affects the performance of the proposed antenna, particularly in terms of gain and return loss. Experimentation with different ground dimensions confirmed this observation.

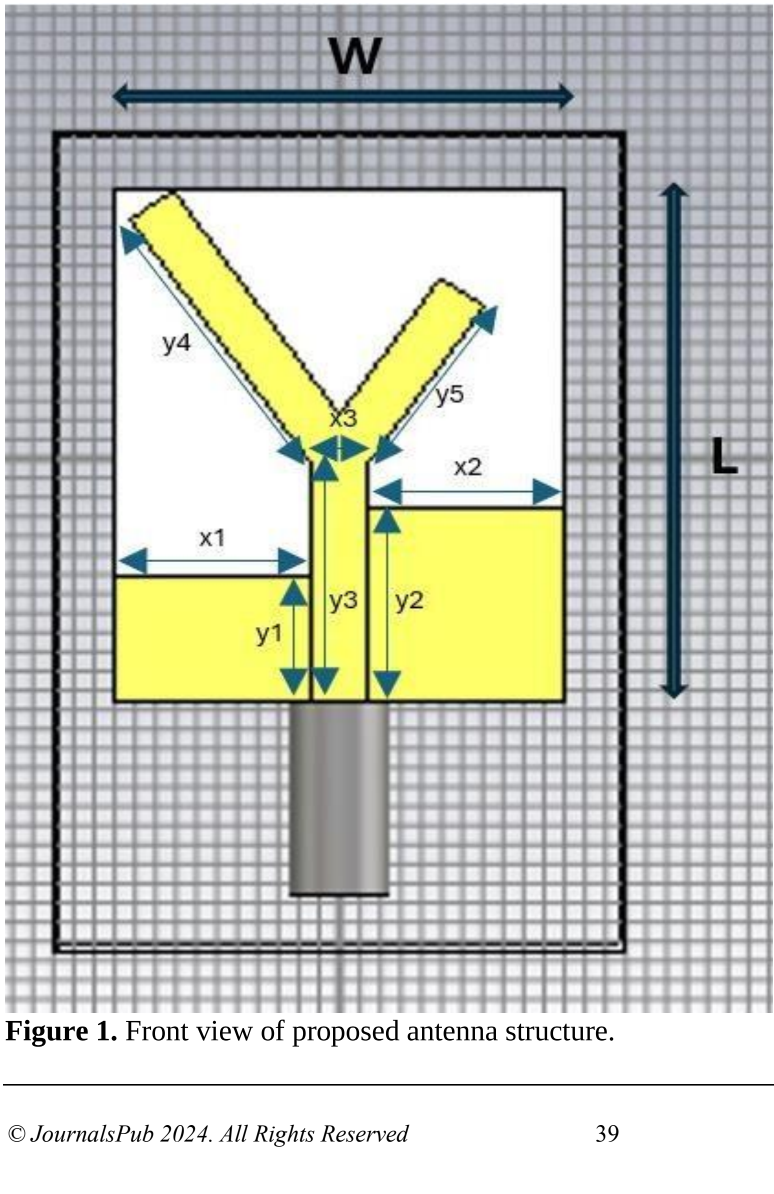

Figure 1. Front view of proposed antenna structure.

The final dimensions of the proposed antenna are selected following a comprehensive parametric study of various parameters. The design parameters of the antenna are outlined in Table 2. CPW feeding is employed to improve impedance matching with the Y-shaped radiating patch.

Table 2. Dimension of proposed antenna.

Parameter	Value(mm)	Parameter	Value(mm)
L	26.5	y3	12.5
x1	12.45	x4	2.6
y1	18.5	y4	16
x2	12.45	x5	2.6
y2	15	y5	10.5

RESULTS AND DISCUSSION

As depicted in Figure 1, the proposed antenna comprises Y-shaped metallic strips along both sides of the feed, resulting in a symmetric radiation pattern on either side of the feed. Frequency reconfigurability is achieved using two variable resistors with connecting stubs. Altering the resistor values leads to changes in voltage, affecting the current distribution of the stubs and thereby directly influencing the operational frequency, which can be reconfigured within the 25–28 GHz range. Simulation of the proposed antenna and validation of results are conducted using CST Microwave Studio.

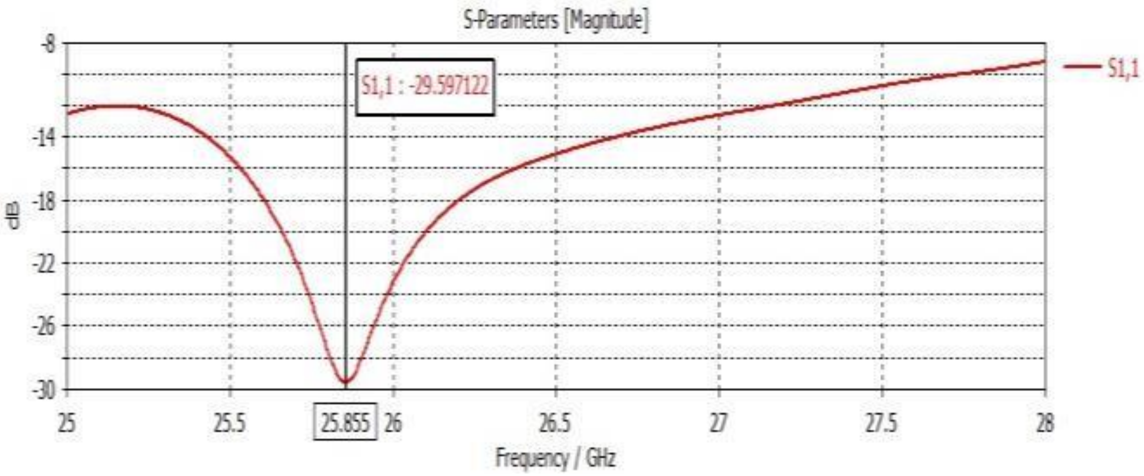

Figure 2. Simulated and measured result of S11 parameter.

In Figure 2, the reflection coefficient results of the proposed antenna structure, both simulated and measured, are presented. It is evident that the simulated and measured S11 (dB) results are in excellent agreement across a wide frequency band. The simulated impedance bandwidth of the proposed antenna (S11 < 10dB) ranges from 25 to 28 GHz, with a resonant frequency at 27 GHz. This notable bandwidth is achieved through the implementation of CPW feeding technique and the careful selection of dielectric materials for the design.

Figure 3 shows the proposed graph of the voltage standing wave ratio (VSWR). The frequency result obtained is at 25.855 GHz and the corresponding VSWR is of 1.06 which is around the ideal value of 1.

In Figure 4, the axial ratio in dB of the proposed antenna structure is presented. It demonstrates that the proposed antenna structure exhibits circular polarization characteristics at the resonance frequency of 27 GHz. Circularly polarized E and H fields propagate energy in both vertical and horizontal planes simultaneously. As circularly polarized antennas transmit and receive E–H fields in all planes, signal power loss is minimized, ensuring efficient transmission and reception.

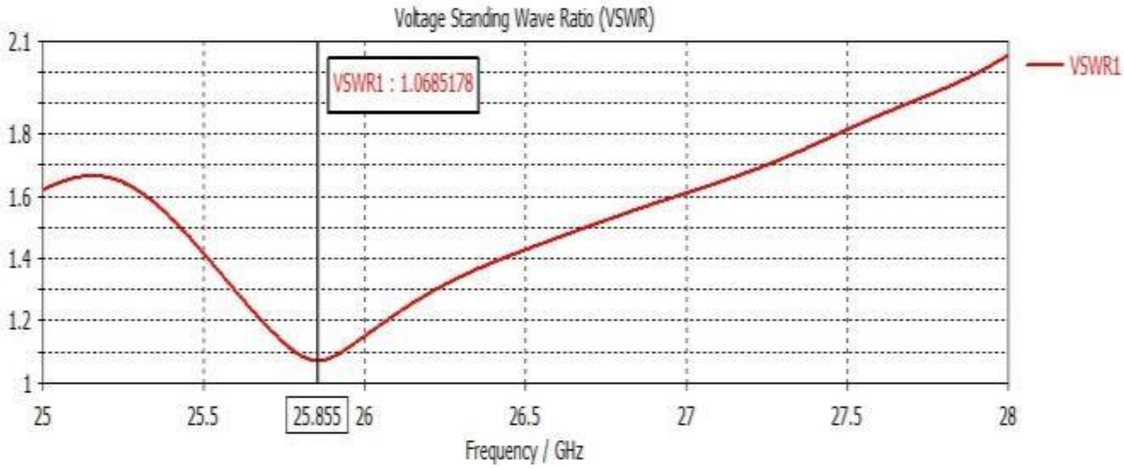

Figure 3. Simulated and measured results of the VSWR.

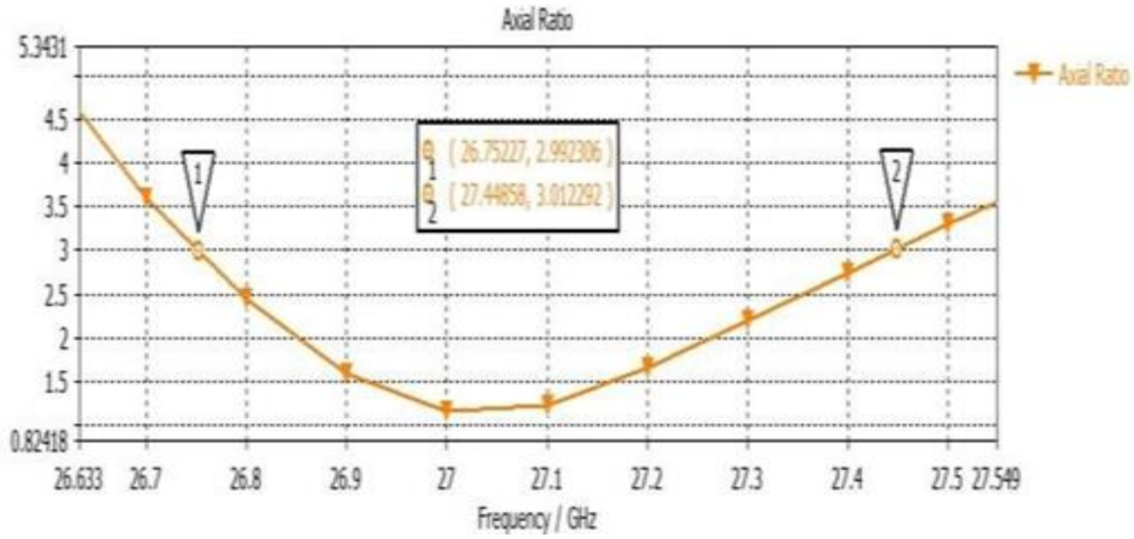

Figure 4. Simulated and measured result of axial ratio.

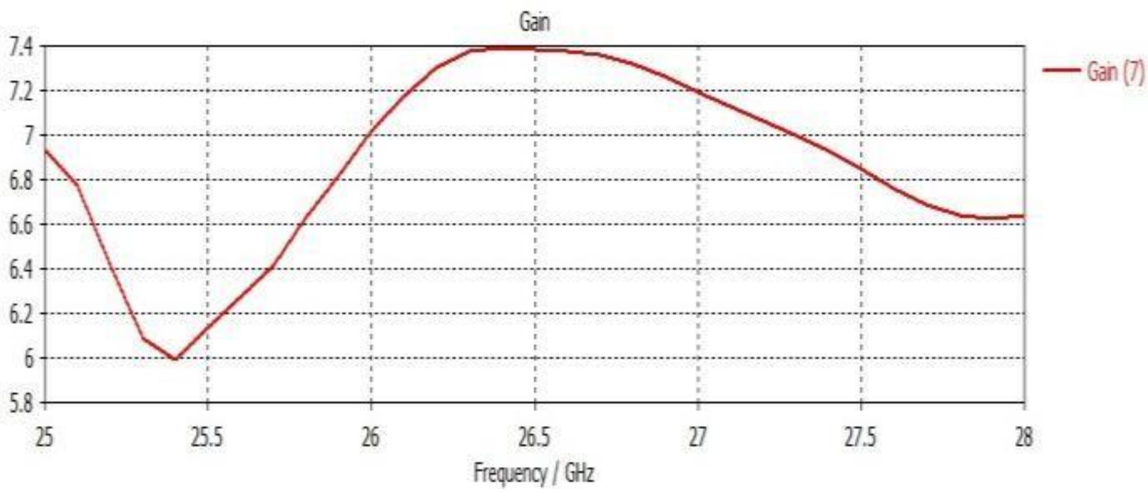

Figure 5. Simulated and measured result of gain.

In Figure 5, both simulated and measured results of the gain in dB for the proposed antenna are illustrated. The proposed antenna achieves a maximum simulated and measured gain of 7 dB, as indicated in the Figure 5. This notable gain is attributed to the improved impedance matching facilitated by the CPW feeding technique employed in the antenna design.

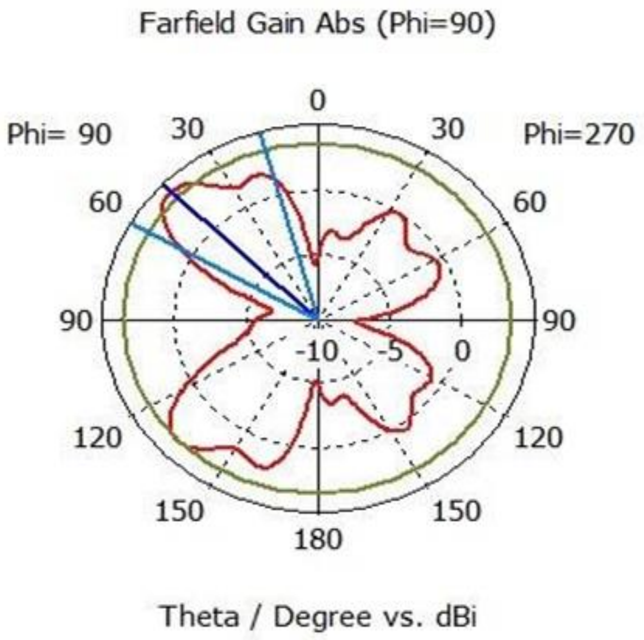

Figure 6. Simulated and measured far-field results.

In Figure 6, the radiation efficiency of the proposed antenna is depicted, indicating an impressive efficiency of 97.1%. Additionally, Figure 6 displays the E- and H-plane patterns of the proposed antenna at 27 GHz. Furthermore, in Figure 7, the simulated vector current distribution of the CPW antenna at 27 GHz is illustrated, providing insights into the antenna's electromagnetic behavior at the given frequency.

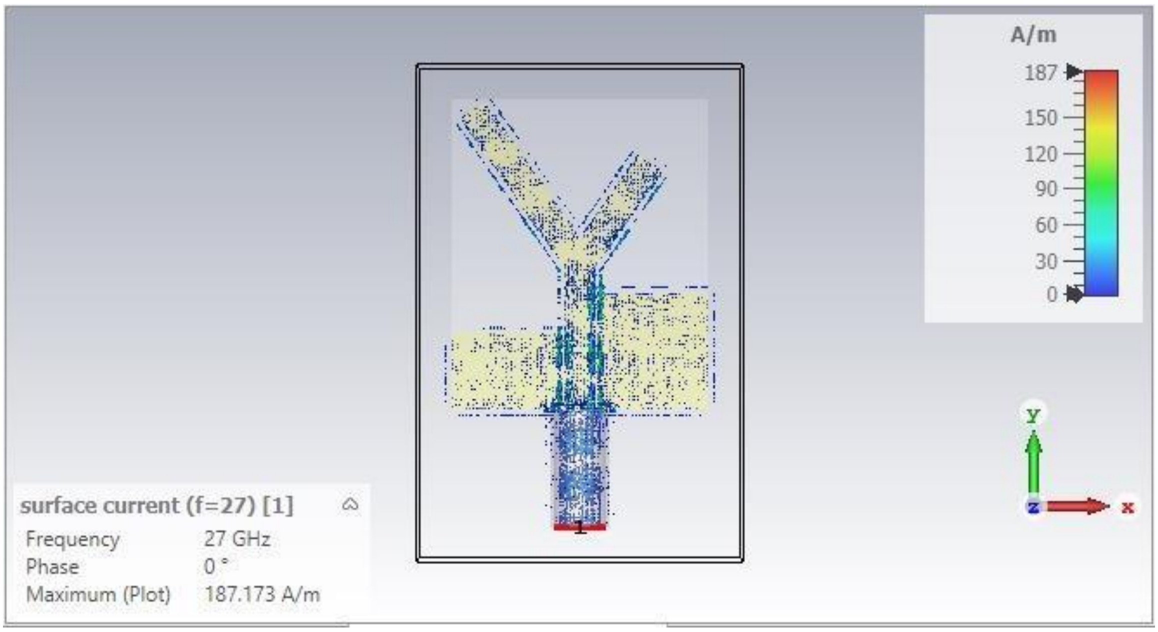

Figure 7. Surface current density at 27 GHz.

The simulated radiation efficiency of the proposed antenna across all working frequency bands consistently exceeds 97.1%. Additionally, it is noted that while the gain of the proposed antenna decreases with an increase in the value of resistance, it remains above 7 dB within the frequency of operation.

$$\eta = \frac{P_{rad}}{P_{total}}$$

where P_{rad} is the radiated power and P_{total} is the total input power supplied to the antenna.

CONCLUSION

This study introduces a circular-shaped coplanar waveguide (CPW) antenna on a substrate designed for 5G applications. The proposed CPW antenna is intended to operate within the 5G spectrum range of 25–28 GHz. Through thorough evaluation, the antenna demonstrates commendable performance across various metrics including S-parameters, gain, axial ratio, voltage standing wave ratio, and efficiency. Both measured and simulated results are provided to substantiate the efficacy of the proposed CP antenna for 5G applications.

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