Development of an internet of things microstrip antenna for turbo code off-grid emergency communications

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ABSTRACT

Technologies and other things are fully automated, meaning signal processing and microstrip antennas for communication are essential because of their compact size and versatility. Due to inefficiency and other factors, traditional communication methods fail, which means some emergency communication systems encounter difficulties. MATLAB was used to simulate a microstrip antenna for turbo code off-grid emergency communication and signaling of internet of things (IoT) devices. A criterion is followed to determine whether a microstrip antenna's behavior meets the emergency communication requirements. The results show that the system's transfer function satisfies the required conditions to meet efficient communication and signaling, especially in emergencies. The step response peaked at 1.04 and an overshoot of 4.6%, meeting the conditions for efficient communication. Besides that, the generated Bode plot and Nyquist plot display the required behavior, meaning that the microstrip antenna can function as a communication device for emergency situations.

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1. INTRODUCTION

In the current world, where many things and technologies are fully automated, signal processing and the utilization of microstrip antennas have become evident in their capabilities to communicate with other devices and technologies for advanced automated communication or signaling [1]. In modern communication systems, microstrip antennas have become ideal and significant due to their compact size and ability to fit in more compact devices and circuits, the ease of fabrication and manufacturing of components, and versatility over a wide range of possible applications [2], [3].

These microstrip antennas are particularly valuable in emergency communication and signaling, wherein reliable and efficient communication is essential for immediate prompt responses and effective coordination of response teams [4]. Furthermore, these antennas are easily portable with their lightweight and compact design, making them ideal for handheld devices and portable communication systems, which are used by first responders and rescue teams over various ranges of frequencies [5]. It is beneficial to responders and rescue teams in compatibility with different communication systems to better inform the respondents of the situation. Microstrip antennas can be easily integrated with modern communication technologies like

GPS, Wi-Fi, and internet of things (IoT) devices, making these antennas easily integrated into emergency communication systems, enabling features such as real-time tracking and coordination over varying distances [6]-[8]. This study generally focuses on the development and simulation of such application of microstrip antennas in emergencies for improved communication and signaling to various concerned parties to further improve the response and action of the involved parties. In order to simulate and employ data-gathering methods, the paper will focus on using the programming language MATLAB to depict and implement the application to determine the response and behavior of such signals and to correlate with the related research on the topic.

In the modern world, there exist various limitations on emergency response technologies, such as how reliable and efficient these emergency response technologies are, how robust they can be, the communication establishment stability and consistency, and proper working across different frequency bands. These drawbacks may hinder effective communication and coordination during calamities. Microstrip antennas may provide an answer to that problem due to their simple yet flexible design, signaling capabilities in communication systems in terms of their compatibility with modern communications technologies [9], wide operating frequency range [10], and strong linkages capable of meeting the demands of emergency communication and signaling solutions, enhancing efforts for responding to disasters as well as improving communications.

Thus, it becomes necessary to ensure a clearer correlation between the functionalities of microstrip antennas and emergency communication systems to appreciate how their functionalities align with the specific needs and criteria of emergency response systems. Among other traits of microstrip antennas, it is necessary to consider their properties like compactness, frequency versatility, and ease of integration that can meet the demands of reliable and fast communications in crises. Researchers can identify areas for improvement by studying fitting behavior, understanding actual performance in various emergencies, and optimizing design to develop efficient, responsive, and robust communication systems. This understanding will inform improvements in antenna technology to ensure it meets the crucial requirements for effective emergency response operations.

Microstrip antennas initially originated from regular antennas, which transmit vibrations that can easily send signals and communications from one point to another. An example of such antennas is the radios, which transmit frequencies that send sounds, images, data, and other information forms, making wireless communication possible. However, it was later developed and studied further, which produced the microstrip antenna that involved more advanced technology regarding electromagnetic waves. The microstrip antenna has various advantages that revolutionized the modern world as these microstrip antennas are lightweight, occupy low volume, and have a low-profile planar configuration, making them simple to implement and integrate with various other circuits along with its properties of being cost-efficient and adaptable. They also have low scattering cross sections, are robust, capable of withstanding shock and vibration, and are adapted for use with embedded antennas in wireless devices.

Advancing public safety communications: toward future-ready infrastructure: an article authored by Crespo-Bardera *et al.* [11] explores the development of a conformal antenna array designed for emergency communication, particularly enhancing public safety communication capabilities. This 4.9-GHz antenna, integrated into a helmet, aims to enhance the communication skills of the first responders without compromising portability and lightweight requirements [11]. The research is focused on ensuring high data rate transmission and reliability in emergency scenarios, crucial for effective public-safety operations performance evaluations, including bandwidth and radiation patterns, reflection coefficient, and specific absorption rate, ensuring the suitability and safety of the antenna for practical use. This aligns with the broader microstrip antenna applications in emergency communication and signaling by providing robust, reliable, and high-performance critical communications solutions in emergency response efforts.

MATLAB-based microstrip patch antenna for S-band wireless communications: the article focuses on designing and simulating a microstrip antenna operating in the S-band frequency range, specifically at 2.5 GHz. The idea is to produce the most cost-effective, least space taken, and offer good performance whilst achieving the most advantages on a microstrip patch antenna. The antenna design uses MATLAB for simulation to achieve optimal performance metrics such as low return loss, high gain, and excellent directivity. The substrate material used in this study is Rogers RO3006, utilized for its low loss and high permittivity. The simulated results indicate a reflection coefficient of -42.476 dBi, a gain of 6.1 dBi, and a directivity of 7.1 dBi, demonstrating the antenna's efficiency and effectiveness for wireless communication applications. This article is relevant for emergency communication systems in terms of having the least weight and high performance of wireless communication. The study is vital to the design and process, especially regarding simulation testing of optimality and performance for emergency case scenarios [12].

Characterization of ultrawideband microstrip antennas: a run-through of the primary applications of various antenna types was conducted by Dhande [13]. Microstrip patch antennas are advantageous over conventional antennas in modern communication systems due to their compact profile and cost-effective manufacturing techniques. Additionally, these antennas play a crucial role in the development of advanced communication technologies. Significant research has been conducted on these antenna systems [2]. One example is the flexible, lightweight, and wearable microstrip antennas [3]. As such, these are considered robust and have a convenient mounting capability due to their slim design, simple production, and lightweight. It comprised of a conductive element applied to one face of a dielectric substrate, which can have a planar or non-planar geometry [14]-[16].

IoT-based solutions for emergency response systems: emergency response systems require off-grid to ensure that responders can communicate and coordinate, regardless of the conditions. Even in grid power losses, telecom outages, or possible remote locations, recent studies have shown that a resilient system is needed for fast and uninterrupted deployment of needs. One notable study is a load-balancing optimization where IoT deployments in constrained disaster response operations have improved reliability [17]. Several studies also in antenna design have delved into low-cost and low-power antenna, but applications are for robust environments and long-range radio technologies [18]. These studies demonstrate the potential of IoT in improving emergency response systems through various optimization techniques, addressing challenges such as resource constraints, service quality, and real-time information sharing in disaster scenarios.

Emergency communication systems and signals face significant problems and challenges in ensuring reliable operations, especially when traditional communication methods fail due to certain factors and lack of efficiency. Despite rapid advancements in technology and methods of emergency communications, existing systems often lack in the areas of device portability, features of timely deployability, and the ability to function across a diverse range of frequency bands. In emergency situations, certain factors may hinder communication lines, such as unreliable sensors, the need to set up communication links, and the network architecture of the vicinity [19]. Thus, current emergency communication systems exhibit flaws requiring more robust, secure, and advanced signaling technology. Traditional communication systems are often rendered inoperative due to physical damage or overloading during disasters, affecting the functionality of the communication system, which emphasizes the need for alternative solutions that are robust and adaptable to the dynamic nature of emergency scenarios. Establishing and maintaining communication across various conditions is also crucial in coordinating with rescue teams and ensuring the timeliness of disseminating information. Regarding addressing the issue of adaptability, another challenge is the necessity for systems that can seamlessly integrate with existing technology while being resilient to environmental factors such as extreme weather, physical obstructions, and interference. Also, this article summarized in Table 1 the lacking approaches in previously published studies on the utilization of microstrip antennas for turbo code off-grid emergency signaling communications of IoT devices.

Table 1. Lacking in the approaches of previously published studies

Topic	Details	Lacking in the approaches
An overview of microstrip antenna [6], [20]	Microstrip antennas are widely used in modern wireless communication due to their low profile, ease of fabrication, and compact size.	However, they are inherently limited by narrow bandwidth, low gain, and low efficiency, which present significant challenges—especially for advanced or broadband applications.
Ultra-wideband antenna for X-band and WiMAX applications [21]	Microstrip antennas are limited by single operating frequency, low impedance bandwidth, relatively large size at lower frequencies, and polarization issues.	Improve key performance parameters of microstrip antennas, such as gain, return loss, cross-polarization, and impedance bandwidth.
Applications of microstrip antenna in IoT [22]	Wireless wearable body area networks are increasingly being implemented in hospitals, medical centers, and patient care as one of the potential choices.	Challenges such as miniaturization limits, narrow bandwidth, low gain, polarization mismatch, detuning from nearby components, and environmental sensitivity, which collectively hinder stable and efficient communication.

In this study, the researchers aim to express, observe, and determine the behavior of the microstrip antenna in MATLAB to adapt to the appropriate criteria for emergency communications and signaling of IoT devices. Achieving these objectives also requires attaining the following: correlating the behavior of the microstrip antenna with a viable representation of the time response of the signal and generating and depicting the behavior of the signal through step responses. Although, the current simulation assumes an ideal, noise-free environment, which may not accurately reflect real-world conditions.

2. METHOD

For the different characteristics of variables of the transfer functions, each variable is explicitly chosen for characteristics that would fit the given criteria. Most of the variable values are derived from older studies that would fit the given criteria for microstrip antennas for communications with the specifics of emergency scenarios. Firstly, for our resonant frequency, it is noted that 3.5 GHz is used in communications signaling [23]. Secondly, for the damping ratio, it has opted to use 0.7 as it is the average and optimum damping condition with its near-best performance [24]. A high frequency is applied for the circuit as a modern communication system for the natural frequency value as it enables higher bandwidth [25].

To understand how to fit the transfer function for off-grid emergency communication, testing for specific criteria is done to determine if the given values are feasible for further analysis, as depicted in Figure 1. Two criteria, setting time and overshooting, are looked upon to determine the feasibility of the transfer function. The value for the setting time should be less than 1, and the overshoot should be less than 5% to ensure that the system meets its criteria. Once the system meets the criteria, system analysis is done to observe its characteristics and behavior. Each plot and analysis method gives specific characteristics that could further qualify the system to improve emergency communication significantly using antennas. For example, a Bode plot could determine the stability of a system by using either a magnitude representation or a phase shift to determine its frequency response, which is widely used in the analysis of signal processing and determining its filtering.

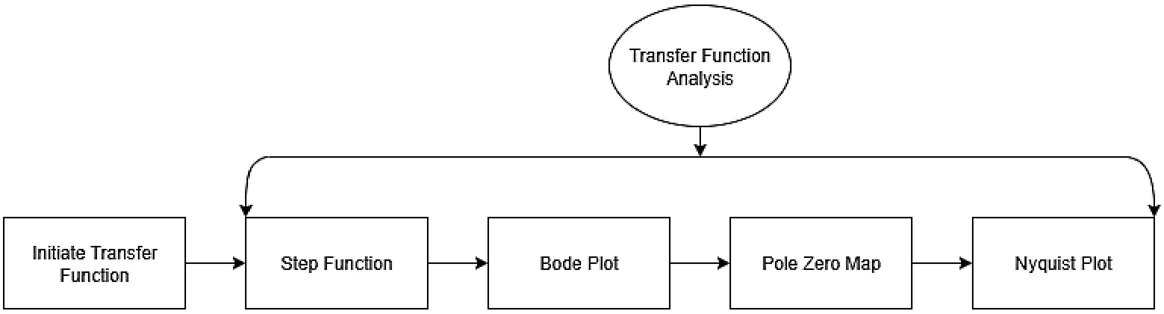

Figure 1. Flow chart diagram of the method

2.1. Characteristics of the simulated microstrip antenna

The antenna was simulated in MATLAB with the following structure and parameters. The structure is depicted in Figure 2, where this image is generated utilizing the ‘ant=patchMicrostrip; figure; show(ant);’ code. The snippet of the parameters utilized in this simulation is depicted in Figure 3, where it shows the code of the frequency utilized and the damping ratio.

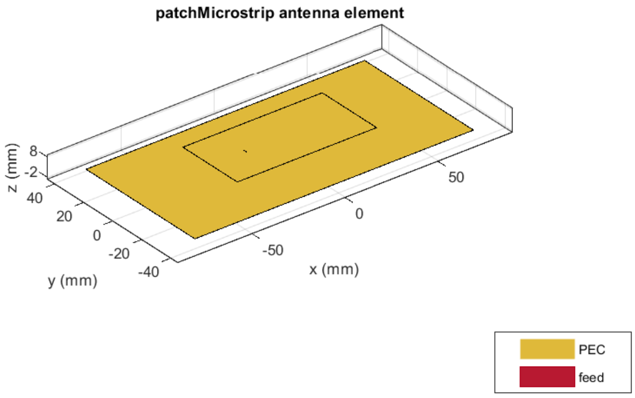

Figure 2. Microstrip patch antenna

```
% parameters for the microstrip antenna system
f_n = 3.5e9; % Resonant frequency in Hz
omega_n = 2 * pi * f_n; % Natural frequency in rad/s
zeta = 0.7; % Damping ratio to balance overshoot and response time
```

Figure 3. Microstrip antenna parameters code

3. RESULTS AND DISCUSSION

The transfer function of the simulated microstrip antenna is depicted in Figure 4, a MATLAB script showing the numerator, denominator, and variable. The step response characteristics are shown in Figure 5, depicting a rise time of 9.672×10^{-11} seconds, a settling time of 2.7188×10^{-10} seconds, an overshoot of 4.5986%, and a peak of 1.046. These values meet the criteria for off-grid emergency communications, which require a settling time of less than 1 second and an overshoot of less than 5%. The step response is depicted in Figure 6.

```
Transfer Function of the Microstrip Antenna System
  tf with properties:

      Numerator: {[0 0 4.8361e+20]}
    Denominator: {[1 3.0788e+10 4.8361e+20]}
       Variable: 's'
```

Figure 4. Transfer function of the microstrip antenna system

```
Step Response Characteristics:
Rise Time: 9.6712e-11 seconds
Settling Time: 2.7188e-10 seconds
Overshoot: 4.5986 %
Peak: 1.046
The system meets the criteria for off-grid emergency communications.
```

Figure 5. Step response characteristics of the microstrip antenna

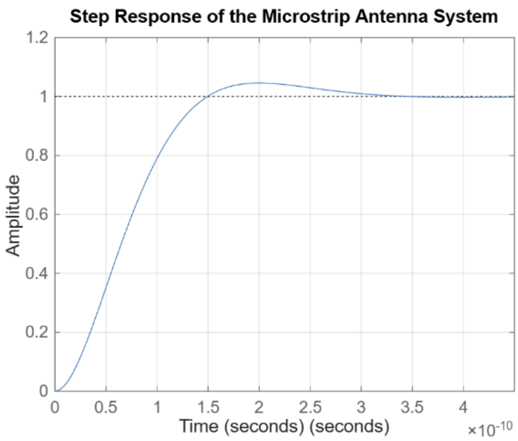

Figure 6. Step response of the microstrip antenna

The pole-zero map depicted in Figure 7 indicates stability and appropriate damping, with all poles located in the left half of the s-plane, signifying a stable system. The absence of zeros simplifies the analysis, highlighting that the location of the poles primarily governs the system's behavior. The graph proves the stability and well-damped responses that satisfy the system's criteria.

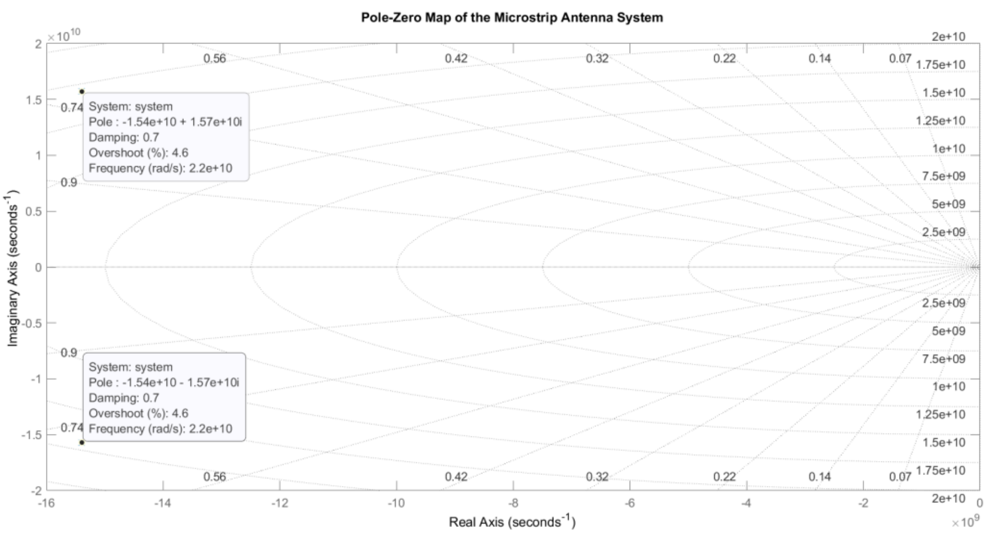

Figure 7. Pole-zero map of the microstrip antenna system

Figure 8 shows the Bode plot of the system simulation. As depicted in the figure, the Bode plot confirms that the system satisfies the criteria for withstanding the microstrip antenna in off-grid emergency situations. The magnitude plot shows the inverse relationship between frequency and gain, showing how the high-frequency components are reduced while the low-frequency signals are passed through.

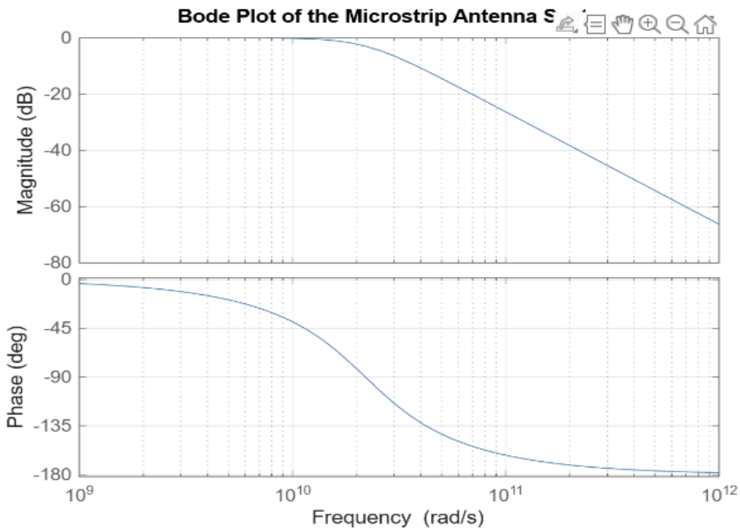

Figure 8. Bode plot of the microstrip antenna system

Figure 9 shows a Nyquist plot. This plot depicts that the system is stable since it does not encircle the critical points and is far from the origin. All the graphs shown ensure that the system has fast response times, minimal overshooting, and stable behavior, showing the system's overall reliability during off-grid emergencies.

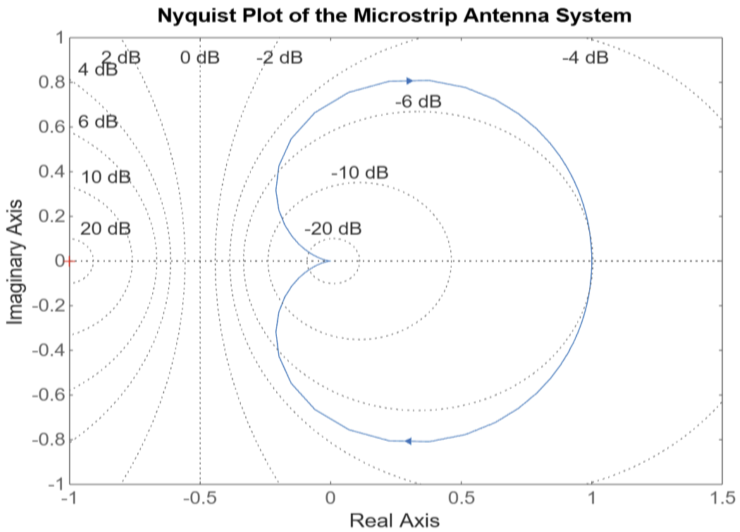

Figure 9. Nyquist plot of the microstrip antenna system

3.1. Analysis of data

The concepts behind feedback and control systems determine whether the microstrip antenna meets the criteria for functioning as an emergency communication system. Figure 2 shows the coefficients for the transfer function. Due to the high frequencies required by emergency communication systems reaching billions or gigahertz, the coefficients reach high values. This means that the system may have the following characteristics: stronger response, stability impact, and frequency behavior. The stronger response indicates that the system is more sensitive to inputs, which can lead to higher outputs. On the denominator, the values determine the stability of the system. The high values can mean the system is potentially slower or unstable or vice versa. Lastly, in terms of frequency, the system responds to various frequencies, possibly enhancing or reducing specific frequency components.

Figures 3 and 4 cover the step response of the microstrip antenna. The rise time is significantly low, meaning it quickly reaches the final steady-state value. This signifies that the microstrip antenna system is efficient and functioning properly at a given transfer function. The fast time means that it can be used in emergency communication systems, which are required in emergencies. The overshoot rating is also less than 5%, which indicates that the microstrip antenna is stable and well-damped. The low overshoot percentage generally means the microstrip antenna performs well without any issues. It also signifies that the system is accurate and efficient.

The Bode and Nyquist plots indicate that the generated microstrip antenna can function accurately and efficiently in emergency communications systems. Overall, the results of the MATLAB simulation show that the microstrip antenna created for emergency communication systems is highly functioning and efficient due to its low overshoot percentage, fast settling time, and fast-rising time. Given the widespread technological advancements whilst prioritizing the efficiency of costs, microstrip antennas are becoming one of the most reliable technologies. Microstrip antennas are very reliable, given their small sizes, but are efficient for receiving and transmitting signals. Since communication transmission is one of their strongest packages, the authors applied this antenna for off-grid emergency communications. Additionally, they are lightweight and portable, making them perfect for incorporation into handheld devices and portable communication systems used by emergency response teams and disaster management workers.

4. CONCLUSION

In this study, the authors used MATLAB to analyze the performance of microstrip antennas for emergency communications. The authors examined the system’s transfer function to ensure it met the requirements for effective emergency communication, given a settling time of less than a second and an overshoot of less than 5%. Overall, all the graphs further confirm the stability of the system and its proper damping. Aside from that, it showed a deep dive analysis of the system, further proving its suitability for off-grid emergency communications. In conclusion, microstrip antennas are a practical solution for reliable and efficient communication in off-grid emergencies. This study emphasizes their potential to enhance communication capabilities significantly and provides valuable insights for the future development of emergency response technology.

The authors would like to recommend implementing the microstrip antenna in a real setting rather than a simulation setting. It must also be integrated with other systems to ensure that it functions correctly and efficiently, not just on its own. It is also recommended that the angle or placement of the microstrip antenna must also be considered. This would determine whether it would lessen noise and interference in communication. Since the study used MATLAB, machine learning or deep learning methods, especially its parameters, can improve the system further. Rather than manual trial and error of parameters, letting artificial intelligence handle the work will greatly maximize time. Most importantly, microstrip antennas must be tested in real emergencies, whether in actual or drill training. This would help researchers evaluate the efficiency and effectiveness of microstrip antennas for communication. This would also help them improve the technology in many ways.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

DATA AVAILABILITY

Data availability does not apply to this paper.

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