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AIRBORNE SAFETY IN THE AGE OF 5G: ASSESSING THE POTENTIAL INTERFERENCE BETWEEN C-BAND AND AERONAUTICAL RADAR ALTIMETER

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ABSTRACT:

The recent deployment of 5G technology in the C-band frequency range has raised concerns regarding potential interference with aeronautical radar altimeters. 5G technology utilizes the C-band in the range of 3.7-3.98 GHz, which partially overlaps with the frequency range used by radar altimeters operating in the range of 4.2-4.4 GHz, resulting in an increased possibility of interference between the two systems. In this study, a comprehensive methodology was employed to conduct an interference analysis, investigating the compatibility between 5G wireless systems and radar altimeters. This involved implementing a realistic scenario that replicated the operational interaction between radar altimeters and 5G systems, with the goal of identifying the impact of 5G networks on radar altimeter performance. This paper outlines the scenarios leading to interference, and suggests feasible methods to overcome this issue.

1. INTRODUCTION

The future of wireless communication promises to provide a networked society with unrestricted access to information and data exchange. This is made possible by integrating advanced technologies into existing communication networks (Mendonça et al., 2022).

5G, being the latest generation communication platform, offers high flexibility in a variety of different ways. The main objectives of 5G cellular networks are to minimize latency, enlarge capacity, improve quality of service, and provide higher data rates (Navarro-Ortiz et al., 2020). However, despite the benefits brought by 5G technologies, the allocation of particular bands in the 5G spectrum has raised some concerns, especially in the aviation industry.

Over the past few years, there has been a significant annual increase in both air traffic and number of passengers transported. Even at cruising altitudes, mobile users seek uninterrupted broadband connectivity with sufficient speed, reliability, and capacity — primary objectives for 5G communication systems (Ancans et al., 2017). A crucial requirement in aviation also involves the efficient exchange of data or information between pilots and air traffic controllers (Airbus, 2023). Nonetheless, the implementation of 5G services potentially poses a risk to aeronautical equipment, particularly radio altimeters.

The paper is organized as follows. In Section 2, we provide a summary of previous research relevant to our study's subject matter. In Section 3, a comprehensive overview of the operation of radar altimeter is provided. Section 4 explores the detailed analysis of interference and the methodology employed. In Section 5, the results obtained from the analysis are presented, along with suggested countermeasures. Section 6, concludes the paper by summarizing the key findings and their implications. Finally, Section 7 outlines potential advancements and areas for future exploration.

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2. RELATED WORK

In October 2020, Radio Technical Commission for Aeronautics (RTCA) issued Paper No. 274–20/PMC-2073, where it shared important findings indicating a significant risk posed by 5G C-band to radar altimeters in all types of civil aircraft including commercial transport airplanes: business, regional and general aviation airplanes; and both transport and general aviation helicopters (RTCA, Inc, 2020). Additionally, International Air Transport Association (IATA) and International Federation of Air Line Pilots' Associations (IFALP) have collaborated and jointly published a document sharing their concerns regarding the impact of 5G technology on radar altimeters (IATA and IFALPA, 2020). The majority of their findings align with those presented by the RTCA. By considering the worst-case exceedance of the safe interference limit found by the RTCA, Liu et al (2022) conducted a comprehensive interference analysis using Monte Carlo (MC) simulation method and calculation of received interference signal strength.

In recent literature, a comprehensive analysis was conducted on the impact of 5G C-band cell towers on aircraft altimeter systems (Rawat, 2022). It was carried out as a response to the FAA's directive, which temporarily suspended the use of auto-landing systems at some of U.S. airports due to concerns about potential interference from recently installed 5G towers. Through precise modeling of 5G Base Stations (BSs) and assessment of wireless channel interactions with radar altimeters, the study highlighted the complexities of this technological overlap. The analysis findings emphasized the need of collaboration between telecommunication companies and aviation authorities to ensure both technological advancement and aviation safety.

Baylis and Marks II (2022) discussed the challenges posed by the roll-out of 5G systems radiating in C-band, particularly its coexistence with commercial aircraft radar altimeters. As a solution, the authors suggested an automatic radar altimeter avoidance system integrated with Air Traffic Control (ATC). This system generates real-time exclusion zones for radar altimeter frequencies based on predefined flight trajectories, assuring interference prevention. Building on this, Baylis et al. (2023) proposed an interference mitigation technique that involves the communication of aircraft with air traffic control to report locations and receive flight path instructions. Based on this data, an automated algorithm co-located with air traffic control calculates a dynamic exclusion zone. This zone transmits information about spectral, spatial, and temporal mask limitations to 5G and future 6G BSs using the relevant spectrum near the flight's approach path. The BSs would then adjust their emissions to align with spectral criteria based on their location, frequency, and usage time. Another component of the solution entails the development of circuitry within 5G towers capable of adapting to various configurations to accommodate their surroundings.

A Convolutional Neural Network (CNN) deep learning model was developed by Amaireh and Zhang (2023) with the purpose of classifying and identify 5G NR and radar altimeter signals, aiming to detect harmful interference, thereby improving aviation safety as a whole. The findings show notable interference impacts on radar altimeters resulted by different configurations of 5G BSs, particularly at lower altitudes. Moreover, the results showcase the remarkable performance of the CNN model in accurately classifying signals with high levels of accuracy, sensitivity, and specificity.

Roshan, Gupta, and Akhtar (2023) proposed a Frequency Selective Surface (FSS) technique as a solution to the interference challenges posed by sub-6 GHz 5G band signals. Their methodology was centered on designing a FSS that could effectively block unwanted signals from BSs. This shield helps maintain the reliability and accuracy of radar altimeters.

3. OPERATION OF RADAR ALTIMETER

In both commercial and civil aviation, radar altimeter is a mandatory equipment for all flight safety systems (Kang & Chung, 2017). Unlike traditional pulsed radar systems, a Frequency Modulated Continuous Wave (FMCW) radar altimeter transmits a continuous signal that constantly varies in frequency, known as a chirp (Choi, Jang, & Roh,2015). This continuous signal transmission not only provides enhanced accuracy and reliability but also showcases the FMCW system's superior ability to detect sudden and minor frequency changes, improving its effectiveness in handling complex terrains and rapidly changing altitudes (Emerson, 2023). When the transmitted signal reaches the ground, it reflects off the surface and then returns to the radar altimeter's receiving antenna. By comparing the frequency of the transmitted signal with the received echo, the altimeter is able to accurately calculate the aircraft's Above Ground Level (AGL) using Equation 1 (ITU-R M.2059-0, 2014). A visual representation of the frequency difference between the transmitted and received signal of a FMCW radar system is shown in Figure 1.

$$H = \frac{c\Delta t}{2} = \frac{c\Delta f}{2(df/dt)} \tag{1}$$

where: H = AGL in m
c = speed of light in $\mathrm{m\,s^{-2}}$
Δt = difference in time in s
Δf = difference in frequency in Hz
$\frac{df}{dt}$ = transmitter frequency shift in Hz/s

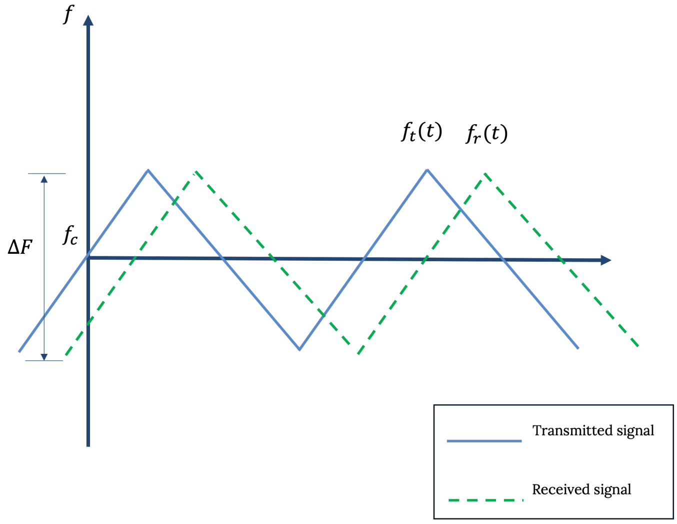

Figure 1. Frequency difference between transmitted and received signal

AGL data play a significant role in ensuring safe and efficient flight operations. These measurements are crucial for many safety-related systems and navigation protocols, as shown in Figure 2. The Terrain Avoidance and Warning System (TAWS), for example, relies on accurate AGL data to warn pilots of potential ground collisions, while the Traffic Collision Avoidance System (TCAS) uses it to avoid mid-air collisions by providing real-time altitude data of surrounding aircraft. Similarly, the Windshear Detection System (WSDS) depends on AGL data to identify and inform pilots of potentially dangerous wind conditions that could jeopardise the aircraft's stability. Both Flight Control System (FCS) and the Autoland system, which are critical for the aircraft's navigation and landing procedures, rely heavily on accurate AGL measurements to function properly (Leslie, 2022). Given the crucial significance of these systems, any errors or faults in the radar altimeter can be disastrous. Faulty readings can lead to improper decision-making by pilots (Minotra & Feigh, 2017). This not only puts at risk the safety of passengers and flight crew on board but also poses a threat to ground staff and infrastructure. As a result, assuring the reliability and precision of radar altimeters is critical to sustaining the highest levels of aviation safety.

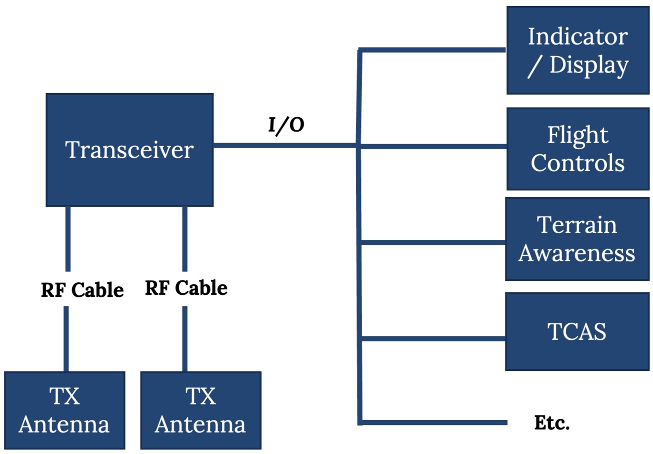

Figure 2. Integration of radar altimeter output with safety-related aviation systems

4. INTERFERENCE ANALYSIS AND METHODOLOGY

Radar altimeters operate by radiating signals at relatively low power levels, usually around the magnitude of one watt (Jha et al., 2022) . To compensate for this low transmission power, these altimeters are equipped with highly sensitive receivers capable of efficiently capturing and processing the reflected signals (Thulasi & Kashwan, 2016). However, this enhanced sensitivity presents both advantages and challenges. While this enables for accurate altitude readings, it also exposes the system to external radio frequency interference. Any such interference, particularly if it occurs near or within the altimeter's operational frequency range, can degrade its performance, resulting in potential inaccuracies in altitude readings or malfunctions in the radar altimeter system (Singh et al., 2017).

Interference becomes especially problematic with the installation of 5G BSs radiating in C-band around airports. As illustrated in Figure 3, C-band frequency range (3.7-3.98 GHZ) is very close to the operating frequency of radar altimeter (4.2-4.4 GHZ), thus increasing the likelihood of interference between these two systems (Sobieralski & Hubbard, 2022). The possibility of interference arises due to the fact that 5G transmissions in the C-band have the potential to generate strong signals that could overwhelm the comparatively weaker signals emitted by radar altimeters, thereby reducing their ability to accurately measure altitude (Halawi et al., 2022).

In this paper, a comprehensive simulation-based methodology is employed to examine the effects of 5G communication systems, specifically those operating within the C-band frequency range, on FMCW radar altimeters used in modern aircraft (Nebylov & Yanovsky, 2013). The simulation methodology adopted in this study is implemented to mimic real-world conditions as closely as possible. This is achieved by generating a variety of random scenarios to account for the unpredictability and complexity of real-world environments. Integral to these scenarios is the positioning of the 5G BSs. Rather than using a set or pre-defined locations for these stations, the approach incorporates an element of randomness, positioning the 5G BSs arbitrarily within the operational coverage area of the radar altimeter. The coverage area of a radar altimeter, shown in Figure 4, is visualized as a circular region, with its area reducing as the aircraft altitude decreases (Son & Chong, 2020). The cumulative probability of the interference power received at the radar altimeter is then calculated for various altitudes and 5G BSs emission levels.

The method utilized in this paper focuses on creating realistic interference scenarios by considering various practical factors. the study takes into account the use of a digital altimeter, commonly referred to as D2, which is widely employed in aircraft installations worldwide. Furthermore, the simulation incorporates the presence of 5G BSs that are representative of those utilized in different locations globally. Table 1 provides a summary of the key specifications of the radar altimeter and 5G BS used in the simulation (Cramer, 2013). By considering these aspects, the analysis aims to provide insights into the potential interference effects specific to real-world scenarios.

The calculation of interference power in each snapshot involves taking into account multiple factors, including the transmitted power of each 5G BS, path loss, and the gain of both the 5G BS and radar altimeter, as described in Equation 2.

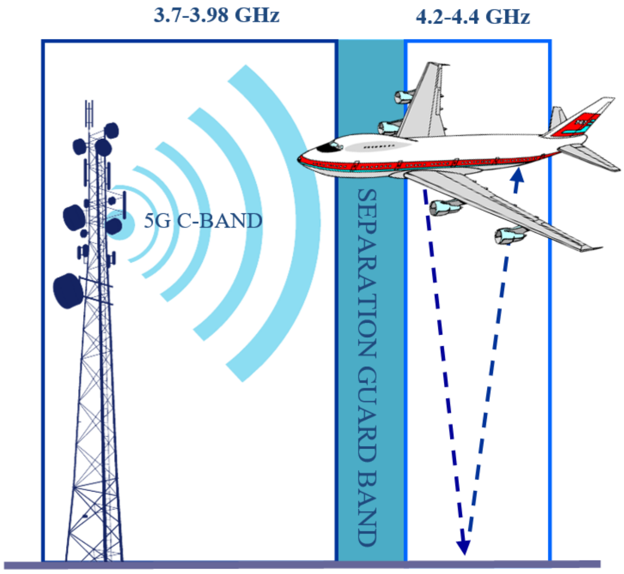

Figure 3. Overlapping frequencies of 5G Base Station (BS) and radar altimeter

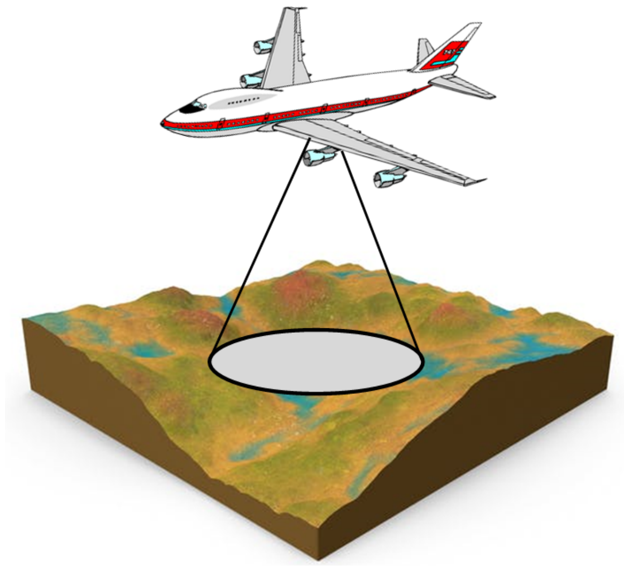

Figure 4. Radar altimeter region of coverage

$$P_{RX} = PSD_{5G} + G_{5G} - L_{prop} + G_{RA} - L_{RX} \quad (2)$$

where P_{Rx} = interference power in dBm/MHz
PSD_{5G} = power spectral density of transmitter in dBm/MHz
G_{5G} = gain of transmitter in dBi
L_{prop} = propagation loss in dB
G_{RA} = gain of receiver in dBi
L_{RX} = receive path cable loss in dB

Radar Altimeter Parameters		
Parameter	Value	Unit
Center frequency	4300	MHz
Transmitted power	26.02	dBm
Emission bandwidth	150	MHz
Noise figure	8	dB
IF bandwidth	0.312	MHz
Antenna gain	11	dBi
Protection criteria (I/N)	-6	dB
AIL	-94.7	dBm/100MHz
5G BS Parameters		
Parameter	Value	Unit
Center frequency	3950	MHz
Channel bandwidth	100	MHz
Cell radius	0.6	km
Transmitted power	35	dBm/MHz
Element gain	5	dBi
Antenna height	25	m
Tilt angle	6	degrees

Table 1. Radar altimeter and 5G base station parameters

In each snapshot simulation, path loss is computed utilizing Equation 3, an integral value that is promptly updated within the received interference power equation, showing its constant influence throughout the process (Al-Hourani, Kandeepan, & Jamalipour, 2014). The analysis of interference heavily relies on the path loss, which is significantly influenced by variables such as distance, frequency, propagation environment, and obstacles (Engelbrecht, Fuss, Schwark, & Michler, 2014). In rural environments, path loss is typically lower due to the limited presence of tall buildings and obstacles that could affect the propagated signals. In suburban and urban settings, the signal may encounter increased path loss levels because of the increased number of tall buildings and constructions, with urban areas typically exhibiting even greater path loss due to their higher building density and size compared to suburban regions (Schumacher, Merz, & Burg, 2019). The correlation between path loss and distance within different propagation environments is demonstrated in Figure 5.

$$PL = 20\log_{10}(d) + 20\log_{10}(f_{tx}) + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_{5G} - G_{RA} \quad (3)$$

where $FSPL$ = free space path loss in dB
d = distance between transmitter and receiver in m
f_{tx} = center frequency of the transmitter in Hz
c = speed of light in $\mathrm{m\,s^{-2}}$
G_{5G} = gain of transmitter in dB
G_{RA} = gain of receiver in dB

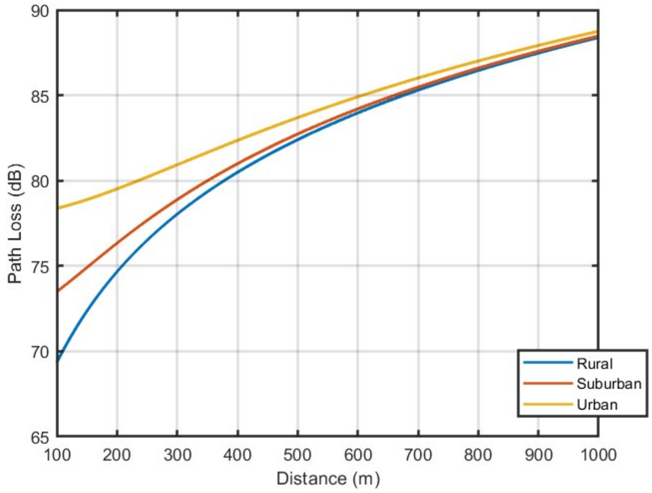

Figure 5. Path loss variation with distance for different propagation environments

5. RESULTS AND COUNTERMEASURES

The possibility of interference between 5G BSs and radar altimeter arises mainly during takeoff and landing procedures (Singh, 2017). This study focuses on altitudes associated with the landing phase in an urban environment, beginning where the aircraft aligns with the standard glide slope, a path that an airplane follow on its final approach to land (Yasentsev et al., 2021). This analysis primarily focuses on altitudes where interference could potentially occur, enabling us to determine accurately the specific circumstances and locations where interference mitigation techniques are required .

Figure 6 demonstrates the cumulative probability of interference power received at various radar altimeter altitudes. The graph clearly indicates that, across all the altitudes evaluated, there exists a probability that the interference power will exceed the Acceptable Interference Level (AIL), which in this context, is a predefined threshold set for the selected radar altimeter for the analysis. The cumulative probability provides significant insight into a specific level of interference power and the likelihood of it being achieved or even lower. Therefore, it enables us to visualize the entire range of potential interference power values that the radar altimeter receiver might experience. For instance, at an altitude of 50m, there is roughly a 98% probability that the interference power received by the radar altimeter will fall within or below the range of -90 dBm/100MHz.

Various strategies have been proposed in the literature to reduce the potential of interference caused by 5G towers. One effective approach involves reducing the power emitted by 5G towers, thereby decreasing the overall received interference power at the radar altimeter (FAA, 2022). It is crucial, however, to strike a balance when implementing this power reduction strategy. While mitigating interference is essential, it is also important to maintain sufficient coverage to meet the demands of modern telecommunications (Akpado et al., 2013). To evaluate the effectiveness of this mitigation strategy, testing was conducted at the lowest altitude. By addressing interference concerns at this critical altitude, it ensures the safety of flight operations across the entire range of altitudes. Figure 7 demonstrates the significant decrease in interference power received at an altitude of 50 m when limiting the radiation power to 25 dBm/MHz.

6. CONCLUSION

The primary objective of this paper is to assess the potential interference that may arise from the coexistence of radar altimeters and 5G BSs within real-world operational scenarios. To achieve this, a comprehensive interference analysis methodology is employed, which involves continuous calculations of the interference power received by radar altimeters from a number of randomly generated 5G BSs. This method takes into account various factors, such as the geographical distribution of BSs, antenna patterns, signal propagation characteristics, and the frequency bands utilized by both radar altimeters and 5G systems. The analysis results indicates a greater probability of interference occurring at lower altitudes, which is a critical phase of flight where precise altitude measurements are vital for safe aircraft operations.

In order to address and mitigate the potential interference risk, a strategy involving the reduction of transmission power of 5G BSs has been proposed and evaluated. This strategy aims to mitigate interference by reducing the transmission power of 5G BSs in certain situations or specific geographic areas, especially in areas where aircraft operate at lower altitudes. The implementation of this strategy proved to be effective, resulting in a significant decrease in interference power levels.

7. FUTURE WORK

While the current study has provided significant insights into the potential interference between radar altimeters and 5G systems in C-band, there remain several avenues for further exploration and enhancement. One promising approach involves assessing interference in real airport environments, accounting for the precise locations of 5G BSs and actual flight trajectories, thereby enhancing the results of our analysis. Moreover, our research can expand its focus on mitigation strategies, extending beyond the control of 5G transmission power to include strategies like antenna down tilting and the creation of exclusion zones. These improvements will lead to a deeper understanding of the problem, enabling radar altimeters and 5G systems to coexist.

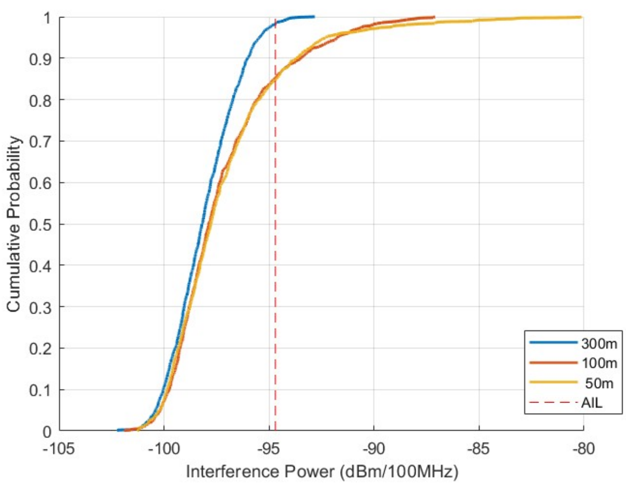

Figure 6. Cumulative probability of received interference power

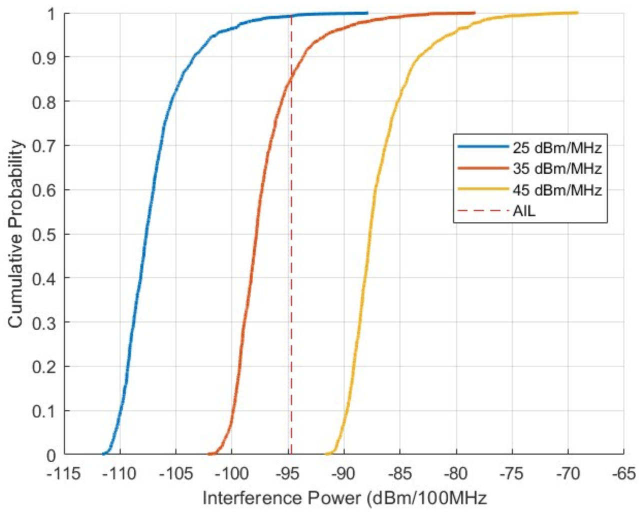

Figure 7. Cumulative interference power probability at 50 m altitude across different power levels

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