PROFESSIONAL AVIATION SAFETY SPECIALISTS

1200 G Street NW, Suite 750, Washington, DC 20005
Telephone: (202) 293-7277 Fax: (202) 293-7727

Founded 1977

ANALYSIS OF 5G DEPLOYMENT

PROFESSIONAL AVIATION SAFETY SPECIALISTS, AFL-CIO

FEBRUARY 2022

The following is an analysis conducted by the Professional Aviation Safety Specialists on 5G deployment and the potential for radio frequency interference with National Airspace System equipment.

INTRODUCTION

There is the potential for newly deployed 5G radio access technology to cause radio frequency interference (RFI) in the nation's air traffic control system. This paper looks at the known interference potential with the RADAR/Radio altimeter in aircraft, as well as other potential interference issues that may arise with various ground- and space-based navigation systems within the National Airspace System (NAS).

Since 1977, the Professional Aviation Safety Specialists, AFL-CIO (PASS), has represented more than 11,000 employees of the Federal Aviation Administration (FAA) and Department of Defense (DoD) who install, maintain, support and certify air traffic control and national defense equipment, inspect and oversee the commercial and general aviation industries, develop flight procedures, and perform quality analyses of complex aviation systems used in air traffic control and national defense in the United States and abroad.

Nearly 700 million air travelers fly throughout the U.S. each year and PASS-represented employees are there to ensure the safety of the aviation system. Any mistakes or missteps could be catastrophic for the American flying public. As the demand for air travel continues to increase, so does the need to maintain the highest level of safety, integrity and reliability of the NAS. From inspectors who ensure industry compliance with FAA safety standards to systems specialists who protect the safety and efficiency of critical aviation systems, PASS-represented employees are focused on safety, every step of the way.[1]

METHODOLOGY

Utilizing extensive review of various aviation and telecommunication industry white papers as well as conducting a literary review of research papers within the Institute of Electrical and Electronics Engineers (IEEE) library, PASS has reviewed and developed the following analysis of the 5G radio, focusing on 5G and its potential to cause harmful interference with both NAS and user equipment. Spectrum analysis techniques as defined in the FAA's radio frequency interference course developed and taught at the William J. Hughes Technical Center in Atlantic City, N.J., were utilized in analysis of all potential interference hazards identified in this paper.[2]

For the purposes of this research, the union analyzed the potential for harmful interference caused by frequency allocation, power radiation levels, spurious and erratic transmissions, as well as other unintentional harmful interference caused by the improper operation or failure of the 5G radio. The goal and the methods used were to take a safety perspective viewpoint in order to analyze all potential hazards, along with how to identify them, while simultaneously developing a means to mitigate the hazards for all stakeholders involved.

Careful consideration and time were dedicated to reviewing the design and use of the technology being deployed by the telecommunications industry for use in the 5G radio. PASS ensured that all aspects of beam management, radio location, frequency allocation, tower heights and power levels were considered in the analysis of 5G in regard to aviation equipment and potential interference, utilizing

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[1] Professional Aviation Safety Specialists. "About PASS." https://passnational.org/index.php/about-pass/about-pass

[2] Federal Aviation Administration, William J. Hughes Technical Center, "RFI Resolution Course."

similar criteria as seen in the South Korean research on 5G conducted by the Electronics and Telecommunications Research Institute.[3] Any mathematical formulas, equations or techniques are from referenced material and online resources.

LITERARY REVIEW

Radio Frequency Interference: An Overview

Radio frequency interference (RFI) is a well-known phenomenon in the electromagnetic spectrum.[4] Research into what types of RFI exist, such as intermodulation and how to mitigate the effects on communication equipment, date back 100 years or more and is well documented research.[5] Modern day RFI is still an issue that many manufacturers try to address during the engineering and design phase of any electronic device. Even with multiple aspects of RFI taken into consideration during design, unforeseen issues often arise or there are issues that simply cannot be avoided. Regarding the aviation industry, there are multiple types of interference reported each day within the NAS which affect the operation of NAS components. As more users enter or become adjacent to the frequencies that are utilized for safety of life applications, it is extremely important that all aspects of RFI be considered and mitigated before they are introduced into the NAS and become unknown risks.

Harmful interference as defined by the FAA Spectrum Engineering & Policy department is any emission, radiation, or induction that obstructs, or repeatedly interrupts, a radio communications service operating in accordance with established regulations. Some types of intentional interference are: Phantom controller, electronic attack (military), GPS jammers and any illegal operation by an unauthorized user. Some types of unintentional interference are brute force, spurs, intermodulation, as well as faulty, degraded and/or aging electronic equipment (see "Interference Concerns" below). Most RFI experienced by the FAA is unintentional in nature and takes cooperation between multiple stakeholders to resolve.[6]

Aviation Band of Frequencies

The introduction of 5G radios into the aviation band of frequencies adds to an already complex environment of the electromagnetic spectrum. Many of the traditional unintentional RFI scenarios become an area of concern due to the proximity of frequency allocation, as well as the physical location or proximity of the 5G radio emitters. By design, 5G is intended to operate within the frequency range and power thresholds set forth by the Federal Communications Commission (FCC) and should not infringe on the use of any other adjacent frequencies.[7] It is important to note that the telecommunications industry's 5G radios encompass a large variety of equipment and manufactures.

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[3] Ho-kyung Son and Young-jun Chong, *Interference Analysis for Compatibility Between 5G System and Aeronautical Radio Altimeter*, published as part of 2020 International Conference on Information and Communication Technology Convergence (ICTC), October 21 – 23, 2020.

[4] NASA. "The Electromagnetic Spectrum," modified March 2013. https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html.
U.S. Department of Homeland Security, *Radio Frequency Interference Best Practices Guidebook*, February 2020.
Arecibo Observatory. "Sources of Radio Frequency Interference." https://www.naic.edu/~sondy/rfi.html.

[5] K. Chang, *Intermodulation Noise and Products Due to Frequency-Dependent Nonlinearities in CATV Systems*, published as part of IEEE Transactions on Communications (Volume 23, Issue 1), January 1975.

[6] Federal Aviation Administration, William J. Hughes Technical Center, "RFI Resolution Course."

[7] CFR Title 47.

These multiple types of 5G radios fall under 3rd Generation Partnership Project's (3GPP)[8] n77 technical standards, which cover spectrum allocation from 3.3GHz to 4.2GHz. The aviation band has utilized the spectrum from 4.2GHz to 4.4GHz for RADAR altimeters for over 40 years. The introduction of the 5G radios places a non-safety of life user near a frequency band which is utilized in safety of life applications.[9]

The reason for concern regarding this added allocation is warranted. Over the years, as more users are introduced into a spectrum allocation block, the users—especially in non-safety of life applications—begin to interfere with one another and the spectrum becomes noisy and degraded due to the number of emissions in close frequency to one another. Radio frequency interference has been increasingly observed in data recorded by several airborne and spaceborne radar sensing systems.[10] It is important that before new users enter the spectrum, an assessment of the risks to aviation are performed to assure that safety of life applications can be maintained. Listed below in the table are the authorities for documenting RFI and reporting.

Table 1. Authority Contact Information for RF Interference Reporting[11]

Authority Contact	**Information**
FCC 24/7 Operations Center	https://fccprod.service-now.com/psix-esix/ • Phone: (202) 418-1122 • Email: FCCOPS@fcc.gov Non-Aviation
GPS Outages: USCG	https://www.navcen.uscg.gov/?pageName=gpsUserInput
Aviation GPS Outages: FAA	https://www.faa.gov/air_traffic/nas/gps_reports/
Military GPS Outages worldwide: GPSOC	https://gps.afspc.af.mil/ (may not open for non-military users)

One major reason that PASS is concerned with RFI related to 5G radios is due to experience with new devices over the past 10 to 15 years. With the introduction of 4G LTE and WiFi devices, there was an increase of RFI with systems such as the Terminal doppler weather RADAR and other NAS equipment. Radio frequency interference issues with broadband transmission media have been an important capacity and coverage issue for 4G, LTE, WiFi and other deployments. Interference modes unrecognized previously have risen to importance in the new wireless environment. Some of the issues encountered with 4G (e.g., from FM to LTE, CATV to LTE, and LTE to CATV) raise valid concern with 5G deployment.[12]

RADAR Altimeters

PASS represents bargaining unit employees at the FAA who are on the front lines when it comes to documenting and finding interference issues. Other unions in the aviation industry have spoken loudly

[8] 3GPP. https://www.3gpp.org/.
[9] Federal Aviation Administration, "Safety Alert for Operators: Risk of Potential Adverse Effects on Radio Altimeters when Operating in the Presences of 5G C-Band Interference," December 23, 2021.
[10] The National Academies Press, "Summary of the Radio-Frequency Interference Workshop," November 8, 2013.
[11] U.S. Department of Homeland Security, *Radio Frequency Interference Best Practices Guidebook*, February 2020.
[12] Chris Horne, LBA Blog, "4G LTE Radio Interference Forum Debuts," November 11, 2013. https://www.lbagroup.com/blog/4g-lte-radio-interference/

about their concern of interference issues on 5G deployment, and PASS would like to echo those concerns, as well as describe some of the added complexity around the issue.

PASS-represented airways transportation systems specialists (ATSS), FAA job series 2101 employees, are located at airports across the nation and have a very complex job. An ATSS is often asked to document any complaints of interference and track and locate the source. This task is not an easy one as the source of interference is often not known and can be very difficult to find if it is not a continuous interference. When a pilot or controller reports RFI, the ATSS is notified to investigate what may be the cause. Often this may include interfacing with multiple entities and agencies to identify the source, creating a long process that takes a great amount of time.

The first step is information gathering, trying to find out how often the interference happens and if it was reported by multiple users. In the case of 5G, the issue becomes a safety concern because of several factors: including but not necessarily limited to the location of the emitters, the power of the emitters, the frequency allocation of the emitters, and degraded or broken emitters and their interference potential (known and unknown). According to the FAA, the current *known* interference caused by the 5G emitters is with RADAR altimeters.[13] These altimeters are used by many systems on the aircraft and any interference creates a significant safety risk in low visibility landing situations and various other situations.

Because of its long history of integrity and accuracy the RADAR altimeter is integrated as a core sensor feed into the avionics suite of many aircraft, adding necessary information and data points to complete a logic sequence in many modern and automated aircraft systems. For instance, upon landing, the RADAR altimeter is used to assist in verifying that an aircraft has reached the ground and to initiate a sequence involving other systems (ground spoilers, thrust reversers, autobraking systems, etc.) that slow the aircraft in a timely and predictable manner. Airlines calculate performance data based on the full functionality of these systems and the FAA authorizes flight crews to plan for and utilize certain runway lengths based on the availability of those systems. If the weather is a concern and the aircraft or its crew is not able to utilize the full complement of systems, the required length of runway increases greatly. In December 2021, the FAA issued two Airworthiness Directives (ADs) that were prompted by a determination that radio altimeters cannot be relied upon to perform their intended function if they experience interference from wireless broadband operations in certain frequencies. During takeoffs and landings, as a result of this interference, certain airplane systems may not properly function. With the current 5G deployment, as with all ADs issued, PASS-represented employees in Aviation Safety are tasked with ensuring the ADs are complied with by the aviation community.

Of specific concern is that the RADAR altimeter is used by airlines and by many smaller operators such as Helicopter Air Ambulance (HAA) operators performing emergency medical transportation. When conducting HAA operations, many takeoffs and landings are off airport. HAA flight crews are picking up trauma patients by the side of the road on improvised landing sites that have not had a full analysis of the possible 5G interference afforded to similar operations at airports and heliports. Some of these landing sites can be in very close proximity to cellular towers. It is in the best interest of all stakeholders that a failure situation is considered and planned for properly. At a minimum, the capability to alert the telecommunications service provider of an out of tolerance frequency, or power output, should be considered on all deployed devices.

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[13] Federal Aviation Administration, "Safety Alert for Operators: Risk of Potential Adverse Effects on Radio Altimeters when Operating in the Presences of 5G C-Band Interference," December 23, 2021.
Federal Aviation Administration, AD 2021-23-12 and AD 2021-23-13.

Interference Concerns

The introduction of the 5G radios (NR) emitter towers in proximity of landing environments or communication and navigational equipment means that there is a new source of potential RFI that did not previously exist.

The largest area of concern for interference with 5G radios (NR) exists with the radio altimeters located in the aircraft. The system provides data to both the pilot display and automated systems on airframes, such as ground proximity warning, terrain awareness and warning (TAWS), flight control and deployment of altitude dependent systems. The radio altimeter is a critical safety function in landing/take-off, low level maneuvering, and avoiding changes in terrain that may not be visible at night or during bad weather. The technical requirements are that the FMWC altimeter sweeps at 200MHz, with a transmit power ranging from 0.1 to 100 watts. The protection criteria as per the International Telecommunication Union (ITU) standard is that desensitization occurs at I/N = -6dB.[14]

In a study by the Aerospace Vehicle Systems Institute ("AVSI") project team on the "Effect of Out-of-Band Interference Signals on Radio Altimeters," it was stated that while the altimeters considered in the testing are representative of the majority of systems fielded by commercial and private aviation, it is not a comprehensive set of data for all altimeters operating under all conditions.[15] The same holds true for the 5G radios. There are different service providers and carriers deploying different radios that are manufactured by multiple vendors, thus the potential for interference is greatly expanded and dependent upon what type of 5G radio is interfering with what type of altimeter.

Brute Force

Excessive output power and the location of the 5G radios (NR) emitters have the potential to cause brute force. If 5G radios are near the aircraft's radio altimeter, communication or navigation receivers, there is potential for RFI. Every receiver has a point at which a signal outside its Radio Frequency band pass will break through and overload. The receiver becomes desensitized, causing the receiver to be driven into nonlinear operation.[16] The undesired signal gets detected in a highly garbled manner or the receiver becomes so desensitized that signal detection is impossible. [17]

The location and power output of the 5G emitters near airports raises concern for potential brute force scenarios with Navigational Aids (NAVAIDS) such as Instrument Landing Systems (ILS), Distance Measuring Equipment (DME) and other ground-based navigation systems. Unless the source is extremely strong, the signal may not be detectable on the ground making it necessary to get a flight inspection aircraft in the area to identify the source.

An additional aspect of concern for brute force is the beam management utilized by 5G radios (NR). The beam management technology allows the 5G radio to focus concentration on the user equipment (UE)

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[14] International Civil Aviation Organization (ICAO), "Radio Altimeter Spectrum," February 6, 2018. https://www.icao.int/NACC/Documents/Meetings/2018/RPG/RPGITUWRC2019-P08.pdf

[15] Notice of Ex Parte Meeting, GN Docket No. 18-122, Aerospace Vehicle Systems Institute ("AVSI"), "Effect of Out-of-Band Interference Signals on Radio Altimeters," February 2020.

[16] J. Gavan and M. B. Shulman, *Effects of Desensitization on Mobile Radio System Performance Part I: Qualitative Analysis*, published as part of IEEE Transactions on Vehicular Technology, November 1984.
Tian Tian, Hongshun Zhang and Yanzhi Hu, "Study on UWB compatibility with airborne receivers of Tactical Air Navigation System, 2008 World Automation Congress.

[17] Federal Aviation Administration, William J. Hughes Technical Center, "RFI Resolution Course."

from the base station tower (gNB) toward the users. This creates a scenario where the beam management system can aim and direct the power toward an aircraft on final approach, causing the possibility for brute force to be increased if the UE on the aircraft is not in airplane mode.[18]

Spurious Emissions

Any electronic device has the potential to generate spurious emissions. When an electronic device radiates on an unintended frequency, such as transmitting the same frequency as another device, that is a spurious emission. In many cases, radios and electronics generate spurious emission when operating normally. The 5G radios have the potential to generate spurious emissions.[19] These spurious emissions on a frequency, or frequencies, outside the assigned bandwidth are often generated from faulty transmitters or radio frequency amplifiers. Any signal above -104 dBm at a receiver's input has the potential to cause RFI.[20]

The testing and data on what types of spurious emissions a 5G radio is capable of emitting while in normal operation or failed states has not been gathered. The problem when deploying new equipment into the aviation band of the spectrum is knowing exactly how that device operates and whether or not it has sufficient filtering on the output of the transmitters amplifier section to prevent spurious emissions.

Erratic Emissions

The location of the 5G radio near airports or in close proximity to communications and navigations equipment off an airport also raises the potential for erratic emissions. Erratic emissions, which is a specific type of spurious emissions, radiate off the assigned frequency to the radio and sweep across the frequency spectrum. These signals are highly dependent on several factors such as power level, temperature and humidity. Often these are very hard to source due to the intermittent nature of the RFI on specific frequencies caused by the sweeping nature, even though the source is constant [21]

The testing and data on what types of erratic emissions a 5G radio is capable of emitting while in normal operation or failed states has not been gathered. As with spurious emissions, the aviation industry does not know if the 5G radio will generate erratic emissions. The major difference with erratic emissions compared to spurious emissions is the erratic emissions have the potential to take out or interfere with multiple types of equipment simultaneously as it sweeps across an often very broad range of spectrum.

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[18] Giordani, M., M. Polese, A. Roy, D. Castor, and M. Zorzi. "A tutorial on beam management for 3GPP NR at mmWave frequencies," IEEE Comm. Surveys & Tutorials, Q1 2019.
IEEE Spectrum, Engineering Resources.
https://engineeringresources.spectrum.ieee.org/?pt=dir&page=engineeringresources.
MathWorks, *Hybrid Beamforming for Massive MIMO Phased Array Systems*.
https://www.mathworks.com/content/dam/mathworks/white-paper/gated/93096v00_Beamforming_Whitepaper.pdf.
MathWorks, Visual Antenna Coverage Map and Communication Links.
https://www.mathworks.com/help/comm/ug/visualize-antenna-coverage-map-and-communication-links.html.

[19] Federal Aviation Administration, William J. Hughes Technical Center, "RFI Resolution Course."
IEEE Spectrum, Engineering Resources.
https://engineeringresources.spectrum.ieee.org/?pt=dir&page=engineeringresources.

[20] Federal Aviation Administration, William J. Hughes Technical Center, "RFI Resolution Course."
U.S. Department of Homeland Security, *Radio Frequency Interference Best Practices Guidebook*, February 2020.

[21] Federal Aviation Administration, William J. Hughes Technical Center, "RFI Resolution Course."

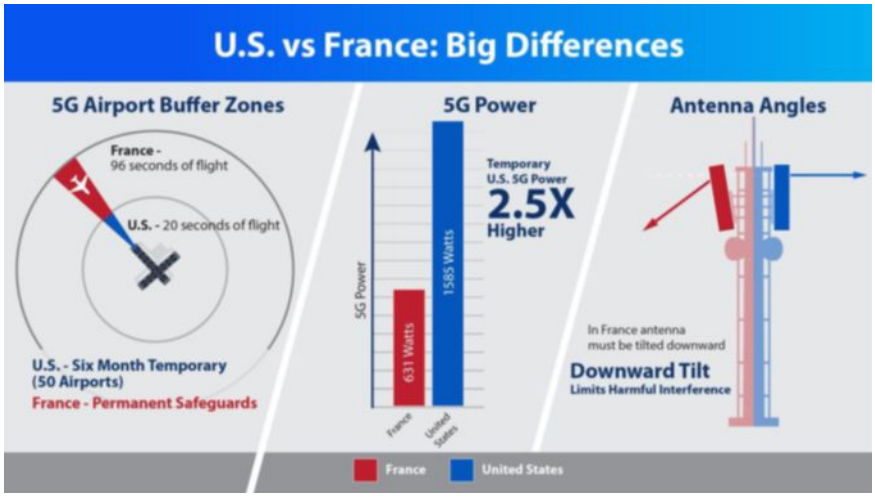
RFI Resolution and Mitigation

The process for RFI resolution and mitigation can be a collaborative effort and should include all stakeholders to preempt any interference, and then address it if it still occurs. It is paramount that all aspects are considered to keep the aviation industry safe.

FAA, aviation industry and telecommunications communication systems and compatibility assessments with currently fielded radio altimeters are not "one size fits all," so the RTCA SC-239 Assessment[22] is a good starting place, but we must continue this work to ensure the two industries can exist in the safest way possible.

Additional solutions to safe progress may include:

- All manufacturers of 5G radios should send their radio to the FAA Technical Center for evaluation by the Spectrum Engineering division for testing for possible RFI scenarios.
- Different placement of antennas relative to airfields, including beam management.
- No radiation zones in the direction of airports and facilities that support aviation safety.
- Radiate the 5G radios at lower output power levels.
- Install antennas tilted downward to reduce potential interference with flights (see graphic below).
- Height restrictions on 5G radio towers to reduce line of sight to aviation equipment.
- Fault detection and reporting on 5G radios to assist in faster RFI resolution.
- Apply stringent spurious emission standards within aviation safety bands to 5G radios in the United States.



[22] Radio Technical Committee for Aeronautics, SubCommittee-239, Low Range Altimeter, "Assessment of C-Band Mobile Telecommunications Interference Impact on Low Range Radar Altimeter Operations" (RTCA Paper No. 274-20/PMC-2073) October 7, 2020. https://www.rtca.org/wp-content/uploads/2020/10/SC-239-5G-Interference-Assessment-Report_274-20-PMC-2073_accepted_changes.pdf

CONCLUSION

PASS recognizes the efforts of airline unions and other aviation organizations for raising concerns about 5G deployment and protecting the safety of the flying public. We also would like to thank the FAA and the telecommunications industry for working together to implement and deploy 5G in the safest way possible. The delay and identification of 50 airports with wireless transmitters in close proximity to runways is a good start, but we must also protect small airports, helicopters and general aviation.

The aviation safety concerns raised regarding interference to radio altimeters from wireless operations pose a hazard to the flying public. The current stop-gap solution is a preliminary response to mitigate the threat of 5G to aviation safety. However, it does not establish a sufficiently comprehensive and predictable framework for permanently addressing imminent and potential hazards to aviation caused by 5G radio interference.

PASS believes that there is a need to reinvest in the personnel within the FCC and FAA who are dedicated to preventing interference issues before they arise and resolving them when they occur. Over the past 10 years, the FCC has closed multiple field offices. The state of Florida has only one FCC office to investigate and deal with all reported RFI issues in the entire state. In addition, the FAA does not have adequate staffing in the job series 2101 or 0856 field for those who specialize and resolve RFI issues.

The addition of 5G will complicate the RFI resolution process by adding new interference potentials. It is crucial that federal agencies and telecommunications companies dedicate resources toward the prevention of 5G interference as future 5G rollouts are planned.