December 07, 2020

Marlene H. Dortch *via ECFS*
Secretary
Federal Communications Commission
445 12th St S.W., Room TW-A325
Washington, DC 20554

Re: Written Ex Parte Presentation – ***Proposed Mitigations for Flexible Use Licenses to Protect Existing Aeronautical Radar Altimeters*****, GN Docket No. 18-122**

Dear Ms. Dortch,

In April 2020, RTCA, Inc. ("RTCA") formed a Multi Stakeholder Group ("MSG") under the auspices of RTCA Special Committee 239 ("RTCA SC-239") after an open invitation for public participation.[1] On October 08, 2020, RTCA provided the FCC with the final MSG technical report ("RTCA MSG Report") defining the interference that can be anticipated from new flexible use licensees that will be operating in the 3700-3980 MHz band to existing aeronautical radar altimeters (also commonly referred to as "radio altimeters") operating in the 4200-4400 MHz band.[2] The RTCA MSG Report is particularly compelling because it is the only radar altimeter-5G compatibility study that has been completed using deployment and system information provided by the commercial mobile industry, the radar altimeter manufacturers, and the aviation industry.

The undersigned representatives of the aviation and aerospace industry (the "Aviation Community") respectfully submit that the results of the RTCA MSG Report warrant the implementation of mitigations by the new flexible use licensees in order to protect aviation safety, while allowing new 5G operations in the 3700-3980 MHz to move forward.[3] The Aviation Community present the recommended mitigations herein as the appropriate basis for serving the public interest in aviation safety and resolving the pending petition for reconsideration of the Commission's March 3, 2020, *Report and Order* in the above-referenced

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[1] *See* Letter from Terry McVenes, President & CEO, RTCA, to Marlene H. Dortch, Secretary, FCC, Notice of Multi-Stakeholder Group Meeting, GN Docket No. 18-122 (filed Apr. 20, 2020).
[2] *See* "Assessment of C-Band Mobile Telecommunications Interference on Low Range Radar Altimeter Operations," RTCA Paper No. 274-20/PMC-2073 (rel. Oct. 7,2020), attachment to Letter of Terry McVenes, President & CEO, RTCA, Inc., to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122 (filed Oct. 8, 2020). This letter uses "5G" to reference flexible use operations that would be permitted under the FCC's Rules in the 3700-3980 MHz band.
[3] The Aviation Community consists of the Aerospace Industries Association ("AIA"), Aerospace Vehicle Systems Institute ("AVSI"), Air Line Pilots Association International, Aircraft Owners & Pilots Association ("AOPA"), Airlines For America, Inc ("A4A"), .Aviation Spectrum Resources, Inc., Garmin International, Inc., General Aviation Manufacturers Association, Helicopter Association International, Honeywell International Inc., International Air Transport Association, National Air Carrier Association and Regional Airline Association.

docket[4] which seeks appropriate protection in the Commission's Rules for safety-of-life radar altimeters operating in the 4200-4400 MHz Band.[5]

SUMMARY OF MITIGATION RECOMMENDATIONS

Given the results of the RTCA MSG Report, the Aviation Community has considered what mitigations can be implemented by the aviation industry and flexible use operators. In light of hurdles that cannot be surmounted in the short- or mid-term with mitigations implemented by the aviation industry and as new 5G systems are introduced into the 3700-3980 MHz band, flexible use licensees should be required to implement mitigations to protect public safety (particularly that of air passengers and crews, as well as persons on the ground) by not causing harmful interference to existing radar altimeters. Specifically, as detailed later in this document and in the Annexes, the Aviation Community recommends the following mitigations considering the results of the RTCA MSG Report:

- An interference threshold limit in the 3700-3980 MHz band that flexible use base stations should not exceed at the edge of operating areas where aircraft fly (dependent on aircraft operating altitude).
- Reduce flexible use base station conducted spurious emissions limits across the 4200-4400 MHz band to -48 dBm/MHz.
- Limit effective isotropic radiated power ("EIRP") total power of User Equipment ("UE") operating while on board aircraft to -16 dBm.
- Reduce flexible use UE conducted spurious emissions limits across the 4200-4400 MHz band to -30 dBm/MHz for UEs outside of aircraft and -57 dBm/MHz for UEs on board aircraft.

Finally, additional mitigations are needed to adequately protect radar altimeters on helicopters conducting low-altitude operations, especially in very close proximity to flexible use base stations. Therefore, the Aviation Community recommends that the Commission, the Federal Aviation Administration ("FAA"), helicopter operators, radar altimeter manufacturers, and the commercial mobile industry cooperatively investigate additional options to ensure radar altimeters operating on helicopters and other low flying vehicles are adequately protected.

INTRODUCTION

Making additional spectrum available for 5G is an important national objective being pursued by the Commission. However, in the 3700-3980 MHz Band, this should be done in a way that ensures adequate protection of existing safety-critical radar altimeter systems, as the

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[4] *Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, GN Docket No. 18-122, Report and Order and Order of Proposed Modification, 35 FCC Rcd 2343 (2020) ("*Report and Order*").

[5] *See* Petition for Partial Reconsideration of the 3.7-4.2 GHz Band Report and Order filed by the Aerospace Industries Association, the Aerospace Vehicle Systems Institute, Air Line Pilots Association International, Airbus, Aviation Spectrum Resources, Inc., Garmin International, Inc., the General Aviation Manufacturers Association, the Helicopter Association International, Honeywell International Inc., the International Air Transport Association, and the National Air Transportation Association (collectively, the "Aviation Representatives")., GN Docket No. 18-122 (May 26, 2020) ("Aviation Petition"). *See also Expanding Flexible Use of the 3.7 to 4.2 GHz Band*, GN Docket No. 18-122, Report and Order and Order of Proposed Modification, 35 FCC Rcd 2343 (2020) ("Report and Order").

Commission's Chairman himself has recognized.[6] The RTCA MSG Report demonstrated in multiple real-world operational scenarios that flexible use, as permitted by the FCC's Rules, can be expected to generate harmful interference to radar altimeters. Radar altimeters are critical sensors used by the automatic flight guidance systems and numerous other safety-related aviation systems that rely on the accuracy and integrity of the radar altimeter output. This need was demonstrated for all types of aircraft, including commercial air transport airplanes; regional, business, and general aviation airplanes; and both transport and general aviation helicopters (also commonly referred to as rotorcraft). Such harmful interference, if realized, would endanger the lives of crews, passengers, and persons on the ground.

The Aviation Community have developed recommended mitigations based on the findings in the RTCA MSG Report and presents them here as the basis to allow the Commission to achieve the implementation of new 5G capability in the C-Band while protecting existing radar altimeters from this potential interference.[7] Immediate incorporation of these protection requirements, or effective equivalents, in the Rules implementing flexible use in the 3700-3980 MHz frequency band is needed to provide guidance and certainty to auction participants that will ensure the continued safe operation of radar altimeters aboard aircraft while supporting the deployment of 5G systems in the band. The Aviation Community submits that the RTCA MSG Report and these mitigations form the basis for resolving the *Aviation Petition*.

As noted above, the RTCA MSG Report was the result of a multi-stakeholder effort. While representatives of the commercial mobile industry initially attended the RTCA MSG and were very welcome, for reasons of their own they did not fully participate in the work leading to the RTCA MSG Report. Instead, they chose to withdraw from the group and only submitted critiques when the RTCA MSG Report was presented for public comments, feedback that was taken into account when the RTCA MSG Report was finalized.[8] Importantly, the commercial mobile industry is on the record in this docket agreeing that multi-stakeholder efforts represent a critical opportunity to make progress on the technical concerns raised in the *Aviation Petition*.[9]

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[6] Letter of Ajit Pai, Chairman, FCC, to Rep. Peter A. DeFazio, U.S. House of Representatives, at 1 (Jan. 24, 2020) ("Pai Letter") (" Any actions the Commission takes regarding this band [*i.e.*, the 3.7-4.2 GHz Band] will be carefully designed so that aircraft are able to use altimeters in a continuous and uninterrupted manner. . . . We will continue to carefully assess the potential impact of the Commission's actions in this band on the critical operations by helicopters and airplanes that use altimeters.").

[7] Notably, based on the same RTCA MSG Report, the French government, in late November, imposed mitigation requirements on commercial mobile operators licensed at 3800 MHz and below to protect several types of radar altimeters, pending further study. *See* L'Agence Nationale des Fréquences (ANFR) technical note on "Protection of Radio Altimeters in the 4200-4400 MHz Band" (published Nov. 30, 2020), available at https://www.anfr.fr/fr/gestion-des-frequences-sites/bande-3490-3800-mhz/.

[8] *See* Letter of Terry McVenes, President & CEO, RTCA, and Dr. David Redman, Director, AVSI, to Marlene H. Dortch, Secretary, FCC, written *ex parte* presentation, GN Docket No. 18-122 at 1-2 (filed Nov. 19, 2020)(noting that "[t]he RTCA MSG Report was subject to a public review process prior to its publication and received an extensive list of comments from various stakeholders, including CTIA, that were considered and discussed. All comments received, and the RTCA MSG agreed resolutions, were incorporated into the final version of the RTCA MSG Report." (footnote omitted)).

[9] *See. e.g.,* CTIA, Opposition to Petitions for Reconsideration, GN Docket No. 18-122, at 6 (June 26, 2020)(endorsing "the Commission's explicit interest in multi-stakeholder consideration of the coexistence issues raised in the petitions" as the way to address the aviation industry's concerns about interference to radar altimeters); Opposition of T-Mobile U.S.A, Inc., GN Docket No. 18-122, at 7 (June 26, 2020)(touting the Commission's

The mitigations presented herein afford existing radar altimeters, which are crucial to the continued safe operation of most aircraft, the protections promised by Chairman Pai while allowing the flexible use licensing of 3700-3980 MHz to proceed and a framework conferring certainty on bidders in the upcoming auction in that band what it will take to protect radar altimeters.[10]

BACKGROUND

The safety of aviation operations in the United States, despite its excellent record in recent decades, should never be taken for granted. All aviation navigation and related systems undergo a rigorous certification process before the FAA to ensure their airworthiness.[11] Many of these systems rely upon access to allocated spectrum on a non-interference basis, and one of the most essential aviation systems is the radar altimeter. Radar altimeters not only inform cockpit crew of the aircraft's actual height above terrain, but they provide vital input to a number of other systems aboard aircraft, including automatic flight control systems, terrain awareness and warning systems ("TAWS"), and traffic collision avoidance systems ("TCAS"), to ensure safety during takeoff, climb, flight, approach, and landing phases. Radar altimeters operate globally in a single spectrum band (4200-4400 MHz), and their operation must be free from harmful interference not just in the vast majority of operational scenarios, but in *all* scenarios.[12] Radar altimeters are used in critical aircraft operations where undetected erroneous outputs could have catastrophic consequences resulting in the total loss of aircraft and potentially loss of many lives. As harmful interference is a common-mode failure condition, *i.e.,* one that can affect multiple systems simultaneously, undetected erroneous outputs that might result from such interference could affect one or more flight guidance systems with potentially catastrophic results.

Following the encouragement of the Commission in its *Report and Order*, several MSGs were formed to address the various outstanding coexistence issues with the introduction of flexible usage licensees in the 3700-3980 MHz band.[13] The first of these was formed by RTCA in April 2020, after a public call for participation, to determine the potential for Radio Frequency ("RF") interference into radar altimeters from future flexible use licensees operating in the nearby 3700-3980 MHz range.[14]

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suggestion "that AVSI and other aviation interests can establish a multi-stakeholder group to address any matters relating to harmful interference from terrestrial wireless use" as a means to address the aviation industry's concerns); Opposition of AT&T, GN Docket No. 18-122, at 4 (June 26, 2020)(espousing multi-stakeholder efforts to address the complex coexistence issues concerning the introduction of flexible use in the 3700-3980 MHz and to work towards efficient technical solutions). The Aviation Representatives, while agreeing that multi-stakeholder efforts were an important tool to address the coexistence issues between flexible use operations and radar altimeters, disagreed with these commercial mobile industry stakeholders that the pursuit of such multi-stakeholder work should displace consideration of the *Aviation Petition*, rather than inform its proper resolution. Aviation Representatives, Consolidated Reply to Oppositions to Aviation Petitioners' Petition for Partial Reconsideration, GN Docket No. 18-122, at 9-10 (July 9, 2020).

[10] *See* Pai Letter.

[11] *See, e.g.,* FAA, TSO-C87a, Airborne Low-Range Radio Altimeter (May 2012).

[12] The Commission, in its *Report and Order,* recognized that radio altimeters must operate free from harmful interference. *Report and Order* ¶ 390 ("Radio altimeters are critical aeronautical safety-of-life systems primarily used at altitudes under 2500 feet above ground level (AGL) and must operate without harmful interference.")

[13] *See id.* ¶ 333.

[14] *See* note 1, *supra*.

The potential for harmful interference required further study based on additional inputs, as the preliminary assessments prepared by AVSI and filed in this docket made clear, before the need for possible mitigations, or the lack of any need, could be ascertained.[15] Fortunately, the RTCA MSG Report represents a material advance beyond the preliminary assessments conducted by AVSI because the MSG had at its disposal information not only from radar altimeter manufacturers, but also the commercial mobile industry, thanks to public 3GPP standards and the exchange of information within the Technical Working Group 3 ("TWG-3"), another multi-stakeholder effort.[16] As a result of that information exchange, and the inclusion of additional radar altimeter models that the earlier AVSI preliminary assessments did not study, the RTCA MSG Report provides a detailed assessment of expected interference to radar altimeters from potential fundamental *and spurious* emissions from new flexible use licenses expected in the 3700-3980 MHz band under the Rules established in the *Report and Order*.[17] The assessment included expected base station and UE operations and their interactions with a range of existing radar altimeters, based on both radar altimeter parameters detailed in Recommendation ITU-R M.2059 and parameters obtained from empirical interference testing using simulated 5G waveforms.[18] The analysis defined usage categories to characterize both the potential civil aircraft operations and specific altimeters which are known to be installed and used on airframes conducting those types of operations on a daily basis. These consist of:

- Usage Category 1 – covering commercial air transport airplanes, both single-aisle and wide-body.
    - Radar altimeters are required equipment on such commercial air transport airplanes supporting mandated TAWS and TCAS capabilities.[19]

[15] *See* "Behavior of Radio Altimeters Subject to Out-Of-Band Interference," attachment to Letter of Dr. David Redman, Director, AVSI, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122 (Oct. 22, 2019); "Effect of Out-of-Band Interference Signals on Radio Altimeters," attachment to Letter of Dr. David Redman, Director, AVSI, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122 (Feb. 4, 2020); "Helicopter Air Ambulance RF Interference Scenario," attachment to Letter of Dr. David Redman, Director, AVSI, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122 (July 2, 2020).

[16] Letter of Max Fenkell, on behalf of AIA, and Kara Graves, Assistant Vice President, Regulatory Affairs, CTIA, to Marlene H. Dortch, Secretary, FCC, GN Docket No. 18-122 (Nov. 13, 2020). While TWG-3 was specifically setup to study coexistence issues, it is notable that "[a]s TWG-3 previously reported to the Commission, the group does not plan on submitting any technical reports or recommendations for Commission consideration." (*id.* at 4, footnote omitted)

[17] The analysis conducted in the RTCA MSG Report was only for single base stations. Thus, it could not account for planned deployment of multiple base stations and their potential for aggregate interference that could be even worse than the potential interference already shown in the RTCA MSG Report.

[18] *See* Recommendation ITU-R M.2059, Operational and Technical Characteristics and Protection Criteria of Radio Altimeters Utilizing the Band 4 200-4 400 MHz, (02/2014) ("Rec. ITU-R M.2059"). Rec. ITU-R M.2059 has been published since 2014, well before the Commission reached its decision on this issue, but spurious emission limits in the 4200-4400 MHz band were seemingly not considered in the *Report and Order*.

[19] 14 C.F.R. § 121.135 for TAWS and 14 C.F.R. § 121.356 for TCAS.

- There are an estimated minimum of 10,548 up to 15,822 radar altimeters on 5,274 U.S.-registered airplanes in active service in this category.[20]

- Usage Category 2 – covering all other fixed-wing airplanes not included in Usage Category 1, including smaller regional, business aviation, and general aviation airplanes.
  - Radar altimeters are required equipment on regional airplanes supporting mandated TAWS and TCAS capabilities.[21] Radar altimeters are also required equipment on certain business aviation and general aviation airplanes supporting mandated TAWS capabilities.[22]
  - There are an estimated minimum of 25,618 up to 54,465 radar altimeters on an estimated 23,961 to 52,808 U.S.-registered airplanes in active service in this category.[23]

- Usage Category 3 – covering both transport and general aviation helicopters.
  - Radar altimeters are required equipment on helicopters operated under a Part 135 certificate.[24] Included under the umbrella of Part 135 are helicopter air ambulance ("HAA") operations. For HAA operations, FAA Rules further require the use of a helicopter TAWS to alert the pilot when flying dangerously close to the terrain or other obstacles, often utilizing the output from the radar altimeter to do so (although this is not explicitly required).[25]

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[20] Estimate based on 2019 narrow-body and wide-body jet inventory obtained from Forecast International's "U.S. Commercial Aircraft Fleet 2019" (© 2020) ("2019 Commercial Fleet"), available at http://www.fi-aeroweb.com/U.S.-Commercial-Aircraft-Fleet.html, and assumes two or three radar altimeters per airplane. As noted in the RTCA MSG Report at 36, many aircraft can have multiple radar altimeters installed to ensure the necessary accuracy and resilience needed for certification requirements.

[21] 14 C.F.R. § 121.135 for TAWS and 14 C.F.R. § 121.356 for TCAS.

[22] 14 C.F.R. § 135.154 and 14 C.F.R. § 91.1045 require TAWS for all turbine-powered airplanes configured with 10 or more passenger seats. Many operators not covered by the mandate have also voluntarily equipped their airplanes with TAWS due to its safety benefit.

[23] Regional jet portion of estimate based on 2019 Commercial Fleet regional jet inventory and assumes two radar altimeters per airplane. Business and general aviation airplane portion of estimate based on CY 2018 FAA General Aviation and Part 135 Activity Surveys Table 3.1 ("CY2018 Table 3.1") Number of Active Aircraft by Primary Use by Aircraft Type and CY 2013 FAA General Aviation and Part 135 Activity Surveys Table AV.1 ("CY2013 Table AV.1") Radar Altimeter Equipage Percentages. The CY2013 Table AV.1 Radar Altimeter Equipage Percentages were used because that is the most recent year that FAA recorded such data. The business and general aviation estimate includes turbojets, 1- and 2-engine turboprops, and 1- and 2-engine piston airplanes and assumes one radar altimeter per airplane even though larger turbojets and turboprops often have two radar altimeters. CY2018 Table 3.1 available at https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2018/media/2018GA_Survey_Chapter_3_Tables_508_Compliant_12DEC2019V1_(002)-1.xlsx. CY2013 Table AV.1 available at https://www.faa.gov/data_research/aviation_data_statistics/general_aviation/CY2013/2013_GA_Survey_Avionics_Tables.xlsx.

[24] 14 C.F.R. § 135.160. Many operators not covered by the mandate have also voluntarily equipped their helicopters with a radar altimeter due to its safety benefit.

[25] 14 C.F.R. § 135.605.

- There are an estimated minimum of 4,987 up to 5,379 radar altimeters on an estimated 4,987 to 5,379 U.S.-registered helicopters in active service in this category.[26]

Note that internationally registered aircraft entering U.S. airspace are not included in these estimates. Radar altimeters are deployed on international aircraft, and these aircraft require the same protection from harmful interference while operating in the United States National Airspace System ("NAS"). There are an estimated 3,200 international commercial air transport airplanes that enter the U.S. NAS, many of them on a regular basis.[27] There are also international business and general aviation airplanes entering the U.S. NAS, the numbers of which cannot be readily estimated.

The RTCA MSG Report conclusions identified several areas of harmful interference to radar altimeters that require mitigation action as flexible use licensees deploy in the 3700-3980 MHz range for the continued safe function of existing radar altimeters. This filing, after reviewing the prospects for mitigations implemented by the aviation industry, focuses on effective mitigations that can be implemented by the wireless industry in new C-Band flexible use installations, which are necessary at least until the aviation industry can implement appropriate long-term mitigations.

This filing provides mitigations for both flexible use *fundamental emissions* in the 3700-3980 MHz band and flexible use *spurious emissions* falling within the radar altimeter 4200-4400 MHz band. The Aviation Community notes that the proposed mitigation to protect radar altimeters from spurious emissions falling into the 4200-4400 MHz band from new flexible licensees are especially critical, since there are not even theoretical mitigations that could be put in place by the aviation industry to protect radar altimeters from these emissions.

OBJECTIVES OF PROPOSED MITIGATIONS

In formulating proposed mitigations, the Aviation Community used the data made available in the RTCA MSG Report, the only detailed assessment available considering interference from 5G emissions into radar altimeters arising from flexible use operations in the 3700-3980 MHz range. Given the extremely stringent operating environments in which aviation safety systems such as radar altimeters must operate, the mitigations were developed using aviation industry best-practice safety analysis methods based on a worst-case approach intended to account for all

[26] Estimate based on CY2018 Table 3.1 Number of Active Aircraft by Primary Use by Aircraft Type and CY2013 Table AV.1 Radar Altimeter Equipage Percentages. The CY2013 Table AV.1 Radar Altimeter Equipage Percentages were used because that is the most recent year that FAA recorded such data. The estimate includes multi- and 1-engine turbine, and piston helicopters. One radar altimeter is assumed for each helicopter. 100% equipage is assumed on Part 135 helicopters due to the 14 C.F.R. §135.160 mandate; helicopters not operated under Part 135 used the CY2013 Table AV.1 Radar Altimeter Equipage Percentages appropriate to the helicopter type. This is considered a reasonable estimate even though a small percentage of Part 135 helicopters are exempt from the mandate.

[27] *See* FAA ADS-B Current Equipage Levels, International Air Carrier Aircraft Equipage and Avionics Performance Data table's 1-Dec-20 count of Good Installs providing a broadly equivalent estimate of foreign commercial air transport airplanes entering the U.S. NAS, available at https://www.faa.gov/nextgen/equipadsb/installation/current_equipage_levels/.

potential aircraft operations. A worst-case approach is necessary when analyzing RF interactions with aeronautical safety systems to achieve the levels of safety required by modern aviation operations.[28] To protect life, many radar altimeters are intended to operate to levels as stringent as one undetected failure per billion flight hours. Therefore, any analysis of their performance should reflect this exceptional level of required integrity.[29] For comparison, this requirement is several orders of magnitude greater than the assurances required by demanding wireline or commercial mobile communications application.

PROSPECTS FOR MITIGATIONS BY AVIATION

Modification of Existing Radar Altimeters

Short-term mitigations such as additional filtering capabilities for existing radar altimeters are not the simple fix that it might first appear to those outside the aviation industry. At a minimum, the addition of significant filtering represents a modification of the radar altimeter system and accompanying wiring, hardware and potentially software modifications. Considering such a modification to a system critical to the safe function of an aircraft, the entire system and its interaction with those systems dependent upon the data from the radar altimeter would likely require an aircraft to undergo an extensive recertification process. A corresponding period for new production of the updated radar altimeter equipment, and subsequent aircraft installation campaign would also be necessary. A certification approval process would take five years or more to accomplish and, even then, may not be technically feasible for all radar altimeters. Second, some radar altimeter designs may not even be able to meet the required performance with the inclusion of an additional Band Pass Filter ("BPF") with sharp roll-off. Such a filter will introduce additional insertion loss in the receiver path, which may impact the sensitivity performance of the radar altimeter system. Third, a BPF with steep roll-off may have significant group delay variation in the passband, which can affect both the accuracy and sensitivity performance of the altimeter system for the case of frequency-modulated continuous wave ("FMCW") altimeters (which comprise the majority of radar altimeters used in civil and commercial aviation). Fourth, it is not yet clear if the mechanical installation characteristics of such filters would allow them to simply be added in all affected airframes – the environment to modify existing avionics or cabling is limited at best and impossible at worst.

Moreover, any filter-based mitigations the aviation industry could introduce would only focus on interfering signals in the radar altimeters' pass band. The addition of retrofit filtering would do nothing to mitigate the effect of ***spurious emissions*** in the 4200-4400 MHz band arising from flexible use operations in the 3700-3980 MHz band, a harmful interference threat documented for the first time in the RTCA MSG Report.

Development of Future Radar Altimeters

[28] *See* ICAO Doc 9718, "Handbook on Radio Frequency Spectrum Requirements for Civil Aviation, Volume I: ICAO spectrum strategy, policy statements, and related information" – Second Edition at 9-8 (2018) ("ICAO Doc 9718"), available at https://www.icao.int/safety/FSMP/Documents/Doc9718/Doc9718_Vol_I_2nd_ed_(2018)corr1.pdf.

[29] *See* RTCA MSG Report at 10.

The aviation and aerospace industries have already begun the development of a new radar altimeter performance standard for incorporation into future designs and FAA certification processes. This new performance standard would complement, and may even eventually supersede the need for some of, the mitigations undertaken by flexible use deployments and operations recommended below. This effort will update the relevant performance standard and attempt to account for the spectrum environment that is rapidly changing in the vicinity of 4200-4400 MHz, both in the U.S. and globally. This new performance standard is targeted for publication as early as the fourth quarter of 2022.[30] However, after the new performance standard is developed, the FAA must publish the certification requirements (*i.e.,* Technical Standard Order ("TSO")) for the new equipment, the new equipment must be designed and developed by manufacturers and subsequently certified by the FAA, and only then – after a period which optimistically will be no sooner than 4-5 years from today – can the manufacture, airframe certification, and installation of the new systems begin, followed by a natural lifecycle of aircraft replacement over several decades.

One possibility to accelerate the deployment of radar altimeters designed, certified, and produced under new TSOs and tolerant of 5G transmissions in nearby spectrum would be for the 5G community, as new entrants to the band, to reimburse the affected manufacturers and flight operators in replacing their current radar altimeter systems, once new authorized equipment becomes available. Given the financial crisis currently impacting aviation, reimbursement could accelerate the date at which the mitigations required of flexible use licensees could be phased out. However, the details of such an arrangement would need to be agreed to by all parties, naturally, and a specific proposal is beyond the scope of this filing.

RECOMMENDED MITIGATIONS FOR NEW FLEXIBLE USE LICENSEES

Given the challenges with mitigations implemented by the aviation industry, mitigations implemented by flexible use licensees at the outset are critical if current radar altimeters – and aviation safety – are to be protected as new 5G systems are introduced into the 3700-3980 MHz band. Based on the RTCA MSG Report, including the parameters of the existing Rec. ITU-R M.2059, the developed interference tolerance masks ("ITMs"), and the subsequent analysis by the RTCA MSG, the Aviation Community advocates for the following mitigations as the basis to protect all existing radar altimeters. These proposed mitigations will ensure that radar altimeters can continue to operate effectively at performance levels demanded of aviation safety-of-life systems.

To facilitate understanding, the following recommendations are split between measures put in place for base stations and those put in place for UEs. The discussion of mitigations in these two categories is correlated to the radar altimeter Usage Categories to give further clarity on why the mitigations are recommended.

Base Station Mitigations

[30] *See* RTCA SC-239 Terms of Reference, at 3 (Initial revision approved Apr. 17, 2020), available at https://www.rtca.org/wp-content/uploads/2020/08/SC-239-TOR-Approved-04-17-2020.pdf.

Given the multitude of potential scenarios and RF interactions between aircraft and future 5G networks, it would be impossible for the Aviation Community to recommend an exact specification for each base station that covers all potential aviation scenarios. Instead, the Aviation Community proposes that each base station deployment be assessed by network operators to ensure they meet the following criteria to protect all Usage Category 1, 2 and 3 radar altimeters.

1. **Fundamental emission limits in the 3700-3980 MHz band:** Figure 1 defines the maximum aggregate power spectral flux density interference threshold that is needed to protect any Usage Category 1, 2 and 3 radar altimeters as a function of aircraft operating altitude up to 2500 ft height above ground level ("AGL").[31] The interference threshold curve incorporates all individual radar altimeter ITMs, aircraft antenna parameters, and expected operational parameters of the aircraft into a single figure (see Annex A for explanation of how the curve was derived). At this time the aviation community recommends the ITU-R Recommendation P.528-4 propagation model at 1% availability should be used to calculate the necessary worst-case aggregate RF interaction between the base station and the aircraft as used in the RTCA MSG Report.[32] Additional models could be considered for urban centers that provide similar adequate statistical assurance while better modelling aspects such as building shadowing, multi-path and other urban specific considerations.[33]

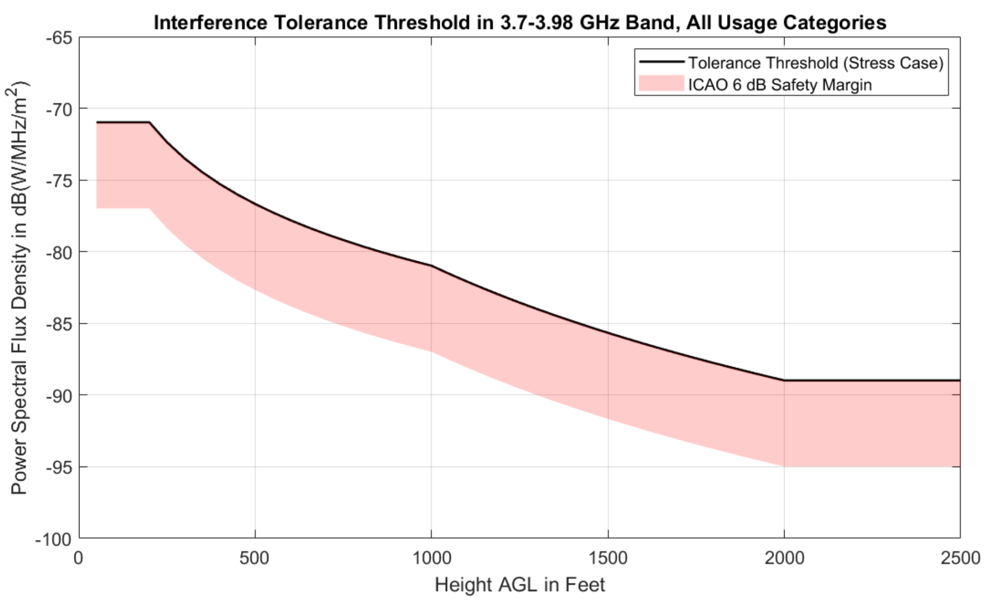

Figure 1

[31] Usage Category 1 radar altimeters can operate up to 7000 ft height AGL, see Annex A for specific power spectral flux density interference thresholds for aircraft fitted with these types of altimeter when operating above 2500 ft height AGL.
[32] *See* RTCA MSG Report at 18. Recommendation ITU-R P.528-4, "A propagation prediction method for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands" (Aug. 2019), available at https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.528-4-201908-I!!PDF-E.pdf.
[33] The calculations should also include the aviation safety margin of 6 dB in accordance with ICAO policy. *See* ICAO Doc 9718, Section 9.2.22 at 9-8.

2. **Spurious emissions limits in the 4200-4400 MHz band:** The conducted spurious emissions limit for base stations should be reduced from -13 dBm/MHz as currently listed in the *Report and Order*[34] to -48 dBm/MHz across the 4200-4400 MHz band (the -13 dBm/MHz limit specified in the *Report and Order* outside of the 4200-4400 MHz band has no impact on any radar altimeters). This mitigation covers all operational aircraft scenarios and altimeters, with Annex B providing additional details on the parameters and information used in its development.

Application of Base Station Mitigations for Protection of Radar Altimeters on Usage Category 1 and 2 (Fixed-Wing) Aircraft

To protect fixed-wing aircraft, the interference threshold curve in Figure 1 should be applied anywhere aircraft with Usage Category 1 and 2 Radar Altimeters are operating. The Aviation Community recommends compliance with the curve be required in the following conditions:

a. **All points at or above obstacle clearance surfaces defined in 14 C.F.R.** §§ **77.19 and 77.21.**

b. **Approach and departure paths at and near airports:** In order to protect against loss of radar altimeter function during a windshear encounter, the above curve also applies along approach and departure paths from an airport at any point where the aircraft is expected to be at or below 1500 feet AGL.[35] This nominally corresponds to a horizontal distance out to 4.7 nautical miles along approach and departure paths from each runway end. Any 5G base stations which may be deployed or provide coverage in these critical flight areas, accounting for both the nominal approach and departure paths and the flight paths needed for missed approach maneuvers, must comply with the interference threshold limits throughout the entire flight volume in order to protect all Usage Category 1 and 2 radar altimeters.

An example of the application of the mitigations for Usage Category 1 and 2 radar altimeters in a specific flat terrain scenario is included in Annex C, using both attenuation of a single base station's EIRP in the elevation plane and also a separation distance from airports and aircraft operating areas.

Application of Base Station Mitigations for Protection of Radar Altimeters on Usage Category 3 (Helicopter) Aircraft

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34 *Report and Order* ¶ 343.

35 During a windshear encounter, aircraft fly through a volume of airspace where the wind speed and direction are rapidly changing. This can cause the aircraft's airspeed to rapidly decrease. Airspeed is a critical aerodynamic parameter which determines how much lift can be generated, and therefore whether the aircraft can sustain flight. During a windshear encounter, the radar altimeter and TAWS provide automated audio (voice) callouts of the terrain clearance, which is critical information for a pilot who is executing the windshear escape maneuver. Loss of or erroneous radar altimeter information and these callouts would be a significant detrimental effect to a successful windshear escape.

The Aviation Community notes a significant exception to effectiveness of the above mitigations when considering Usage Category 3 radar altimeters used by helicopters, as the operational profile of helicopters takes them significantly closer to obstacles such as base stations. No specific rules exist that prohibit how close helicopters can operate relative to such structures, other than the judgment of the pilot. Helicopter pilots can fly as close as 100 ft to base stations, and may need to in order to complete their mission (*e.g.,* a medical evacuation), at all possible elevations and azimuth angles to the base station. Such scenarios may also encompass the helicopter flying directly into the main beam of the base station. Attempting mitigations for victim systems in the main beam of Advanced Antenna System base stations with only 100 ft of pathloss would be difficult for any system, let alone an aviation safety system such as radar altimeters. If a mitigation was placed on base stations to prevent interference to Usage Category 3 radar altimeters operating in the main beam, then the maximum EIRP would need to be significantly lower than the recommendations above. The Aviation Community appreciates that meeting such a requirement would place greater constraint on flexible use operations than those needed to protect fixed wing aircraft, but as noted above, it is likewise not feasible for a quick modification of affected helicopters to ensure they continue to operate interference free. Therefore, it is recommended that the Commission, the FAA, helicopter operators, and the commercial mobile industry investigate additional options to protect the operation of low-level helicopter operations.[36]

User Equipment (UE) Mitigations

Mitigations for UEs Operating External to the Aircraft

The analysis from the RTCA MSG Report demonstrated that UE emissions external to the aircraft operating within the limits contained within 3GPP standards should not breach the harmful interference threshold.[37] 3GPP standards provide that conducted spurious UE emissions not exceed -30 dBm/MHz in the 4200-4400 MHz band.[38] Therefore, the Aviation Community recommends maximum conducted spurious UE emissions should be -30 dBm/MHz in the 4200-4400 MHz band for UEs external to the aircraft, to align with the 3GPP standard and to achieve the RTCA MSG Report results. This would be a change from the *Report and Order* conducted spurious UE emissions limits of -13 dBm/MHz.

Mitigations for UEs Operating Internal to the Aircraft

In response to a draft of the RTCA MSG Report, mobile representatives contended that Commission Rules already do not permit operation of UEs on board active aircraft.[39] However, the Aviation Community underscores that rigorous aviation safety analysis depends upon accounting for all foreseeable conditions and that experience makes clear that one cannot simply *assume* 100% regulatory compliance by passengers in operating their personal devices. As the

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[36] The Aviation Community would also suggest Unmanned Aircraft System ("UAS") operators may have a significant interest in such discussions given some mission types may fly with either existing and future radar altimeter designs.
[37] *See* RTCA MSG Report at 83-85.
[38] *See id.* at 27.
[39] *See id.* at 146.

Commission may know, UEs do not specifically implement fail-safe technologies that automatically *prevent* operation on aircraft. Furthermore, it is clear from FAA and industry studies that operation of UEs indeed do occur onboard active aircraft, and this situation must be addressed.[40] Therefore, the following user equipment mitigations are necessary for new flexible use licensees to protect all radar altimeters while onboard an aircraft. Annex D provides additional details on the derivation of the recommendations below.

1. **UE Onboard Power Limits:** UEs operating while on board an aircraft should be limited to a maximum of -16 dBm EIRP total power. This is based on the exceedance of the tolerance threshold by 46 dB observed in the RTCA MSG Report for the case of UEs operating onboard a Usage Category 3 aircraft,[41] when the UEs are assumed to have a total EIRP of 30 dBm. Therefore, an EIRP of -16 dBm or less is required to stay below the threshold.

2. **UE Onboard Conducted Spurious Emissions Limits:** The conducted spurious emissions limit for UE operated on aircraft should be reduced from -13 dBm/MHz as currently listed in the *Report and Order*[42] to -57 dBm/MHz across the 4200-4400 MHz band (the -13 dBm/MHz spurious conducted emission limit for UEs specified in the *Report and Order* outside of the 4200-4400 MHz band had no impact). This limit is based on the exceedance of the tolerance threshold by 27 dB observed in the RTCA MSG Report for the case of UEs operating onboard a Usage Category 3 aircraft,[43] where the UEs were assumed to have a spurious emissions level of -30 dBm/MHz (therefore, a spurious emissions level of -57 dBm/MHz or less is required to stay below the threshold).

[40] Survey data from the Consumer Electronics Association and Airline Passenger Experience Association showed almost one-third of passengers report they have accidentally left a Portable Electronic Device ("PED") turned on during a flight. 43% of passengers incorrectly believe it is acceptable to use PEDs while taxiing to the runway, 32% while in the air before reaching the altitude where PEDs are approved for use, and 26% while the plane is in its final descent. *See* "A Report from the Portable Electronic Devices Aviation Rulemaking Committee to the Federal Aviation Administration" (Sep. 30, 2013), available at https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/PEDARC-11082012.pdf.
[41] *See* RTCA MSG Report at 85.
[42] *Report and Order* ¶ 347.
[43] *See* RTCA MSG Report at 86.

CONCLUSION

Adoption of the foregoing recommended mitigations by flexible use licensees provides a path for a successful resolution of the *Aviation Petition*. The Aviation Community believes these mitigations provide the basis for the best possible methods to protect avaiation safety in the short- and long-term while allowing 5G deployment in the 3700-3980 MHz to go forward following the upcoming auction. As a practical matter, it will be many years before the aviation industry will be able to implement effective mitigations to protect new radar altimeters themselves. Until that time, to protect air passengers, crews, and persons on the ground, the Commission should require flexible use licensees to adopt the foregoing mitigations to hasten the economic advantages promised by 5G operations in the C-Band, while simultaneously avoiding the monumental impact that would result from the severe disruption of civil aviation necessary if no flexible use mitigations are adopted.

Respectfully submitted,

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ANNEX A
DERIVATION OF POWER FLUX SPECTRAL DENSITY PROTECTION CURVES FOR RADAR ALTIMETERS.

The aggregate interference threshold curve in the main text is the aggregate worst-case derivation of all three radar altimeter usage categories. It is driven primarily by the requirements of Usage Category 2 radar altimeters, based upon the empirical results of the RTCA MSG Report. Operational specifics of the different Usage Category altimeters must also be considered in applying the mitigations, such as airport stand-off distances applicable to base stations for radar altimeters on Usage Categories 1 and 2 aircraft. The interference threshold curves derived for each Usage Category individually are provided below in Figures 2, 3 and 4:

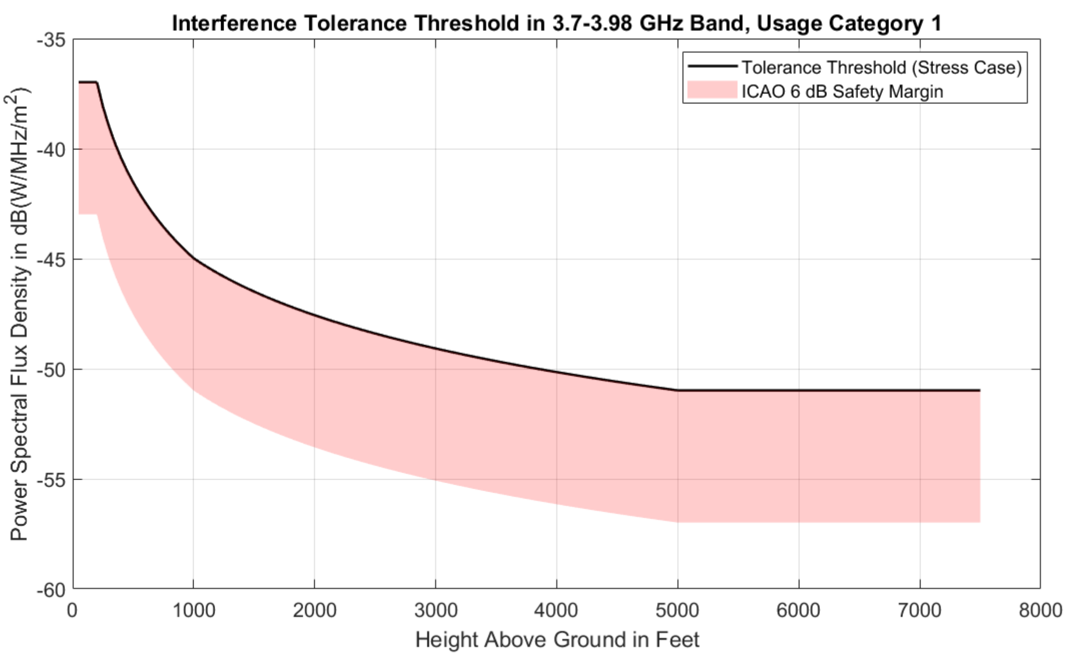

Figure 2

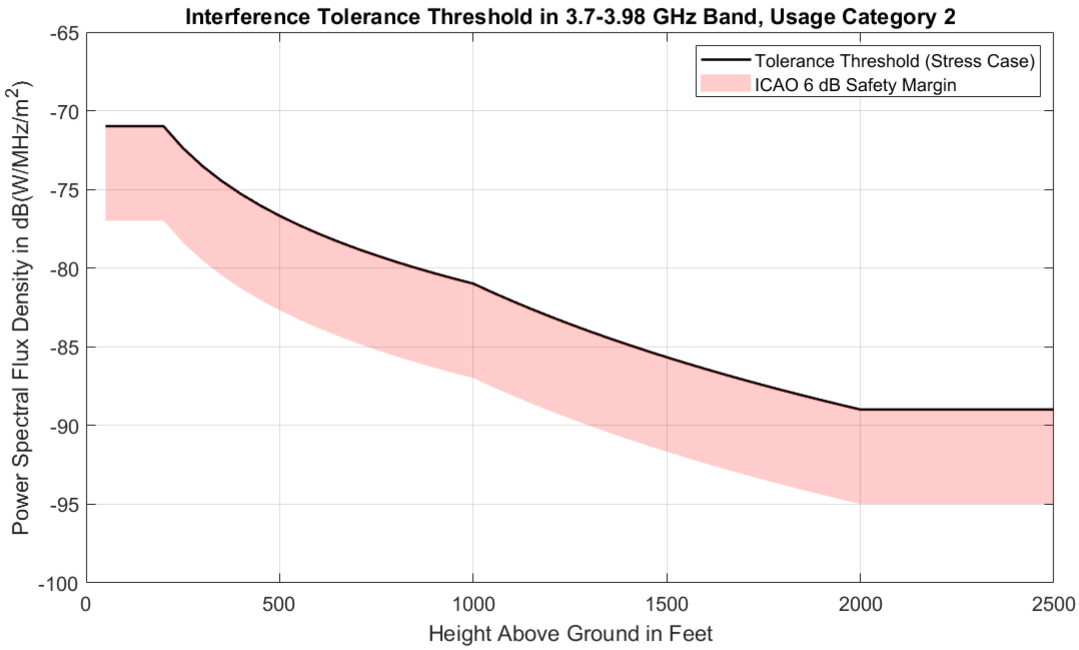

Figure 3

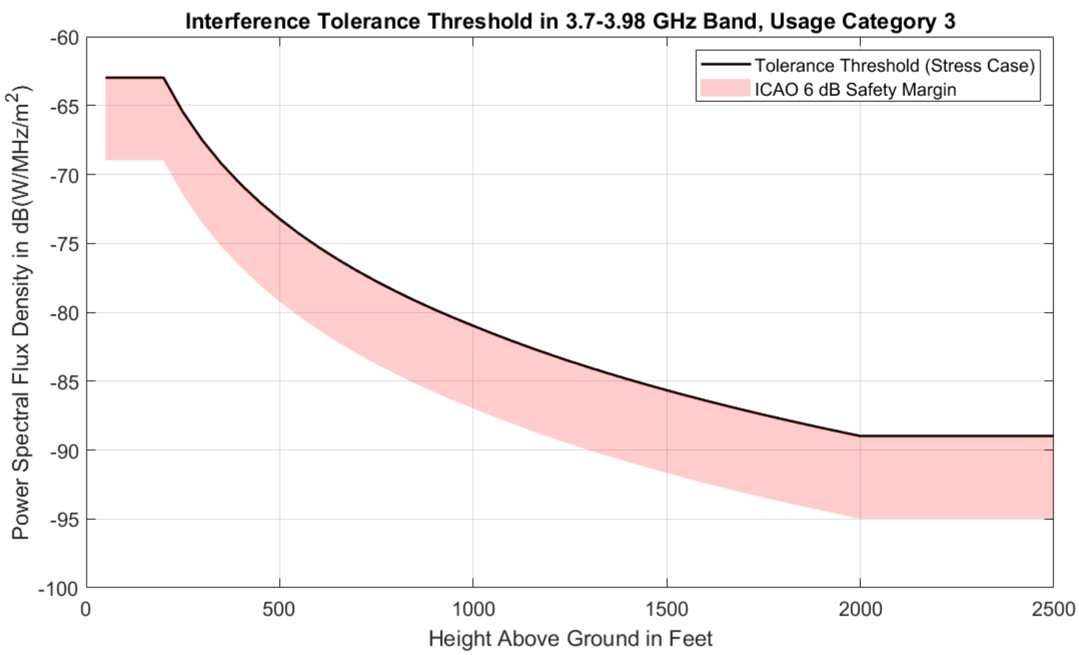

Figure 4

Each of these three curves simply translates the interference tolerance masks ("ITMs") given for each radar altimeter Usage Category in the RTCA MSG Report from a set of power spectral density ("PSD") values in dBm/MHz at the radar altimeter receiver input port to a set of power spectral flux density values in dB(W/MHz/m^2) incident on the aircraft in the 3700-3980 MHz band. Therefore, the curves allow for the interference tolerance thresholds for each radar altimeter Usage Category to be expressed in a manner that is fully independent of the actual aircraft installation or operational parameters. The thresholds are defined only in terms of the interference signal power flux density at a given point in space in which an aircraft may be operating. Interference power spectral flux density from 5G emissions sources, including the aggregation of multiple emissions sources, can be determined at various points in space based on the PSD of each emissions source and an appropriate propagation model. For points in space in which aircraft of a given Usage Category may be operating at the specified height above ground, a comparison of the computed interference level can be made to these thresholds to identify whether harmful interference occurs.

The interference threshold curves were derived by first taking the ITM for each Usage Category (in dBm/MHz at the radar altimeter receiver input port), adding the 3 dB of receive path cable loss used in the RTCA MSG Report[1] to obtain a PSD at the receive antenna output port, and then dividing out the effective area of the receive antenna based on its gain to obtain power spectral flux density. Since the radar altimeter receive antenna gain is a function of the angle relative to the boresight direction, and the boresight direction may vary based on the pitch and/or roll angle of the aircraft, separate power spectral flux density thresholds were computed across all possible signal directions of arrival. The aircraft pitch and roll were assumed to be limited to ±20° and the reference radar altimeter pattern in the 3700-3980 MHz band provided in the RTCA MSG Report was used.[2] This antenna pattern has a uniform gain of approximately 0 dBi across a beamwidth of ±70°. Therefore, when allowing for up to ±20° of aircraft pitch or roll, roughly the same power spectral flux density threshold will be obtained across all signal directions of arrival in the range of ±90° from the vertical. This power spectral flux density value is then taken as the threshold for each altitude.

[1] *See id.* at 49-54 for ITMs. *See id.* at 32 for cable loss.
[2] *See id.* at 31-32.

ANNEX B
CALCULATION OF SPURIOUS EMISSION LIMITS FOR BASE STATIONS

This Annex provides additional details on the parameters and information used in the development of base station spurious emissions limits recommendations in light of the RTCA MSG Report results. While Usage Category 2 radar altimeters were the most impacted by these types of emissions, for clarity the results for the other two radar altimeter usage categories are also explained below. It should also be noted that based on information provided by the 5G wireless community through TWG-3, the RTCA MSG Report assumed a conducted spurious level of -20 dBm/MHz for all base stations.[1] This is different than the specified conducted spurious level of -13 dBm/MHz for base stations in the *Report and Order*.[2]

Of the different radar altimeter usage categories, Usage Category 2 radar altimeters experienced the worst-case exceedance of the tolerance threshold by spurious interference at 28 dB.[3] Therefore, the maximum safe limit is -20 dBm/MHz minus 28 dB, or -48 dBm/MHz. This also complies with Rec. ITU-R M.2059, as the worst-case spurious tolerance threshold for Usage Category 2 in the RTCA MSG Report was within 2 dB of the worst-case Rec. ITU-R M.2059 receiver desensitization level.

For Usage Category 1 radar altimeters, in-band exceedance level of -16 dBm/MHz shows that the -13 dBm/MHz conducted spurious emissions specified in the *Report and Order* would exceed these levels by 3 dB across the 4200-4400 MHz band.[4] The Aviation Community understands that this value was not explicitly raised as a concern in the RTCA MSG Report because the commercial mobile industry information exchanged as part of TWG-3 suggested that commercial mobile equipment would not emit above -20 dBm/MHz.[5] However, the Commission's Rules currently are not so limiting.

For Usage Category 3 radar altimeters, the worst-case exceedance of the tolerance threshold by the recommended -20 dBm/MHz conducted spurious emission was 12 dB.[6] Therefore, the maximum safe conducted spurious emission limit for this Usage Category is -32 dBm/MHz (-20 dBm/MHz minus 12 dB).

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[1] *See id.* at 20-22, 25 and 141-142.
[2] *Report and Order* ¶ 343.
[3] *See* RTCA MSG Report at 72.
[4] *See id.* at 68.
[5] *See id.* at 20-22, 25 and 141-142.
[6] *See id.* at 74.

ANNEX C
EXAMPLE BASE STATION MITIGATIONS FOR USAGE CATEGORIES 1 AND 2 RADAR ALTIMETERS (LARGE COMMERCIAL TRANSPORT AND SMALLER FIXED WING AIRPLANES)

The following example of base station mitigations applies the parameters specified in the main body of this filing to show how the flat terrain scenarios developed in the RTCA MSG Report could be applied to Usage Category 1 and 2 radar altimeters. The example presumes a single base station and uses a simultaneous combination of both attenuation of the 5G signal by elevation and separation distances around an airport to achieve the necessary protection. If either is altered, the other must be adjusted to compensate.

1. An example single base station operating up to a maximum height of either 30 meters for a non-rural deployment, or 35 meters for a rural deployment, would be required to operate within the angle dependent EIRP limits depicted in Figure 5. This example derivation excludes scenarios with aircraft altitudes less than 200 feet (since below this point the interference tolerance of radar altimeters is expected to increase, both due to decreased interference from other radar altimeters operating in the vicinity, and increasing signal levels for the radar return from the terrain), and with line-of-sight distances along a slant direction (*i.e.,* slant range) between the aircraft and base station of less than 200 feet (since it is expected that base station installations and lower-altitude Usage Category 1 and 2 aircraft operations can be suitably separated to prevent these aircraft from flying within 200 feet of a flexible use base station).

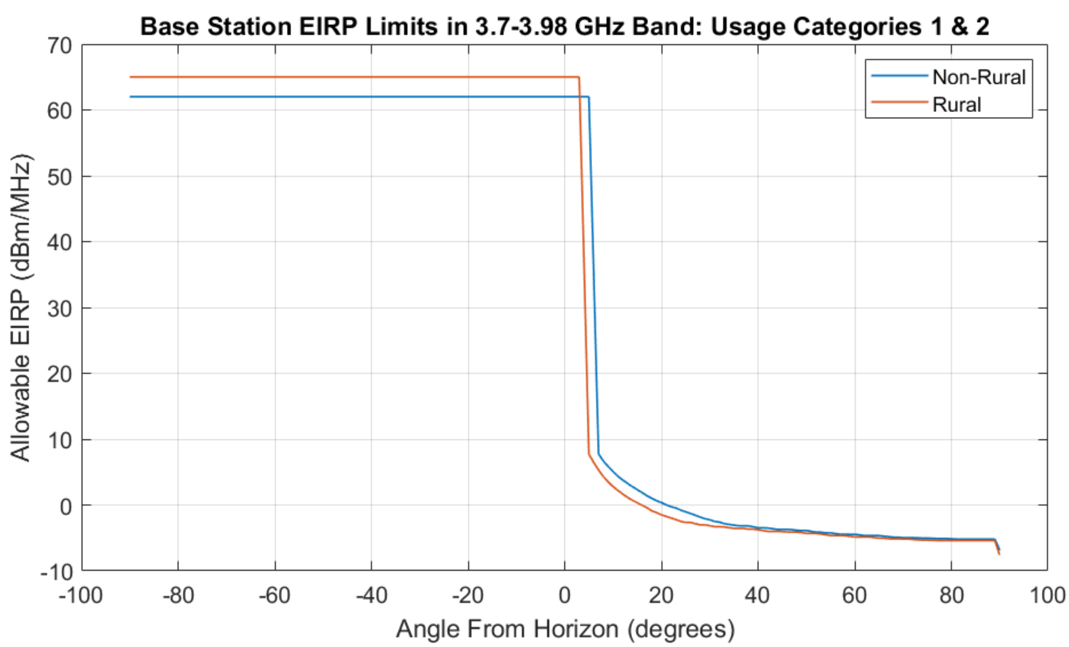

Figure 5

2. In the vicinity of airports, this example base station operating in 3700-3980 MHz would not be deployed within 0.6 NM (about 1.1 km) from the end of each runway threshold or ±300 meters laterally from the runway centerline.

The same parametric analysis methods outlined in the RTCA MSG Report were used to derive the EIRP limits shown above.[1] The aircraft pitch/roll angle was limited to 20 degrees, which is the range in which radar altimeters must meet the most stringent performance requirements. Further, scenarios with aircraft heights less than a certain minimum value or with slant ranges between the aircraft and base station less than a certain minimum value were excluded based on the assumption they can be prevented from occurring through appropriate aeronautical operational restrictions. The minimum altitude and slant range values assumed vary for some of the radar altimeter usage categories. Using the same propagation model and radar altimeter installation characteristics (antenna pattern and cable loss) assumed in the RTCA MSG Report,[2] the EIRP limits are derived such that the computed interference PSD will be equal to the safe interference limit. Therefore, for this flat terrain scenario the EIRP limits do not rely on any assumptions regarding the actual base station physical deployment parameters other than its mast height (which is needed to determine the propagation geometry and elevation angle).

[1] *See id.* at 13.
[2] *See id.* at 18 for the propagation model. *See id.* at 31-32 for the radar altimeter installation characteristics.

ANNEX D
CALCULATIONS OF MITIGATIONS TO BE IMPLEMENTED BY USER EQUIPMENT WHILE OPERATING ON BOARD AIRCRAFT TO PROTECT RADAR ALTIMETERS

This Annex provides additional details on the parameters and information used in the development of UE fundamental and spurious emissions limits recommendations in light of the RTCA MSG Report results. While Usage Category 3 radar altimeters were the most impacted by these types of emissions, for clarity the results for other two radar altimeter usage categories are also explained. It should also be noted that based on information provided by the 5G wireless community through TWG-3, the RTCA MSG Report assumed a conducted spurious level of -30 dBm/MHz for all UEs.[1] This is different than the specified conducted spurious level of -13 dBm/MHz for UEs in the *Report and Order*.[2]

Of all the different radar altimeter usage categories, Usage Category 3 radar altimeters had the worst-case exceedance of the tolerance threshold by emissions from UEs operated onboard aircraft, both for UE fundamental and spurious emissions. For fundamental UE emissions, the RTCA MSG Report concluded that UEs operating onboard a Usage Category 3 aircraft exceeded the tolerance threshold by 46 dB.[3] Given the expected fundamental emissions when the UEs are assumed to have a total EIRP of 30 dBm, an EIRP of -16 dBm or less is required to stay below the threshold. Additionally, for UE spurious emissions, the RTCA MSG Report concluded that UEs operating onboard a Usage Category 3 aircraft exceeded the tolerance threshold by 27 dB.[4] As the UEs were assumed to have a spurious emissions level of -30 dBm/MHz, a spurious emissions limit of -57 dBm/MHz or less is required to stay below the threshold. These limits will protect all existing radar altimeters and are also in compliance with protection criteria established in Rec. ITU-R M.2059 in scenarios where UEs may be operating onboard an aircraft.

For aircraft operating Usage Category 1 radar altimeters, the RTCA MSG Report concluded that UEs each emitting an EIRP of 30 dBm onboard those aircraft is not expected to have any impact based on the fundamental emissions in the 3700-3980 MHz band.[5] However, for the same Usage Category 1 radar altimeters, it did conclude that the conducted spurious emissions limit of -23 dBm/MHz for user equipment would exceed the tolerance threshold for radar altimeters in that Usage Category.[6] While below the assumed conducted spurious level of -30 dBm/MHz noted above, these spurious emissions would exceed the -13 dBm/MHz limits specified in the *Report and Order.*

The RTCA MSG Report concluded that UE fundamental emissions above a maximum of -3 dBm EIRP total power would exceed the protection criteria of Usage Category 2 radar altimeters. This was based on the exceedance of the tolerance threshold by 33 dB observed in the RTCA

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[1] *See id.* at 20-22, 25 and 141-142.
[2] *Report and Order* ¶ 347.
[3] *See* RTCA MSG Report at 85.
[4] *See id.* at 86.
[5] *See id.* at 85.
[6] S*ee id.* at 86.

MSG Report for the case of UEs operating onboard a Usage Category 2 aircraft,[7] when the UEs are assumed to have a total EIRP of 30 dBm. Therefore, an EIRP of -3 dBm or less is required to stay below the threshold. Additionally, the RTCA MSG report concluded that the conducted spurious emissions limit for user equipment would need to be reduced to -44 dBm/MHz across the 4200-4400 MHz band to protect all Usage Category 2 radar altimeters. This limit is based on the exceedance of the tolerance threshold by 14 dB observed in the RTCA MSG Report for the case of UEs operating onboard a Usage Category 2 aircraft,[8] when the UEs are assumed to have a spurious emissions level of -30 dBm/MHz (therefore, a spurious emissions level of -44 dBm/MHz or less is required to stay below the threshold).

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[7] *See id.* at 85.
[8] *See id.* at 86.