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Agenda Item 4: Radio Altimeters – FSMP.006.02
a) Radio Altimeter Technical and Policy Developments

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SUMMARY

This paper shares updates related to DRAFT FAA requirements and guidance for interference tolerant radio altimeter systems.

1. INTRODUCTION

1.1 On July 3rd, 2025, a congressional mandate was passed requiring the United States Federal Communications Commission (FCC) to auction at least 100 MHz in the upper C-band (3.98 – 4.2 GHz) for terrestrial wireless flexible use by July 4th, 2027. This band is directly adjacent to the 4.2-4.4 GHz band, which has a primary allocation to the aeronautical radionavigation service in the United States, and is reserved exclusively for airborne radio altimeters (RA). The Federal Aviation Administration (FAA) began aligning rulemaking timelines with the FCC to support aviation by defining the required actions and applicability. To ensure safe, efficient, and reliable aviation operations in the presence of interference signals in the upper C-band, the FAA proposed new regulations for all aircraft with RAs and compatibility conditions for adjacent band users. This paper provides an overview of the proposal. The FAA plans to publish a final rule later this year, which may alter the details of this proposal based on comments that are received from the various stakeholders.

2. BACKGROUND

2.1 RAs measure aircraft height above terrain and obstacles using low-power signals in the 4.2 – 4.4 GHz frequency band, which is reserved exclusively for radio altimeters installed on board aircraft world-wide. Accurate RA data is critical for pilots as well as integrated aircraft automation, navigation, and safety systems. Historically, radio frequency interference (RFI) was not a problem for RAs because receiver filtering was sufficient to reject interference from relatively low power transmitters in adjacent spectrum bands as well as unwanted emissions into 4.2 – 4.4 GHz. In 2021, the RFI environment in frequencies below the 4.2– 4.4 GHz band substantially changed in the United States when wireless providers began offering services that are below, and near to, the RA band (i.e., 3.7 – 3.98 GHz)[1]. Laboratory testing, as developed in RTCA, Inc. Special Committee 239 (SC-239), demonstrated the interference susceptibility of operational RA models to the wireless 5G waveform that would be used in the lower C-band. The compatibility analysis demonstrated that relatively large separation distances were required between RAs and 5G transmitters to provide enough attenuation to not interfere with the RA.

2.2 With the auction of lower C-band licenses to wireless services and service rules set by the FCC, RAs would be susceptible to interference from high-power signals in the neighboring spectrum bands and unwanted (spurious) emissions from those wireless base stations into the 4.2 – 4.4 GHz band, which could result in loss or erroneous altitude readings if not properly mitigated, once the 5G base stations began transmitting. Anomalous RA output to downstream applications can cause aircraft to maneuver in an unsafe manner at low altitude or prevent collision avoidance technology from functioning properly. The pilot might not be able to detect the error or adjust the flight path in time to maintain continued safe flight and landing resulting in catastrophic outcomes.

2.3 Due to this unsafe condition, the FAA issued airworthiness directives (ADs) to require lower C-band interference tolerant RA equipment or restrict certain operations for aircraft that posed the highest safety risk. In response, the aviation industry provided RA retrofit solutions for these aircraft and the wireless industry stepped up to voluntary constraints in addition to countless other onerous processes and procedures by both industries to maintain safe coexistence.

3. PROBLEM STATEMENT

3.1 For continued allocation of frequency spectrum near the 4.2 – 4.4 GHz band, mandatory and long-term solutions must be achieved for the aviation and wireless industry through appropriate frequency band separation no longer relying on burdensome constraints to aviation and wireless operations and returning all aircraft in the National Airspace (NAS) to the same level of safety and functionality provided prior to 2021.

4. CURRENT RA LIMITATIONS

4.1 As part of working with RA manufacturers to assess this new interference environment, each provided any test data available for existing Airworthiness Directive (lower C-band) interference compliant RAs. This data showed auctioning additional spectrum higher in frequency than 3.98 GHz, even a single additional 20 MHz channel[2], to high-power wireless would be problematic for existing RAs which are minimally compliant with the ADs and more than 45% of the fleet including large transport airplane operators are equipped with the minimum. Without additional retrofits to address this new upper C-band interference environment, the FAA would need to prohibit operations in a significant portion of the fleet causing substantial operational and economic impacts and disruption to the NAS and flying public from flight delays, cancellations, and groundings. Table 1 summarizes the achievable performance of the existing lower C-band interference tolerant RAs, broken down by specific frequency ranges within the upper C-

[1] Other nations began offering similar services, however, following different and generally more restrictive limitations on frequency, emitted power, and physical location in comparison to wireless operations in the U.S.

[2] Assumes spectrum will be auctioned in 20 MHz license sub-blocks as in 3.7–3.98 GHz allocation.

band. Performance above 4.2 – 4.4 GHz band is provided specifically for this audience. The power flux-density (PFD) indicates the minimum interference tolerance at 500 feet height above ground level (HAGL) and below, measured as a root mean square (RMS) in decibel-watts per square meter per MHz (dBW/m2/MHz).

Table 1 - RA Performance in the Upper C-band

Frequency range (MHz)	**Power flux-density, RMS (dBW/m^2 /MHz), 0-500 feet HAGL**
3980 < f < 4100	−40
4100 ≤ f < 4200	−67
4200 to 4400	−105
4400 < f < 4500	−56
4500 ≤ f ≤ 4600	−49

4.2 There are also thousands of RA systems that have not been modified to be tolerant to lower C-band wireless services under the current voluntary agreement and are more susceptible to interference than shown in Table 1.

5. FUTURE (NEXT GENERATION) RA PERFORMANCE

5.1 SC-239/EUROCAE WG-119 is developing Minimum Operational Performance Standards (MOPS) for the next generation RA systems to guarantee the robustness against existing and planned in band and out of band interference threats . The joint committee has completed a draft of the MOPS that is undergoing validation, which involves testing and analysis with prototype new designs to ensure that the requirements are both achievable and sufficient to meet the industry's needs.

5.2 The draft MOPS included an interference tolerance mask (ITM) that informed the FAA proposed interference tolerance requirement (i.e., § 91.220(b)) and provided the RA parameters for the FAA safety and compatibility analysis. These new RA will be able to withstand interference from adjacent spectrum band users including high-power wireless within 40-60 MHz of 4.2 – 4.4 GHz band without constraints on aviation or wireless operations. The ITM is defined at the system level, i.e. the power flux density (PFD) at the RA antenna face which accounts for both RA antenna and transceiver interference rejection capabilities with the lowest tolerance capability within the 4.2 – 4.4 GHz band (constant PFD) and monotonically increasing tolerance capability as the frequency/spectrum channels extend away from the band edges, achieving maximum tolerance 60-70 MHz (and beyond) from the band edges.

5.3 These new RAs are maximally interference tolerant while continuing to provide highly accurate altitude readings for pilots and integrated aircraft safety systems. In light of the FAA’s statutory mandate to maintain the safety of all aircraft in the NAS, the FAA is not requiring changes to the intended function or performance requirements of RA systems. The proposed rulemaking defines an interference environment within which the intended RA system functions, performance is achieved, and continued operational safety is maintained.

5.4 The FAA is proposing in § 91.220(b) to specify the RA interference tolerance necessary not only to address the lower and upper C-band, but also a broader range of frequencies surrounding the 4.2 – 4.4 GHz band (3 – 5.6 GHz). Table 2 shows the RA system interference tolerance requirement applicable to different frequency ranges from an altitude of 0 - 500 HAGL. The interference environment is specified as a PFD at the surface of the aircraft antenna, measured as RMS in dBW/m²/MHz, Figure 1 illustrates the interference environment defined in Table 2.

Table 2 – Next Generation RA Performance

Frequency range (MHz)	Power flux-density, RMS (dBW/m² /MHz), 0-500 feet HAGL
3000 ≤ f < 4000	9.5
4000 ≤ f < 4100	9.5
4100 ≤ f < 4150	9.5
4150 ≤ f < 4160	6.5
4160 ≤ f < 4180	−1
4180 ≤ f < 4190	−17
4190 ≤ f < 4200	−34
4200 ≤ f ≤ 4400	−82
4400 < f ≤ 4410	−33
4410 < f ≤ 4430	−21
4430 < f ≤ 4440	−8
4440 < f ≤ 4450	−1
4450 < f ≤ 4460	6.5
4460 < f ≤ 4500	9.5
4500 < f ≤ 4600	9.5
4600 < f ≤ 5600	9.5

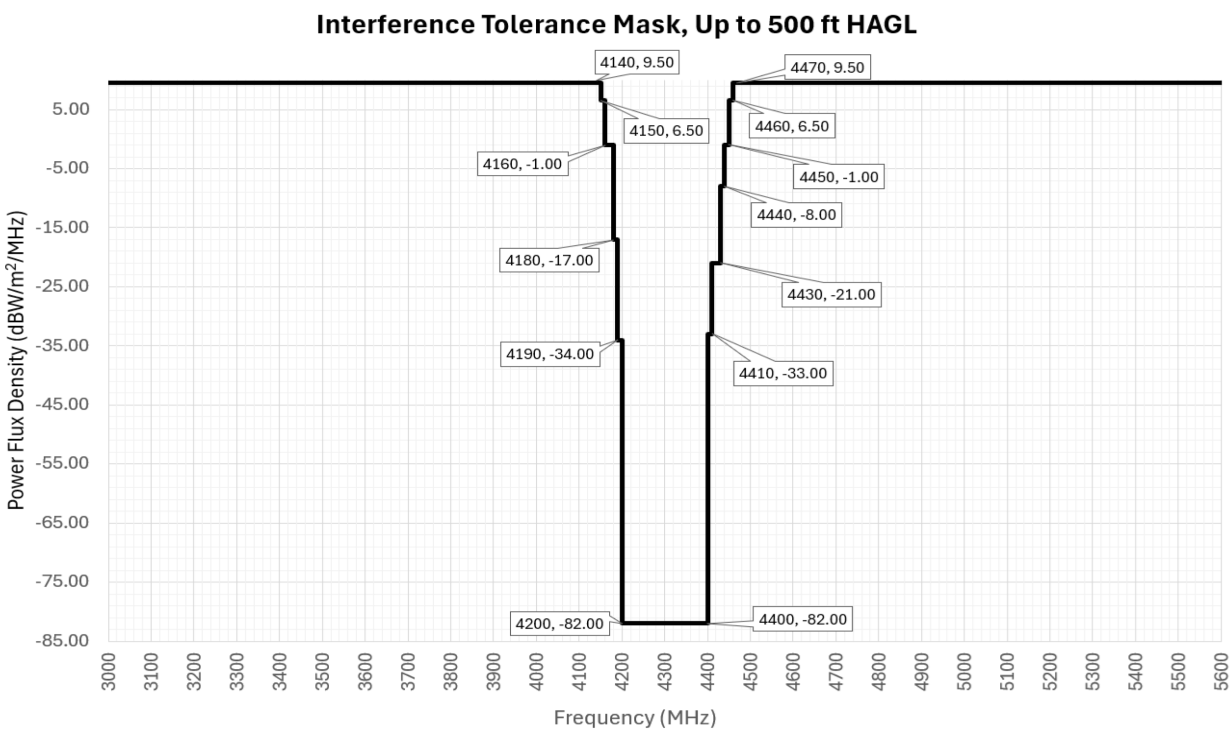

Figure 1 - Graphical Depiction of ITM

6. SAFETY AND COMPATIBILITY ANALYSIS

6.1 The purpose of the FAA safety and compatibility analysis was to ensure the safe operation of RAs and integrated systems, support efficient (i.e., no constraints or coordination needed) high-power wireless spectrum allocation to the greatest extent, and help to identify channel bands appropriate for other low-power services. Based on this analysis, RA systems compliant with § 91.220 will support reallocating more than the required 100 MHz of additional spectrum for high-power wireless without coordination and operating constraints (i.e., 65 dBm/MHz EIRP up to 4.16 GHz). The contextualization formula used to demonstrate this is:

PFD (in dBW/m2/MHz) = **EIRP** (per polarization, in dBm/MHz) – 30 – 10*log10(4*pi) – 20*log10(**MSD** (in meters)) + **SAFETY MARGIN**

PFD = power flux density at the RA antenna surface, in dBW/m^2/MHz.
EIRP = effective isotropic radiated power from wireless emitter, in dBm/MHz.
MSD = minimum separation distance between wireless emitter and RA antenna, in meters.

6.2 As long as the calculated PFD meets the ITM, then the RA is fully tolerant without any additional coordination or constraints needed, since the ITM reflects the maximum safely tolerable environment. Therefore, the ITM levels of +9.5 dBW/m2/MHz up to 4150 MHz, with a 35 ft. (10.67 m) MSD, can tolerate up to 65 dBm/MHz per polarization (or 68 dBm/MHz total EIRP for dual-pol emitters, like wireless base stations). Further, the ITM level of +6.5 dBW/m2/MHz from 4150–4160 MHz can tolerate up to 62 dBm/MHz per polarization (or 65 dBm/MHz total EIRP for dual-pol emitters). There would be no need for an EIRP elevation mask to limit the emissions downwards/towards the horizon. The emissions could occur at this limit in any direction as it is written in the current 3.7–3.98 GHz FCC Report and Order (R&O).

6.3 The 35-foot MSD has a basis in regulation for one engine out take-off clearance requirements and has been determined to be applicable to a broader range of aircraft operations and normal and non-normal conditions as well. The 3 dB reduction in the received power is a characteristic of broadband wireless antennas, which have orthogonal cross polarized elements with the power split equally between them. A 6 dB safety margin above the expected interference environment is applied to account for unknown issues internal or external to the RA system that could impact the safe operation of the RA which requires high levels of availability, continuity, and integrity due to catastrophic risks if there is failure. This safety margin is aligned with the ICAO recommendation in Doc 9718, *the Handbook on Radio Frequency Spectrum Requirements for Civil Aviation*, which specifies that a safety margin of 6 - 10 dB is to be applied for aeronautical safety systems. Since the FAA is actively working with spectrum regulators and users to ensure compatibility, a minimum safety margin is applied.

6.4 For compatibility with respect to emissions into the 4.2 – 4.4 GHz band, the RA system must continue to operate while withstanding the aggregate interference from all emissions sources into the band, including, but not limited to, the interference from lower and upper C-Band wireless transmissions. The in-band power flux density (PFD) of -82 dBW/m^2/MHz can tolerate up to -33 dBm/MHz spurious EIRP per polarization (or -30 dBm/MHz total EIRP for dual-pol emitters) from wireless transmitters. The equation below outlines the contextualization formula used and the parameters that are applied to determine in-band compatibility.

PFD (in dBW/m2/MHz) = **EIRP** (per polarization, in dBm/MHz) – 30 – 10*log10(4*pi) – 20*log10(**MSD** (in meters)) + **SAFETY MARGIN + AGGREGATION**

6.5 The additional aggregation factor is based on cell towers which have multiple systems housed on the same tower. An upper limit of three base stations is assumed, with the effective aggregate interference of all other base stations and mobile units no greater than that of a single base station at the MSD. This limiting case has an aggregate interference that is 6 dB higher than a single base station.

6.6 RA performance requirements for operations above 500 feet HAGL are not specifically addressed in the proposed rulemaking because, a maximum 5G transmitter height of 450 - 465 feet is the consensus of the wireless and aviation industry. Also, up to 500 ft. is the most critical/highest risk considering interference that prevents the RA system from operating normally is less likely above this height, and the consequence is also reduced, as there is more time to recover after interference. This also represents the constraining scenario for the RA equipment considering the other conditions of the proposed rule (MSD, EIRP up to 4.16 GHz, etc.). If there is compatibility at 500 ft., then there is also compatibility at aircraft altitudes above this because interference signals get weaker at a faster rate than the interference tolerance decreases. This is supported by the draft MOPS and best achievable approach to defining the ITM levels and RA characteristics and limitations with respect to providing maximum interference tolerance while maintaining intended function and supporting the aircraft installation. These characteristics and limitations include receiver sensitivity as a function of altitude with respect to in-band and near band interference tolerance (as sensitivity increases with altitude, interference tolerance decreases) and receiver selectivity and power handling capability with respect to out of band interference tolerance where increasing power may approach permanent damage limits for the receiver front-end components or arcing inside of the receiver bandpass filter affecting the performance. Balancing these factors, the highest possible altitude at which the maximum interference level could be sustained is 500 ft. This also helps to maximize and simplify spectrum compatibility and analyses.

7. CONDITIONS FOR FUTURE SPECTRUM COMPATIBILITY

7.1 The FAA proposed rulemaking is a companion to the FCC proposal to expand wireless services in the C-band (3.7 – 4.2 GHz) in the contiguous United States. The FCC proposal is in line with the FAA up to 4.16 GHz (180 MHz) allocation for high-power wireless or less based on a variety of factors outside of the control of the FAA or aviation industry. The FAA requirements are defined based on maximum interference tolerance (best-achievable) RA capability, rather than tailored to a fixed RFI environment. Compatibility was designed to provide the largest possible number of 20 MHz sub-blocks, as close to 4.2 GHz as possible, with the highest possible EIRP in each block, and fewest deployment/operational constraints as possible. With future RAs, full spectrum compatibility is achievable, with EIRP limits only, for all current and planned wireless implementations to within 40 MHz of the 4.2–4.4 GHz band (as long as unwanted emissions are compatible with RA in-band tolerance levels). There is no need for direct coordination, emitter deployment limitations, etc.

7.2 The FAA specifies unwanted (spurious) limits in the EIRP domain to fully bound the radiated energy ensuring the correct values needed for compatibility are understood and achieved without restricting the wireless service providers antenna designs and future evolution. Conducted emission limits do not provide sufficient information to complete the compatibility analysis and require antenna characteristics and parameters to be defined, bound to a worst-case condition to support FAA safety criteria, and controlled. Specifying unwanted (spurious) emission as an EIRP limit is feasible based on wireless equipment manufacturer feedback and will also reduce regulatory burden for all stakeholders. To ensure compatibility in the long-term, some additional industry agreed upon wireless parameters would need or benefit from regulatory constraints on technical characteristics such as antenna polarization, emitter height, allowable collocated systems, etc.

8. RA SYSTEM RETROFIT EQUIPMENT, INSTALLATION, TESTING, AND CERTIFICATION

8.1 The FAA has developed Advisory Circular (AC) 20-199*, Installation of an Airborne Low-Range Radio Altimeter System,* to provide guidance for the installation approval and means of compliance with the proposed interference requirement (i.e., § 91.220(b)). Although RTCA SC-239/EUROCAE WG-119 have completed a draft of the MOPS for next generation RA systems, the requirements are currently being validated and, unfortunately, a published version of the document will not be available in time to support the FAA rulemaking or new Technical Standards Orders (TSO) at this time. Therefore, the AC addresses an ITM only solution which allows type certificate (TC) applicants (including amended type certificate (ATC) and supplemental type certificate (STC)) to meet the RFI interference criteria in the AC while retaining the existing TSO-C87(), *Airborne Low-Range Radio Altimeter*, performance and testing basis as an acceptable means of compliance.

8.2 The AC also addresses re-use of existing antennas, which is expected to support the RA transceiver for compliance to the maximum interference tolerance capability while maintaining the intended function of the RA system for most retrofit installations. Note that based on trade-off analysis, there is a limit to the total interference rejection that is achievable without compromising accuracy and due to a variety of factors, interference rejection is more appropriately addressed in the RA transceiver. A flat maximum antenna gain is used to bound data on existing airplane installations and provides minimal performance risk allowing for variations in production, installation conditions and constraints, installed performance, and over the life of the antenna. It also provides minimal compatibility risk considering aircraft operations and maneuvers, and the angle of interference into the RA system allowable per regulations and requirements. The AC also provides RFI injection test setup and testing consistent with the draft MOPS. For installation approval, an applicant is required to demonstrate that any modification to the aircraft meets the FAA's airworthiness regulations for TC (including ATC and STC). The extent of the design, analysis and testing of the installed equipment can vary significantly on the change impact to the aircraft integration. For installations only affecting the RA equipment (i.e., box swap) with new/improved filtering to address the more stringent RFI requirements with minimal to no impact on the performance of the RA or systems integrated with the RA, the FAA assumes that the aircraft installation can rely heavily on, and be done in parallel with, the equipment compliance demonstration. The change impact also bounds the scope of the AC guidance that should be considered during the retrofit installation.

9. TIMELINES

9.1 The proposed FAA regulations would require all aircraft equipped with RA operating under Part 121 and those aircraft with RA operating under Part 129 with 30 or more passenger seats or a payload capacity of more than 7,500 pounds to comply by the date the FCC authorizes wireless services in the upper C-band and wireless voluntary mitigations are removed for the lower C-band. The FAA expects this will be achievable in the 2029 to 2032 timeframe based on a variety of factors. All other aircraft equipped with RAs would be required to comply with the same performance requirements two years later. The proposed timeline for the retrofit is intended to reflect the urgency of expanding wireless services and therefore, the FAA has requested feedback from RA suppliers, aircraft manufacturers, and operators with data to support a feasible yet aggressive deadline. The FAA compliance times will be provided in the FAA final rule.

10. INTERNATIONAL CONSIDERATIONS

10.1 As airspace rule changes affect all aircraft, regardless of country of registration, the FAA is providing information on its proposed rulemaking for RA interference tolerance in the United States. This information may also be useful to States and the FSMP for discussions on the development of the new SARPS and Docs for radio altimeters.

— END —