International Civil Aviation Organization

Twenty Eighth Meeting of the Communications/ Navigation and Surveillance Sub-group (CNS SG/28) of APANPIRG

Bangkok, Thailand, 01July - 05 July 2024

Agenda Item 5: Aeronautical Mobile Communications Service and Aeronautical electromagnetic spectrum utilization

5.4 Other issues related to aeronautical communications service and aeronautical radio spectrum management, especially on 5G implementation and potential impacts to aircraft radio altimeters

GUIDANCE MATERIAL ON THE PROTECTION OF RADIO ALTIMETER FROM POTENTIAL HARMFUL INTERFERENCE FROM CELLULAR 5G COMMUNICATIONS

(Presented by the Secretariat)

SUMMARY

As informed through FSMP-WG/15 IP/09, the Secretariat has been working with FSMP and the ICAO MID Regional Office Radio Altimeter (RADALT) Action Group (AG) to develop and finalize guidance material to protect radio altimeters from potential harmful interference from new cellular broadband technologies such as 5G.

The WP/02 of FSMP-WG/16 presented the latest draft of this guidance material for comments and endorsement before processing its publication as an ICAO circular.

On 19 January 2024, it was informed that the draft Circular 360 **Guidance on Safeguarding Measures to Protect Radio Altimeters from Potential Harmful Interference** is at the final stage of the development/publication in the ICAO HQ, which is now available at ICAO Store.

1. INTRODUCTION

1.1 The radio altimeter, which operates in the frequency band 4.2-4.4 GHz, is a critical safety system used to determine the height of an aircraft above terrain and obstacles. Its information is essential to enable safe flight operation, including navigation functions, on all commercial aircraft as well as a wide range of other civil aircraft. If not properly mitigated, harmful interference to the function of the radio altimeter during any phase of flight may pose a serious safety risk to passengers, crew and people on the ground.

1.2 ICAO has received studies from several States and organizations regarding the potential interference to radio altimeters. These studies generally conclude that some models of radio altimeters will not operate as required due to interference if new cellular broadband technologies (5G) are deployed in frequency bands close to the frequencies used by radio altimeter’s operation (4.2-4.4 GHz) and in the close vicinity of where aircraft operations take place. Several States have already implemented temporary technical, regulatory, and operational mitigations on new 5G systems in order to protect radio altimeters while the aviation industry is working on long-term solutions to update and retrofit altimeters in order to ensure compatibility between cellular broadband technologies (5G) and aviation systems.

1.3 The issue has been raised and discussed not only at ICAO FSMP but also at high level meetings, including the recent 41st Assembly of ICAO, as well as several recent ICAO regional meetings.

1.4 To deal with this issue, the ICAO MID Office established a Radio Altimeter (RADALT) Action Group (AG) which started to develop guidance material to protect aircraft operations from potential radio altimeter interference (MIDANPIRG DECISION 19/23), which was shared with FSMP through FSMP-WG/15 IP/09. The FSMP Secretary has received inputs from several FSMP members, which were in turn provided to the RADALT AG to assist in further refining their guidance material.

2. DISCUSSION

2.1 The Technical Commission of the ICAO Assembly 41st session held from 29 September to 5 October 2022 reviewed several working papers on potential interference from 5G deployment to the radio altimeter and encouraged States and regions to actively participate in spectrum protection activities and to endorse the ICAO position for the World Radiocommunication Conference 2023 (ITU WRC-23).

2.2 Based on a proposal of the Technical Commission, the Assembly adopted Resolution A41-7 *"Support of the ICAO policy on radio frequency spectrum matters*", which supersedes Assembly Resolution A38-6. This resolution urges Member States to consider, as a priority, public and aviation safety when deciding how to enable new or additional services, and to consult with aviation safety regulators, subject matter experts and airspace users, to provide all necessary considerations and to establish regulatory measures to ensure that incumbent aviation systems and services are free from harmful interference.

2.3 In addition, the Technical Commission recalled relevant HLCC 2021 Recommendations, and requested ICAO and its Member States to continue taking necessary measures and efforts to ensure that radio altimeters and other aeronautical systems are free from harmful interference, including implementation of mitigation measures, sharing of best practices, as well as development of relevant provisions and guidance.

2.4 Recognizing the good guidance material developed by RADALT AG, the successful coordination outcome between RADALT AG and key members of FSMP, as well as a strong request from the Technical Commission for providing a global guidance material on this matter, the Secretary would like to consider the use of this guidance material, as developed by RADALT AG and further refined by FSMP, as a base document to be ultimately published as an ICAO circular.

2.5 Prior to the editorial process, the FSMP Secretary would like to seek final comments from FSMP members as well as FSMP's endorsement of this material as a global guidance material. After a discussion on the paper, the FSMP-WG/16 meeting endorsed the material broadly and agreed to provide comments to the ICAO Secretariat after the meeting.

2.6 On 19 January 2024, it is informed that the draft Circular 360 **Guidance on Safeguarding Measures to Protect Radio Altimeters from Potential Harmful Interference** is now at the final stage of the development/publication in the ICAO HQ. The Advanced edition(unedited) – 2024 is provided in **Attachment A** to this paper.

2.7 In June 2024, the ICAO **Circular 360** has been approved by and published under the authority of the Secretary General. The official publication is available at ICAO store in digital or printed format for USD 33.00.

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper;
b) review the contents of **Attachment A**;
c) encourage States/Administrations to order **Circular 360** from ICAO Store if necessary; and
d) discuss any relevant matter as appropriate.

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ICAO

Circular 360

Guidance on Safeguarding Measures to Protect Radio Altimeters from Potential Harmful Interference

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CONTENTS

ACRONYMS AND ABBREVIATIONS

3D	Three-dimensional
3GPP	3rd Generation Partnership Project
5G	Fifth generation technology standard for International Mobile Telecommunications (IMT)
ACAO	Arab Civil Aviation Organization
ACAS	Airborne collision avoidance systems
ACMA	Australian spectrum regulator
AD	Airworthiness directive
AFGCS	Automatic Flight Guidance and Control Systems
ANFR	National Frequencies Agency
AVSI	Aerospace Vehicle Systems Institute
CAA	Civil aviation authority
CASA	Australian Civil Aviation Safety Authority
CFIT	Controlled flight into terrain
CITC	Communications and Information Technology Commission
CNS SG	Communication, Navigation, and Surveillance Sub-Group
DAL	Design Assurance Level
dBi	Decibel relative to an isotropic antenna
dBm	Decibel relative to one milliwatt
DGAC	French Civil Aviation Authority
EASA	European Aviation Safety Authority
ECC	Electronic Communications Committee
EIRP	Effective isotropic radiated power
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDR	Frequency dependent rejection
FMCW	Frequency modulated continuous wave
FMSP	Frequency Spectrum Management Panel
GACA	General Authority of Civil Aviation
HLCC 2021	High-level Conference on COVID-19
IAP	Instrument approach procedure
IATA	International Air Transport Association
IBI	In-band interference
ICAO	International Civil Aviation Organization
ICCAIA	International Organization for Aerospace Industry Associations
IF	Intermediate frequency
IFR	Instrument flight rules
ILS	Instrument landing system
IMC	Instrument meteorological conditions
IMT	International Mobile Telecommunications
ISED	Innovation, Science and Economic Development Canada
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union – Radiocommunication Sector
MFCN	Mobile/Fixed Communications Networks
MOPS	Minimum operational performance standards
NCD	No computed data
NOTAM	Notice to Air Missions
OCS	Obstacle clearance surface
OFCOM	Office of Communications
OOBI	Out-of-band interference
PSD	Power spectral density
PWS	Predictive wind shear
RF	Radio frequency

RSZ	Runway safety zone
RRs	Radio regulations
RTCA	RTCA, Inc. (formerly Radio Technical Commission for Aeronautics)
SARPs	Standards and Recommended Practices
STC	Supplemental type certificate
TAWS	Terrain awareness warning system
TC	Type certificate
TCAS	Traffic alert and collision avoidance system
TCCA	Transport Canada Civil Aviation
TRP	Total radiated power
TSO	Technical standard order
TX/RX	Transmitter/receiver
WBB	Wireless broadband
WP	Working paper
WRC	World Radiocommunication Conference

EXECUTIVE SUMMARY

1. The radio altimeter[1], which operates in the frequency band 4 200 – 4 400 MHz, is a mandated critical aircraft safety system used to determine an aircraft's height above terrain and obstacles at all times during the flight. Its information is essential to enable safety-related flight operations and navigation functions on all commercial aircraft as well as a wide range of other civil aircraft. Such functions and systems include terrain awareness, aircraft collision avoidance, wind shear detection, flight controls and functions to automatically land an aircraft. If not properly mitigated, harmful interference to the function of the radio altimeter during any phase of flight may pose a serious safety risk to passengers, crew, and people on the ground.

2. ICAO has received studies from several States and organizations regarding the potential interference to radio altimeters. These studies generally conclude that several makes and models of radio altimeters will not operate as intended if new cellular broadband technologies (i.e., 5th generation cellular network technology (5G)) are deployed at high powers in frequency bands close to the radio altimeter's frequencies of operation.

3. Several States have already implemented temporary technical, regulatory, and operational mitigations on new 5G systems to protect radio altimeters while the aviation industry is working on long-term solutions to redesign and retrofit altimeters to improve compatibility between cellular broadband technologies (such as 5G) and aviation systems.

4. The Radio Altimeter Action Group of the Middle East Air Navigation Planning and Implementation Regional Group developed regional guidance material (MID Doc 015) which they provided to the Frequency Spectrum Management Panel (FSMP). In line with a recommendation agreed by the High-level Conference on COVID-19 (HLCC 2021), FSMP further refined MID Doc 015 and developed this circular which provides background information, several examples of technical and operational measures taken by some States, and essential information for States, aiming at assisting States to consider necessary measures to protect radio altimeters from potential harmful interference. Images and tables originating from the Aviation Spectrum Resources, Inc. (ASRI); Communications and Information Technology Commission (CITC) Saudi Arabia; French Civil Aviation Authority (DGAC); the U.S. Federal Aviation Administration (FAA); Innovation, International Organization for Aerospace Industry Associations (ICCAIA); International Telecommunication Union (ITU); Japan Civil Aviation Bureau (JCAB); National Frequency Spectrum Agency in France (ANFR); and Telecommunication and Digital Government Regulatory Authority UAE, have been reproduced with permission.

5. This circular is composed of four chapters as follows.

a) **Chapter 1 – Background on 5G and frequency band allocation**: This chapter describes the working arrangements and regulatory framework managed by the radiocommunication sector of the International Telecommunication Union (ITU) for the allocations of radio frequency (RF) spectrum and adoption of radio regulations (RRs). It also provides an overview on the current allocations of 5G at a global level.

b) **Chapter 2 – Potential impacts of 5G on radio altimeters during aircraft operations**: This chapter provides an overview on the radio altimeters' characteristics, its critical safety functions and technical concerns raised following the allocation of 5G bands close to radio altimeter frequency bands. This chapter also provides a list of potential operational safety hazards and their severity that may be caused by interference associated with the deployment of 5G cellular broadband ground infrastructure.

c) **Chapter 3 – Methodologies for defining safeguarding measures for aerodromes and heliports and a long-term plan for evolution of the radio altimeter**: This chapter provides a summary of approaches and methodologies that can be used to set protection zones, taking account of the aircraft altitude during the various stages of approach and landing, to reduce the probability of interference occurring by imposing limitations on the deployment of 5G base stations at aerodromes and in areas surrounding aerodromes. It also provides a set of requirements and guidance that should be implemented by aircraft operators to restrict the use of 5G user equipment and devices on board an aircraft.

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[1] In some aviation publications, the radio altimeter is also known as the radar altimeter or the Low Range Radio Altimeter.

d) **Appendix – Short-term safeguarding measures adopted at regional and global levels**: This appendix provides a summary of the measures adopted by States to protect radio altimeters onboard aircraft from potential harmful interference caused by 5G. It also summarizes the on-going and planned activities by regional organizations and standard making organizations to define new radio altimeter specifications.

Chapter 1

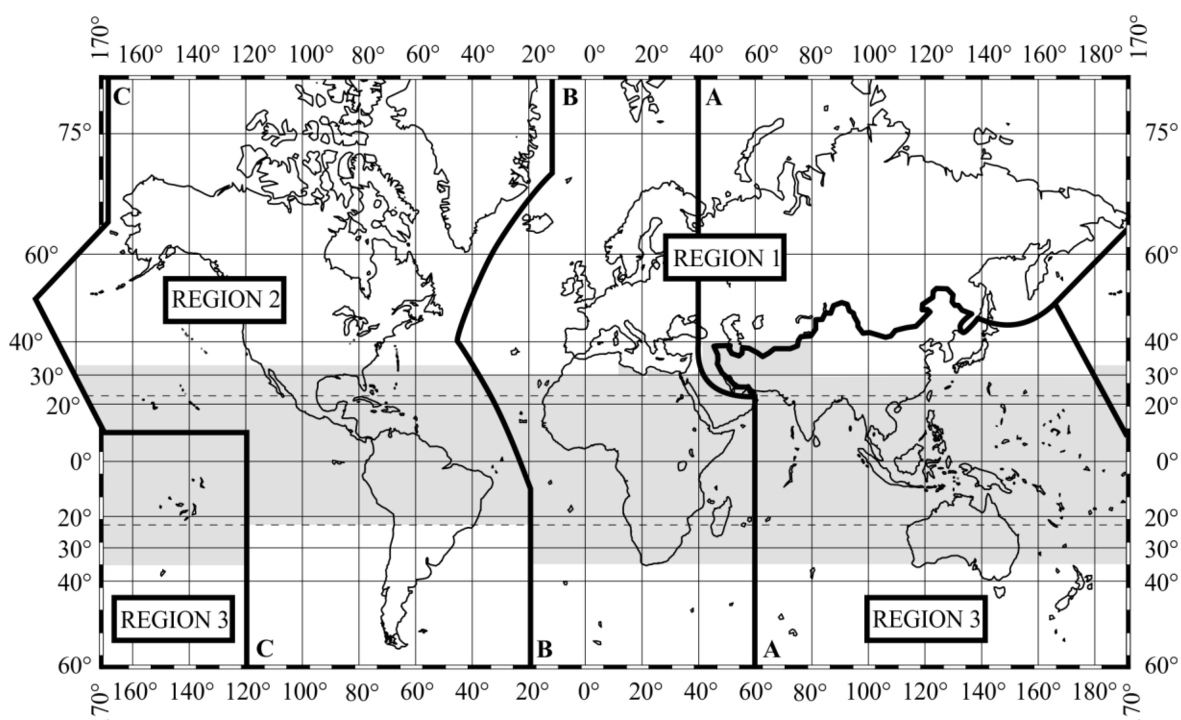
BACKGROUND ON 5G AND FREQUENCY BAND ALLOCATION

1.1 THE ROLE OF THE RADIOCOMMUNICATION SECTOR OF THE INTERNATIONAL TELECOMMUNICATION UNION (ITU-R)

1.1.1 The International Telecommunication Union (ITU-R) is responsible for ensuring efficient and economical use of the radiofrequency (RF) spectrum by all radio communication services. It develops and adopts the international spectrum allocations and associated regulations on the use of the RF spectrum.

1.1.2 The radio regulations (RR) are an internationally binding treaty on Member States regulating how RF spectrum is used. It is the basis for the global harmonization of RF spectrum use for all users of spectrum, including aviation and International Mobile Telecommunications (IMT) users. To enable new technologies and changes in spectrum usage, an ITU World Radiocommunication Conference (WRC) is held every 4 years where the RRs are revised and updated.

1.1.3 For the allocation of frequencies in the RRs, the world is divided into three regions as shown in Figure 1 below:



The shaded part represents the Tropical Zones

Source: ITU

Figure 1. ITU Regions

(*Image reproduced by kind permission of ITU*)

1.1.4 The RR allow the mobile service use of the frequency range 3 400 – 4 200 MHz. Through footnotes, 3 400 – 3 600 MHz (in regions 1, 2 and 3) and 3 600 – 3 700 MHz (in region 2) are identified for use by these administrations wishing to implement IMT. This identification does not preclude the use of this frequency band by any application of the services to which it is allocated and does not establish priority in the RR.

1.2 GLOBAL SPECTRUM SITUATION FOR 5G

1.2.1 Accommodation of the growth in demand for new spectrum for mobile telecommunications requires access to regionally or globally harmonized spectrum to provide additional IMT services including higher data rates. The frequency ranges 3 300 – 4 200 MHz and 4 400 – 4 900 MHz provide good propagation and data rates and are of global interest to IMT proponents. Variations of usage are seen regionally. For example, while the main band used in Europe is 3 400 – 3 800 MHz, China and India are planning to utilize 3 300 – 3 600 MHz. In Japan, 3 600 – 4 100 MHz are to be utilized for IMT. Utilization of similar frequency ranges for IMT is being considered in North America (3 450 – 3 980 MHz), Latin America, the Middle East, Africa, Australia, etc. At WRC-15 (held in November 2015), a total of 45 countries signed up to the IMT identification of the 3 300 – 3 400 MHz band. Furthermore, there is interest in China to utilize the 4 800 – 5 000 MHz frequency range and Japan currently utilizes the 4 500 – 4 900 MHz frequency range for IMT. The majority of IMT deployment in these bands is 5G technology based on standards from the 3rd Generation Partnership Project (3GPP).

1.2.2 Each State is responsible to develop spectrum management policies and regulations that comply with the international treaty obligations of the RR while meeting national spectrum needs[2]. One of the main tools to manage the spectrum is the National Frequency Allocations Tables, which show how the spectrum can be utilized for each RF service. States and national spectrum regulators all over the world are considering (or have considered) allowing 5G cellular systems to operate in parts of the frequency ranges 3 400 – 4 200 MHz and 4 400 – 4 900 MHz ("C-band[3]"). As these potential allocations are adjacent to the band used by radio altimeters, they pose potential safety hazards unless appropriate mitigations are implemented.

1.2.3 It is of paramount importance that, in support of safe aircraft operations, Member States and national regulators note Article 4.10 of the ITU RR:

> *ARTICLE 4 Assignment and use of frequencies*
>
> *. . .*
>
> *4.10 Member States recognize that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies.*
>
> *. . .*

1.2.4. Also, when evaluating the required protection of the radio altimeter, it is useful to refer to Recommendation ITU-R M.2059-0 (02/2014), which provides the relevant characteristics and protection criteria of radio altimeters utilizing the 4 200 – 4 400 MHz frequency range[4].

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[2] RTCA Inc. and EUROCAE are developing a guidance document that captures global deployment parameters and is to be published in 2023 as DO-399. These parameters must be quantified and are necessary inputs to a proper RF compatibility analysis that accounts for frequency separation, radiated power and direction, and proximity to aircraft.

[3] The C-band is a designation by the Institute of Electrical and Electronics Engineers (IEEE) for a portion of the electromagnetic spectrum in the microwave range of frequencies ranging from 4.0 to 8.0 gigahertz (GHz). The C-band is used for many satellite communications transmissions, some Wi-Fi devices, some cordless telephones, as well as some radar and weather radar systems.

[4] *https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2059-0-201402-I!!PDF-E.pdf. ("ITU-R M.2059").*

Chapter 2

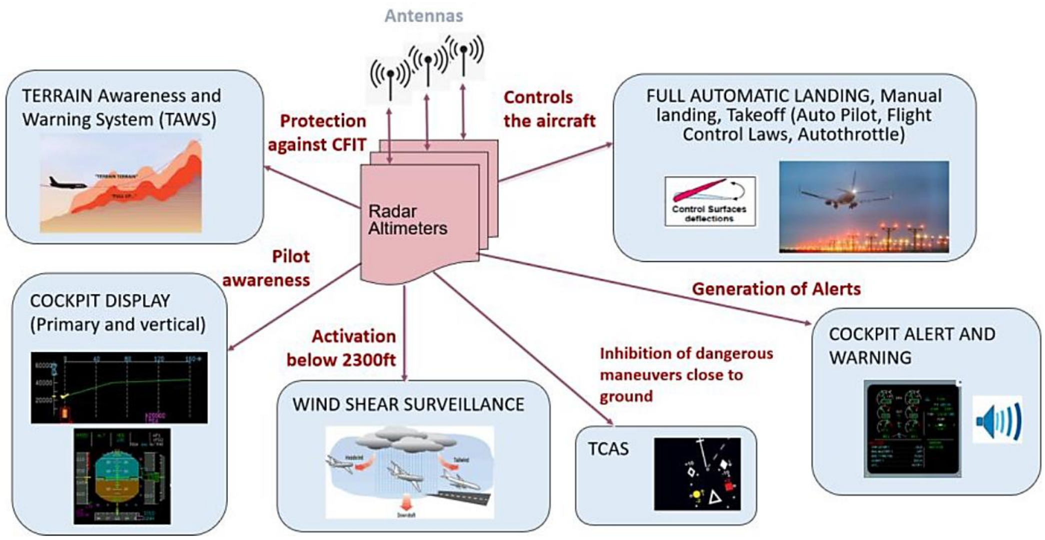
POTENTIAL IMPACT OF 5G ON RADIO ALTIMETERS DURING AIRCRAFT OPERATIONS

2.1 INTRODUCTION

2.1.1 The frequency band 4 200–4 400 MHz is allocated to the aeronautical radionavigation service and is reserved for use by radio altimeters installed onboard aircraft by Article 5, footnote No. 5.438 of the RR. Additionally, this band is also allocated to the aeronautical mobile (route) service, reserved exclusively for use by wireless avionics intra-communication systems by Article 5, footnote No. 5.436 of the RR.

2.1.2 The radio altimeter, also sometimes referred to as a radio altimeter, is the only sensor onboard aircraft capable of providing a direct measurement of the clearance height above the terrain and any obstacles. It plays a vital role in providing situational awareness to the flight crew and is an essential component of an aeronautical safety-of-life application during aircraft operations.

2.1.3 Furthermore, the output from the radio altimeters is also used to enable and enhance several different safety and navigation functions throughout all phases of flight on all commercial aircraft and a wide range of other aircraft. The main radio altimeters functions are illustrated in Figure 2.



Source: ICCAIA

Figure 2. Main radio altimeter functions
(*Image reproduced by kind permission of ICCAIA*)

2.1.4 The radio altimeters are designed to operate for the entire life of the aircraft in which they are installed. Since installed life typically exceeds 30 years, a variety of radio altimeter implementations exist, at a wide range of equipment age, performance, and tolerance.

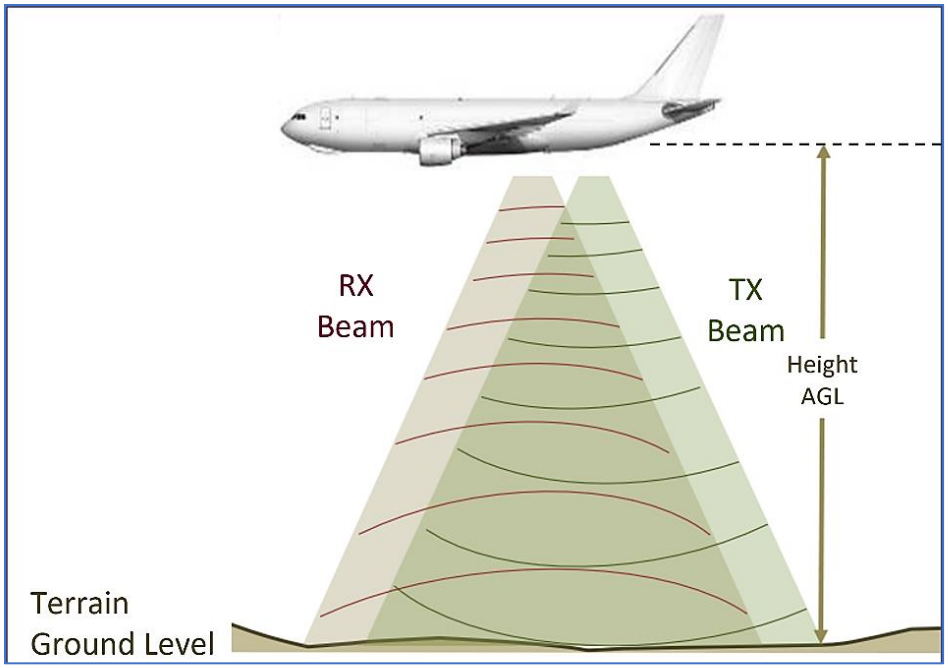
2.2 RADIO ALTIMETERS CHARACTERISTICS

2.2.1 General characteristics

2.2.1.1 Technical characteristics for several types of radio altimeters operating within the frequency band 4 200 – 4 400 MHz can be found in Recommendation ITU-R M.2059[5]. In particular, Table 1 and Table 2 give the technical parameters of several radio altimeter models.

2.2.1.2 Because of the importance of radio altimeters to safely operate an aircraft, they are included in the minimum equipment list for aircraft certified for passenger service. Furthermore, depending on the aircraft functions supported by the radio altimeter, they must be certified at a safety criticality rating or Design Development Assurance Level (DAL) of "A", for all transport aircraft, and a DAL of "B" for business and regional aircraft. DAL is a safety criticality rating from level A to E, with levels A and B being the most critical and requiring the most stringent certification process[6].

2.2.1.3 Radio altimeter systems on a single aircraft consist of up to three identical radio altimeter transceiver (Transmitter/Receiver, Tx/Rx) units with their associated equipment. All Tx/Rx units operate simultaneously but independently from one another. The radio altitude is computed from the time interval it takes a signal originating from the aircraft to be reflected back from the ground. Radio altimeters designed for use in automated landing systems are required to achieve an accuracy of up to ± 3 ft (±. 0.9 m) at low altitudes. Figure 3 is an illustration of the transmit and receive beams of radio altimeter signals.



Source: ICCAIA

Figure 3. Radio altimeter transmit and receive signals
(*Image reproduced by kind permission of ICCAIA*)

[5] *https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2059-0-201402-I!!PDF-E.pdf*
[6] DAL A is assigned "If a Catastrophic Failure Condition (FC) could result from a possible development error in an aircraft/system function or item" and DAL B is assigned "If a Hazardous/Severe Major Failure Condition could result from a possible development error in an aircraft/system function or item". See SAE Int'l, *ARP4754A - Guidelines for Development of Civil Aircraft and Systems,* Sec. 5.2.1, p.38. Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, www.sae.org. For a description of Failure Conditions, *See also,* U.S. Federal Aviation Administration (FAA), *Advisory Circular* AC No. 25.1309-1A – *System Design and Analysis*, (1988-06-21), Par 6.h. ("AC 25.1309-1A") Available from https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_25_1309-1A.pdf.

2.2.1.4 There are two types of radar waveform modulation methods for radio altimeters:

a) Linear frequency modulation continuous wave or simply frequency modulated continuous wave (FMCW) radio altimeters; and

b) Pulse modulated.

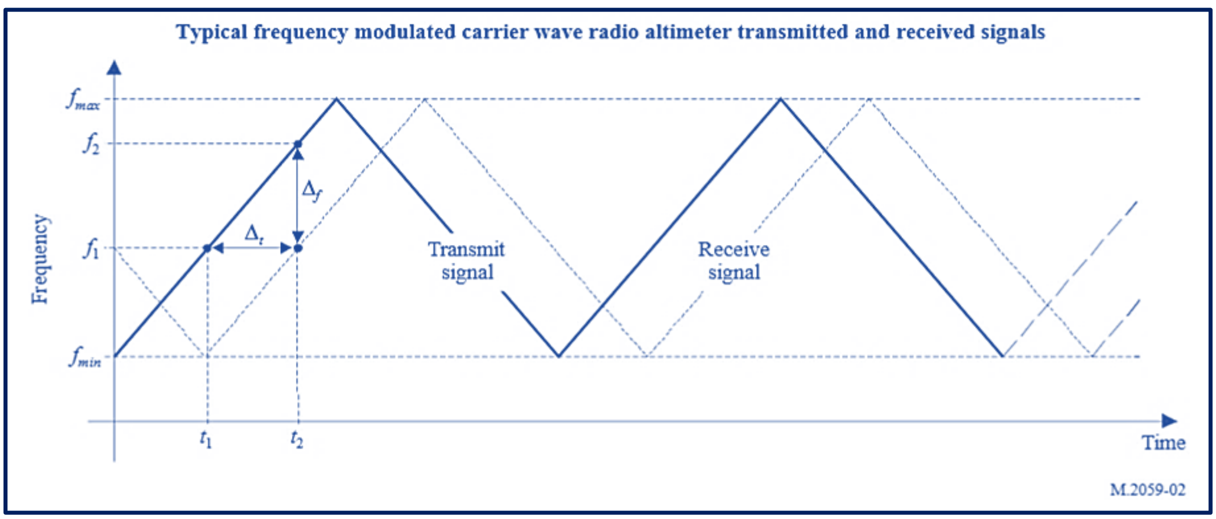
Characteristics of those two types of radio altimeters will be explained in the following sections.

2.2.2 **Frequency modulated continuous wave (FMCW) radio altimeters**

2.2.2.1 FMCW radio altimeters operate by a Tx/Rx unit working in conjunction with separate transmit/receive antennas. Operation requires a signal from the transmit antenna to be directed to the ground. When the signal hits the ground, it is reflected back to the receive antenna. The system then performs a time calculation to determine the distance between the aircraft and the ground, as the altitude of the aircraft is proportional to the time required for the transmitted signal to make the round trip.

2.2.2.2 It is important to note that FMCW radio altimeters do not have a fixed frequency. One can find the chirp bandwidth of a sample of analogue FMCW radio altimeters in Table 1 of Recommendation ITU-R M.2059. Source: ***ITU***

illustrates the typical FMCW radio altimeter transmit and receive signals.



Source: ITU

Figure 4. FMCW modulation

(*Image reproduced by kind permission of ITU*)

2.2.3 **Pulsed radio altimeters (Pulsed-type radio altimeters)**

2.2.3.1 The pulsed-type radio altimeter uses a series of pulses of RF energy transmitted towards the Earth to measure the absolute height above the terrain immediately underneath the aircraft. The time difference between the transmitted pulse and the received pulse is measured, and that time is proportional to the height of the aircraft. Pulsed radio altimeters are emitting at a fixed frequency (generally 4 300 MHz). However, the emission bandwidth could vary (see for example, radio altimeter D4 in Table 2 from Recommendation ITU-R M.2059).

2.3 TECHNICAL CONCERNS INTRODUCED BY IMT OPERATIONS

2.3.1 Radio altimeters which were developed and deployed in compliance with long-established standards and national regulations, have reliably performed their intended function for at least 40 years. However, they were not designed for compatibility with new high power, broadly and densely deployed terrestrial sources of potential interference operating in adjacent and nearby bands. Thus, high-powered IMT fundamental signals have the potential to cause harmful interference. Unwanted IMT emissions falling in the 4 200 – 4 400 MHz frequency band at levels currently specified in international standards can cause harmful interference due to desensitization in current radio altimeter equipment deployed on aircraft worldwide. As radio altimeters are safety equipment that must reliably provide their intended function in all aircraft operations, and especially in low-visibility conditions, any risk of harmful interference from new IMT sources must be mitigated.

2.3.2 In the United States, following an auction by the Federal Communications Commission (FCC) of the 3 700 – 3 980 MHz frequency band, RTCA, Inc formed a task force to assess the interference impact of wireless broadband (WBB) operations in the 3 700 – 3 980 MHz band on radio altimeters. Based on the work of the task force using empirical radio altimeter interference tolerance threshold data from the Aerospace Vehicle Systems Institute (AVSI)[7] and IMT technical information provided by 5G operators in the United States, RTCA published a report entitled, "Assessment of C-band Mobile Telecommunications Interference Impact on Low Range Radio altimeter Operations" where it identified potential risk of interference that can be caused by 5G base stations operating within the band 3 700 – 3 980 MHz[8]. This was the first available assessment of the potential for harmful interference based on altimeter tolerance thresholds for adjacent band interference with characteristics matching 3GPP 5G C-band waveforms for various aircraft heights above ground level. This effort confirmed cautions given in Recommendation ITU-R M.2059 and added detail for several types of altimeters, although it was limited to 3 700 – 3 980 MHz. Further testing was repeated independently by radio altimeter manufacturers and others with similar results. This effort also confirmed that exceedance of interference limits can result in erroneous valid altitude outputs as well as loss of output, both potentially without failure annunciation, due to a single common cause of simultaneous interference above the limit of multiple radio altimeters.

2.3.3 Recommendation ITU-R M.2059 explains three primary electromagnetic interference coupling mechanisms between radio altimeters and interfering signals from other transmitters: receiver overload, desensitization, and false altitude generation.

2.3.4 While all factors must be considered in compatibility studies, receiver overload is generally associated with high-powered out-of-band signals from transmitters operating in spectral proximity to the radio altimeter frequency band. The protection criteria in Recommendation ITU-R M.2059 is stated as:

$$I_{RF} \geq P_{T,RF}$$

where $P_{T,RF}$ is generally the receiver 1 dB compression point, which is model-specific, and I_{RF} is the aggregated interference power at the input to the receiver, accounting for cable losses and the overall frequency dependent rejection (FDR) imposed by the antenna characteristics and the receiver's preselect filter. Note that FDR is not standardized in existing minimum performance specifications, though Table 3 in Recommendation ITU-R M.2059 does indicate a RF selectivity based on attenuation increasing from 0 dB in the radio altimeter band to a maximum of 40 dB with a slope of 24 dB per octave away from the band edges.

2.3.5 While FDR suggested in Recommendation ITU-R M.2059 was based on radio altimeter designs existing at the time the recommendation was approved, these designs still operate on deployed aircraft and are anticipated to be in operation for years to come, until new designs meeting standardized interference tolerance requirements can be developed, approved, installed, and fielded. Thus, radio altimeters must be protected from high-power C-band IMT emissions operating in frequencies near the radio altimeter band through an appropriate compatibility strategy that considers both mitigations based on C-band IMT network deployment and emissions limits, and on aviation equipment and operations.

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[7] *See AVSI, "AFE 76s2 Report Derivation of Radio altimeter Interference Tolerance Masks Volumes I-III". ("AVSI Test Reports") Available from: https://avsi.aero/avsi-publishes-volume-iii-of-the-afe-76s2-report.*

[8] *RTCA, Inc., "Assessment of C-Band Mobile Telecommunications Interference Impact on Low Range Radio altimeter Operations", RTCA Paper No. 274-20/PMC-2073, October 7, 2020. ("RTCA Assessment Report") Available (with Errata) from: https://www.rtca.org/wp-content/uploads/2020/10/SC-239-5G-Interference-Assessment-Report_274-20-PMC-2073_accepted_changes.pdf.*

2.3.6 Recommendation ITU-R M.2059 also specified protection criteria related to RF energy from interference signals that falls into a radio altimeter's intermediate frequency (IF) bandwidth. Desensitization is related to the intensity of the in-band interfering signal and is limited by a maximum interference-to-noise ratio of -6 dB. False altitude reports are hazardous misleading information that can cause critical safety systems to respond inappropriately and can occur when interference signals are detected as frequency components during spectral frequency analysis of the overall IF bandwidth in FMCW radio altimeters.

2.3.7 Unlike out-of-band signals, RF energy from interference that falls within the radio altimeter band cannot be filtered. Since the transmit power of radio altimeters is limited (1–2 watts typically to accommodate unavoidable leakage from the transmitter into the receiver), radio altimeter receivers must be sensitive enough over the full FMCW sweep bandwidth to meet altitude tracking, sensitivity and accuracy requirements. Thus, current radio altimeters are extremely susceptible to in-band interference. Furthermore, these considerations present significant challenges to increasing the in-band interference tolerance limits of future radio altimeters if those altimeters are to maintain the current intended function.

2.4 POTENTIAL OPERATIONAL IMPACTS OF LOSS OR ERRONEOUS DATA OF THE RADIO ALTIMETER [9]

2.4.1 Based on the RTCA Assessment Report, the following sections provide a summary of some of the potential impact that compromised radio altimeter performance can have on aircraft safety and operations[10]. Also, section 2.4.4 illustrates typical radio altimeter failures with specific impact descriptions. It is important to note that those potential impacts described in section 2.4 are not exhaustive and are intended to give a general idea of the types of specific impacts that may be experienced along with their severity.

2.4.2 **Loss of situational awareness**

2.4.2.1 On all types of aircraft, situational awareness of the flight crew is paramount to ensuring safe flight operation, especially when flying in busy airspace, close to the ground, or in low-visibility scenarios such as instrument meteorological conditions (IMC). The radio altimeter plays a critical role in these operating conditions. Not only do radio altimeters provide a displayed indication of height above terrain to the flight crew, but they also form the basis of auditory altitude callouts during landing procedures, as well as enabling traffic alert and collision avoidance system/airborne collision avoidance system (TCAS/ACAS) and terrain awareness warning system (TAWS) advisories and warnings.

2.4.2.2 Erroneous or unexpected behavior by a radio altimeter directly leads to a loss of situational awareness for the flight crew. Not only does this have an immediate impact on the ability of the flight crew to maintain safe operation of the aircraft, it also requires the flight crew to attempt to compensate by using other sensors and visual cues, if available. This compounding situation leads to a risk of task saturation for the flight crew, particularly during operations or phases of flight that require continuous crew engagement, such as final approach and landing procedures.

2.4.3 **Controlled flight into terrain (CFIT)**

2.4.3.1 In the most extreme cases, loss of situational awareness may lead to controlled flight into terrain (CFIT), which is when the pilot flies the aircraft into the ground. This situation is nearly always a devastating event resulting in aircraft hull loss and a high likelihood of loss of life or severe injuries to the flight crew and passengers. The frequency of CFIT accidents in earlier generations of aircraft operations was unacceptably high, providing a key motivation for the introduction of radio altimeters during the 1970s, as well as the subsequent development of TAWS. This has greatly reduced the risk of CFIT, as long as the radio altimeter and associated systems are functioning properly.

2.4.3.2 CFIT may still occur in modern aircraft operations due to undetected erroneous output from the radio altimeter(s), which is considered hazardously misleading information during certain phases of flight or operational conditions (such as IMC). If hazardously misleading information is presented to the flight crew, TAWS or automatic flight guidance and control systems (AFGCS), it may lead to incorrect and dangerous flight operations, resulting in insufficient time to correct the error before a catastrophic result such as CFIT.

[9] RTCA Assessment Report (Assessment of C-Band Mobile Telecommunications Interference Impact on Low Range Radio altimeter Operations), https://www.rtca.org/wp-content/uploads/2020/10/SC-239-5G-Interference-Assessment-Report_274-20-PMC-2073_accepted_changes.pdf

[10] See section 5 of the RTCA Assessment Report.

2.4.4 **Specific aircraft operational impacts**

2.4.4.1 On commercial air transport and regional aircraft, high-end business aviation aircraft and some general aviation aircraft and helicopters, radio altimeters are used as a safety-critical navigation sensor by the AFGSC, and also provide input into systems such as TCAS/ACAS, predictive wind shear (PWS) and TAWS. This usage by a variety of safety critical systems leads to the possibility of specific operational impacts that go beyond a general loss of situational awareness or increased potential risk of CFIT.

2.4.4.2 Table 1 illustrates typical radio altimeter failures with specific operational impacts that may be encountered due to undetected erroneous outputs or unanticipated loss of a signal (indicated as a "No Computed Data" or "NCD" condition) from the radio altimeter on commercial or civil aircraft that utilize the radio altimeter for functions such as those mentioned in the preceding paragraph. For each impact, the severity is assessed in accordance with the U.S. Federal Aviation Administration (FAA) system safety analysis guidelines[11]. The severity of each condition may be determined to be minor, major, hazardous/severe major, or catastrophic, with each severity classification having its own allowable occurrence rate[12]. The allowable occurrence rate is described in Table 1.

Table 1. Severity classification

The allowable occurrence rate	Severity classification
1 x 10^{-3} per flight hour or less	minor failure conditions
1 x 10^{-5} per flight hour or less	major failure conditions
1 x 10^{-7} per flight hour or less	hazardous/severe major failure conditions
1 x 10^{-9} per flight hour or less	catastrophic failure conditions

Table 2. Radio altimeter failures with specific operational impacts[13]

Radio altimeter failure	Operational impact	Flight phase	Severity
Undetected erroneous altitude	Just prior to touchdown, the aircraft performs a flare maneuver to avoid a hard landing. The flare may be performed manually by the flight crew, using auditory callouts of radio altimeter readings, if sufficient visibility is available. In low-visibility conditions, the flare may be controlled by an auto-land function. Erroneous radio altimeter readings in either case can result in the potential for CFIT with little or no time for the flight crew to react.	Landing – flare	Catastrophic
Undetected erroneous altitude	Erroneous input to the AFGCS affects aircraft attitude commands and altitude, as well as flight control protection mechanisms.	All phases of flight	Catastrophic
Unanticipated NCD	Undetected loss of PWS display to flight crew, preventing awareness of wind shear impact to vertical profile in front of the aircraft.	Landing	Hazardous/ severe major
Unanticipated NCD	Undetected loss of TCAS/ACAS inhibition near the ground, leading to potential erroneous descent advisory alert and associated possibility of CFIT in low-visibility conditions.	Approach, landing, takeoff	Hazardous/ severe major
Undetected erroneous altitude	Erroneous triggering of TAWS reactive terrain avoidance maneuver, forcing mandatory response from flight crew and leading to potential traffic conflicts in surrounding airspace.	Approach, landing, takeoff	Major

[11] See references in RTCA Assessment Report paragraph 5.3,
[12] See AC 25.1309-1A, Par 10.b.
[13] Source: RTCA Assessment Report – Table 5-1.

Radio altimeter failure	Operational impact	Flight phase	Severity
Unanticipated NCD	Aircraft landing guidance flight control laws violated leading to unnecessary missed approach and go-around, jeopardizing safety of surrounding airspace.	Approach, landing	Major
Unanticipated NCD	Loss of capability to perform approach and landing in low-visibility conditions (Category II/III approach), leading to unnecessary diversion and jeopardizing safety of surrounding airspace.	Approach, landing	Hazardous/ severe major
Unanticipated NCD	Loss of capability to warn flight crew in case of excessive aircraft descent rate or excessive terrain closure rate (TAWS Modes 1 and 2 alert protection not active).	All Phases of Flight	Major
Unanticipated NCD	Loss of capability to warn flight crew of potentially dangerous loss of height after takeoff (TAWS Mode 3 alert protection not active).	Takeoff, go-around	Major
Unanticipated NCD	Loss of capability to warn flight crew of potentially dangerous aircraft configuration (for example, landing gear, slats and flaps) based on height above terrain (TAWS Mode 4 alert protection not active).	Landing	Major
Unanticipated NCD	Loss of capability to warn flight crew that aircraft is dangerously below glide path during precision instrument approach (TAWS Mode 5 alert protection not active).	Landing	Major

Source: ICAO MID Doc 015

2.4.4.3 Airworthiness regulations require that safety risk with hazard severity “catastrophic” be “extremely improbable”, with likelihood on the order of once per one billion operations as indicated in Table 2. Furthermore, any failure due to a common cause shall be prevented, regardless of likelihood, for all aircraft. This requires an RF compatibility assessment that includes a rigorous analysis of all foreseeable conditions, including limit conditions and malfunction conditions that may be unlikely but could be foreseeable unless explicitly restricted or prevented. This approach requires consideration of all factors including expected variation of multiple factors such as radio performance, RF propagation, antenna gain patterns, aircraft approach paths and all possible interference source locations. This necessarily includes consideration of all possible interference source locations that are not prohibited in RRs or obstacle clearance rules based on current and anticipated procedure designs for any situation that could foreseeably occur and realize the potential hazard.

2.4.4.4 Lower severity hazards may be tolerable if they can be expected to occur with sufficiently low frequency when assessed using fault trees and functional hazard assessments. However, in the case of RF interference, a lower severity hazard could repeatedly occur for the same aircraft when the conditions for compatibility are not met, which presents a different type of potential safety risk. Using less conservative assumptions in compatibility assessments for lower severity hazard assessments may be reasonable, but the potential for repeated occurrences should be considered. This could necessitate continued monitoring for interference events and operational mitigation on a case-by-case basis.

2.4.4.5 The operational impacts listed in Table 2 are not exhaustive, and other operational impacts that can compromise aviation safety may be encountered. For example, beyond the impact to the automation systems, undetected erroneous altitude provided to a pilot during an emergency procedure can give the pilot an inaccurate perception of the state of the aircraft and cause an unsafe response. The examples provided are intended to give a general idea of the types of specific impacts that may be experienced and their severity.

2.4.4.6 For all the above reasons, malfunction of the radio altimeters can have dire consequences as it relates to safe operation of aircraft. One key element of the overall impact of a malfunctioning radio altimeter is that after several accidents/investigations, for certain emergency procedures, flight crews have been trained to avoid trusting barometric pressure instruments and rely on radio altimeters as the primary sensor for use in those emergency procedures during low altitude and visibility operations. This creates a scenario where the instrument that crews now rely on to execute a low altitude recovery, is potentially misleading without pilot awareness and that could lead them to make a flight control input resulting in a catastrophic outcome.

Chapter 3

METHODOLOGIES FOR DEFINING APPROPRIATE SAFEGUARDING MEASURES FOR AERODROMES AND HELIPORTS AND A LONG-TERM PLAN FOR EVOLUTION OF THE RADIO ALTIMETER

3.1 INTRODUCTION

3.1.1 In 2021, ICAO issued a State letter on potential safety concerns regarding interference to radio altimeters[14]. This letter encouraged administrations to prioritize public and aviation safety when deciding how to enable cellular broadband/5G services in RF bands adjacent or near adjacent to the band used by radio altimeters. Furthermore, at ICAO's 41st Session of the Assembly, held from 27 September to 7 October 2022, the Technical Commission (TC) requested ICAO and its Member States to continue taking necessary actions to ensure that radio altimeters and other aeronautical systems are free from harmful interference, including implementation of mitigation measures, sharing of best practices as well as development of relevant provisions and guidance.

3.1.2 Based on a proposal by the TC, the Assembly adopted Resolution A41-7: *Support of the ICAO policy on radio frequency spectrum matters*. This resolution urges Member States to consider, as a priority, public and aviation safety when deciding how to enable new or additional services, and to consult with aviation safety regulators, subject matter experts and airspace users, to provide all necessary considerations and to establish regulatory measures to ensure that incumbent aviation systems and services are free from harmful interference[15].

3.1.3 A harmonized approach for defining measures that will ensure the continued safe operation of currently installed radio altimeters will promote the ICAO vision of supporting growth of the global civil aviation system. In practice, this is difficult to achieve as individual States have IMT implementations that have different technical parameters (frequency bands, power, etc.). Hence, the approach described below is general, while being based on the best practices shared by several States (refer to the Appendix in this document as well as guidance material developed by MIDANPIRG (MID Doc 015)). The objective for Member States should be to protect current radio altimeters from harmful interference while maximizing compatibility with new IMT services through a coordinated effort by spectrum and aviation regulators to apply sound analysis and the best available data to determine appropriate protective measures.

3.1.4 The approach includes the activities enumerated below and is described in the following paragraphs.

1) determine the set of aircraft subject to radio altimeter safety hazards;

2) define three-dimensional (3D) volume of airspace in which an aircraft can be located that requires protection from safety hazards;

3) determine the tolerance limits for each radio altimeter, as installed;

4) determine the criteria for compatibility with C-band IMT emissions for the currently installed radio altimeters and C-band IMT environments, and

5) determine the required compatibility criteria for future radio altimeter implementations, given the foreseen C-band IMT environment.

[14] *ICAO State letter 21/22 "Potential safety concerns regarding interference to radio altimeters", published on 25 March 2021 https://www.icao.int/safety/FSMP/Documents/5G and Radio Altimeters/StateLetter_2021_022e.pdf*
[15] *https://www.icao.int/Meetings/a41/Documents/WP/wp_623_en.pdf - from page 10 to 12.*

3.2 DETERMINE THE SET OF AIRCRAFT SUBJECT TO RADIO ALTIMETER SAFETY HAZARDS

3.2.1 Civil aviation authorities (aviation regulators) should perform a hazard assessment to determine which aircraft are subject to potential safety hazards based on the safety functions supported by the radio altimeter measurements. This step is independent of the interference tolerance performance of any specific radio altimeter model. It is based on the criticality of the aircraft safety function supported by the radio altimeter (see 2.4). It is important to note that not all aircraft are equipped to support the most critical functions and rotorcraft require specific consideration.

3.3 DEFINE THE 3D VOLUME REQUIRING PROTECTION FROM SAFETY HAZARDS

3.3.1 The volume of airspace in which an aircraft may be located, in both nominal and off-nominal operations, should be determined. This may be unique to each aircraft model and may depend on the integration of the radio altimeter into the aircraft safety functions. However, the protection volume that is ultimately defined should be a superset of the volumes determined for the set of aircraft based on the assessment described in 3.2.

3.3.2 For large aircraft, the methods used by States, as detailed in the Appendix, for example, France (section 2.3), the United States (section 2.9) and guidance material developed by MIDANPIRG (MID Doc 015) to determine if temporary protection measures may be useful. Also, to assist a State's determination of the required 3D protection volume, an example may be the methodology used for calculating the dimensions of the safety zone taken by France. Determination of the total set of mitigation methodologies may need consideration of additional factors, as noted by some of the approaches taken by States and referenced in the Appendix.

3.3.3 For other aircraft, protection volumes must reflect the specific type of operations that those aircraft perform. For example, rotorcraft have distinct flight capabilities and operations that can place them in the proximity to sources of IMT emissions, outside of controlled areas around aerodromes. However, emergency operations require different considerations than fixed heliports.

3.4 DETERMINE TOLERANCE LIMITS FOR EACH RADIO ALTIMETER INSTALLED

3.4.1 Note that while radio altimeters are designed and approved according to international standards, the same model altimeter transceiver that is integrated in an aircraft altimeter system can have different interference tolerance when installed on different aircraft models/types. This is due to the dependence on parameters such as installation geometry, cabling and installation losses, overall frequency characteristic of an altimeter receive antenna (gain and pattern) versus. the frequency of the interference signals.

3.4.2 It should be emphasized that currently installed radio altimeters exhibit interference tolerance thresholds that are significantly different from those based on the SARPs currently under development by the FSMP, as well as the requirements to be established in new minimum operational performance standards (MOPS). However, current equipment will require protection for many years to come, hence tolerance limits need to be determined from empirical measurements of current radio altimeters. Since no requirements for interference tolerance are established to support international standards regulating the approval of current equipment, current radio altimeter models cannot be assumed to meet any specific minimum interference tolerance threshold.

3.5 DETERMINE CRITERIA FOR COMPATIBILITY OF CURRENT ALTIMETERS WITH PENDING C-BAND IMT OPERATIONS

3.5.1 Member States without licensed use of C-band frequencies for 5G operations have more options in developing safeguarding measures to protect radio altimeters since these options include mitigations applied to both C-band IMT emissions as well as aircraft equipment and operations. Compatibility strategies that balance practical controls on emissions from 5G base stations with careful risk assessment based on existing aviation equipment and operations, can minimize the complications that have characterized the rollout of new 5G services in some States. Furthermore, these strategies can be time-based to allow growth in 5G capability based on improvements in radio altimeter interference tolerance;

however, this must be done with deliberate synchronization to prevent unsafe conditions. Finally, mitigation choices may need to consider non-technical influences such as regional economic priorities that can impact deployment schedules or coordination with international efforts to harmonize both IMT and global aviation operations.

3.5.2 Practical controls for C-band IMT emissions can be defined that both support the growth objectives for deployment of 5G and ensure the continued airworthiness of existing aircraft. For example, in the Appendix, in section 2.3, France does not limit the output power of emissions of base stations in the frequency band 3 400 – 3 800 MHz but has provisionally limited the antenna pointing (beam steering) above the horizon around instrument flight rules (IFR) capable aerodromes. Japan (section 2.4) has implemented a 100 MHz guard band on either side of the radio altimeter band and discourages use of the bands 4 000 – 4 100 MHz and 4 500 – 4 600 MHz near runway approaches. Again, it must be noted that these measures are only examples of mitigation options. They are temporary provisions that were developed using the best efforts at that time but are not intended to be generally adopted by States.

3.5.3 C-band IMT emissions' parameters that can be considered in a balanced compatibility strategy include definition of a maximum power spectral flux density (dBW/m^2/MHz), definition of vertical emissions mask, for example, a maximum effective isotropic radiated power (EIRP) versus elevation that limits the amount of RF energy that is radiated above the horizon, and mast height that supports 3D protection volume limits. C-band IMT emissions' mitigations can be combined with aviation operational and aircraft type-specific altimeter tolerance considerations to limit interference exposure to safe levels at specific aerodromes.

3.6 DETERMINE CRITERIA FOR COMPATIBILITY OF CURRENT ALTIMETERS WITH EXISTING C-BAND IMT OPERATIONS

3.6.1 Member States that have already licensed use of C-band frequencies for 5G operations must balance existing license conditions with risk of interference exposure during operations of aircraft equipped with current radio altimeter equipment. These strategies can also be time-based to allow growth in 5G capability based on improvements in radio altimeter interference tolerance; however, this must be done with deliberate synchronization to prevent unsafe conditions. Mitigation choices may also need to consider non-technical influences such as regional economic priorities that can impact deployment schedules, or coordination with international efforts to harmonize both IMT and global aviation operations.

3.6.2 Any compatibility strategy must account for the maximum EIRP, maximum mast height above ground level, emissions power versus elevation limits, and spurious emissions into the 4 200 – 4 400 MHz frequency band that are allowed by regulation. These regulatory limits may be different than "typical" values, or values recommended in voluntary industry standards. However, regulatory limits should be used as worst-case values in compatibility analyses to ensure continued safe operation consistent with aviation regulations.

3.6.3 Determination of the minimum safe separation distance between a C-band IMT transmitter operating at its regulatory limits and an aircraft equipped with a worst-case interference tolerance radio altimeter that cannot exceed tolerance limits for both fundamental and spurious C-band IMT emissions, is a primary component of any compatibility analysis. Appropriate interference tolerance thresholds should be used (considering the aircraft type), aircraft operations supported by a specific aerodrome (considering its local terrain) and the interference tolerance of current radio altimeter based on empirical measurements performed using the C-band IMT emissions' frequencies allowed by State regulation. Interference tolerance data should be validated by relevant experts from the manufacturers of radio altimeter equipment and from the aircraft manufacturers that integrate such equipment or from validated public sources.

3.6.4 Achieving compatibility between C-band IMT transmitters, currently deployed under existing licenses and aircraft operating with existing radio altimeters, have been shown to require mitigations to protect altimeters with current tolerance limits until equipment with higher tolerance limits is fielded on aircraft. While mitigation solutions can be implemented by limiting C-band IMT transmissions alone or by limiting aircraft operations alone, such unilateral solutions may not support the non-technical considerations mentioned in 0. A balanced mitigation solution will likely require coordination between the States' telecommunications and aviation authorities. Transmitter mitigations should be developed and enforced by the telecommunications authority using protection thresholds defined by the aviation authority, and aviation operational mitigations should be developed and enforced by the aviation authority to ensure safety if interference is expected.

3.7 DETERMINE CRITERIA FOR COMPATIBILITY OF FUTURE ALTIMETERS AND IMT OPERATIONS

3.7.1 Continued safe operation of existing aircraft equipped with current radio altimeters while supporting C-band IMT implementation goals to the maximum extent possible, is the immediate and necessary objective of any compatibility strategy.

3.7.2 Future goals of States' compatibility strategies should be to establish fundamental and spurious C-band IMT emissions' parameters and network deployment planning that allow aircraft equipped with new radio altimeters, developed and approved under new radio altimeter interference tolerance requirements that maximize achievable tolerance to out-of-band interference, to operate without continuing coordination between telecommunications and aviation authorities on elevation mask or mast height mitigations. Additionally, aviation authorities must define protection volumes around aerodromes that prevent harmful interference in all nominal and off-nominal aircraft operational scenarios, based on regulatory C-band IMT emission levels and the state of deployment of new radio altimeters.

3.8 PROTECTIVE MEASURES SHOULD BE GLOBALLY HARMONIZED TO THE EXTENT POSSIBLE

A globally harmonized approach for defining measures that will ensure the continued safe operation of currently installed radio altimeters promotes the ICAO vision of supporting growth of the global civil aviation system. C-band IMT operating parameters vary between ICAO Member States, but the global reach of civil aviation operations necessitates a harmonized approach and States' aviation authorities are encouraged to seek coordination through ICAO, as has been done for other aviation safety systems and aerodrome design/operation in the Annexes to the ICAO Convention.

3.9 LONG TERM PLAN FOR THE RADIO ALTIMETER

3.9.1 While the aviation industry recognizes that changes to the RF environment within which radio altimeters operate are inevitable and performance standards must be updated accordingly, this process necessarily takes a significant amount of time given the extreme rigor and caution with which aviation system manufacturers, aircraft manufacturers, aircraft operators and civil aviation authorities (CAAs) work to develop and implement such changes. Even a technical solution that might be viable for retrofit installations would take several years to properly validate and deploy across all affected civil aircraft operating worldwide. Therefore, it is critical that the interference tolerance performance of radio altimeters that are currently in service across a multitude of civil aircraft be understood and that the risks and operational impacts due to interference, be acknowledged.

3.9.2 RTCA/EUROCAE are developing new radio altimeter standards that will improve compatibility with planned IMT environments. The joint SC-239/WG-119 is tasked with developing a complete revision of the existing MOPS to update existing requirements as warranted and to add new RF interference tolerance requirements and test procedures to the new DO-155A/ED-30A MOPS. The joint committee also produced an interim document DO-399/ED-310 entitled "Guidance Document on Radio Altimeter RF Interference Rejection and Tolerance" which is expected to be published in 2023. This new publication is intended to help in the development of RF interference tolerance requirements for the new MOPS.

3.9.3 Once the MOPS is completed, ICAO will commence developing radio altimeter SARPs into the Annexes (refer to the schedule below). Moreover, ICAO continues to assist with future coordination with ITU-R for the inclusion of important regulatory provisions into the RRs with the goal of providing appropriate legal protections for future radio altimeters.

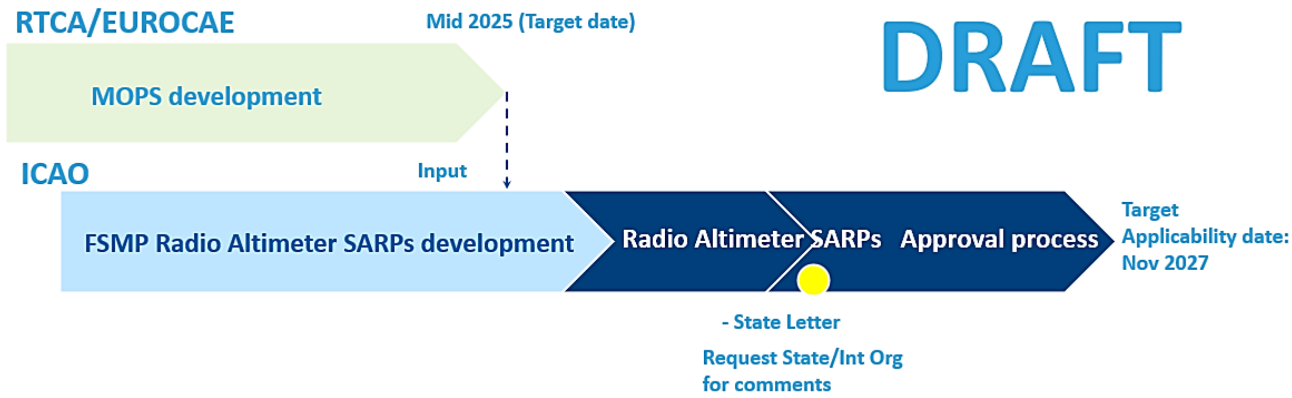
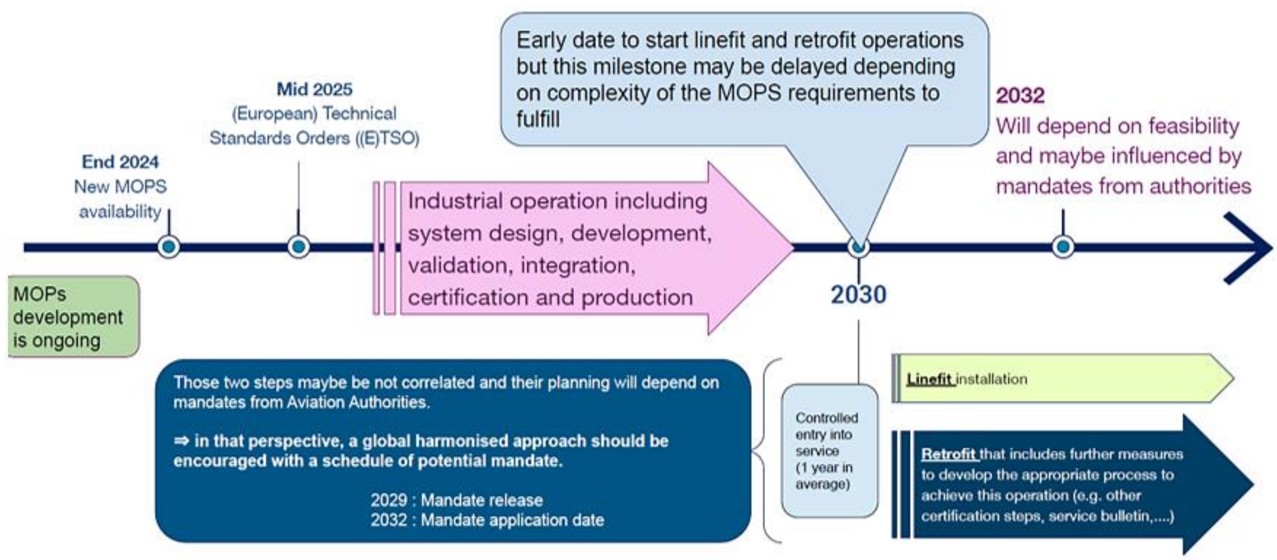


Figure 5. Radio Altimeter SARPs Development Schedule

3.9.4 Publication of the new MOPS and SARPs does not immediately eliminate the risk of harmful interference for currently deployed radio altimeters. Stakeholders should acknowledge that a realistic timeline necessary for ICAO SARPs and RTCA/EUROCAE DO-155A/ED-30A compliant radio altimeters to be put into worldwide service includes a sequence of necessary activities and milestones extending over multiple years (see Figure 6 and explanation described in section3 of the Appendix).



Source: ICCAIA

Figure 6. Expected timeline necessary for ICAO SARPs and RTCA/EUROCAE compliant radio altimeters
(*Image reproduced by kind permission of ICCAIA*)

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Appendix A

SHORT-TERM SAFEGUARDING MEASURES ADOPTED AT REGIONAL AND GLOBAL LEVELS

1. INTRODUCTION

1. The aviation community has raised concerns about potential interference to radio altimeters operating in the frequency band 4 200 – 4 400 MHz from 5G networks deployed in adjacent and nearby bands. As indicated in section 2.3.2, this led to a detailed technical analysis by the RTCA that resulted in the publication of the RTCA Assessment Report in October 2020. The report studied the impact of 5G operations in the 3 700 – 3 980 MHz band based on the United States' FCC's decision to allow deployment of mobile networks in this band. In this assessment, two main interference mechanisms were considered:

a) spurious emissions from 5G transmitters affecting the main altimeter operating band and causing altimeter receiver desensitization; and

b) emissions from the main 5G operating frequency bands (near the radio altimeter's operational frequency band) causing altimeter receiver front-end overload.

2. The RTCA Report compares empirical interference tolerance thresholds, measured by the AVSI for a sample of commercial altimeter models from the major global avionics manufacturers, to estimated fundamental and spurious emissions from 5G equipment operating with technical parameters allowed by the rules established in the FCC auction of the 3 700 – 3 980 MHz frequency band in the United States.

3. The AVSI test results were summarized for three usage categories representing:

a) Category 1: commercial air transport airplanes;

b) Category 2: regional, business and general aviation airplanes; and

c) Category 3: helicopters.

4. For each usage category, 5G interference levels were calculated for different 5G deployment scenarios (urban, suburban and rural), based in part, on technical information provided by United States' 5G operators and different aircraft operational scenarios, and then compared against measured threshold levels. The report concluded that there is a risk of exceeding altimeter interference threshold levels by interference caused by 5G networks operating in 3 700–3 980 MHz band. The values are potentially based on worst-case scenarios noting that no public information is available on the specific altimeters considered.

5. Within ICAO, the Frequency Spectrum Management Panel (FMSP) considered the issue and reviewed submissions from several States. In addition, a correspondence group of the FSMP was established to collect information related to 5G/radio altimeter compatibility through State letter SP 74/1-21/22 advising ICAO Member States of the issue.

6. Several States have already implemented temporary technical, regulatory and operational mitigations on new 5G systems, and additional recommendations for reactive monitoring to protect the radio altimeter while more permanent solutions are being explored. It must be noted that each temporary mitigation, in place today, was implemented taking into account characteristics of each State's 5G operation without considering steps recommended in this circular and therefore have varying protection volumes and levels of mitigated safety risk.

2. MEASURES ADOPTED BY STATES, REGIONAL ORGANIZATIONS AND STANDARD MAKING ORGANIZATIONS

2.1 Australia

2.1.1 The Australian spectrum regulator (ACMA) held multiple public consultations on replanning parts of the frequency band 3 400 – 4 000 MHz for 5G and WBB expansion, with the most recent closing date of the public consultation on 29 March 2023. Currently, 5G operates in Australia in the frequency range 3 565 – 3 700 MHz. The ACMA was planning to release the 3 700 – 4 000 MHz band for 5G services. The Australian Civil Aviation Safety Authority (CASA) published an Airworthiness Bulletin to raise awareness of the potential for interference to radio altimeter systems from 5G systems and to encourage operators to report any radio altimeter or radio altimeter integrated system faults.

2.1.2 Aviation proponents in Australia have formed a Radio Altimeter Co-ordination Group, responding to the various consultations as a block. Individual representatives on this Co-ordination Group also provide separate feedback to consultations on behalf of their respective organizations.

2.1.3 The FAA's Airworthiness Directives are automatically adopted in Australia. CASA has issued an exclusion from the Operation of Airworthiness Directives FAA AD 2021-23-12 and FAA AD 2021-23-13 (CASA 114/21). This exclusion applies to any Australian registered aircraft when it is operated outside the airspace of the United States.

2.1.4 While Australia determines how to implement 5G and WBB above 3 700 MHz, no decisions have been made on what mitigations will be required to protect radio altimeters from harmful interference. The interim mitigations being considered are separated into two groups:

1) For WBB deployments around runways identified in consultation with CASA:

   a) Exclusion zones where no WBB base stations are permitted to be deployed.

   b) Restricted zones where WBB base station deployments are permitted but with obligations to meet a specified power flux density limit.

2) For WBB deployments everywhere:

   a) Additional WBB base station unwanted emission limits in 4 200 – 4 400 MHz based on EIRP spectral density rather than total radiated power (TRP) or conducted power per antenna port.

   b) Maximum WBB base station power limits in the form of EIRP density limits.

   c) Requiring WBB base station antennas to only point or scan below the horizon.

   d) A requirement for WBB base station antennas to minimize grating lobes as much as practicable.

2.1.5 It is the view of the ACMA that these mitigations would only apply above 3 800 MHz and that these interim mitigations will have a proposed end date of 31 March 2025. The Co-ordination Group has suggested to ACMA that mitigation measures should be applied to the whole of the new frequency range (for example, 3 700 – 4 000 MHz), and argued that the measures should remain in place until the new RTCA/EUROCAE radio altimeter standard is published and the aviation industry is able to upgrade or replace existing equipment to meet the new standard.

2.2 Canada

2.2.1 Transport Canada Civil Aviation (TCCA) published the Civil Aviation Safety Alert (CASA) (2021-08)[16] Potential Risk of Interference of 5G Signals on Radio Altimeters (June 2021 and Dec 2021) to raise awareness of the potential risk of 5G interference worldwide and to recommend precautionary operational measures. It also recommended switching off all 5G passenger/flight crew devices and, in case of interference, to report the event to the controlling air traffic service as soon as possible and to file a radio altimeter disturbance/interference incident report.

2.2.2 Innovation, Science and Economic Development Canada (ISED), in June 2023, finished a consultation based on the results of domestic studies on the following two documents to enable the co-existence of 5G with radio altimeters:

a) **SRSP-520, issue 3**: Draft Standard Radio System Plan SRSP-520, Technical Requirements for Fixed and/or Mobile Systems, Including Flexible Use Broadband Systems, in the Band 3 450 – 3 900 MHz, issue 3; and

b) **RSS-192, issue 5**: Radio Standards Specification RSS-192, Flexible Use Broadband Equipment Operating in the Band 3 450 – 3 900 MHz, issue 5[17].

2.2.3 Following the preliminary ISED's decision and a consultation with aviation stakeholders in Canada, a new balanced approach had been proposed by TCCA to establish exclusion zones and protection zones based on the obstacle clearance surface (OCS) to allow air operations to be conducted safely at aerodromes.

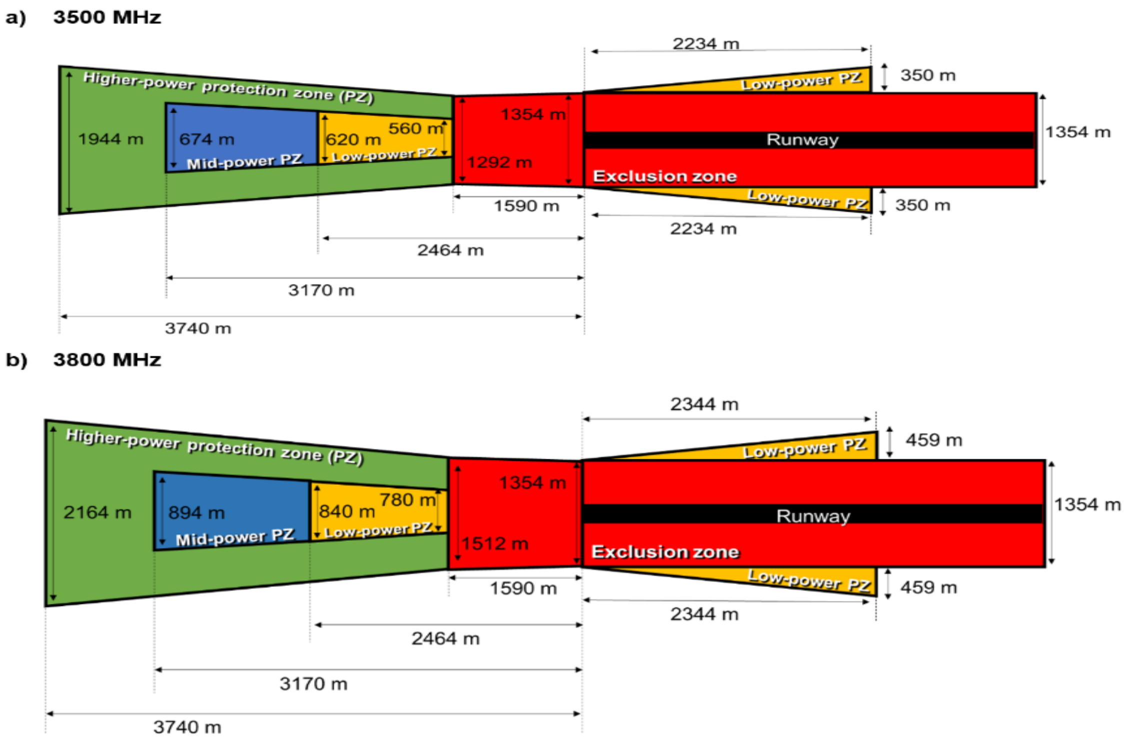
2.2.4 Consequently, ISED reviewed its proposal and issued, on July 11, 2023, a final decision regarding the use of frequency spectrum adjacent to the radio altimeter band: “Decision on SRSP-520, issue 3 and RSS-192, issue 5”. The decisions are as follows:

a) Imposing exclusion and protection zones (Figure A-1) for both 3 500 MHz and 3 800 MHz bands considering the OCS and adopting Transport Canada’s proposed EIRP spectral density curves around 35 airports identified in the map of the exclusion and protection zones. These 35 airports represent over 93 per cent of public and cargo traffic in Canada. This mitigation measure will apply until 1 January 2026.

b) Imposing an airport EIRP mask around the 35 protected airports for both 3 500 MHz and 3 800 MHz bands until 1 January 2026. From 2 January 2026 to 31 December 2027, this airport EIRP mask will only apply to the 3 800 MHz bands in former exclusion zones and in protection zones. Refer to Table A-1.

[16] *https://tc.canada.ca/en/aviation/reference-centre/civil-aviation-safety-alerts/potential-risk-interference-5g-signals-radio-altimeter-civil-aviation-safety-alert-casa-no-2021-08*

[17] *https://ised-isde.canada.ca/site/spectrum-management-telecommunications/en/learn-more/key-documents/decision-srsp-520-issue-3-and-rss-192-issue-5*



Source: ISED, Canada

Figure A-1. Illustration showing the exclusion and protections zones/ SRSP-520, issue 3[18]

[18] Notice of Extension of Closing Date for Reply to Comments on the Consultation on SRSP-520, issue 3 and RSS-192, issue 5 and Further Information Related to Certain Comments Received (canada.ca)

Table A-1. Base station height and power limits[19]

a) Base station height and power limits in protection zones for the 3500 MHz band

Base station height above runway threshold	Low-power protection zone	Mid-power protection zone	Higher-power protection zone
82 ft (25 m)	61 dBm/MHz	61 dBm/MHz	61 dBm/MHz
98.1 ft (30 m)	57.5 dBm/MHz	61 dBm/MHz	61 dBm/MHz
131.2 ft (40 m)	No deployment	61 dBm/MHz	61 dBm/MHz
147.6 ft (45 m)	No deployment	61 dBm/MHz	61 dBm/MHz
164 ft (50 m)	No deployment	58 dBm/MHz	61 dBm/MHz
180.5 ft (55 m)	No deployment	58 dBm/MHz	59.5 dBm/MHz
196.9 ft (60 m)	No deployment	No deployment	No deployment

b) Fixed and base station height and EIRP limits in the 3800 MHz protection zones

Base station height above runway threshold	Low-power protection zone	Mid-power protection zone	Higher-power protection zone
32.8 ft (10 m)	55 dBm/MHz	58 dBm/MHz	60 dBm/MHz
49.2 ft (15 m)	55 dBm/MHz	58 dBm/MHz	59 dBm/MHz
65.6 ft (20 m)	55 dBm/MHz	58 dBm/MHz	58.5 dBm/MHz
82 ft (25 m)	53 dBm/MHz	58 dBm/MHz	58 dBm/MHz
98.1 ft (30 m)	52 dBm/MHz	58 dBm/MHz	58 dBm/MHz
114.8 ft (35 m)	No deployment	55 dBm/MHz	56.5 dBm/MHz
131.2 ft (40 m)	No deployment	52 dBm/MHz	56 dBm/MHz
147.6 ft (45 m)	No deployment	52 dBm/MHz	55 dBm/MHz
164 ft (50 m)	No deployment	51 dBm/MHz	54 dBm/MHz
180.5 ft (55 m)	No deployment	49 dBm/MHz	53 dBm/MHz
196.9 ft (60 m)	No deployment	No deployment	51 dBm/MHz

Source: ISED, Canada

[19] Notice of Extension of Closing Date for Reply Comments on the Consultation on SRSP-520, issue 3 and RSS-192, issue 5 and Further Information Related to Certain Comments Received (canada.ca)

2.2.5 Following its policy on the co-existence 5G radio altimeter in Canada, ISED extended its protection for the radio altimeter, in the band 3 900 – 3 980 MHz. ISED issued two more standards consultation, namely:

a) **SRSP-521**, **issue 1**[20]: “Technical Requirements for Non-Competitive Local Licensed Services, including Fixed and/or Mobile Systems, and Flexible Use Broadband Systems, in the Band 3 900 – 3 980 MHz”, and

b) **RSS-198 issue 1**, “Flexible Use Broadband Equipment Operating in the Band 3 900-3 980 MHz.

2.2.6 In August 2023, ISED issued the RSS-198, issue 1[21] (3 900 MHz band) that in terms of unwanted emissions, is aligned with the RSS-192, issue 3 (3 800 MHz band). For frequencies between 4 200 MHz and 4 400 MHz, the unwanted emission of outdoor base station, indoor base station and fixed service equipment, shall not exceed a TRP or total conducted power (sum of conducted power across all antenna connectors) limit of -30 dBm/MHz.

2.3 France

2.3.1 The National Frequency Agency (ANFR), the spectrum regulator in France, allows flexible use of networks and technology (including 5G) in the frequency band 3 400 – 3 800 MHz. The allocation of the band to the operators is illustrated in Figure A-2. The power spectral density (PSD) of the base stations varies by operator between 62.44 dBm/5MHz to 67.34 dBm/5MHz. However, it should be noted that these limits are not binding and can evolve upwards.

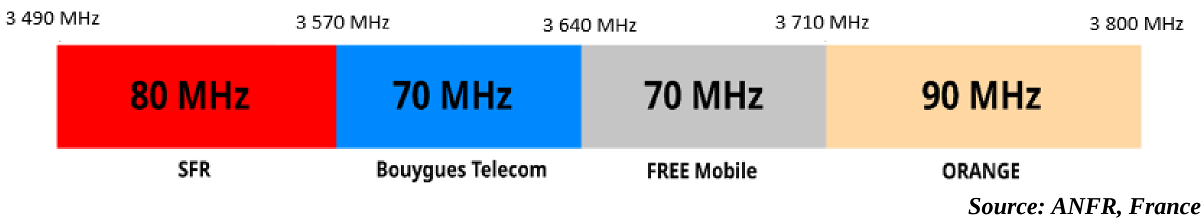


Figure A-2. 5G allocations in France
(*Image reproduced by kind permission of DGAC France)*

2.3.2 Based on the RTCA report, the French Civil Aviation Authority (DGAC), in coordination with ANFR, have defined provisional precautionary measures relating to the geographical location of some 5G antennas in the vicinity of airports with IFR procedures in mainland France to mitigate the risk interference from 5G systems. These measures can be summarized as follows:

a) operators must implement only downward tilt[22];

b) operators must take measures to avoid grating lobes, as far as practicable; and

c) special protection zones are applied to all IFR aerodromes equipped with ILS CAT III facilities[23] and to some helicopter platforms. The methodology used for the calculation of the dimensions of special protection zones is described below (refer to Figures A-3, A-4 and A-5 as well as Table A-2).

2.3.3 Measures described above are verified by the DGAC, based on the information provided by mobile operators and in close cooperation with the ANFR. Moreover, the DGAC has also published a Safety info leaflet[24] in addition to the mitigation measures implemented around all IFR aerodromes.

[20] *https://www.rabc-cccr.ca/ised-standard-radio-system-plan-srsp-521-technical-requirements-for-non-competitive-local-licensed-services-including-fixed-and-or-mobile-systems-and-flexible-use-broadband-systems-in-the-band-390/*
[21] *https://ised-isde.canada.ca/site/spectrum-management-telecommunications/en/devices-and-equipment/radio-equipment-standards/flexible-use-broadband-equipment-operating-band-3900-3980-mhz*
[22] *Following a complaint and legal threats from an operator, this constraint has been lifted during 2021 following a high-level political decision but his constraint remains valid in the “zone de précaution”.)*
[23] *During the same decision as for the antenna tilt (Previous footnote refers), it was decided to limit these restrictions to airfields equipped with ILS CAT III. These decisions were made out of concern for the loss of all means of mitigation*
[24] *https://www.ecologie.gouv.fr/sites/default/files/Safety_Info_Leaflet_2021_01_5G_interferences.pdf*

2.3.4 The special protection zones around all ILS CAT III IFR aerodromes, as illustrated in Figure A-3, are defined as follows:

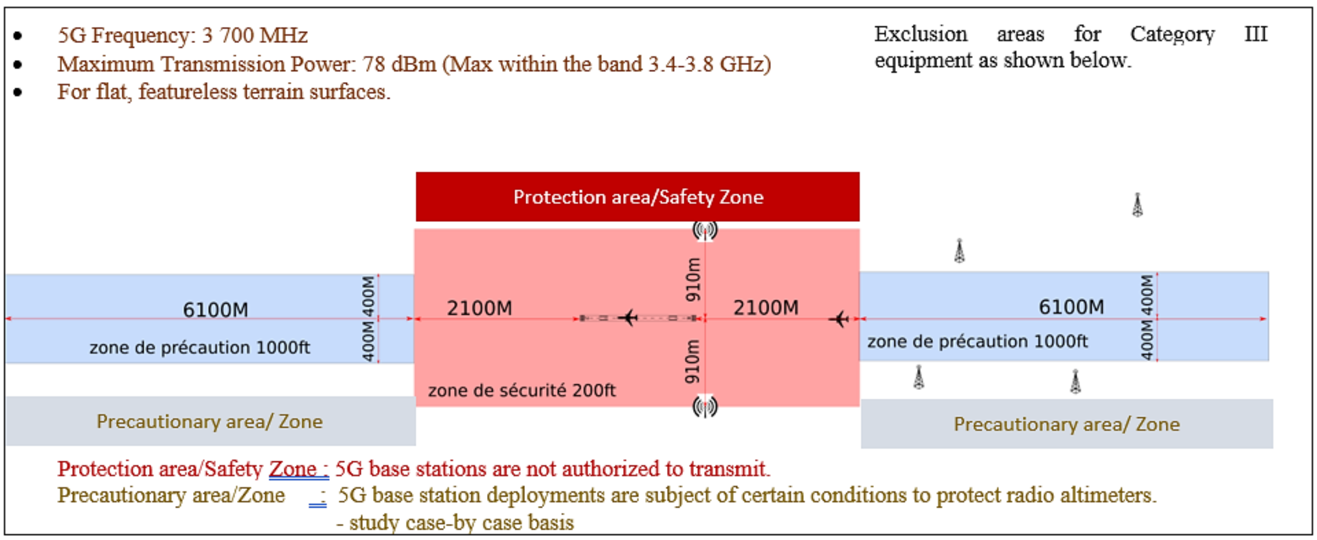
1) **Safety Zone:** where 5G base stations are not authorized to transmit and defined to protect the radio altimeters in the phase of flight where the aircraft is at or below 200 ft (61 m). Safety zone based on the following assumption:

   - 3° slope with a tolerance of 0.375° (for example, 2.625°). Therefore, the aircraft may be below 200 ft (61 m) on the approach path to the runway threshold extended by 1 130 m each side of a base station with a maximum EIRP.
   - 6 dB ICAO safety margin
   - 0 dBi maximum radio altimeters antenna gain below 3 800 MHz based on the RTCA report
   - -19 dBm interference threshold based on the RTCA report (CAT. I below 200 ft (61 m))

   The rectangular safety zone has a width on each side of the runway (protection distance) calculated with previous assumptions and a length extended from each runway threshold by (3 707.3 ft (1 130 m) + the protection distance). The protection distance value depends on the maximum EIRP of the base station (for example, for a base station with the maximum EIRP of +78dBm, the protection distance value is 2 985.6 ft (910 m)[25]).

2) **Precaution zone:** where 5G base stations implementation are coordinated and defined on each side of the safety zone to protect the landing approach below 1 000 ft (305 m).

2.3.5 The protection zones dimensions are based on minimum coupling loss calculations and take into account the free space model (ITU-R P.525) at the frequency of 3 700 MHz.



Source: DGAC, France

Figure A-3. Example of Special protection zones around all IFR aerodromes in mainland France considering a 5G base station with a maximum EIRP of 78dBm

(*Image reproduced by kind permission of DGAC France)*

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[25] *Protection distance =(λ/ (4π)) x 10^((Max EIRP- interference threshold + ICAO Safety margin)/20)*

Table A-2. Measured Threshold in dBm-Out-of-band fundamental emissions

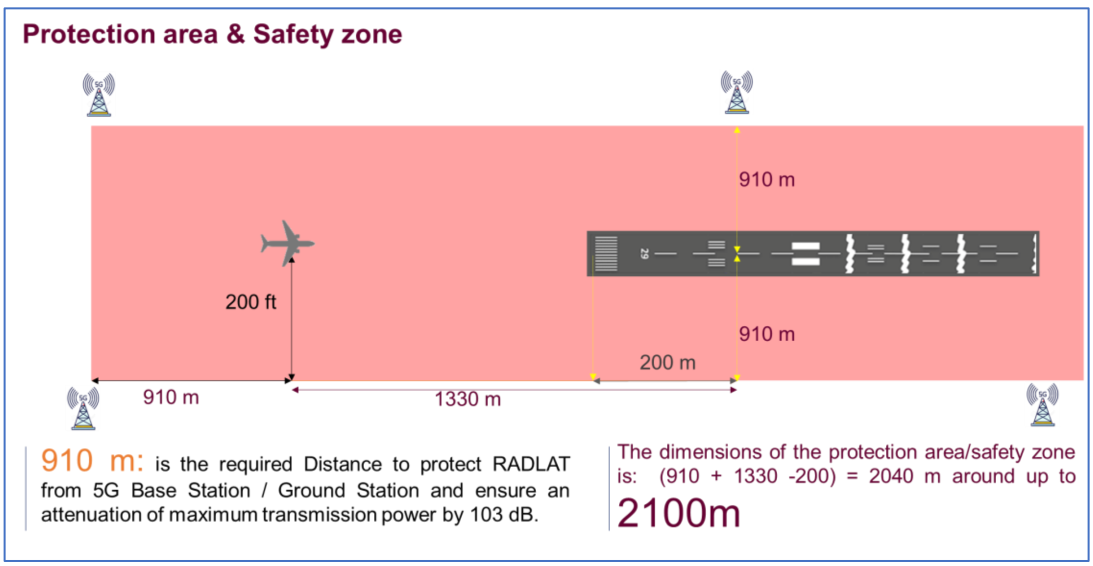
Altimeter	Usage Category 1											
	200 ft, VCOs On (WCLS)			1000 ft, Own-Ship VCOs			5000 ft, Own-Ship VCOs			7000 ft, Own-Ship VCOs		
	3750 MHz	3850 MHz	3930 MHz	3750 MHz	3850 MHz	3930 MHz	3750 MHz	3850 MHz	3930 MHz	3750 MHz	3850 MHz	3930 MHz
F	-13	-15	-16	-20	-21	-24	-27	-28	-30			
L	NB	NB	NB	NB	NB	NB	-9	NB	NB			
T	NB	NB	NB	NB	NB	NB				NB	-7	-14
X	NB	NB	-6	NB	-8	-14	-11	-26	-24			
Y	-9	-8	-5	-15	-14	-17	-25	-25	-26			
ITM (dBm)	-19	-21	-22	-26	-27	-30	-33	-34	-36	-7	-13	-20
dBm/MHz	-39	-41	-42	-46	-47	-50	-53	-54	-56	-27	-33	-40

The free space path loss (FSPL) necessary is:

FSPL=5G base station maximum EIRP-Threshold + Safety Margin
= 78 -(-19) +6
= 103 dB

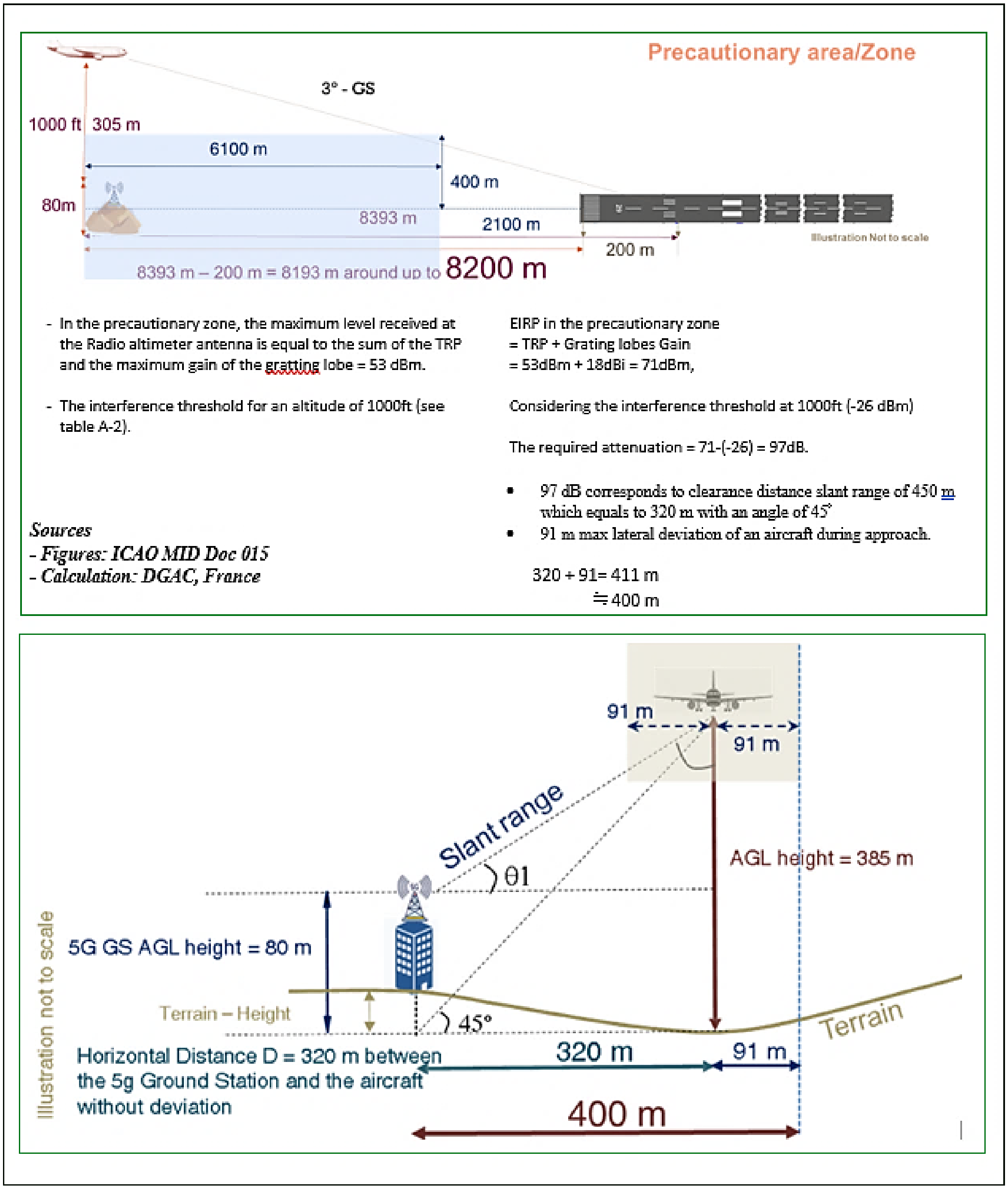
This requires a minimum distance between an aircraft and any 5G Ground Station at least: 2 985.6 ft (910 m)

Source: ICAO MID Doc 015



Source: ICAO MID Doc 015

Figure A-4. Calculation of the dimensions of the safety zone



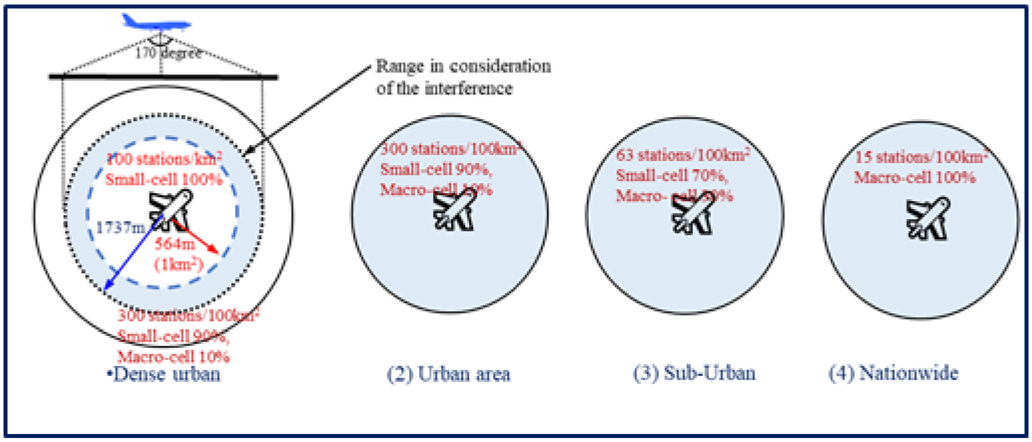
Source: ICAO MID Doc 015

Figure A-5. Calculation of the dimensions of the precaution area/zone

2.4 Japan

2.4.1 In Japan, 5G allocations are in the bands 3 600 – 4 100 MHz and 4 500 – 4 600 MHz which effectively creates a 100 MHz guard band surrounding the radio altimeters band. The Ministry of Internal Affairs and Communications, the spectrum regulator in Japan, in coordination with specialized Institutes, conducted a compatibility study using the parameters described in Recommendation ITU-R M.2059. The study considered the following factors:

a) The base station deployment model is divided into four types of areas that have different densities and ratios of the 5G base stations as shown in Figure A-6. The angle of the range for aggregation is 170º downward, and the area on the surface is calculated by the flight altitude. The maximum radius of the dense urban area model is 564 m (1 km^2). The urban area model is placed surrounding the dense urban area model if the radius of the range of considerations is exceeding the maximum radius of the dense urban area model, according to the flight altitude.



Source: Japan Civil Aviation Bureau, Japan

Figure A-6. Base station Deployment model considered in the compatibility study between 5G base stations and radio altimeters in Japan
(*Image reproduced by kind permission of JCAB*)

b) Two types of 5G base stations were considered as typical models for study. One is the macro-cell base station (with the higher power radiation and higher antenna height) and the other is the small-cell (with the lower power radiation and lower antenna height). The specifications of the 5G base station are described in Table A-3.

Table A-3. 5G base station typical models
(*Image reproduced by kind permission of JCAB*)

	Small-cell base station	Macro-cell base station
Power Density (dBm/MHz)	5	28
Antenna Gain (dBi)	23	23
Ohmic loss of Active Antenna System (AAS) (dB)	3	3
Mechanical tilt (degrees)	10	6
Antenna Height (m)	10	40
Spurious Level	-16 dBm/MHz	-4 dBm/MHz

Source: Japan Civil Aviation Bureau, Japan

2.4.2 Considering the results of the compatibility study between the radio altimeters and 5G base station, the Ministry of Internal Affairs and Communications set the following regulation for 5G base station:

a) To avoid harmful interference to the radio altimeters, a 100 MHz guard band is mandated.

b) Additional requirement for the compatibility to the radio altimeters near the aerodromes are applicable:

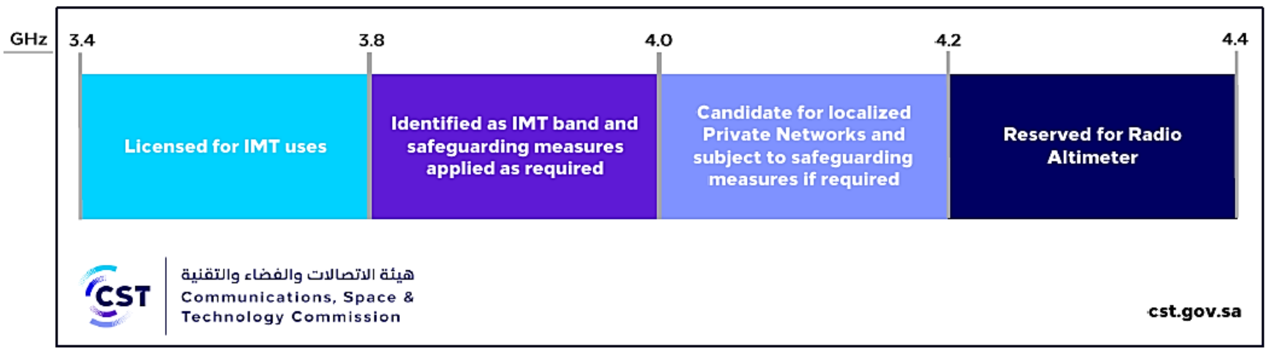
   i) To avoid unwanted emission interference, unwanted emission of the 5G base station into the radio altimeter band should be reduced.

   ii) To avoid the blocking of radio altimeters, the use of the bands 4 000 – 4 100 MHz and 4 500 – 4 600 MHz used for 5G base station should be avoided within 656 ft (200 m) from the approaching path of aircraft.

   iii) For the heliports, the bands 4 000 – 4 100 MHz and 4 500 – 4 600 MHz base station should be kept physically apart more than 164 ft (50 m) for macro-cell base station and 65.6 ft (20 m) for small-cell base station.

2.5 **Saudi Arabia**

2.5.1 The Communications and Information Technology Commission (CITC) is responsible for managing radio spectrum for all users in Saudi Arabia. The CITC planned allocation of 5G IMT in the band 3 400 – 4 000 MHz as shown hereafter.



Source: Communications, Space and Technology Commission, Saudi Arabia

Figure A-7. Saudi Arabia 5G IMT planned allocation
(Figure provided by CST through kind cooperation with the General Authority of Civil Aviation (GACA) of the Kingdom of Saudi Arabia)

2.5.2 In February 2021, the CITC consulted with aircraft manufactures and operators to collect data on the impact of 5G deployment in 3 800 – 4 000 MHz band on the radio altimeter. The main recommendations are summarized as follows:

a) The allocation in the band 3 800 – 4 000 MHz must be subject to protection criteria, technical and operational requirements considering the performance of radio altimeters to avoid any harmful interferences which may include, but are not limited to, separation distance, antenna height, tilt and power.

b) Consideration should be given to the protection of radio altimeters operating on-board helicopters using helipads in built-up areas where 5G deployment is likely to be high-density.

c) These arrangements should be reviewed once the aviation industry finalizes new radio altimeter standards, taking account of 5G deployments as well as the aviation industry will develop transition plans. Once those will be available, the allocation for 5G IMT may be extended in the band 4 000 – 4 200 MHz.

2.5.3 The CITC and the General Authority of Civil Aviation (GACA) are collaborating with "Spectrum Advisory Group" to develop protection criteria for the radio altimeter systems to avoid harmful interference from the 5G networks. Interim measures using France's approach, where exclusion and protection zones are established around major airports, are under consideration.

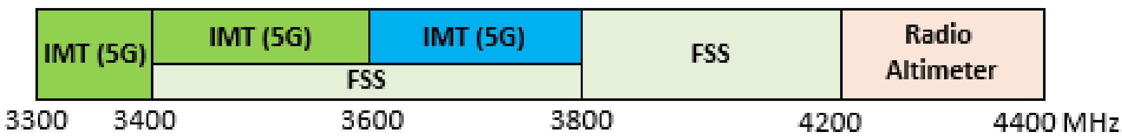
2.5.4 The GACA published an Advisory Circular[26] to all operators of aircraft equipped with radio altimeters and air traffic service providers within Saudi Arabia, informing them of the likelihood of 5G interferences on aircraft systems. This circular provides operational recommendations and invite aircraft operators, pilots and air traffic service units to report to any 5G interference events to the GACA.

2.6 Sultanate of Oman

2.6.1 The Civil Aviation Authority of Oman published a civil aviation safety alert titled "*Potential Safety Concerns Regarding Interference to Radio Altimeters*" as an Aeronautical Information Circular (AIC)[27] in 2021. The purpose of this civil aviation safety alert is to raise awareness of the potential risk of 5G interference and to recommend precautionary operational measures before confirmation of impact of 5G radio waves on radio altimeters.

2.7 United Arab Emirates

2.7.1 The Telecommunications and Digital Government Regulatory Authority is responsible for managing radio spectrum in the United Arab Emirates (UAE). 5G allocations in UAE are in the band 3 300 – 3 800 MHz as illustrated in Figure A-8.



Source: Telecommunication and Digital Government Regulatory Authority, UAE

Figure A-8. UAE Spectrum Use

(Figure provided by Telecommunication and Digital Government Regulatory Authority, UAE through kind cooperation with the General Civil Aviation Authority (GCAA – UAE))

2.7.2 The UAE gives high priority to radio altimeter protection in 4 200 – 4 400 MHz. The UAE plans to use the band 3 800 – 4 000 MHz for IMT, only after completion of technical studies to protect radio altimeters operating in 4 200 – 4 400 MHz and in future, may extend this use up to 4 200 MHz.

2.7.3 The General Civil Aviation Authority of the UAE published a Safety Alert[28] for UAE aircraft operators, informing them about the likelihood of 5G interferences on aircraft systems. This safety alert also recommends monitoring and reporting any 5G interference events.

2.8 United Kingdom

2.8.1 In the United Kingdom (UK), the Office of Communications (OFCOM) is responsible for managing the radio spectrum for all users in the UK. In consultation with the CAA and the Ministry of Defense, OFCOM released the frequency band 3 600 – 4 200 MHz for mobile applications. The frequency band was split in two with the 3 600 – 3 800 MHz auctioned off for 5G mobile services and the 3 800 – 4 200 MHz made available through coordinated local licenses to meet local wireless connectivity needs and innovation in rural areas with a lower radiated power.

2.8.2 Prior to the release of the consultation document for both frequency bands, the UK conducted several theoretical studies with respect to the potential impact on radio altimeters. Various scenarios based on ITU, European Commission (EC) and UK regulations, and taking into account that signals will continue to roll-off in the spurious emission domains as well as other perceived reasonable assumptions. The initial study did not consider the impact of active antenna systems due to modelling difficulties and user equipment was ignored as the power levels are significantly lower and therefore presumed not to be a threat. Subsequent studies have taken into account active antenna systems.

2.8.3 While OFCOM, the CAA and the Ministry of Defense were confident that the deployment of 5G services, especially around airports, would not pose a threat to radio altimeters, given the results of the RTCA studies, the UK has

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[26] *GACA Advisory Circular*

[27] *https://www.caa.gov.om/upload/files/AIC 04-21.pdf*

[28] *https://www.gcaa.gov.ae/en/epublication/admin/Library Pdf/Safety Alerts/SAFETY ALERT 2021-03 - REQUIREMENTS TO MITIGATE 5G INTERFERENCE OPERATIONAL RISKS - ISSUE 01.pdf*

monitored the situation carefully but there has been no evidence of interference caused by the introduction of high power 5G services in the frequency band 3 600 – 3 800 MHz or rural wireless services.

2.9 United States

2.9.1 The United States allocated 3 700 – 3 980 MHz to services including 5G in February 2020 in 20 MHz license blocks that can be aggregated by the same operator up to 100 MHz with the initial operations starting in 3 700 – 3 800 MHz in January 2022, in select areas. The FCC authorized the base station power to 65 dBm/MHz maximum EIRP for rural areas, and 62 dBm/MHz in urban areas, though no limits were placed on antenna positioning or vertical direction of the signal. Additionally, the FCC limited out-of-band spurious emissions levels to -13 dBm/MHz, though the 3GPP standards for 5G provides a better recommended limit of -30 dBm/MHz for certain classes of base stations. In some cases, based on testing, the aviation community has recognized the need for spurious IMT emission levels in the 4 200 – 4 400 MHz band to be no higher than -48 dBm/MHz to ensure adequate performance of the radio altimeter system without additional IMT and/or aviation mitigations.

2.9.2 On 23 December 2021, the FAA issued a Special Airworthiness Information Bulletin on the Risk of Potential Adverse Effects on Radio Altimeters[29], as well as, a Safety Alert for Operators on the Risk of Potential Adverse Effects on when Operating in the Presence of 5G C-Band Interference[30]. Concurrently, two airworthiness directives (ADs), FAA ADs 2021-23-12 and 2021-23-13,were issued: An AD on altimeter interference for fixed wing aircraft [31], and an AD on altimeter interference for rotary wing aircraft[32]. Subsequently, seven additional ADs were issued. These ADs revise the landing requirements, and in certain cases, prohibit landing at certain airports due to the reliance aircraft systems have on radio altimeters. The FAA issued Notices to Air Missions (NOTAMs) prohibiting certain operations. Therefore, FAA ADs must be followed when operating in the United States where a NOTAM is in place. In 2023, the ADs were updated.

2.9.3 The FAA has defined protection areas around active runways as follows:

a) **Runway Safety Zone (RSZ)** – The RSZ is defined as the volume where aircraft are highly likely to be operating during low altitude operations near the runway with 5G C-band emissions meeting maximum power requirements. The RSZ is based on instrument approach procedure (IAP) obstacle clearance surfaces (OCSs) applicable to these low altitude operations (for example, below 500 ft (152.4 m) above ground level) near the runway, specifically, the approach, missed approach, and CAT II/III OCS. Therefore, the RSZ is a 3D volume that begins at the surface on and near the runway, extends approximately 2 nm into the approach area along the extended runway center line, and slopes up based on the OCS as defined by the IAP glide path angle. The width of the RSZ is based on the OCS width at a specific distance from the landing threshold and varies between 1 300 ft (396.2 m) and 3 000 ft (914.4 m) each side of the runway center line. At runways with no IAP, the RSZ is defined by the slope and lateral dimensions of the aerodrome visual approach surface. The volume is defined within the lateral limits from the lowest OCS altitude up to 1 000 ft (304.8 m) above ground elevation. In this area unreliable radio altimeter function can lead to a catastrophic outcome. Acceptance criteria: The radio altimeters must function accurately and reliably in the RSZ.

b) **Performance Buffer**– Initially, the FAA defined Performance Buffer as the zone in which 5G base stations were turned off based on an assessment of radio altimeter performance. Through collaboration with the aviation and wireless industry, this evolved into the current approach, where the 5G signal in space must meet specific PSD requirements in the RSZ volume. Specific PSD requirements met within RSZ vary based on altitude above ground level and are based on minimum required radio altimeter performance. These PSD requirements will continue to evolve as more minimum required radio altimeter performance increases (for example, as more radio altimeters are retrofitted or replaced), to support increased wireless base station power. Figure A-9 below shows an example of the RSZ at Chicago O'Hare International Airport, runway 28R, with the CAT I ILS approach and missed approach OCS in blue and the CAT II/III OCS in red.

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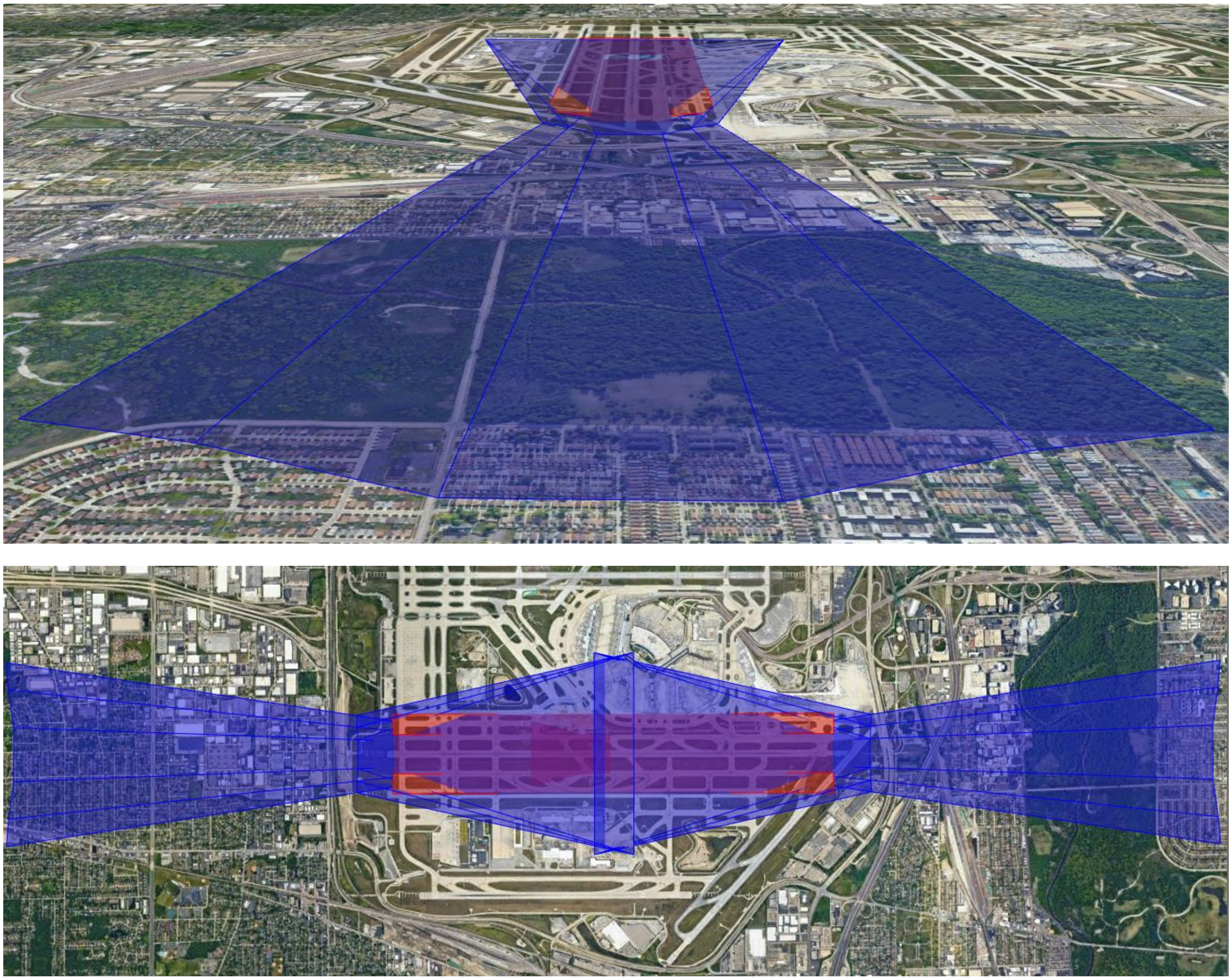
[29] *https://rgl.faa.gov/Regulatory_and_Guidance_Library/rgSAIB.nsf/dc7bd4f27e5f107486257221005f069d/379cfb187d16db10862587b4005b26fc/$FILE/AIR-21-18R1.pdf*
[30] *https://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/safo/all_safos/media/2021/SAFO21007.pdf*
[31] *https://www.faa.gov/sites/faa.gov/files/2021-12/FRC_Document_AD-2021-01169-T-D.pdf*
[32] *https://www.faa.gov/sites/faa.gov/files/2021-12/FRC_Document_AD-2021-01170-R-D.pdf*



Source: FAA, USA

Figure A-9. Example USA protection zones – Chicago O'Hare International Airport Runway 28R
(*Image reproduced by kind permission of FAA*)

2.9.4 To support aviation operations in light of the ADs, the FAA has voluntary agreements with multiple wireless service providers to limit fundamental emissions above the horizon by employing an EIRP vertical mask that reduces emission levels by up to 14 dB at zenith. Compatibility in the altimeter pass band also required agreements with the wireless service provider to limit out-of-band conducted emissions to -48 dBm/MHz. These agreements are effective until January 2028.

2.9.5 From January 2022 to June 2023, the FAA issued monthly Alternative Means of Compliance based on the performance capabilities of the radio altimeter while also considering antennas, cabling, and any other system integration issues. The method aimed to determine the minimum distance away from a 5G antenna the aircraft needs to be to meet the acceptance criteria of the RSZ.

2.10 **Arab Civil Aviation Organization (ACAO)**

2.10.1 ACAO Air Navigation Committee endorsed the following recommendation:

a) urge ACAO Member States to take appropriate measures to reduce the impact of the installation of 5G cellular networks on the air traffic movement in coordination with the concerned national authorities of each country (national telecommunications regulatory bodies) including determining the levels of use of 5G cellular networks near airports and their future plans;

b) task the general administration of ACAO, in coordination with the recently established 5 G Working Group of ICAO Middle East Regional Office, to work on the development of a mechanism at the national and regional levels to report and analyze interference reports resulting from the use of 5G networks; and

c) urge ACAO Member States to support ICAO's position during the 2023 World Telecommunications Conference WRC-23 Meeting held in 2023 through coordination with the national telecommunications regulatory bodies of each Member State.

2.11 **European Aviation Safety Authority (EASA)**

2.11.1 EASA issued a Safety Information Bulletin: SIB No.: 2021-16 on the subject of operations to aerodromes located in the United States with potential risk of interference from 5G ground stations. EASA is actively and continuously assessing how the risk evolves, including monitoring for events. Although EASA maintains its position, concerning the situation, EASA has not found constructive evidence of unsafe conditions.

2.12 **Electronic Communications Committee (ECC)**

2.12.1 In Europe, the ECC has adopted a work item that covers the analysis of unwanted emissions from Mobile/Fixed Communications Networks (MFCN), for example, 5G operating in 3 400 – 3 800 MHz into the 4 200 – 4 400 MHz radio altimeters band as well as the impact of blocking of radio altimeters from 3 400 – 3 800 MHz MFCN in-band emissions. The ECC further agreed to provide relevant long term MFCN operational parameters in 3 400 – 3 800 MHz for the development of future MOPS by RTCA/EUROCAE for resilient radio altimeters. The target date for the ECC report as the deliverable for the analyses, is set for October 2024.

2.13 **International Air Transport Association (IATA)**

2.13.1 IATA continues engaging with governments to mitigate threats to the civil aviation spectrum, including encouraging responsible deployments of 5G. IATA activities focus under four strategic pillars including:

1) Safe and uninterrupted airline operations - civil aviation should not be negatively impacted by any spectrum deployments.

2) Cooperative coordination - government agencies should plan spectrum deployments collaboratively together with industry stakeholders.

3) Protection of civil aviation spectrum resources and establishment of predictable global spectrum environment.

4) Robust aircraft and avionics design with clear and cost-effective migration path.

2.13.2 IATA and its member airlines understand the economic importance of 5G deployments. However, in line with Article 4.10 of the ITU RRs and the SARPs, IATA insists that maintaining current levels of safety for civil aviation must continue to be one of governments' highest priorities.

2.13.3 IATA developed a website that includes a global 5G C-band status dashboard and be accessed at: https://www.iata.org/en/programs/ops-infra/air-traffic-management/5g/

2.14 **ICAO – Frequency Spectrum Management Panel (FSMP)**

2.14.1 The FMSP of ICAO considered the issue and reviewed submissions from several States and International Organizations. In addition, a working group was established to collect information on 5G/radio altimeter compatibility. Based on a proposal from the FSMP Working Group (WG), ICAO's Secretary General issued a State letter expressing potential safety concerns regarding interference to radio altimeters (ICAO SL 21/22 "Potential safety concerns regarding interference to radio altimeters", published on 25 March 2021[33]). This letter encouraged administrations to prioritize public and aviation safety when enabling cellular broadband/5G services in RF bands near those used by radio altimeters. The FSMP WG continues to work on the subject and expects additional contributions from States, and specialized international organizations. The material

[33] *https://www.icao.int/safety/FSMP/Documents/5G and Radio Altimeters/StateLetter_2021_022e.pdf*

produced by the FSMP is publicly available at: https://www.icao.int/safety/FSMP/Pages/default.aspx[34].

2.14.2 Based on WP30[35], presented jointly by IATA, the International Business Aviation Council, the International Coordinating Council of Aerospace Industries Associations, the International Federation of Air Line Pilots' Associations, General Aviation Manufacturers Association and RTCA on "Safety concerns regarding interference to aircraft radio altimeters", the HLCC 2021 adopted the following Recommendation:

Recommendation 5/5 — Mitigating the risk of 5G implementation to safety-critical radio altimeter functions

That States:

a) consider, as a priority, public and aviation safety when deciding how to enable cellular broadband/5G services;

b) consult with aviation safety regulators, subject matter experts and airspace users, to provide all necessary considerations and regulatory measures to ensure that incumbent aviation systems and services are free from harmful interference; and

that ICAO:

c) continue coordinated aviation efforts, particularly at the International Telecommunication Union (ITU), to protect radio frequency spectrum used by aeronautical safety systems.

2.14.3 Furthermore, the Technical Commission (TC) of the ICAO Assembly 41st Session held from 27 September to 7 October 2022, reviewed several working papers on potential interference from 5G deployment and requested ICAO and its Member States to continue taking necessary measures and efforts to ensure that radio altimeters and other aeronautical systems are free from harmful interference, including implementation of mitigation measures, sharing of best practices, as well as development of relevant provisions and guidance. Furthermore, recognizing the criticality of RF spectrum, the TC encouraged States and regions to actively participate in spectrum protection activities and to endorse the ICAO position for the ITU World Radiocommunication Conference 2023 (ITU WRC-23) (see State letter E 3/5-23/60).

2.14.4 Based on a proposal of the TC, the Assembly adopted Resolution A41-7: *Support of the ICAO policy on radio frequency spectrum matters,* which supersedes Assembly Resolution A38-6. This resolution urges Member States to consider, as a priority, public and aviation safety when deciding how to enable new or additional services, and to consult with aviation safety regulators, subject matter experts and airspace users, to provide all necessary considerations and to establish regulatory measures to ensure that incumbent aviation systems and services are free from harmful interference[36].

2.14.5 There are several regional activities to support Resolution A41-7 including the following additional actions adopted by the MID Region:

a) Updating its positions on frequency spectrum use to highlight concerns on 5G band allocations and potential interference with radio altimeters. The position will be submitted for ITU WRC-23 highlighting the concerns.

b) Amending ICAO-MID Frequency Management Ad-hoc Working Group terms of references to add a task to collect and share information on the best practices implemented by States and regional organizations to mitigate potential radio altimeters interference caused by 5G operation.

c) Updating ICAO Spectrum Policy included in Doc 9718, *Handbook on Radio Frequency Spectrum Requirements for Civil Aviation* to strengthen the need to protect the radio altimeter.

d) Raising awareness and emphasizing the importance of the issue with State regulators, both aviation and spectrum, through its regional offices and meetings.

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[34] *https://www.icao.int/safety/FSMP/Pages/default.aspx*
[35] *https://www.icao.int/Meetings/HLCC2021/Documents/WP/EN/SAF/wp_030_en.pdf*
[36] *https://www.icao.int/Meetings/a41/Documents/WP/wp_623_en.pdf - from pages 10 to 12.*

e) Issuing of several ICAO liaison statements to the European spectrum regulator highlighting the need to protect the radio altimeter and to encourage conditions on 5G deployment that can ensure the functionality of current radio altimeters and thus can be accepted by aviation stakeholders.

2.15 RTCA-EUROCAE

2.15.1 Prior to the FCC decision to auction licenses for flexible use including 5G cellular operations in the 3 700 – 3 980 MHz frequency band, the aviation industry expressed concern about the potential for harmful interference to radio altimeters. When the flexible use technical parameters were defined in the FCC authorization, additional study was encouraged to address the concerns raised by the aviation industry.[37] In response, the RTCA invited all stakeholders to participate in a public multi-stakeholder group under its Special Committee 239 (SC-239). Working in cooperation with 5G operators, the multi-stakeholder group conducted an extensive study of 5G emissions, assessing them against radio altimeter performance data provided by the AVSI laboratory testing in simulated common and real-world scenarios, and documenting the results in a publicly available report. The RTCA Assessment Report found that all aircraft types and multiple operations were at risk for harmful interference from both fundamental and spurious 5G emissions. The report also concluded that "5G base stations present a risk of harmful interference to radio altimeters across all aircraft types, with far-reaching consequences and impacts to aviation operations". The RTCA published a YouTube presentation of the radio altimeter issue[38].

2.15.2 Having established the risk of interference to currently deployed radio altimeters that were developed under the existing minimum performance standards, RTCA SC-239 and EUROCAE WG-119 jointly initiated the drafting of a new MOPS for radio altimeters. While work on the new MOPS is currently underway, the following section describes a number of significant milestones that must be achieved before certified aircraft incorporating new radio altimeters begin operations. The new radio altimeters will be developed and approved in accordance with updated requirements in the new MOPS, expected to replace all existing equipment currently in operation worldwide.

3. TIMELINE FOR INTRODUCTION OF NEW RADIO ALTIMETER STANDARDS AND POTENTIAL RETROFITS

3.1 As indicated in Section 3.9, RTCA/EUROCAE are developing new radio altimeter standards that will improve compatibility with planned IMT environments. With ongoing discussions nationally on potential retrofits of radio altimeters to ensure full coexistence with high power 5G services in the adjacent frequency bands, the following sequential factors are recommended to be considered by States when deciding on suitable timelines.

a) **Radio altimeter MOPS update**

The radio altimeter MOPS (DO-155A/ED-30A) are being developed by RTCA and EUROCAE joint committees working to define out-of-band interference (OOBI) tolerances that are high enough to protect radio altimeters from future spectrum changes that are even closer to the 4 200 – 4 400 MHz band. There is a similar expectation that higher in-band interference (IBI) tolerance will be needed given that some regulators have adopted versions of the 5G specifications with high emissions in the radio altimeter band. For radio altimeter manufacturers to be able to support these higher OOBI and IBI tolerances, manufacturers will need time to prototype equipment to validate that they can build equipment that meets the specified performance. DO-155A and ED-30A are estimated to be completed by the end of 2024.

b) **Potential MOPS revision**

As seen regularly in standards development, it is likely that a further revision, for example, "DO-155A Change 1," will be needed to adjust and correct the requirements in the MOPS, which would take additional time to implement.[39] Such validation and potential revisions would require several months, at a minimum, to accomplish.

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[37] *See* U.S. Federal Communications Commission (FCC), "Report and Order of Proposed Modification in the Matter of Expanding Flexible Use of the 3.7 to 4.2 GHz Band" – Dated March 3, 2020. Available from: https://docs.fcc.gov/public/attachments/FCC-20-22A1.pdf
[38] *https://www.youtube.com/watch?v=OpYhjK2MDqM*
[39] This and other similar revisions have a higher likelihood with the pressure to produce the first version of the MOPS as quickly as possible.

c) **Develop technical standard order**

On completion of the MOPS, the airworthiness regulator for the equipment manufacturer should develop and issue a technical standard order (TSO) that provides a full set of equipment requirements to be met by manufacturers. This is a process that takes an additional several months to complete.

d) **Initial build and TSO authorization**

With the TSO, the avionics manufacturer must build a specific model of radio altimeter to the completed TSO for approval by the airworthiness regulator and obtain TSO Authorization, which may take additional one or more years to move a prototyped design to a final design.

e) **Aircraft type certification, supplemental type certification**

For new-airplane production incorporation, the aircraft manufacturer must obtain a modified type certificate (TC) following the TSO authorization, or for retrofits, the radio altimeter manufacturer or operator must obtain a supplemental type certificate (STC) from the airworthiness regulator to install or retrofit the new radio altimeter on each aircraft model upon which the equipment will be installed. This approval is separate from any TSO authorization and must be done individually for each aircraft type. The TC option can take between six (6) to twenty (20) months (depending on the airframer), and the STC can take between six (6) and ten (10) months or more.

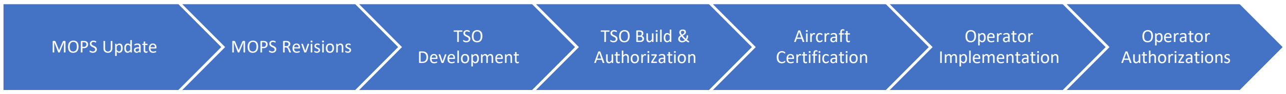
f) **Aircraft operator implementation**

Only after all of the above is completed can an operator (airline) or aircraft manufacturer begin procuring and installing the new radio altimeter on their aircraft and seek operation approvals for their use[40]. In normal times, a full fleet retrofit under an airworthiness authority mandate may take ten plus (10+) years to complete, depending on the extent of cabling or antenna replacement that is required[41]. Faster installation for each aircraft can be achieved if an aircraft is taken out of service rather than waiting for a suitable service window. Given technical, logistical, administrative resources and effort, as well as significant loss of revenue when removed from service for installation, this adds to the opportunity cost that must be borne by the aircraft operator.

g) **Production capacity and supply chain considerations**

Finally, availability of new radio altimeters for installation will likely be constrained by production capacity and supply chain, as it is expected that most countries will require the same modification as quickly as possible.

Note. – Figure A-10 illustrates sequential general steps described above to be considered by States when deciding on suitable timelines.



Source: Aviation Spectrum Resources, Inc. (ASRI)

Figure A-10. Generic timeline of aviation standards development and implementation (up to 10 years in duration typically, and does not reflect proportional time flows)
(*Image reproduced by kind permission of ASRI*)

— END —

[40] Noting that in some airframer cases, the RA is Buyer Furnished Equipment (BFE).
[41] As an example, the most recent precedent for mandating equipage in the United States was the Automatic Dependent Surveillance-Broadcast (ADS-B) Out mandate, which allowed about 10 years for equipment to be designed, receive TSO Authorization, certified via TC or STC, and then installed in aircraft.