Overview on ICAO MID RADALT/5G Guidance material: Supporting States to define Protection areas/zones

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Radio Altimeter (RADALT) Action Group (AG)

The MIDANPIRG/19 meeting held in Riyadh, Saudi Arabia from 14 to 17 February 2022 was apprised of the ICAO State Letter (dated 25 March 2021) on the potential impact of 5G on radio altimeters in the MID Region. The meeting also acknowledged the safety concerns and potential operational impacts. Based on WP/62 presented by IATA; and WP/69 and PPT/71 presented by Saudi Arabia, the meeting agreed to:

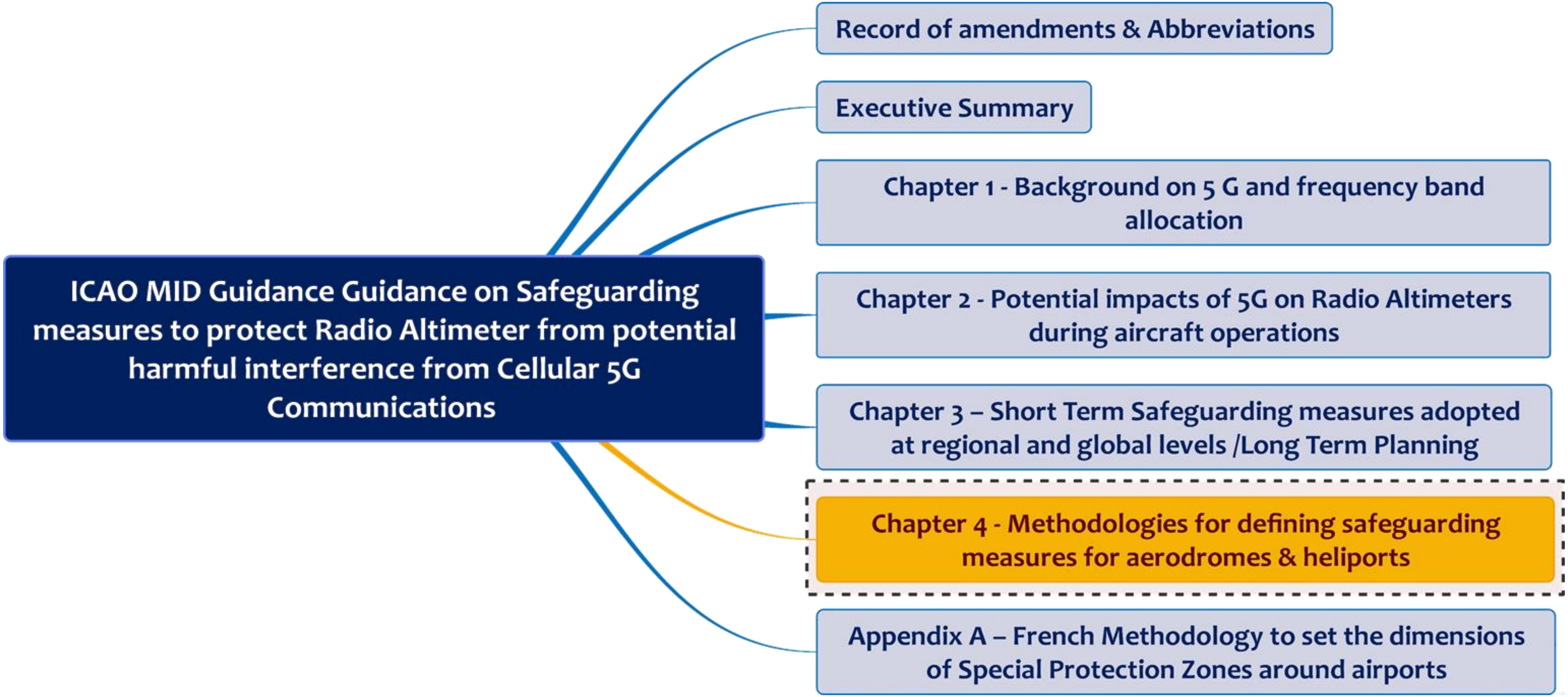
- update the Frequency Management Working Group Terms of Reference to include tasks related to the issue of 5G & Radio Altimeter interferences.

- establish a Radio Altimeter (RADALT) Action Group (AG) to develop guidance material to protect aircraft operations from potential Radio Altimeter interference (*MIDANPIRG DECISION 19/23*).

- task the CNS SG to coordinate with the RASG-MID relevant subsidiary bodies the 5G Safeguarding measures around the aerodromes to protect RADALT from any interference. (MIDANPIRG DECISION 19/24)

https://www.icao.int/MID/MIDANPIRG/Documents/MID19%20and%20RASGMID9/Final%20Report%20Full.pdf – Page 53

Guidance on Safeguarding measures to protect Radio Altimeter from potential harmful interference from Cellular 5G Communications



Methodologies for defining safeguarding measures for aerodromes & heliports: Main references used

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R M.2059-0
(02/2014)

Operational and technical characteristics and protection criteria of radio altimeters utilizing the band 4 200-4 400 MHz

M Series
Mobile, radiodetermination, amateur and related satellite services

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R P.528-5
(09/2021)

A propagation prediction method for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands

P Series
Radiowave propagation

International Civil Aviation Organization

FSMP-WG/11 WP/27 rev1
2021-03-09

WORKING PAPER

FREQUENCY SPECTRUM MANAGEMENT PANEL (FSMP)

Eleventh Working Group meeting

Web Meeting, 1 – 12 March 2021

Agenda Item 3.: Radio Altimeter and Wireless Aircraft Intra-Communications (WAIC) Issues
c) National efforts to implement broadband mobile near 4200-4400 MHz

UK Deployment of Mobile Systems in the Frequency Range 3.6-4.2 GHz and the Theoretical Impact on Radio Altimeters

(Presented by John Mettrop)

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R M.1461-2
(01/2018)

Procedures for determining the potential for interference between radars operating in the radiodetermination service and systems in other services

M Series
Mobile, radiodetermination, amateur and related satellite services

Recommendation ITU-R M.1461 is used as a guideline in analysing the compatibility between radars (including radio altimeters) operating in the radiodetermination service with systems in other services

Report ITU-R M.2319-0
(11/2014)

Compatibility analysis between wireless avionic intra-communication systems and systems in the existing services in the frequency band 4 200-4 400 MHz

M Series
Mobile, radiodetermination, amateur and related satellite services

Radio-altimeter antenna beam is modeled based on the antenna pattern formula provided in this report

Rec. ITU-R SM.337-6

RECOMMENDATION ITU-R SM.337-6*

Frequency and distance separations

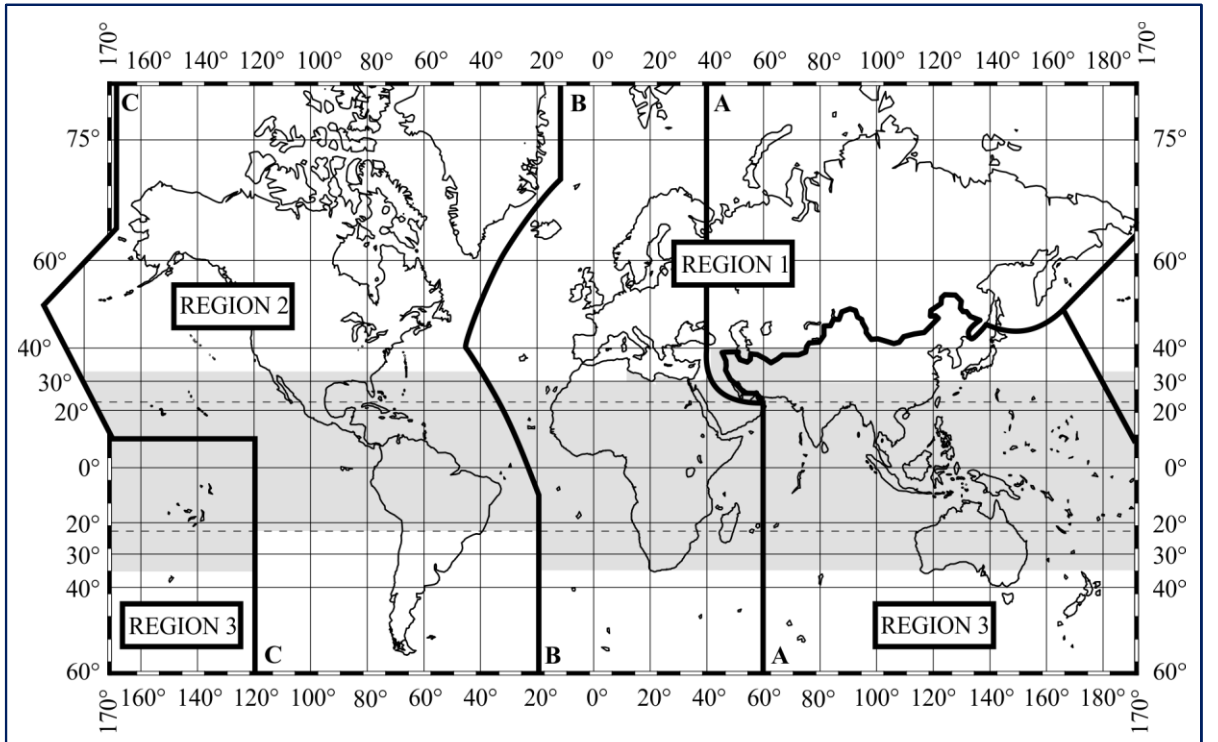
(1948-1951-1953-1963-1970-1974-1990-1992-1997-2007-2008)

Chapter 1: Background on 5 G and frequency band allocation

This chapter describes the working arrangements and regulatory framework managed by Radio communications sector of the International Telecommunications Union for the allocations of radiofrequency (RF) spectrum and adoption of radio regulation. It also provides an overview on the current allocations of 5G at global level including in the Middle East

Country	Operator	5G network status	Commercial launch	Frequency bands
Bahrain	Batelco	5G deployed in network (2019)	Yes, 2019	2496-2690 MHz
	STC[13]	5G deployed in network (2019)	Yes, 2019	2496-2690 MHz
	Zain	5G deployed in network (2019)	Yes, 2020	2496-2690 MHz
Kuwait	Ooredoo	5G deployed in network (2018)	Yes, 2019	4400-5000 MHz
	STC[14]	5G deployed in network (2019)	Yes, 2019	3300-3800 MHz
	Zain	5G deployed in network (2018)	Yes, 2019	3300-4200 MHz
Oman	Omantel	5G deployed in network (2019)	Yes, 2020	3300-3800 MHz
	Ooredoo	Licensed (2018)	Yes	3300-3800 MHz
Qatar	Ooredoo	5G deployed in network (2018)	Yes, 2019	3300-3800 MHz
	Vodafone	5G deployed in network (2018)	Yes, 2019	3300-3800 MHz
Saudi Arabia	Mobily	5G deployed in network (2019)	Yes, 2019	2496-2690 MHz 3300-3800 MHz
	STC	5G deployed in network (2018)	Yes, 2019	2300-2400 MHz 3300-3800 MHz
	Zain	5G deployed in network (2019)	Yes, 2019	2496-2690 MHz 3300-3800 MHz
UAE	Du	5G deployed in network (2019)	Yes, 2019	3300-3800 MHz
	Etisalat	5G deployed in network (2018)	Yes, 2019	3300-3800 MHz[15]

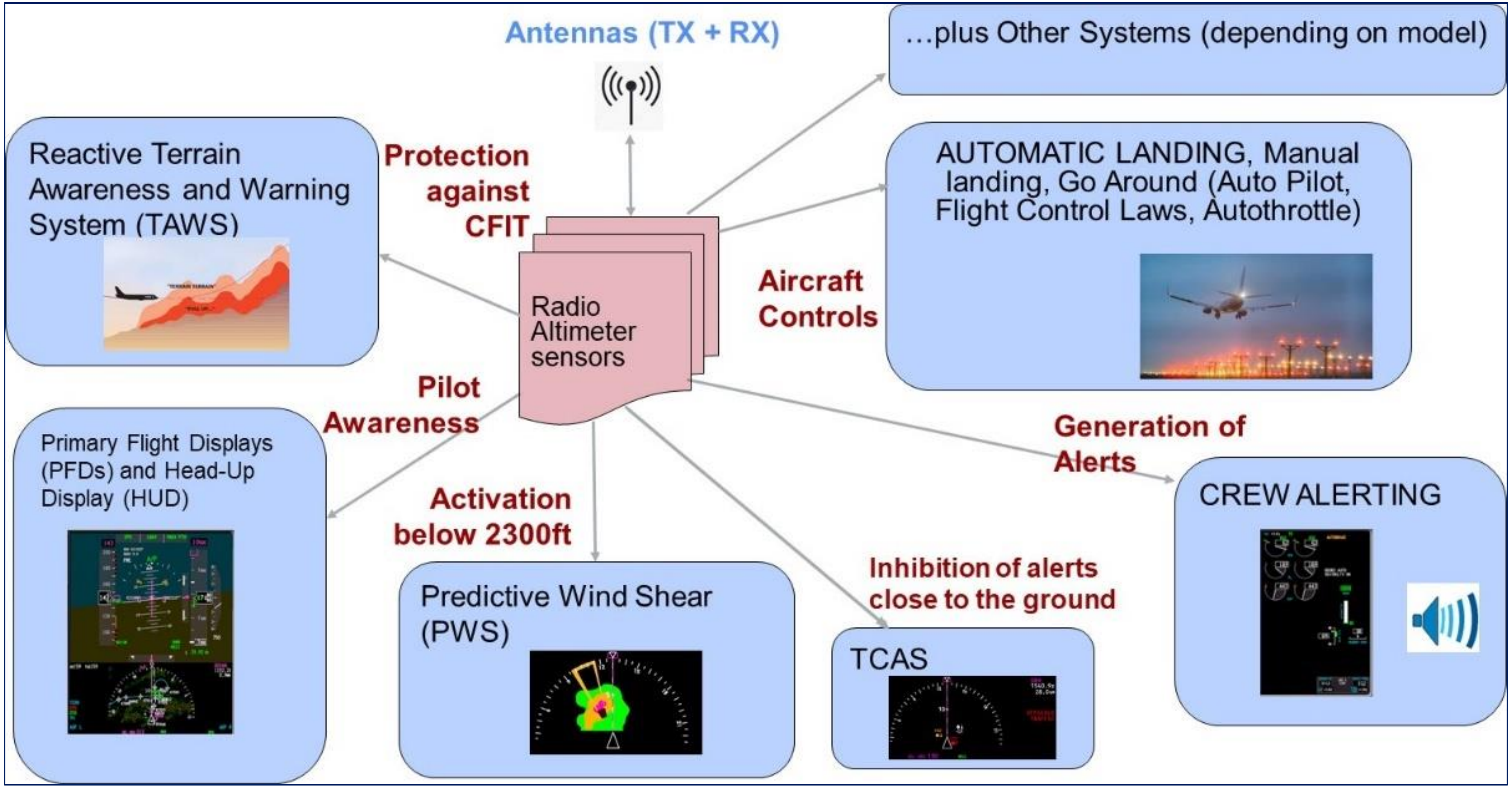
Source: Roadmaps for awarding 5G spectrum in the MENA region – GSMA Document, January 2022



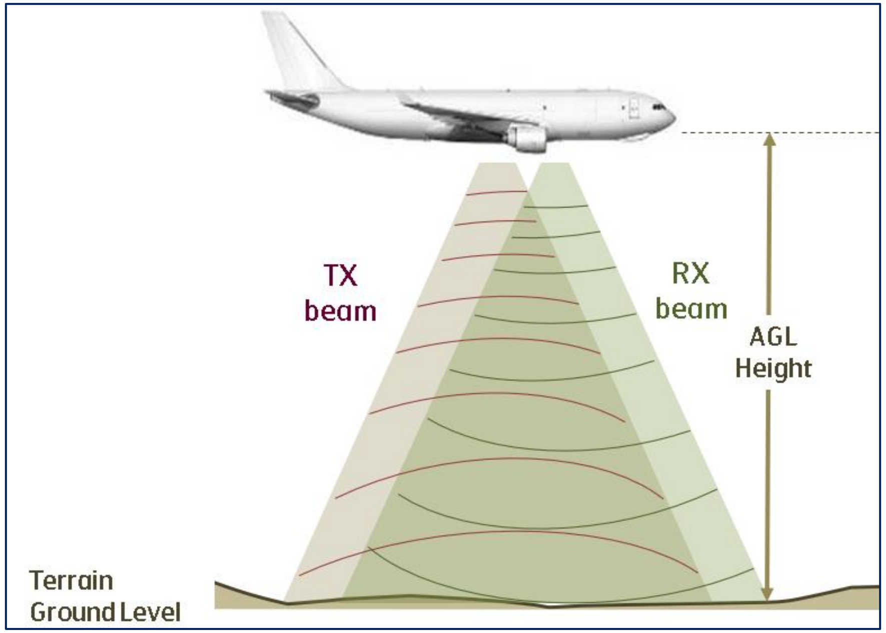
The shaded part represents the Tropical Zones

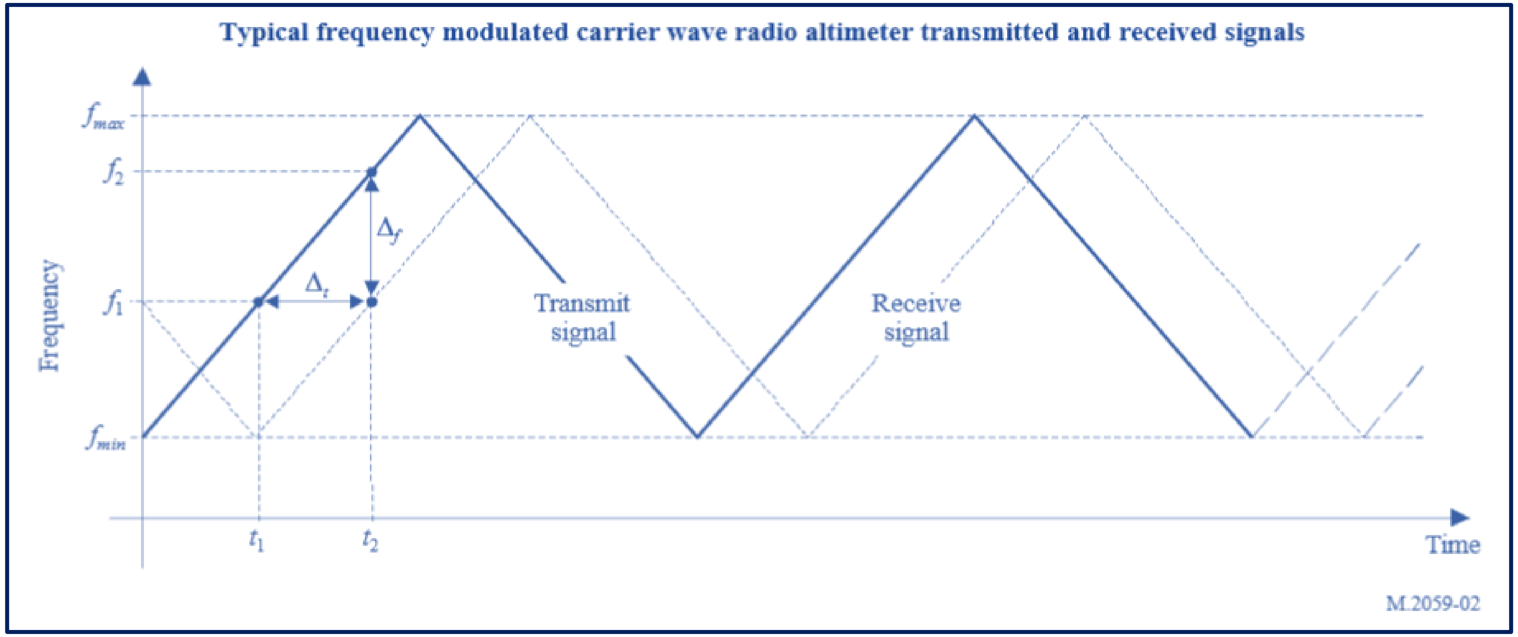
The proximity of 5G frequencies from RADLT frequency band is also covered with reference to note Article 4.10 of the ITU Radio Regulations which states, "ITU Member States recognize that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference."

Chapter 2: Potential impacts of 5G on Radio Altimeters during aircraft operations



Chapter 2: Potential impacts of 5G on Radio Altimeters during aircraft operations





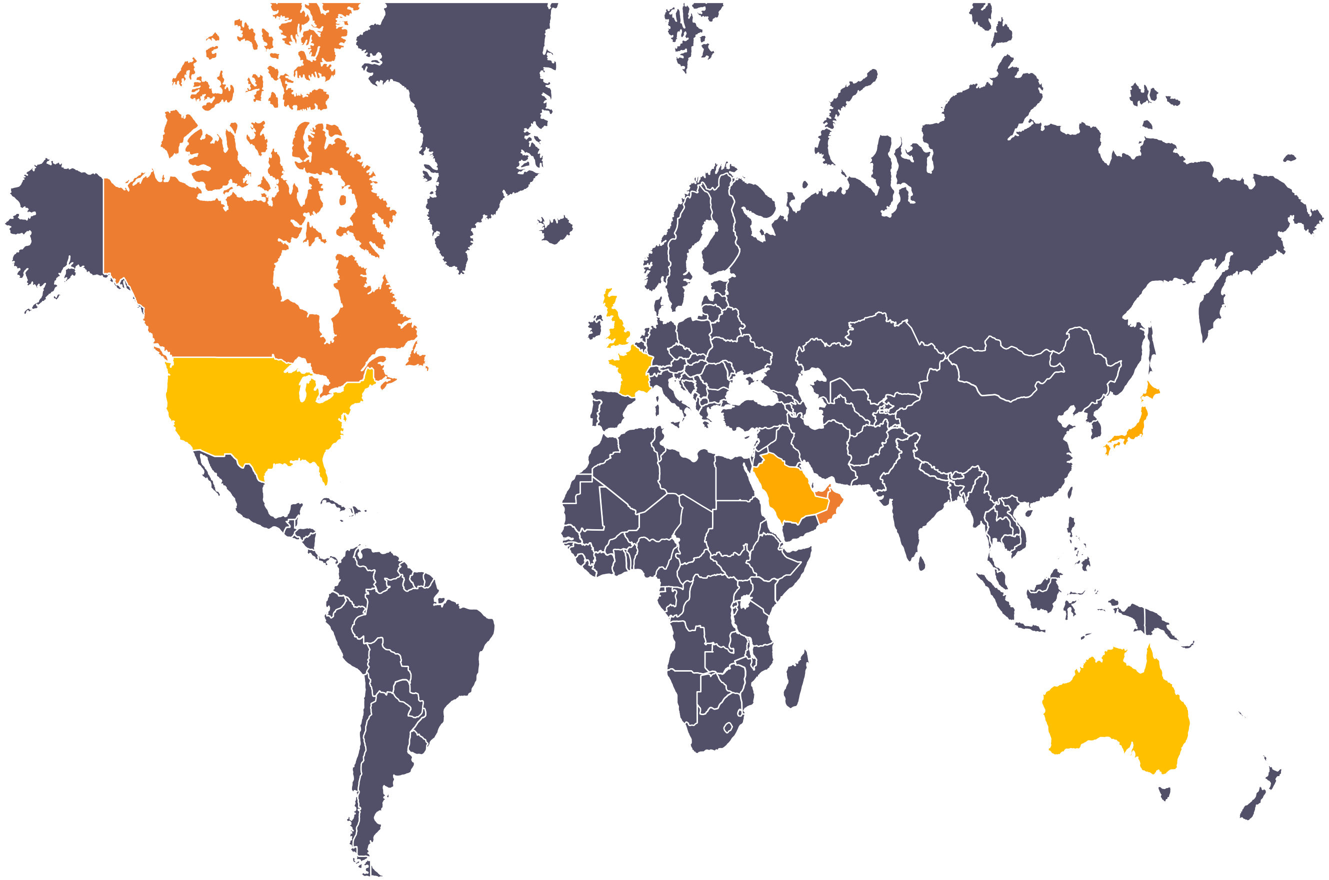
- Continuous-wave of LFMCW (Linear Frequency Modulation Continuous Wave) or FMCW Radio altimeters (Frequency Modulated Carrier Wave); and
- Pulsed modulation.

Chapter 2: Potential impacts of 5G on Radio Altimeters during aircraft operations

Specific Operational Impacts on Aircraft

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
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 Mode 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—e.g., landing gear, slats, 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

Chapter 3 – Short Term Safeguarding measures adopted at regional and global levels /Long Term Planning



Measures adopted by States, Regional Organizations & SDOs

- Australia
- France
- Japan
- KSA
- Oman
- UAE
- United Kingdom
- United States

Arab Civil Aviation Organization

EASA European Aviation Safety Agency

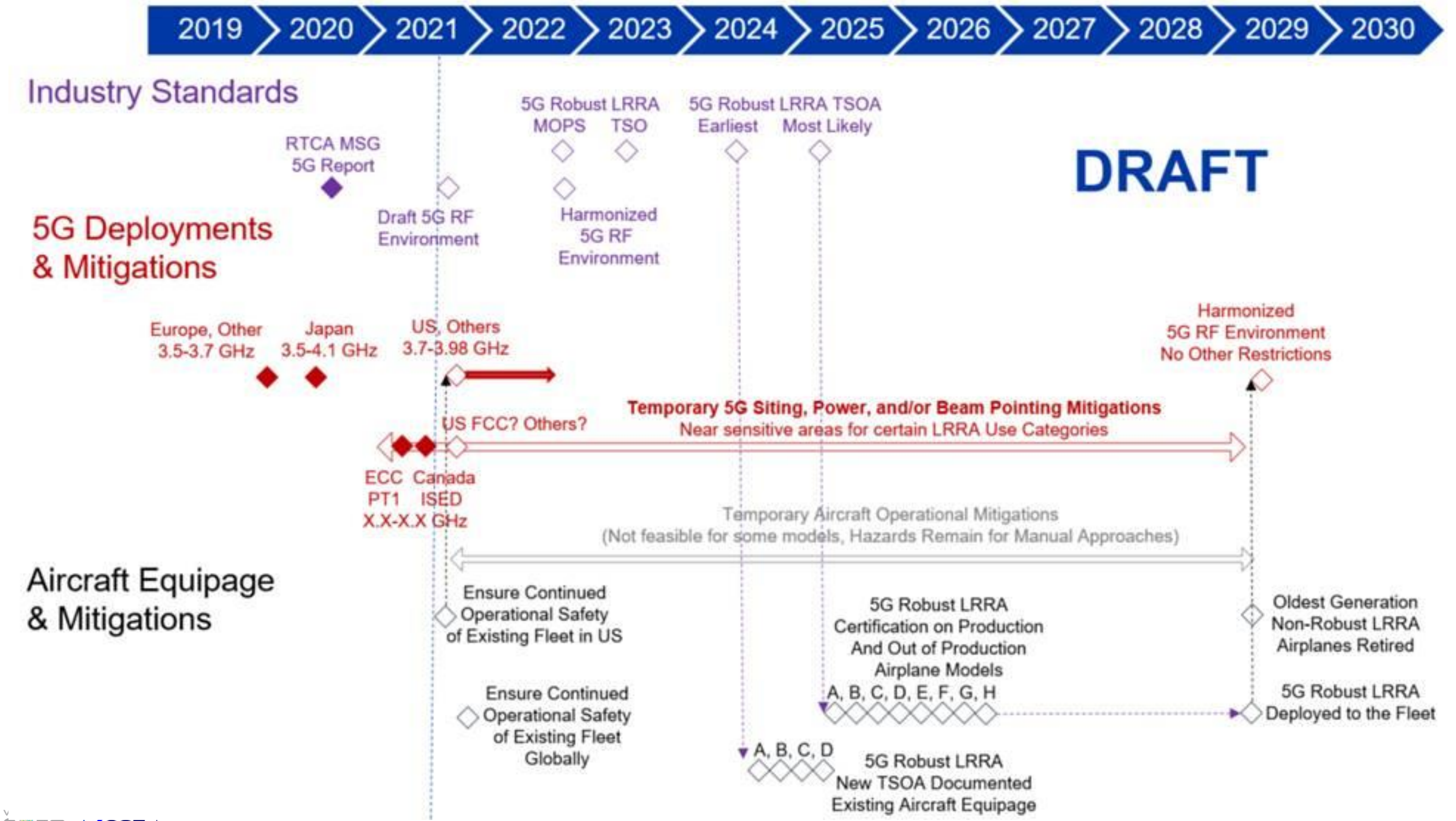
IATA

ICAO OACI ИКАО

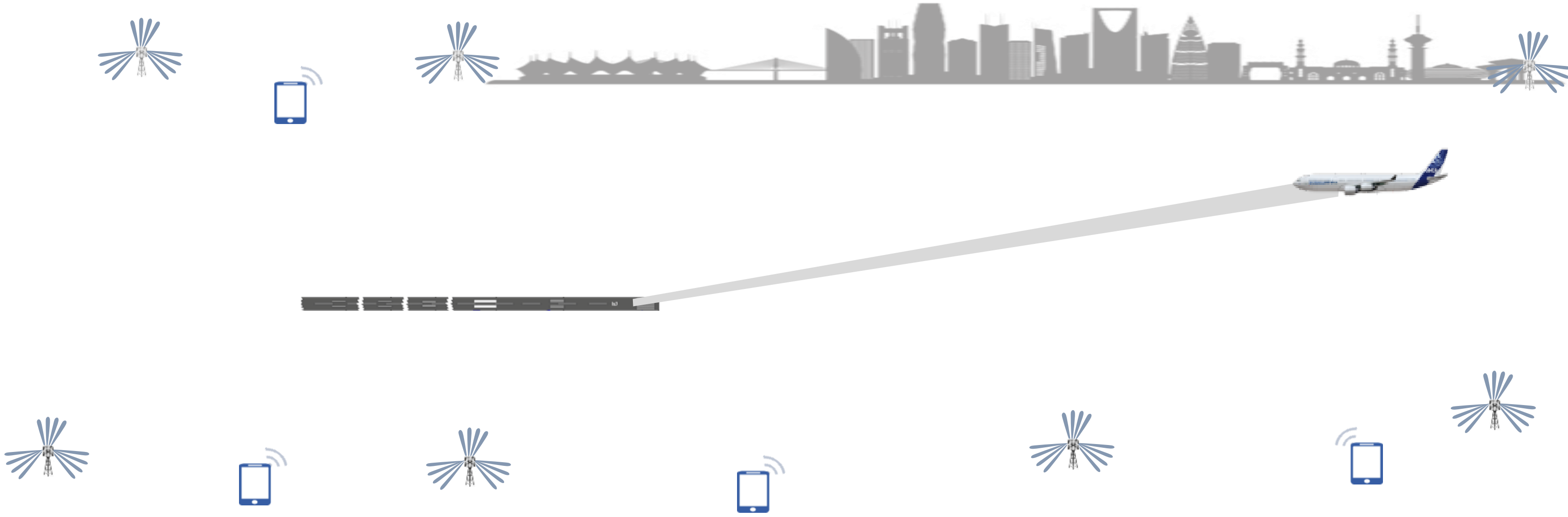
EUROCAE

RTCA

Chapter 3 – Short Term Safeguarding measures adopted at regional and global levels /Long Term Planning



Chapter 4: Methodologies for defining safeguarding measures for aerodromes & heliports: Overview on the Contents



Chapter 1 - Background on 5 G and frequency band allocation

Chapter 2 - Potential impacts of 5G on Radio Altimeters during aircraft operations

Chapter 3 – Short Term Safeguarding measures adopted at regional and global levels /Long Term Planning

Chapter 4: Methodologies for defining safeguarding measures for aerodromes & heliports

- **4.1. Introduction**
- **4.2. Methodology for the protection of Radio altimeters**
  - 4.2.1. General approach and Main considerations
  - 4.2.2. Main activities to define protection criteria
  - 4.2.3. Recommended methodology for the technical study
  - 4.2.4. Recommended Safeguarding and Interference Mitigation Measures
  - 4.2.5. 5G devices used on board aircraft

Appendix A – French Methodology to set the dimensions of Special Protection Zones around airports

Chapter 4: Methodologies for defining safeguarding measures for aerodromes & heliports: Overview on the Contents

Chapter 4: Methodologies for defining safeguarding measures for aerodromes & heliports

- 4.2. Methodology for the protection of Radio altimeters
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  - 4.2.3. Recommended methodology for the technical study
  - 4.2.4. Recommended Safeguarding and Interference Mitigation Measures
  - 4.2.5. 5G devices used on board aircraft
- **4.1. Introduction**

Chapter 4: Methodologies for defining safeguarding measures for aerodromes & heliports

Introduction

- refers to Recommendation ITU-R M.2059: Operational and technical characteristics and protection criteria of radio altimeters utilizing the band 4200 -4400 MHz
- provides an overview on the Interference that may occur from out-of-band and in-band sources and to the main focus of compatibility analysis and studies.
- refer to the main consequences of receiver desensitization, overload, false altitude reports which may imapct the safe conduct of flights
- provides a Summary on the main practical measures that have been codified in national telecommunication regulations and successfully deployed
  - Ensure through testing sufficient spectrum separation between 5G C-band deployments and 4.2-4.4 GHz frequency band used by existing radio altimeters
  - Clearly codify and enforce the maximum power limit for 5G C-band transmission and downward tilting (electronically or mechanically) of 5G C-band antenna
  - Establishment of sufficient 5G C-band prohibition and pre-cautionary zones around airports

Methodologies for defining safeguarding measures for aerodromes & heliports: Overview on the Contents

Cont'd

Three primary electromagnetic interference coupling mechanisms between radio altimeters and interfering signals from other transmitters

Criteria 01

Receiver overload:

Receiver front-end overload where the value depends on each radio altimeters type

Criteria 02

Desensitization

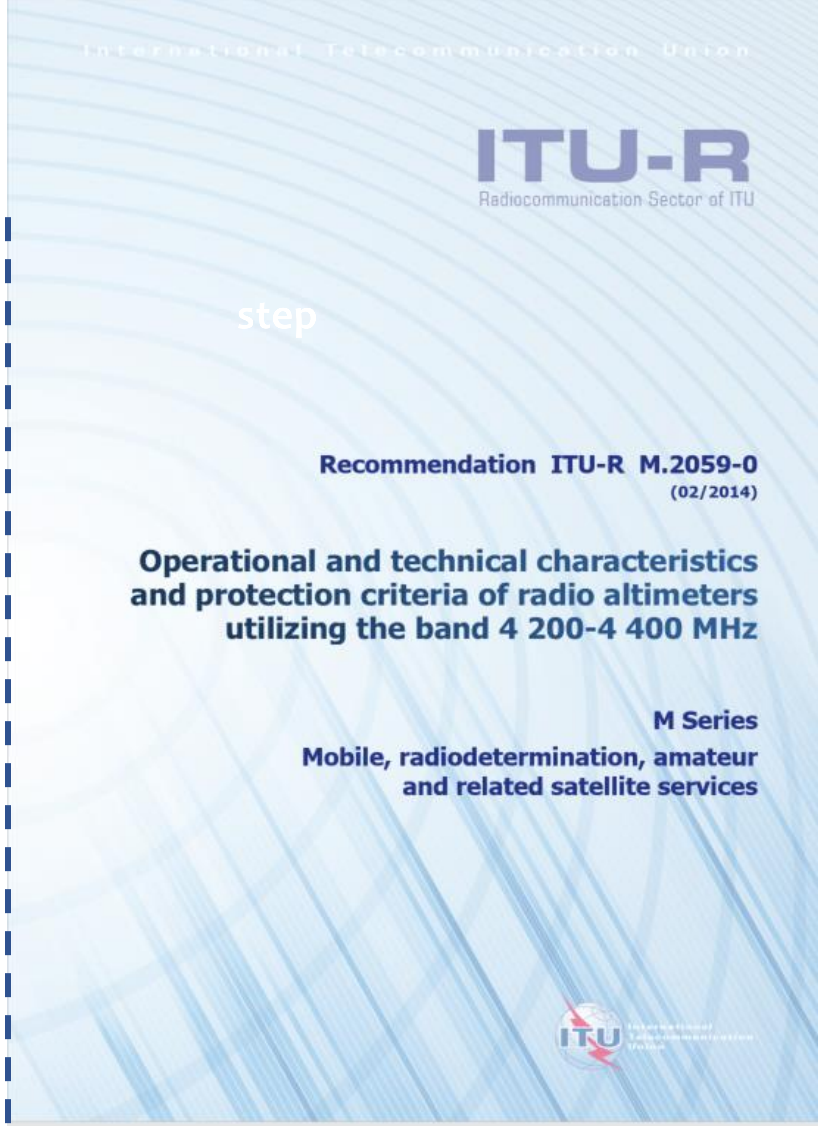
Receiver desensitization which is the common I/N protection criteria of -6dB

Criteria 03

False Altitude Generation:

the False altitude reports which are defined by -143 dBm/100 Hz (–143 dBm considering 100 Hz detector bandwidth

Compatibility studies and protection criteria



Methodologies for defining safeguarding measures for aerodromes & heliports: Overview on methodology for RADALT protection

General approach and Main considerations

General approach and Main considerations

Objective: identify the protection areas around airports and heliports for proper mitigations

- maximum roll of up to +/-30 degrees from the horizontal in all directions,
- The air-to-ground propagation model base don ITU Recommendation ITU-R P.528-4

Characteristics of 5G Base Station to check whether the protection criteria are met for an airplane flying at different heights (50, 200, 1000 ft and 2000 ft (15, 61, 310 and 610 meters)) above the Base Station.

Initial Analysis based on a single base station to verify whether it can pose a threat to the aeronautical systems in the band (for simplicity the aircraft can have zero roll and pitch). If a single base station is predicted to not cause interference, the analysis can be expanded to consider the aggregation of multiple interferers and the roll and pitch of the aircraft.

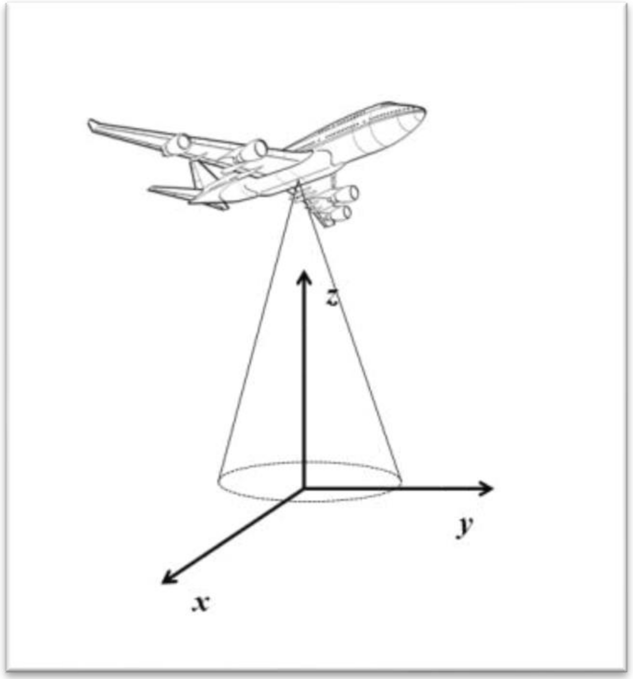
Considerations of the main parameters and factors of 5G network: Power of the 5G base station, Antenna gain, Maximum Effective Isotropic Radiated Power, Location of Base Station, The antenna tilt, Scan angle, rate of use, ground scattering and altitude, Frequency band, Aggregated unwanted emission level, Filtering characteristics of each radio altimeters and associated installation)

General approach and Main considerations

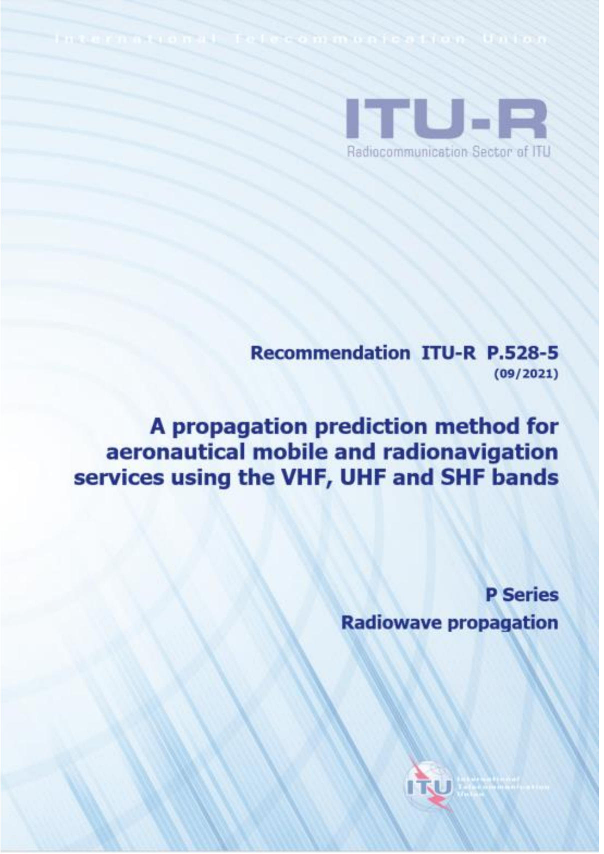
ICAO recommends to consider the following parameters when performing the analysis:

The air-to-ground propagation model (Recommendation ITU-R P.528-427)

The aircraft can have a maximum roll of up to +/-30 degrees from the horizontal in all directions,



- The base station is located at (0,0,0);
- The aircraft is flying along a horizontal path defined by the coordinates (0, ya, ha). The altitude ha of the aircraft is fixed, so that its position varies along the axis y only;
- The radio-altimeter antenna beam is modeled based on the antenna pattern formula available in Report ITU-R M.231928 (§A-3.1.1).



Main activities to define protection criteria

Main activities to define protection criteria

1. Setting of joint working group(s)/committees between national spectrum and aviation regulatory authorities
2. Drafting of detailed report summarizing the main findings of the international working groups and the corresponding administrations. The results and recommendations will be used as temporary and interim measures to protect the radio altimeters until the review of technical standards for RADALTs has been completed.
3. Conduct a detailed scientific technical study including simulations, and lab experiments.
4. perform a field trial, if feasible, to validate the scientific studies, simulations, and lab experiments findings and to ensure the coexistence between the RADLAT and 5G networks based on the applied protection criteria. The research project team should prepare a detailed report summarizing the main findings of field trials.
5. share the detailed report summarizing the main findings of scientific studies and lab experiments with all stakeholders
6. Collect views and concerns and review the interim protection criteria according to the reported findings of scientific studies and lab experiments

Recommended methodology for the technical study

Recommended methodology for the technical study

- Identify the frenquency spectrum range and the area of interest (Usually around aerodromes and heliports)
- Identify the locations of base stations or IMT mobile network (Base stations installed or to be installed). The study considers the separation distance relative to the mobile base station's antenna required between a rural mobile base station and an aircraft in flight
- Identify the list of parameters considering the aircraft operations and the 5G base stations and network deployments: Pitch/Roll, Base station Antenna Heigh & Tilt, Aggregate Effects, Radio Altimeter Receiver Frequency Dependent Rejection
- Identify the separation distance relative to the mobile base station's antenna and an aircraft in flight (Slant angle) at different heights/altitudes
- For each angle during the approach of an aircraft, the separation distance is calculated using the appropriate ITU formula assuming free space path loss (baseline scenario)
- Generalize the baseline scenario, to all possible scenarios and investigate the impact on all radio altimeters taken from Recommendation ITU-R M.2059.
- Summarizes the impact of 5G base stations network and recommend the mitigations measures and required safeguarding and protection areas.

Recommended methodology for the technical study

Cont'd

The UK presented a study at FSMP-Working Group (WG)/11 WP/27 outlining a methodology which could be used to assess the impact of 5G on RADALT. It investigates the potential interference from 5G base stations operating in the frequency range 3.6-4.2 GHz into radio altimeters under various scenarios

01 The study considers the separation distance relative to the mobile base station's antenna required between a rural mobile base station and an aircraft in flight level flight, as illustrated in the next Figure.

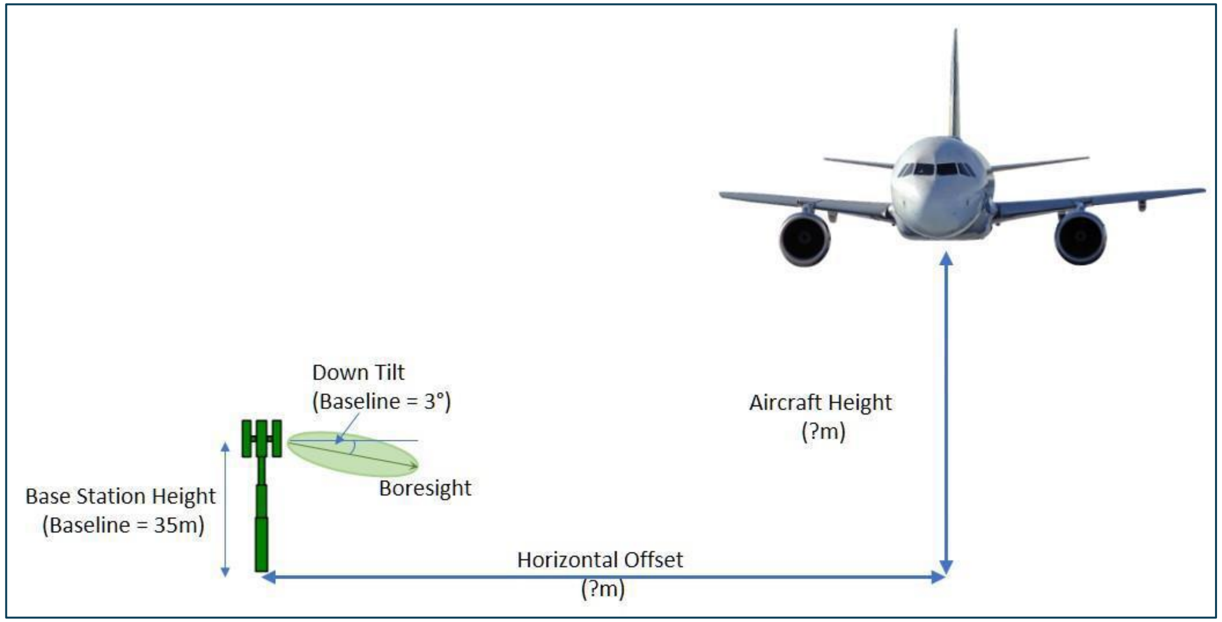
02 The study does not consider the impact of active antenna systems due to modelling difficulties and user equipment as the power levels are significantly lower and therefore presumed not to be a threat.

03 For each angle during the approach of an aircraft, the required separation distance is calculated using the following ITU formula assuming free space path loss:

04 $$PRx=PTx+GTx+AFTx-FSPL+GRx+RxRej-FLRx+SM$$

After re-arranging the above equation, it can be re-written as follow:

$$DKM=10^{\left(\frac{PTx+GTx+AFTx+GRx+RxRej-FLRx-32.4\ 20\ Log\ (FMHz)+SM}{20}\right)}$$

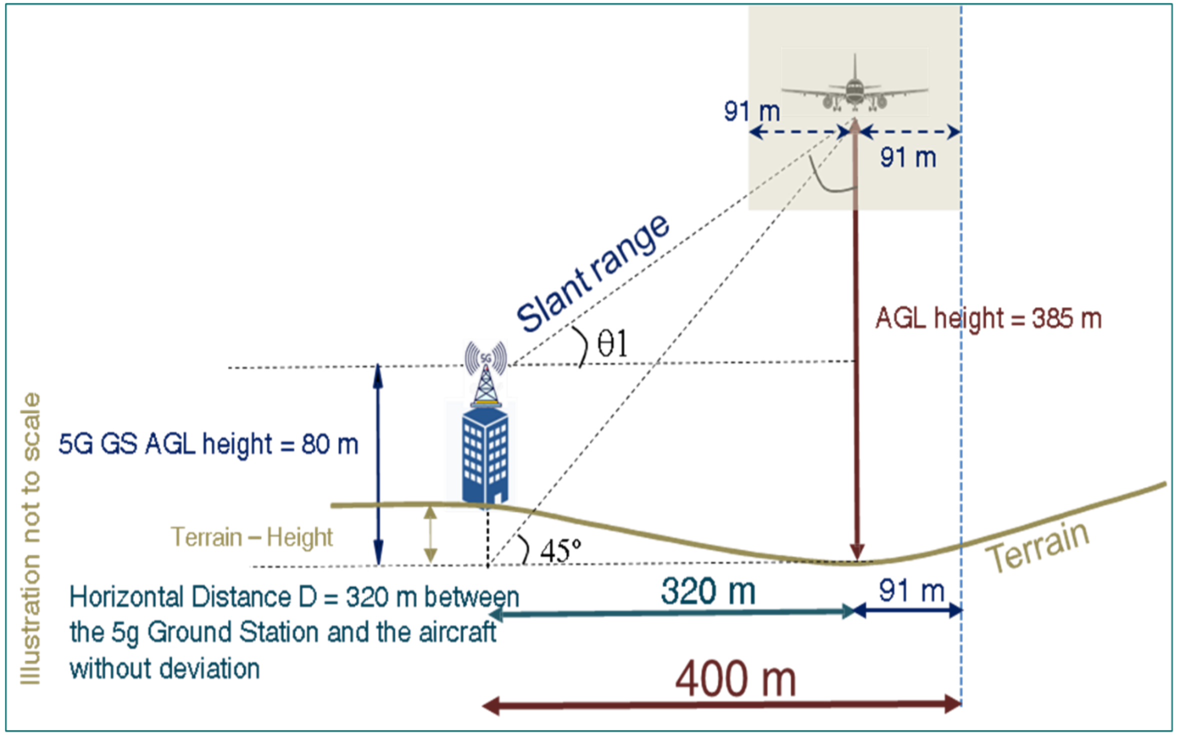


Where:
PRx = Power received (assumed to be the receiver overload threshold)
PTx = Mobile base station power supplied to the antenna port
GTx = Gain of the mobile base station antenna in the direction of the aircraft
AFTx = Transmitter activity factor
FSPL = Free space path loss (=32.4+20log(FMHz)+20Log(Dkm)
FMHz = Frequency
Dkm = Separation distance
GRx = Gain of the radio altimeter antenna in the direction of the mobile base station
RxRej = Adjacent channel rejection of the radio altimeter receiver
FLRx = Feeder loss in the radio altimeter
SM = Safety margin (assumed to be 6dB)

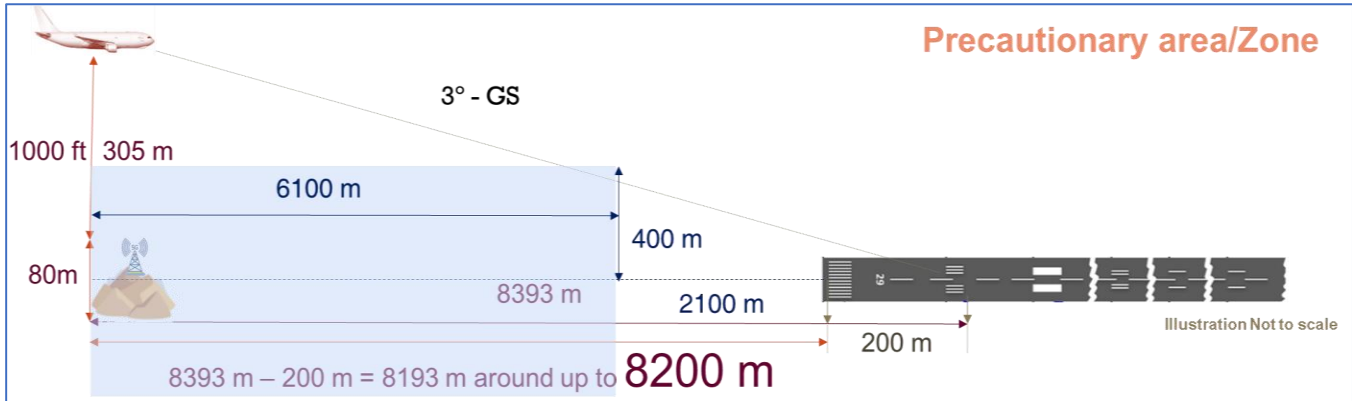
Having established the above baseline scenario, the following variations in the baseline scenario should be investigated for radio altimeters A1 and A3 taken from Recommendation ITU-R M.2059.

Recommended methodology for the technical study

Sample of calculation: Separation distance btw a BS and RADALT



Based on Airbus illustration



For spectrum efficiency: True Radiated Power = 53 dBm

Attenuation at RADALT Receiver: 26 dBm attenuation at 1000 ft

Grating lobes (max antenna gain with elevated angles) : 18 dBi

- 53 + 26 + 18 = **97 dB** required attenuation to the radiated signal in space to protect RADALT
- 97 dB corresponds to clearance distance slant range of 450 m which equals to 320 m with an angle of 45°.
- 91 m max lateral deviation of an aircraft during approach.

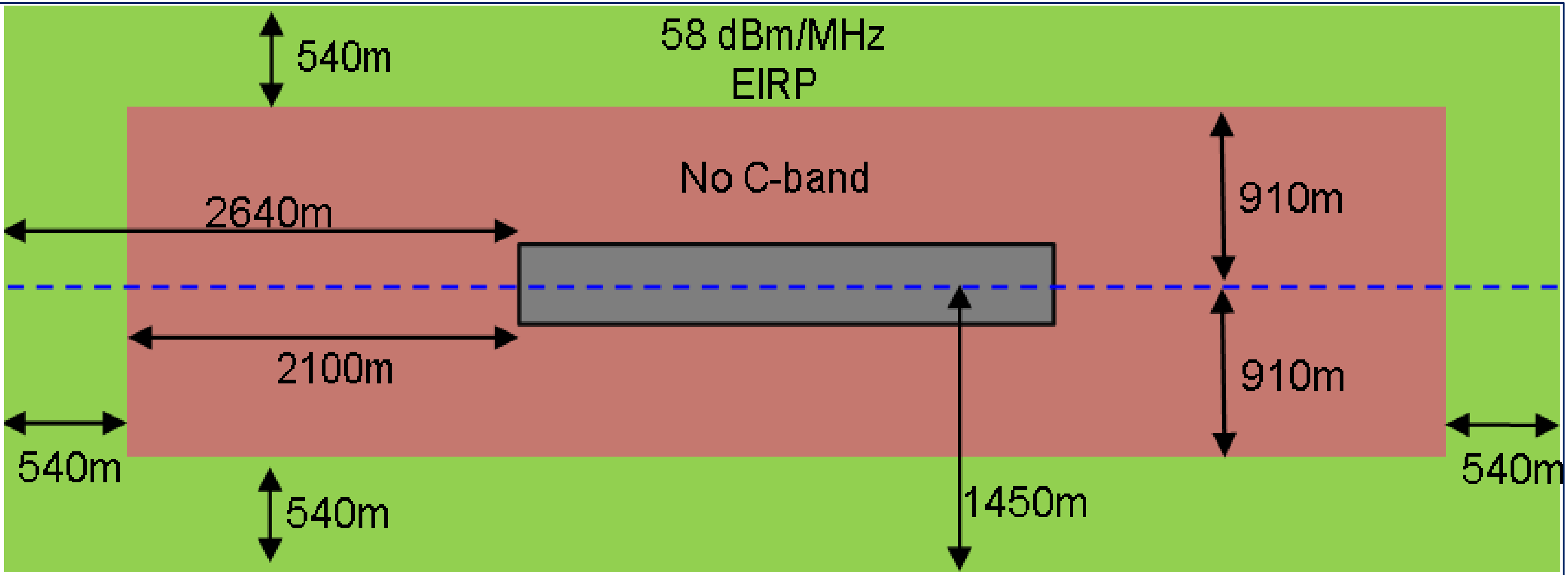
320 + 91 = 411 around down to **400 m**

Recommended Safeguarding and Interference Mitigation Measures

Recommended Safeguarding and Interference Mitigation Measures

- Issuing of safety notices or circulars to aircraft operators highlighting the potential interference of 5G network emissions with aircraft RADALTs
- Adoption of safeguarding measures, and mitigations to protect RADALT around aerodromes/Heliports. The measures should be issued jointly between frequency spectrum management and Civil Aviation Authorities and considered as main requirements to approve the deployment of 5G ground Stations (Base Stations) and associated network.
- Establish protection zones, namely Safety and Precautionary zones, around aerodromes with sufficient technical conditions (such as restricting 5G transmission power) for each zone considering the best practices. The plotting of the RADLAT protection zoning should be shared with all stakeholders.
- Organize regular communications with stakeholders including 5G service provider to share informaiton on the last development and any reported interference.
- Setup appropriate oversight processes to monitor the level of compliance of 5G service providers with the requirements and conditions for the deployment of base stations and network around the aerodromes
- Setup joint investigation committee between frequency spectrum management and Civil Aviation Authorities to analyse any reported interference

Recommended Safeguarding and Interference Mitigation Measures: Sample of protection zones



Note: This illustration is for guidance on the protection zones at an aerodrome. The green area is defined as buffer zone that depends on the location of BS and several other factors.

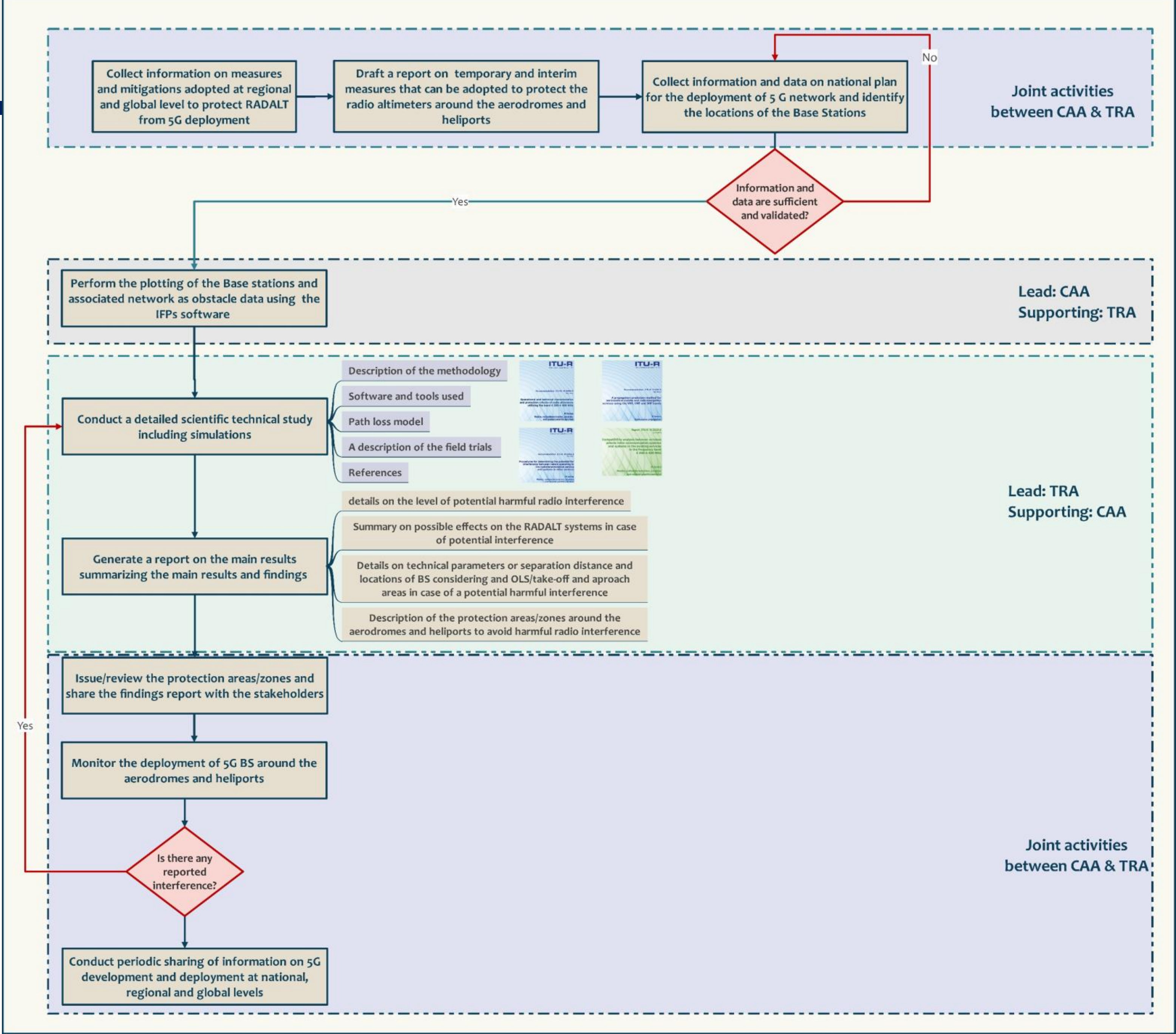
5G Devices used on board

5G devices used on board aircraft

- Issuing of safety notices or circulars to aircraft operators highlighting the potential interference that may be caused by user equipment used on board
- Define operational recommendations for aircraft operators and pilots related to the user equipment with 5G capabilities
  - Remind passengers that all portable electronic devices allowed for transport in checked baggage (including smartphones and other devices) should be turned off and protected from accidental activation
  - Remind passengers to set all portable electronic devices in the cabin and any carried on the aircraft to a non-transmitting mode or turn them off
  - Instruct crew to use 3G or 4G communication devices only when essential communication is required, such as during emergency medical service operations.
- Organize regular communications with aircraft operators and airspace users to share informaiton on the last development and any encountered interference during flights.
- Setup joint investigation committee between frequency spectrum management and Civil Aviation Authorities to analyse any reported interference by user equipment used on board.

Joint activities btw CAA and TRA

Overview of the main joint activities between Civil Aviation Authority (CAA) and Telecommunications Regulatory Authority (TRA)

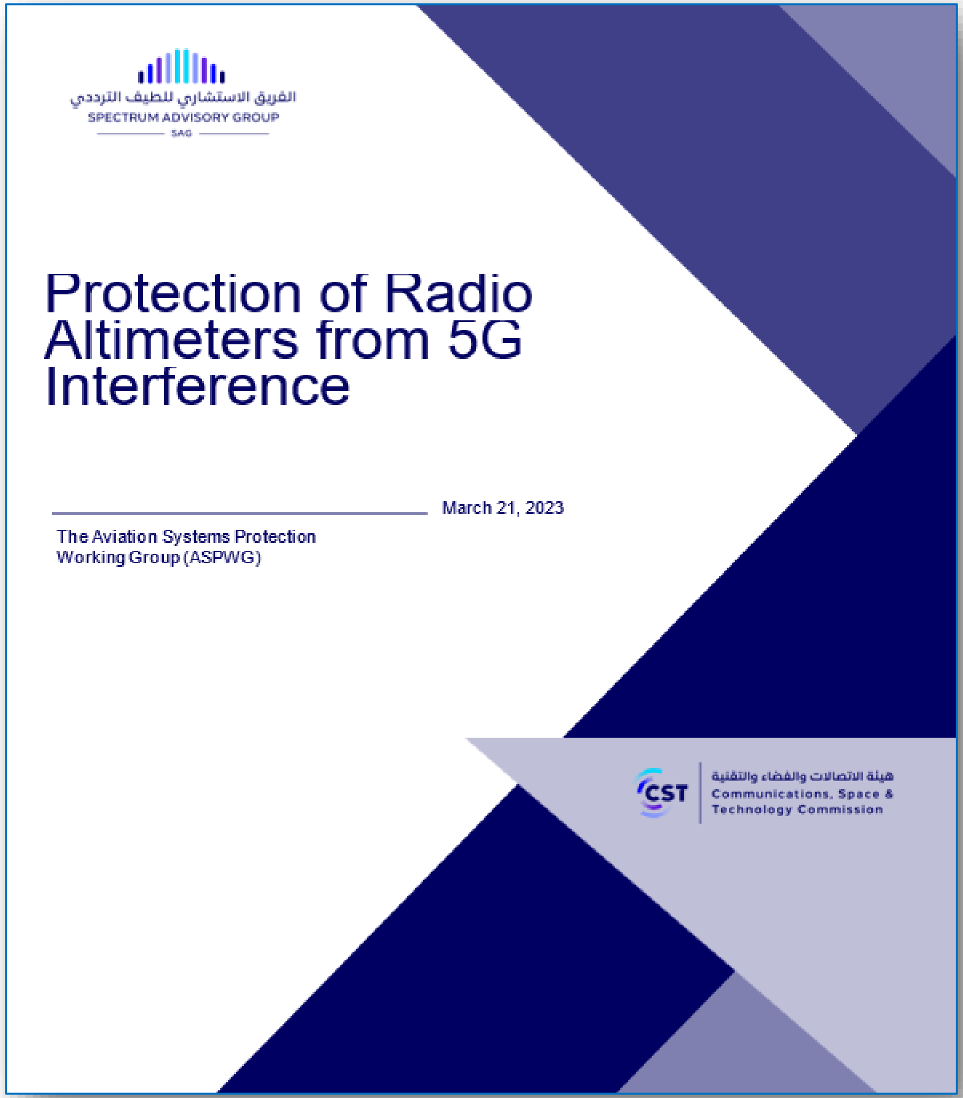


Adaptation of ICAO MID 5G Guidance

Development of Proposal for Protection areas around aerodrome and heliports

Fares ALZAHRANI

RADALT AG Team member (GACA-KSA)


الفريق الاستشاري للطيف الترددي
SPECTRUM ADVISORY GROUP
SAG

Protection of Radio Altimeters from 5G Interference

March 21, 2023

The Aviation Systems Protection Working Group (ASPWG)

هيئة الاتصالات والفضاء والتقنية
Communications, Space & Technology Commission

هيئة الاتصالات والفضاء والتقنية
Communications, Space & Technology Commission

Approach used to protect RADALT during 5G roll-out

- The Communications, Space, and Technology (CST) commission has authorized the n77 frequency band (3700-4000 MHz) for IMT fifth-generation New Radio (5Gnr) IMT services in the Kingdom of Saudi Arabia

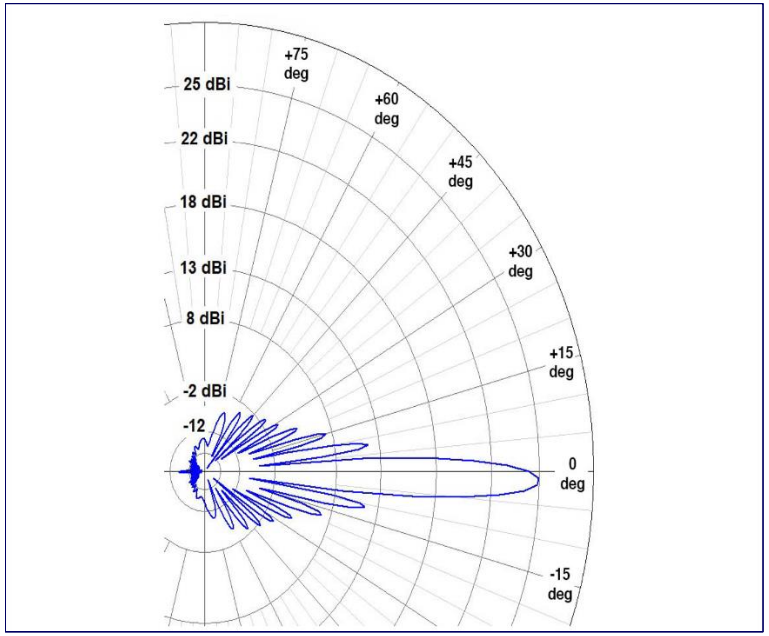
- Due to concerns raised around potential interference between 5G deployment and RADALT, the CST commission initiated a study to evaluate such risk and devise a mitigation plan considering ICAO MID 5G Guidance. Such plan comprises two main phases:
  - **namely interim operation phase with imposed precautionary protection around airport runways and heliports**, and
  - **permanent operation phase based on t he outcome of a detailed scientific test and measurement campaign and considering adopted specifications and standards at global level (ITU and ICAO).**

- The CST Spectrum Advisory Group (SGA) was instructed by the national frequency allocation committee to perform a technical study and provide recommendations for recommended protection criteria to be enforced in the Kingdom of Saudi Arabia during the interim operation phase, enabling the national roll-out of 5Gnr services in the newly allocated C-band frequencies.

5G Emissions and RadAlt Receiver Assumptions

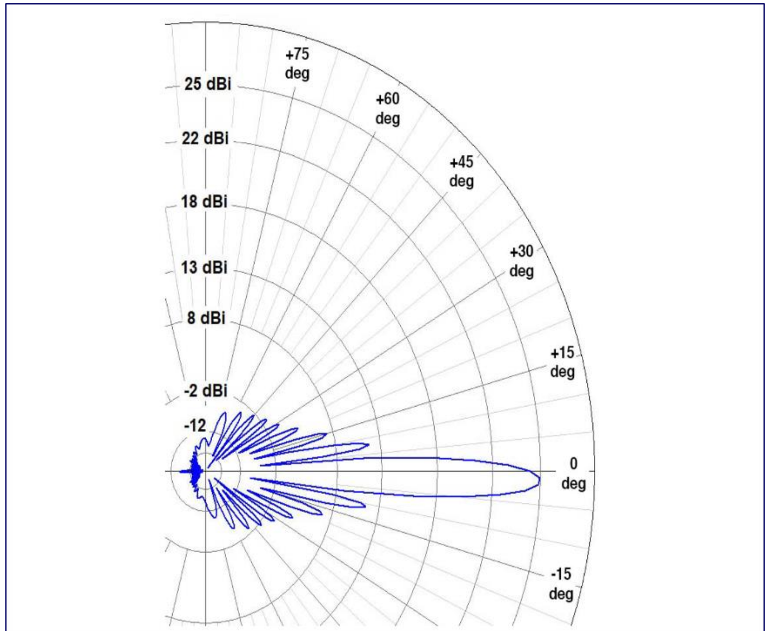
- The ASPWG contacted several original equipment manufacturers (OEM) of the 5G equipment expected to be deployed in the kingdom.

- The ASPWG considered Generic expected specifications and design information and publicly available measured data supplied by U.S. Department of Commerce National Telecommunications and Information Administration (NTIA). Most of the technical parameters assumed in the interim study was based on analysis and measurements presented in the NTIA.

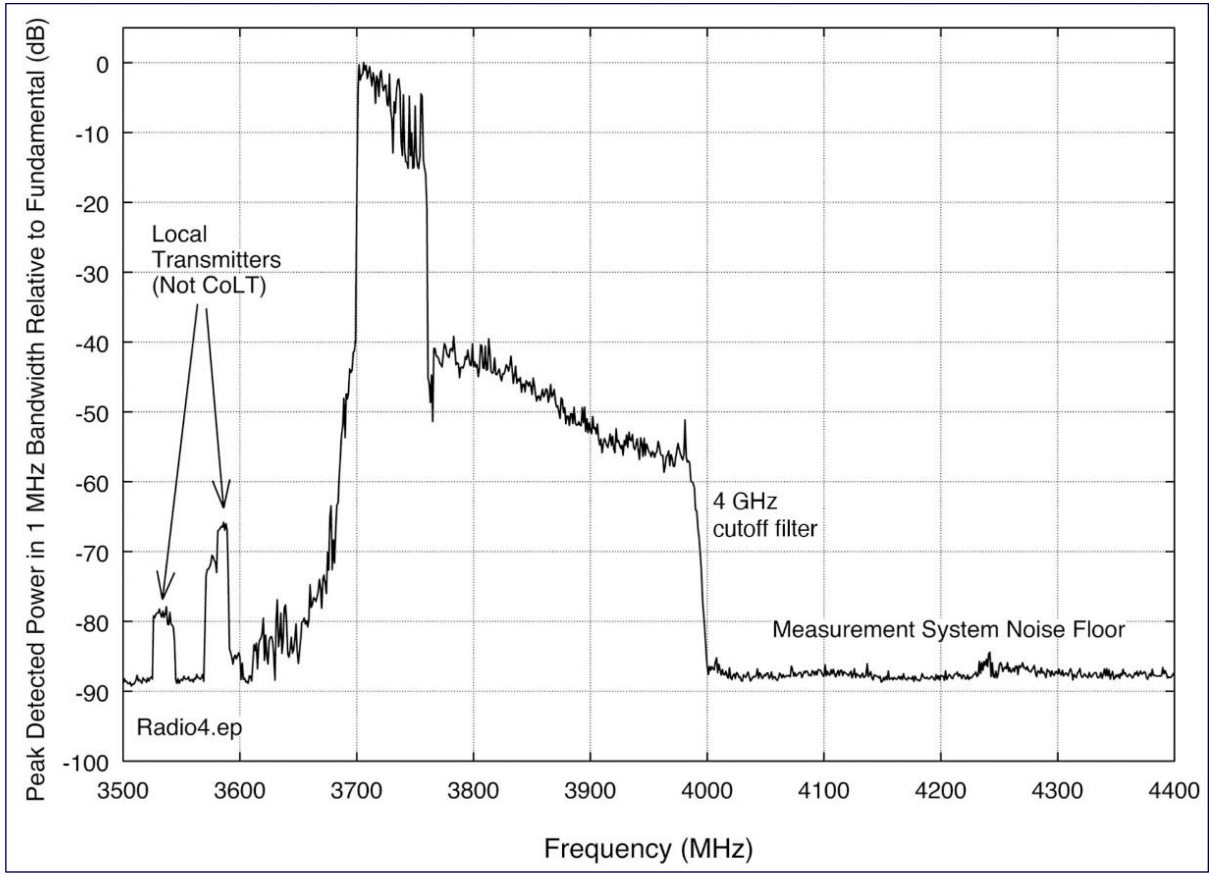


5G Emissions and RadAlt Receiver Assumptions

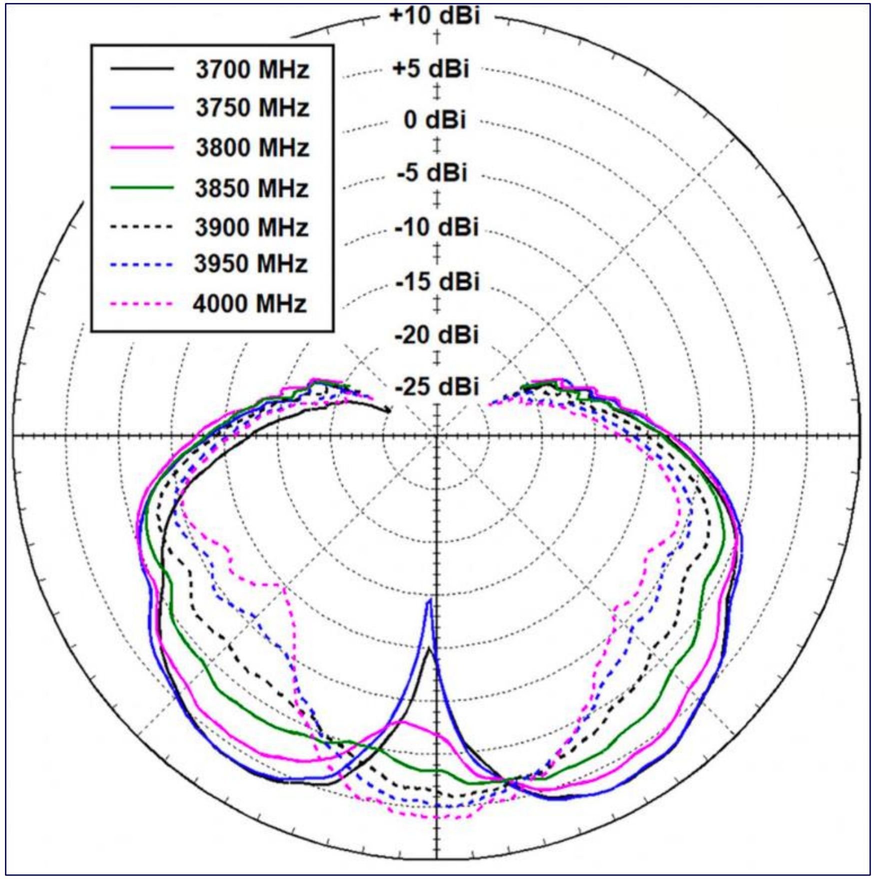
- In accordance with the 3GPP standard and confirmed with measurements by NTIA, the maximum boresight gain from a 5G 64T64R adaptive MIMO antenna array was assumed to be 24.5 dBi.
- A total channel power of 200 watts generated by the 5G base station transmitter is assumed
- A channel bandwidth of 100 MHz was found to be the standard operating mode for such 5G installation
- A maximum power spectral density (PSD) of +57.5 dBm/MHz is assumed to be upper limit of emission by the 5G transmit antenna array at the boresight direction.
- To account for worst case scenarios where the boresight gain of the antenna would be pointed directly at a low-level flying airplane during landing procedure, the maximum gain of the 5G base station antenna was used in the calculations.



Technical specifications and measured data of RADALT



Measured emission spectrum of a typical 5G base station (NTIA Report)

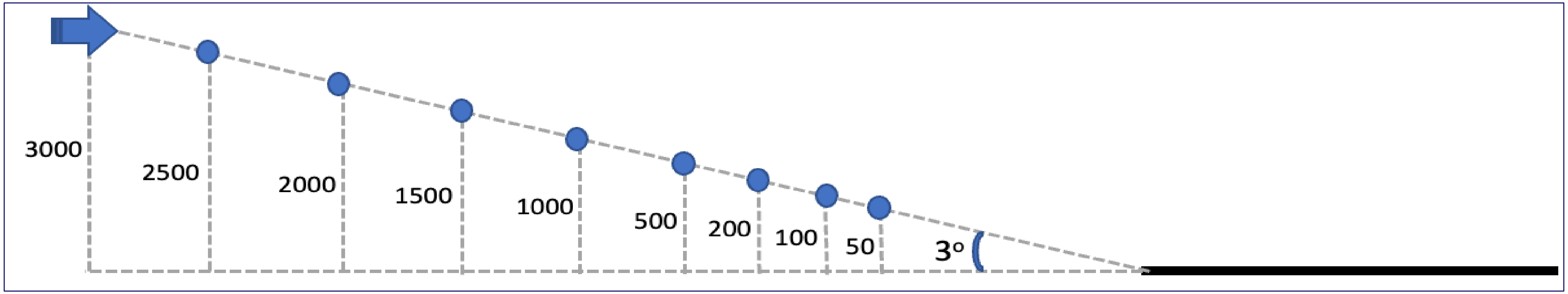


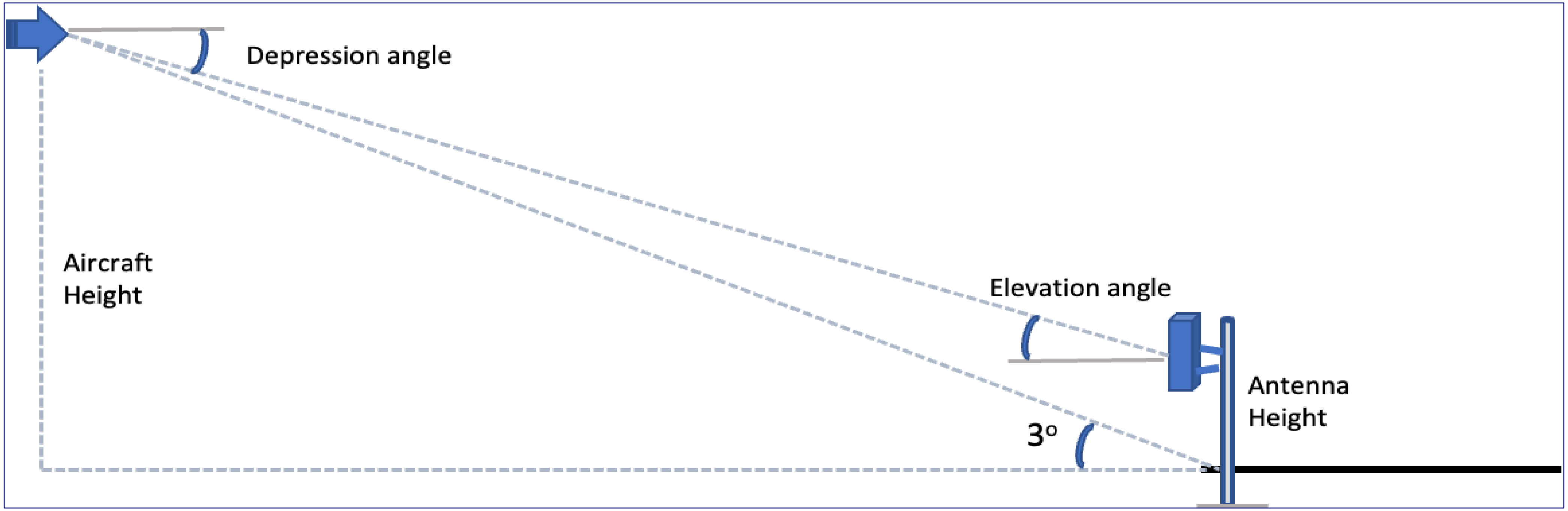
RadAlt antenna radiation pattern measurements (NTIA Report)

Factors considered in the study

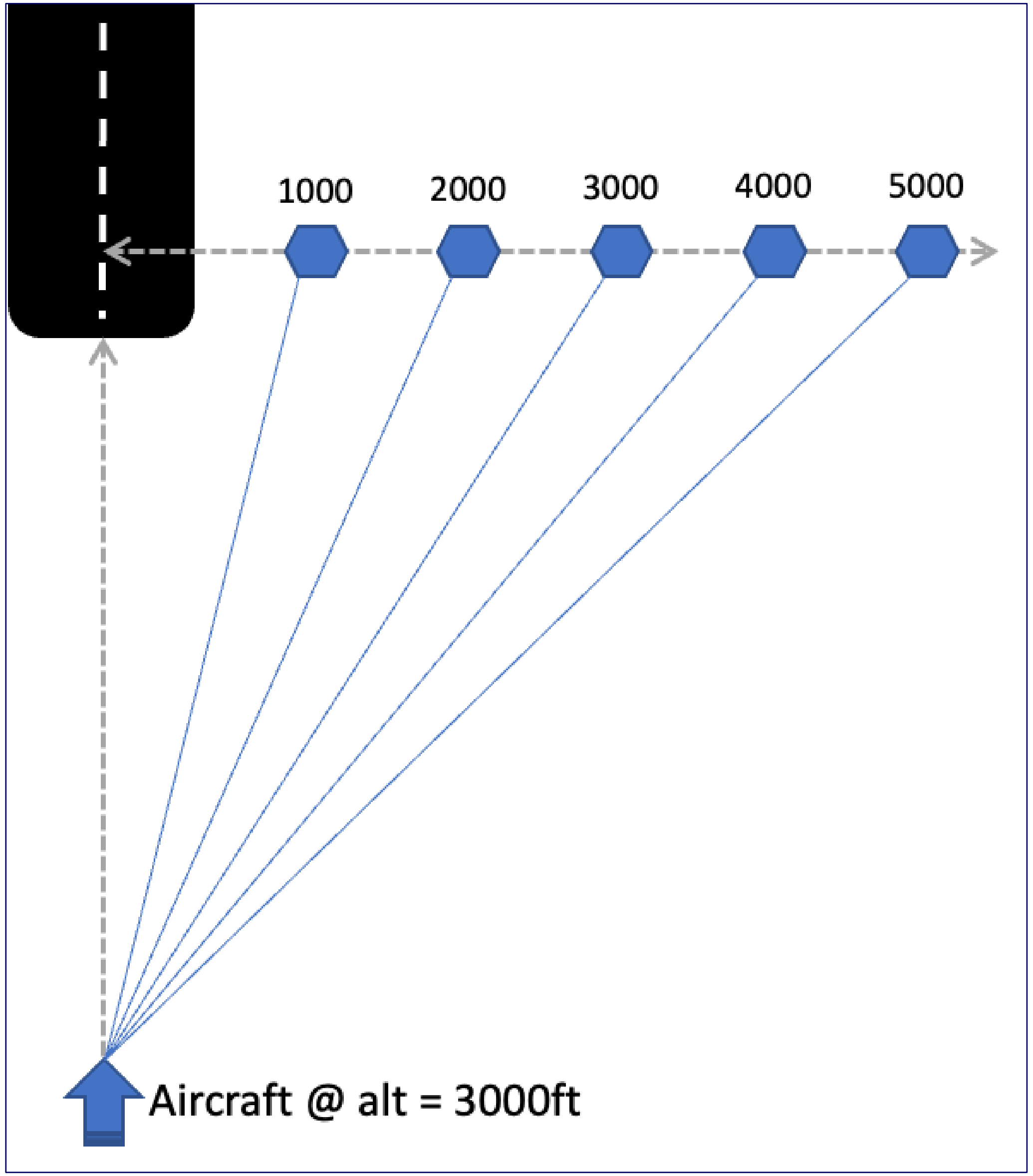
- Nature of front-end filtering and selection of the low noise amplifiers (LNA) at the front end of the radar
- ITU Recommendation ITU-R M.2059 [2] regulates the operational and technical characteristics of radio altimeters, the level of front-end filtering applied by RadAlt manufacturers
- The ITU-R M.2059 [2], out-of-band interference was given a lot of attention in this study due to the nature of the high-level of EIRP emitted by the 5G base stations in the allocated upper C-band frequency range, which is relatively close to the 4200-4400 MHz band. The most critical of such OOB interference is the receiver blocking requirements
- The ITU-R M.2059 [2] recommendation gives blocking specifications for several typical radio altimeters. It gives a worst-case blocking specification of -56 dBm at the RadAlt receiver

Fixed-Wing Aircraft Landing Scenario

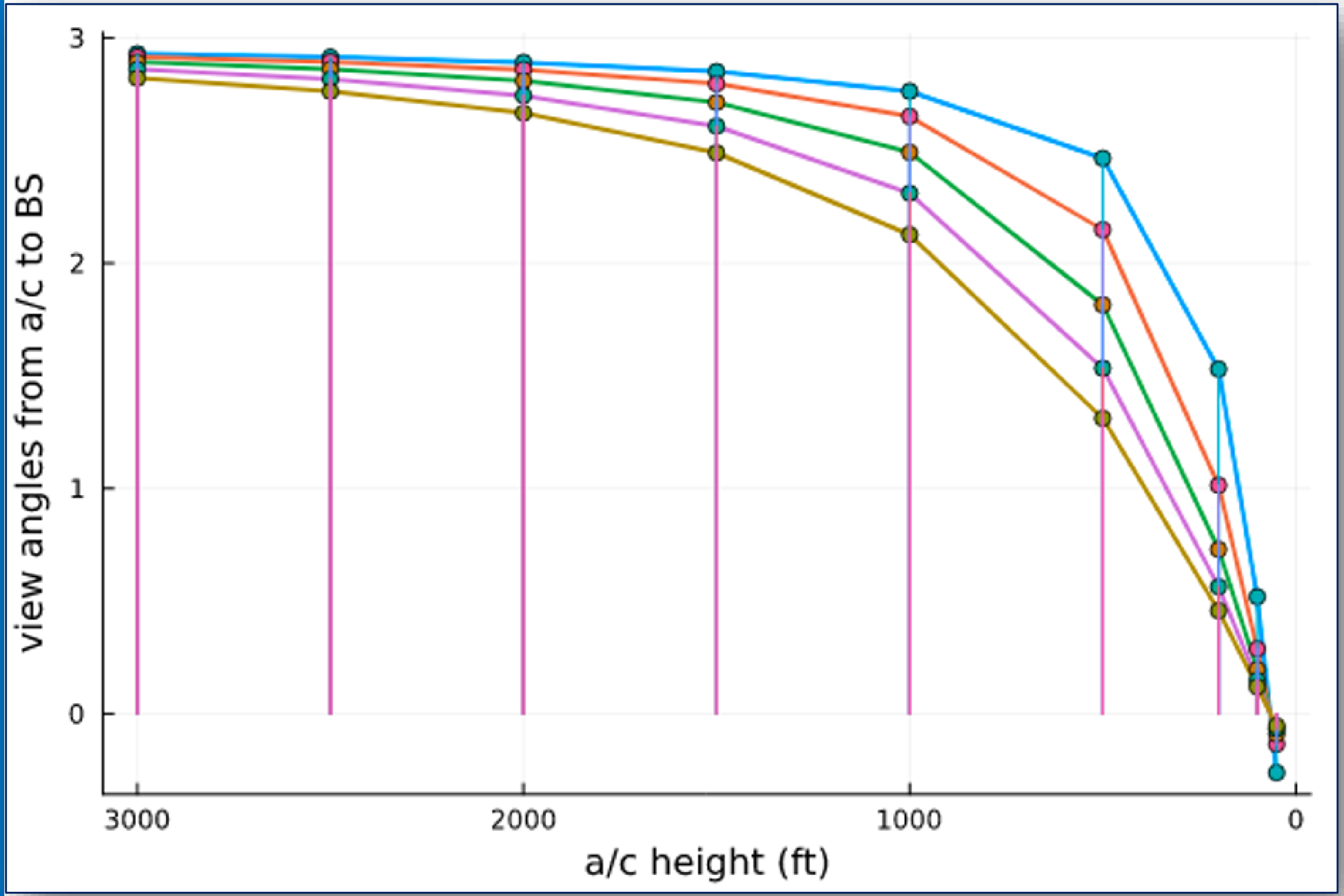




Fixed-Wing Aircraft Landing Scenario

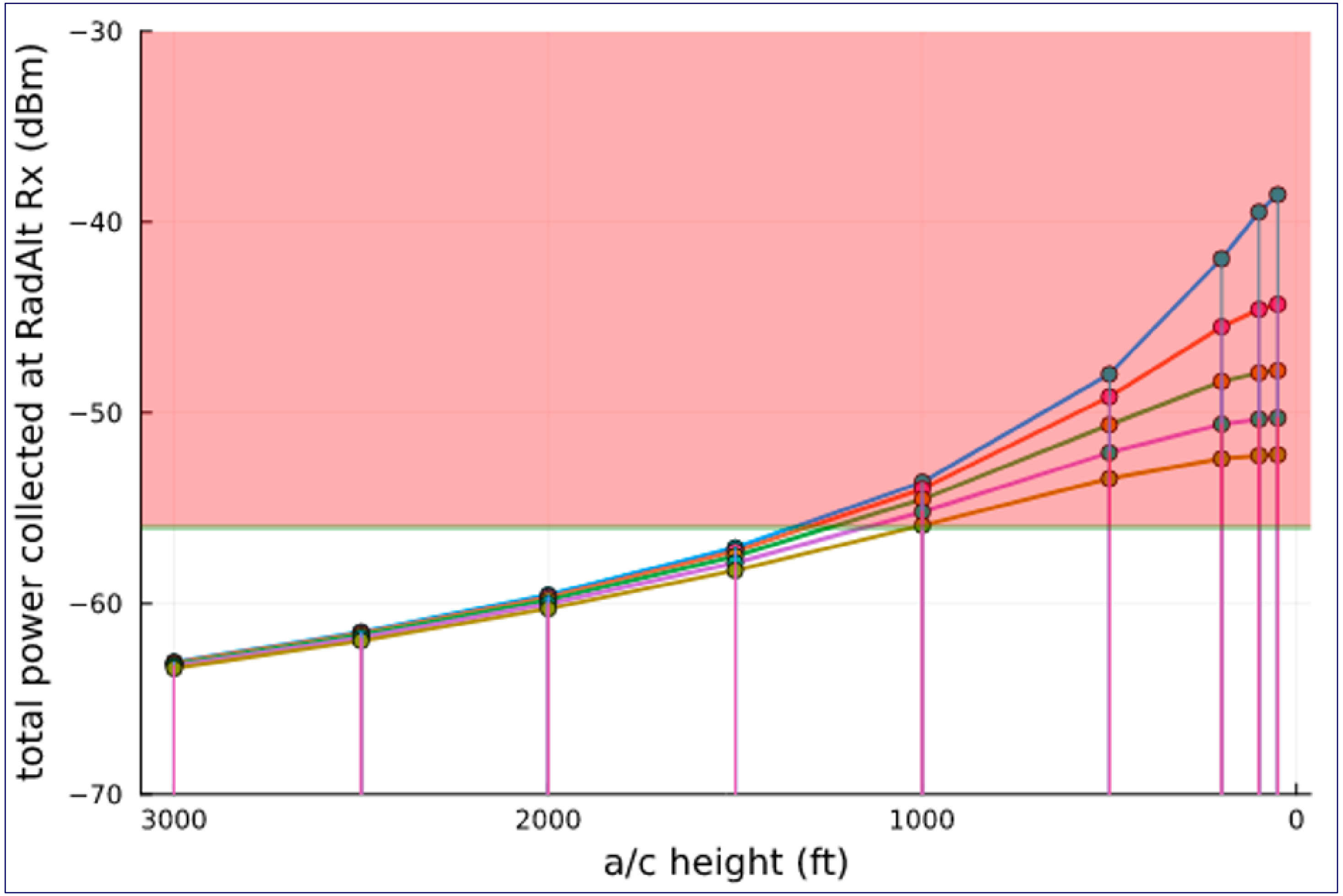


Depression and elevation angles initial results



- Close to full boresight gain from 5G base station antenna can illuminate the aircraft during landing procedure if no tilt-down assumption was made
- The RadAlt antenna gain is not more than -5 dBi at such angles

OOB interference power from the 5G

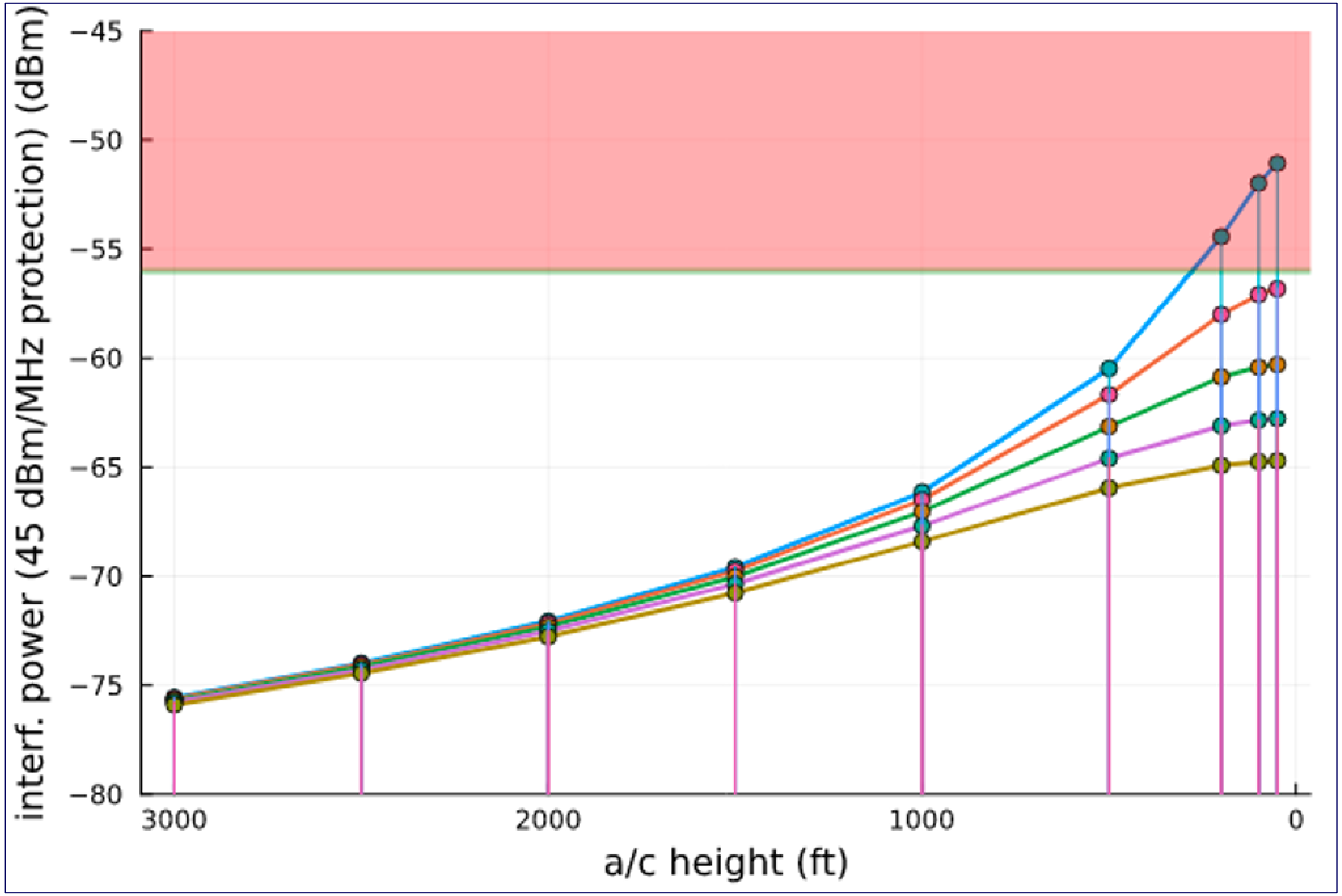


The calculations of the total OOB interference power from the 5G intentional emissions in the allocated frequency band reaching the front end of the RadAlt receiver. The Figure shows plots of the power at the RadAlt receiver expected to be caused by the various base station locations.

The assumed worst-case scenario 5G base station emissions can theoretically create a receiver blocking interference. The above computation was repeated for several lower EIRP emissions from 5G base stations.

It was found that a regulated lower power spectral density of 45 dBm/MHz can be a good strategy for the interim phase

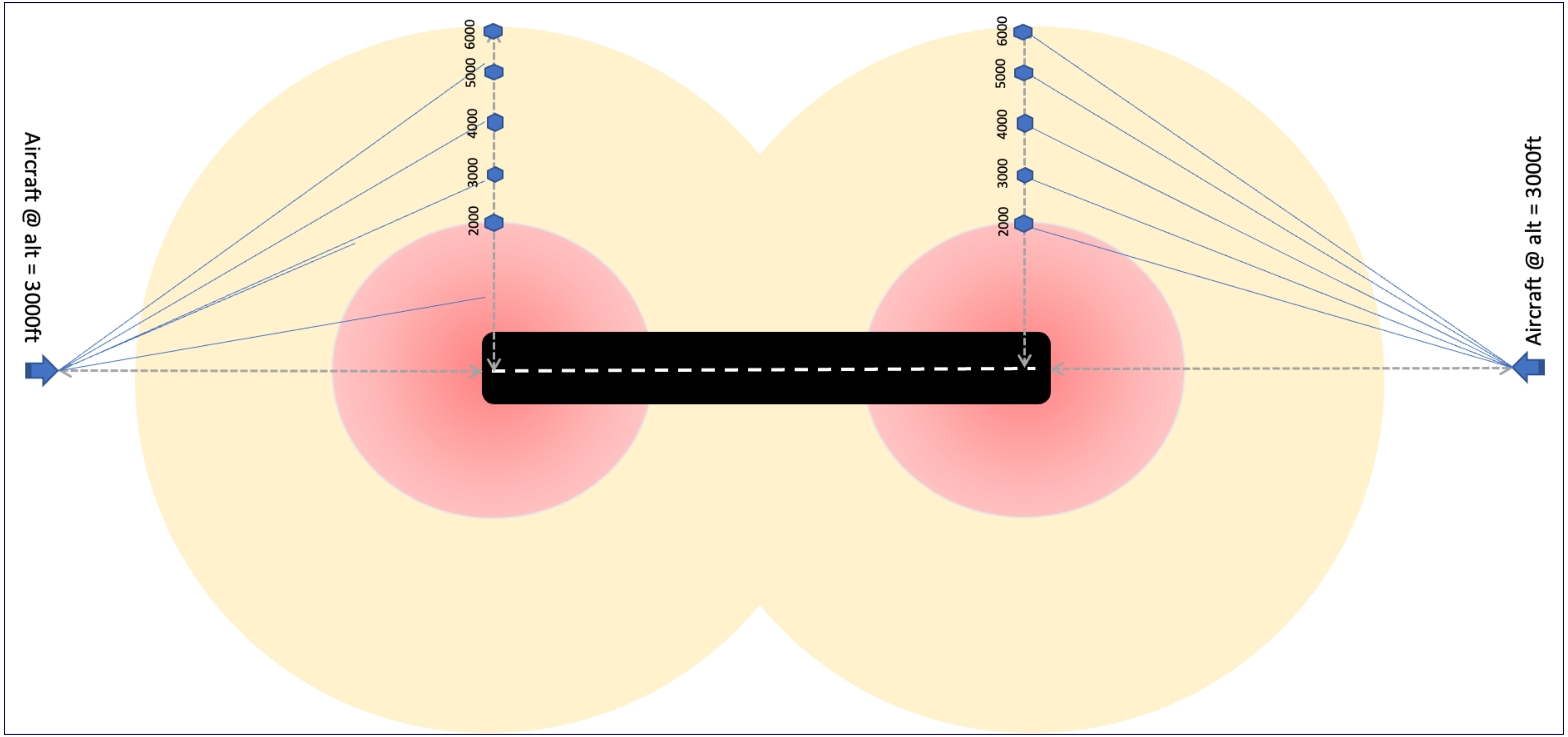
Recommended protection areas



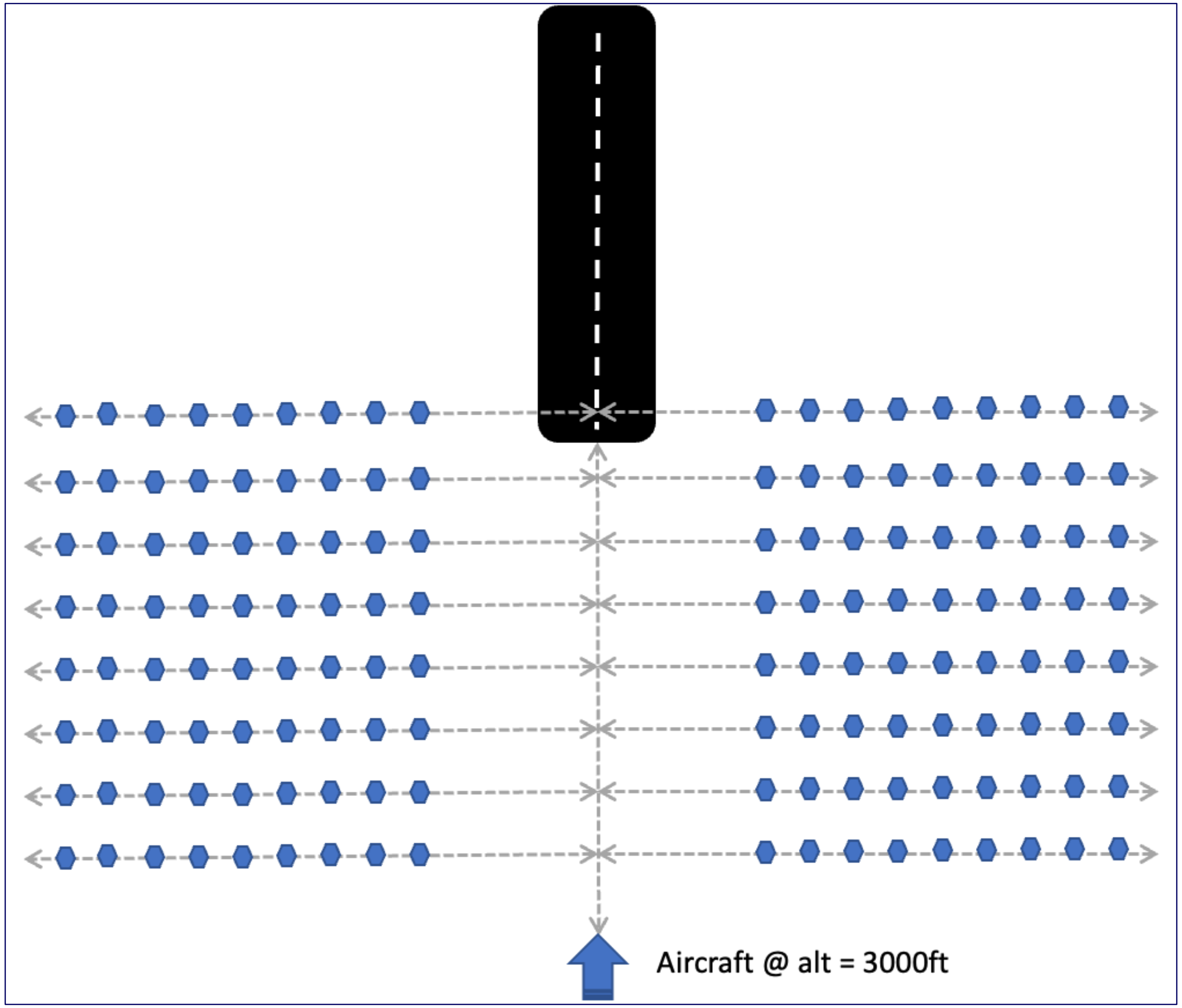
OOB interference power at RadAlt receiver (45 dBm/MHz protection).

The 45 dBm/MHz protection can greatly reduce the probability of interference power exceeding receiver blocking specification for worst-case RadAlt specification if no 5G base stations are within 2000 meters from runway threshold

Recommended exclusion and protection zones (45 dBm/MHz)



Recommended exclusion and protection zones (45 dBm/MHz)



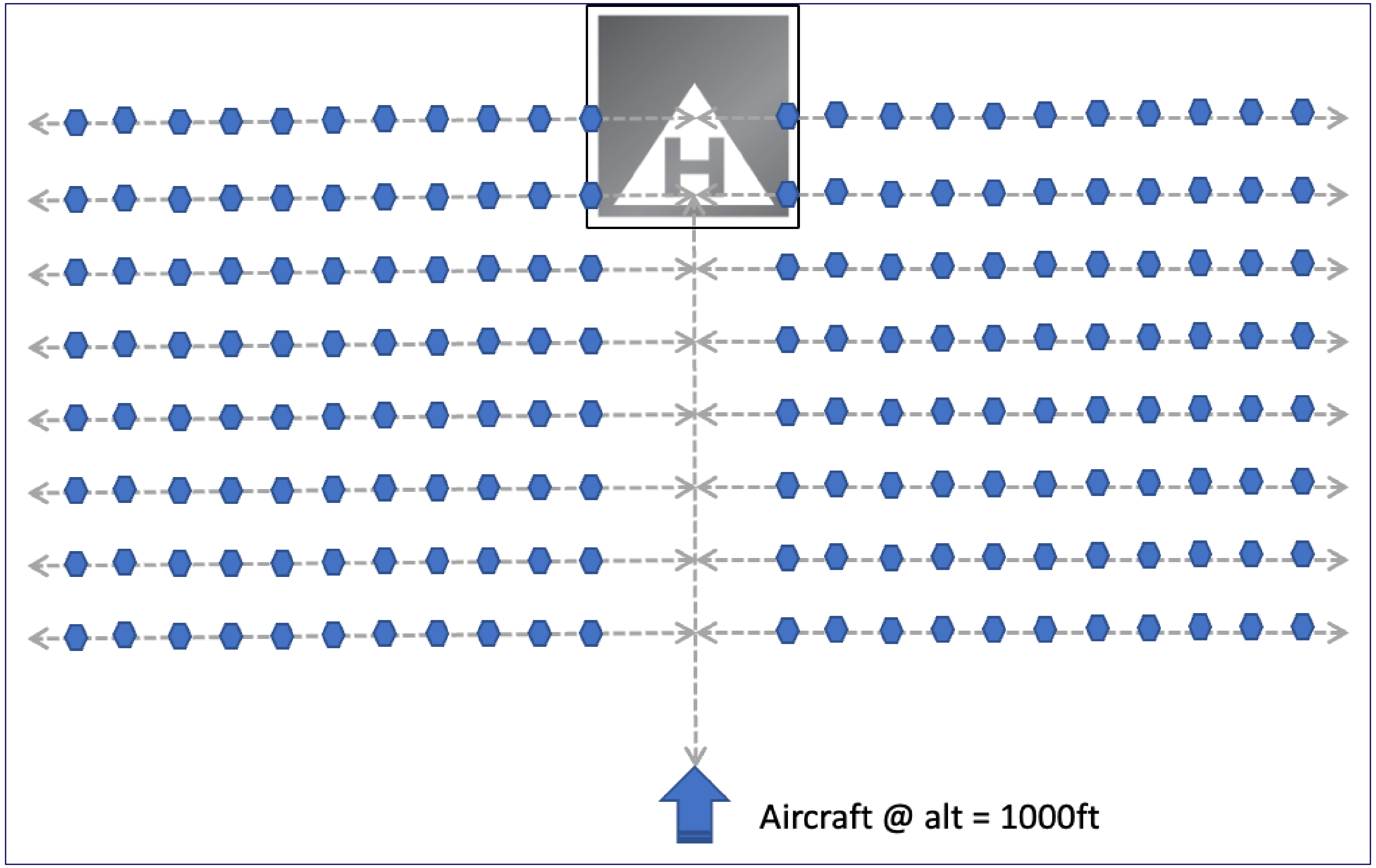
Rotary-Wing Aircraft (Helicopter) Landing Scenario

- Helicopter operations are low level operations and require constant interaction between pilot and flight systems.

- Normal landing approach in a helicopter case starts much closer to the ground (under 500 ft) and follows a descent angle between 7 and 12 degrees.

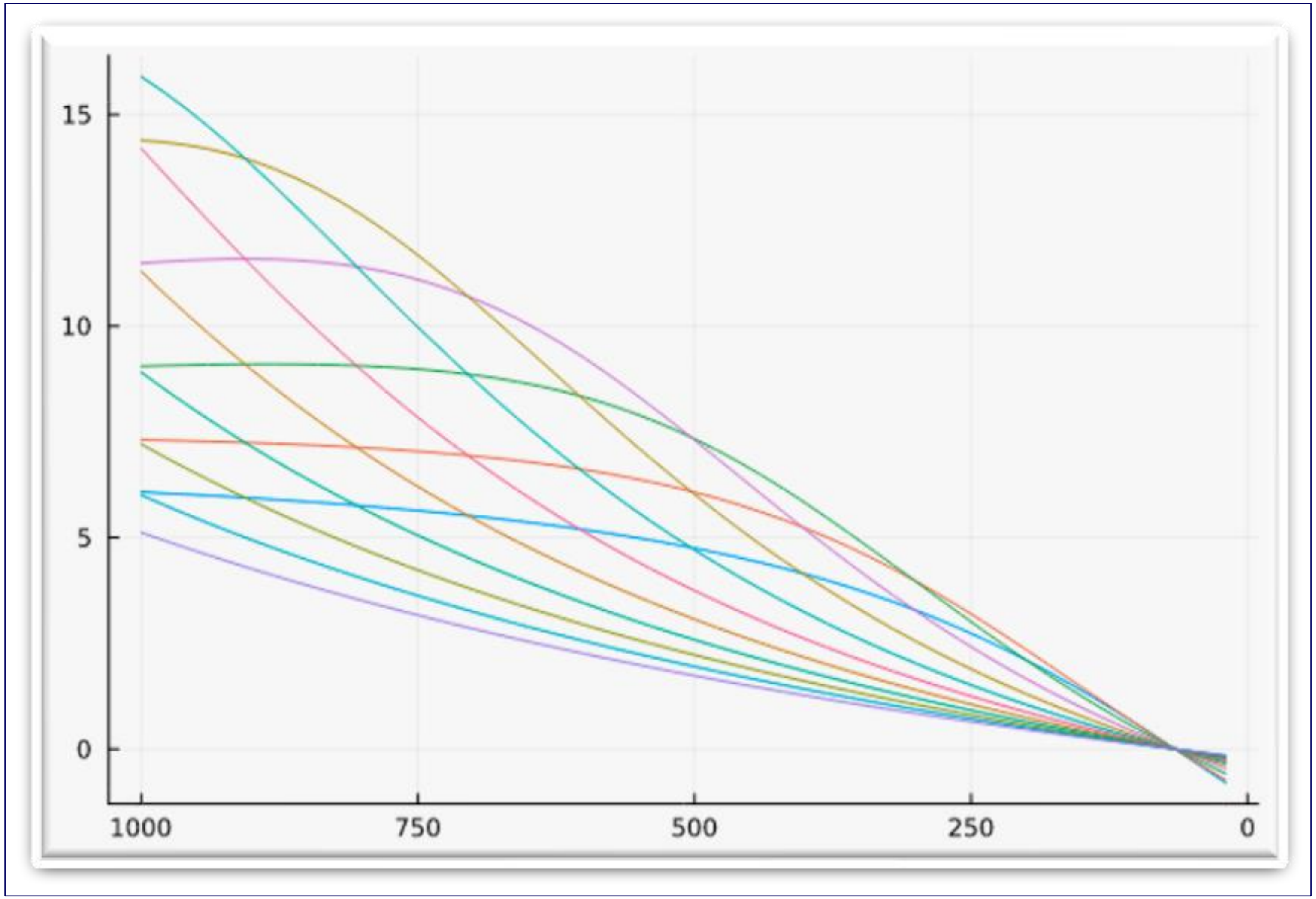
- A shallow approach follows a glide angle of 3 to 5 degrees, whereas a steep approach follows an angle of 13 to 15 degrees. All abnormal approach procedures are highly manual and require good visibility conditions.

- Although during emergencies and medical evacuation it is expected that helicopter can land in non-designated area and in close proximity to base station transmitter, taking such scenarios in this study is unrealistic and other means and measures of safety precautions must be considered.



The 5G base station locations considered in the simulation were distributed alongside the approach line to a heliport with constant separations. 20-meter base station antenna heights were assumed

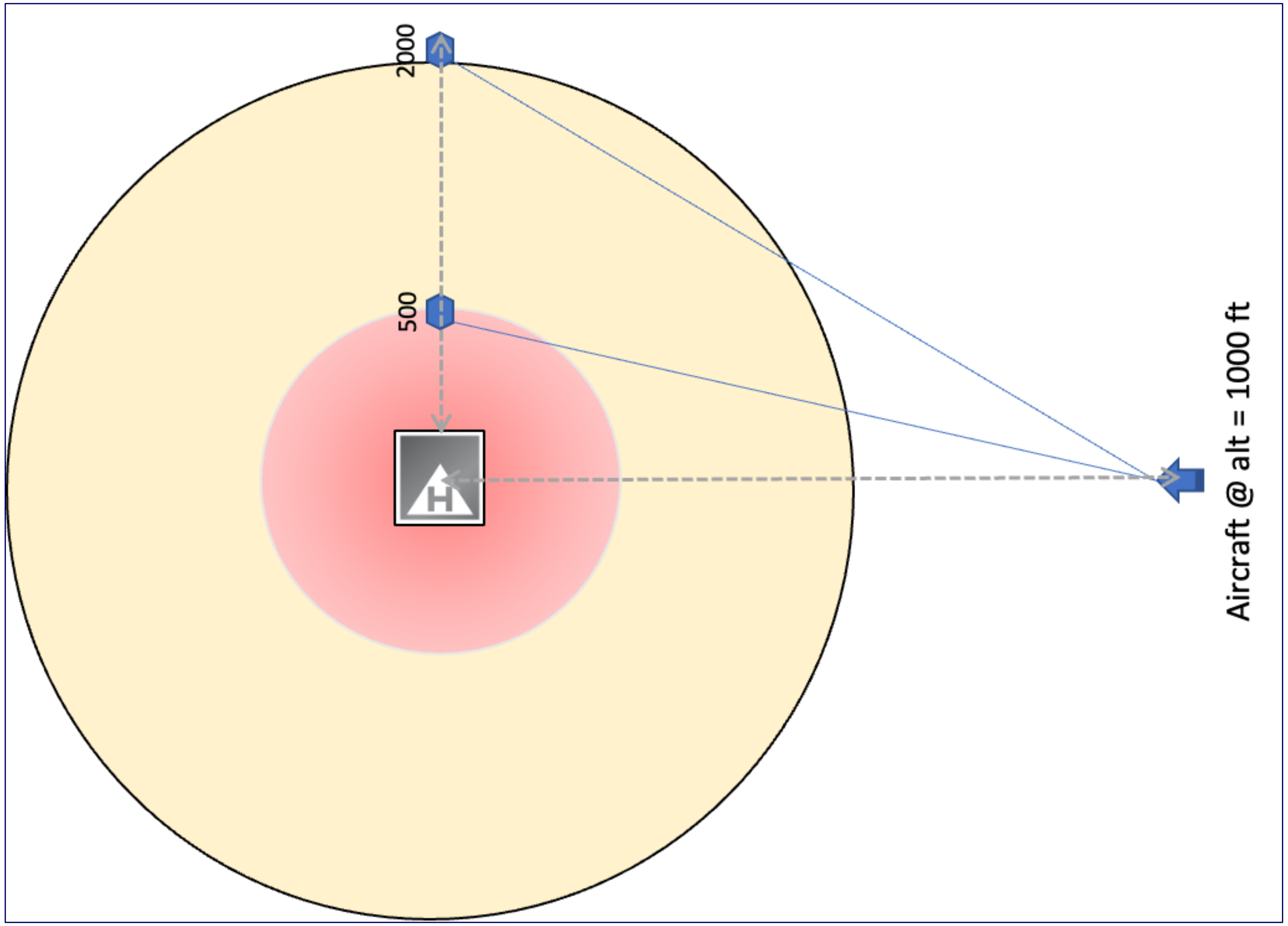
Depression and elevation angles



The depression and elevation angles during such approach, angles were computed for nearest and furthest base stations from an aircraft altitude of 1000 ft until touchdown during normal landing procedure

A depression angle of less than 10 degrees should be assumed for the line-of-sight between RadAlt antenna and base station antenna. The RadAlt antenna gain in such case is always below 0 dBi. The base station antenna gain, on the other hand, is greatly reduced at such greater angles.

Proposal for protection areas around heliports



Assuming a maximum emitted power spectral density of 45 dBm/MHz and antenna radiation pattern modes that points the emitted energy below horizon, it was found that an exclusion zone of 500 meter from Heliport boundary and a protection zone of 2000 meters from Heliport boundary is sufficient during the interim deployment phase

Q & A