|  |  |  |
| --- | --- | --- |
| U.S. Radiocommunications Sector  Fact Sheet | | |
| **Working Party:** ITU-R WP 5B | **Document No:** USWP5B29-22 | |
| **Ref:** 5B/531 Annex 15 on AI 1.7 | **Date:** June 8, 2022 | |
| **Document Title:** WD-PDN Report ITU-R M.[SPACE-VHF] for WRC-23 AI 1.7, Space-based aeronautical VHF communications in 117.975-137 MHz frequency band | | |
| **Author(s)/Contributors(s):**  Chris Tourigny  FAA Spectrum Engineering Services  Sandra Wright  FAA Spectrum Engineering Services  Michael Tran  MITRE | | Phone: 202-267-3071  Email: chris.tourigny@faa.gov  Phone: 202-603-7094  Email: sandra.a.wright@faa.gov  Phone: 703-983-1295  Email: mtran@mitre.org |
| **Purpose/Objective:** This contribution provides updates to the WD-PDN Report for WRC-23 AI 1.7 pursuant to Resolution 428 (WRC-19), on a possible new AMS(R)S allocation to accommodate the relay of VHF communications in 117.975-137 MHz frequency band. | | |
| **Abstract:** Pursuant to Resolution 428 (WRC-19), this contribution provides updates to the WD-PDN Report for WRC-23 AI 1.7 on a possible new AMS(R)S allocation to accommodate the relay of VHF communications in 117.975-137 MHz frequency band. | | |

|  |  |
| --- | --- |
| **Radiocommunication Study Groups** |  |
|  |  |
|  |  |
| Source: Document 5B/531 – Annex 15  Subject: WRC-23 AI 1.7 Report | **Document 5B/** |
| **11 July 2022** |
| **English only** |
| United States of America | |
| working document towards a Preliminary draft new report ITU-r m.[space-vhf]  **Space-based aeronautical VHF communications in 117.975-137 MHz frequency band** | |
|  | |

**Introduction**

Pursuant to Resolution 428 (WRC-19), this contribution provides updates to the WD-PDN Report for WRC-23 AI 1.7 on a possible new AMS(R)S allocation to accommodate the relay of VHF communications in 117.975-137 MHz frequency band.

Attachment: 1

ATTACHMENT

working document towards a preliminary draft new report itu-R m.[space-vhf]

WORKING DOCUMENT RELATED TO WRC-23 AGENDA ITEM 1.7

**Space-based aeronautical VHF communications in  
 117.975-137 MHz frequency band**

Scope

[To be populated later]

Glossary of abbreviations

ADS-B: Automatic dependent surveillance – broadcast

AM(R)S: Aeronautical mobile (route) service

AMS(R)S: Aeronautical mobile satellite (route) service

ANSP: Air navigation service provider

ATC: Air traffic control

DCPC: Direct controller to pilot communications

EPFD: Effective power flux density

FIR: Flight information region

ICAO: International Civil Aviation Organization

LEO: Low earth orbit

MSS: Mobile satellite service

RR: Radio Regulations

SATCOM Satellite communications

SAW: Sound acoustic wave

SOS: Space operation service

SRS: Space research service

VDES: VHF data exchange system

VDL: VHF data link

Relevant ITU-R Recommendations and Reports

Recommendations

[ITU-R M.1231-0](https://www.itu.int/rec/R-REC-M.1231-0-199702-I/en) Interference criteria for space-to-Earth links operating in the mobile-satellite service with non-geostationary satellites in the 137-138 MHz band

[ITU-R M.1232-0](https://www.itu.int/rec/R-REC-M.1232-0-199702-I/en) Sharing criteria for space-to-Earth links operating in the mobile-satellite service with non-geostationary satellites in the 137-138 MHz band

[ITU-R M.2092-0](https://www.itu.int/rec/R-REC-M.2092-0-201510-I/en) Technical characteristics for a VHF data exchange system in the VHF maritime mobile band

[ITU-R P.531-14](https://www.itu.int/rec/R-REC-P.531-14-201908-I/en) Ionospheric propagation data and prediction methods required for the design of satellite networks and systems

ITU-R SA-363-5 Space Operation Systems

[ITU-R SA.609-2](https://www.itu.int/rec/R-REC-SA.609-2-200603-I/en) Protection criteria for radiocommunication links for manned and unmanned near-Earth research satellites

ITU\_R SA.1026-5 Aggregate interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit

[ITU-R SA.1027-6](https://www.itu.int/rec/R-REC-SA.1027-6-201908-I/en) Sharing criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit

Report

[ITU-R SA.2426](https://www.itu.int/pub/R-REP-SA.2426-2018) Technical characteristics for telemetry, tracking and command in the space operation service below 1 GHz for non-GSO satellites with short duration missions

# Description of space-based VHF communications concept

## General concept

Space-based VHF communication is a concept in which aircraft operating in remote regions and oceanic areas provide communications from the aircraft to air traffic control (ATC) via satellite using VHF frequencies within the 117.975-137 MHz range.

This concept, when implemented, is expected to enhance air traffic management and flight operations in oceanic and remote airspace and will complement current aviation use of satellite-based navigation and surveillance technologies.

While currently there are other long-range communication systems, such as HF and SATCOM, available to facilitate communications between aircraft and ATC in remote and oceanic airspace, the performance of these current systems is not adequate to safely support close aircraft-to-aircraft separation in a similar fashion as to what is being applied in dense airspace where terrestrial-based VHF communications infrastructure is predominant. Therefore, this leads to constraints in airspace capacity and efficiency in oceanic and remote areas, where it is not practical to deploy VHF terrestrial infrastructure.

Figure 1 is an illustration of the space-based VHF communication concept. The space segment is able to receive and transmit to standard VHF radios already installed onboard aircraft and is designed to behave as if it was just another VHF-tower located in the sky, with a larger footprint than terrestrial towers.

Figure 1

The space-based VHF communication concept

Diagram

Description automatically generated

This report provides studies on the use of low-Earth orbiting satellites to relay air traffic control messages between the pilot and the controller. Operation of the space-based VHF system within the frequency band 117.975-137 MHz, currently allocated to the aeronautical mobile (Route) service (AM(R)S), aims to utilize existing on-board VHF radios used for terrestrial-based VHF communications, thus being compliant with ITU-R Resolution 428.

A new allocation to the aeronautical mobile satellite (Route) service (AMS(R)S) within this frequency band 117.975-137 MHz is being considered under the agenda item 1.7 of the WRC-23.

AMS(R)S links between aircraft and satellite (shown as “Satellite VHF COM” in Figure 1) will operate within the frequency band 117.975-137 MHz and are the subject of considerations contained in this Report. Feeder links of AMS(R)S systems between earth station and satellite are not implemented within the VHF frequency band and may be accommodated in the fixed-satellite service, therefore consideration of feeder links are out of the scope of this Report.

## High-level objectives

The following objectives and characteristics are considered for the space-based VHF system under study:

– The applications provided are within AMS(R)S communications.

• Voice is the most critical VHF communication application in terms of safety and dependability. It is studied within the sub-band 117.975-136 MHz.

• VHF datalink (VDL) Mode 2 is studied within the sub-band 136-137 MHz, as channels currently assigned worldwide to this application are within this range.

– No change is made on:

• aircraft avionic equipment.

• terrestrial base stations specifications, and configuration of base stations located in flight information regions (FIRs) which do not make use of the space-based VHF service.

– No or minimal change would be made on:

• operational aspects for pilots and controllers.

• terrestrial base stations configuration in FIRs with space-based VHF service.

The service area covered by the space-based VHF system will depend on satellite constellation architecture and design. It can be limited to one or several FIRs, regional or global. The space-based VHF system is primarily intended to cover oceanic and remote areas where terrestrial service is not available, but it could also be used to backup terrestrial stations in case they are affected by a catastrophic event.

To achieve the above objectives, the following tasks were carried out.

– ITU-R carried out sharing and compatibility studies for the co-existence between potential new AMS(R)S systems operating in the frequency band 117.975-137 MHz (Earth-to-space and space-to-Earth), providing voice and data applications as mentioned above, and existing primary in-band and adjacent band services.

– Based on the outcome of the studies, technical and regulatory proposals are provided in the summary section towards a possible new AMS(R)S allocation within the frequency band 117.975‑137 MHz.

– ICAO participation was beneficial in ITU-R sharing and compatibility studies to provide aeronautical operational requirements, between the new AMS(R)S systems and the existing aeronautical systems, and other relevant available operational characteristics.

# Current use of the VHF frequency band 117.975-137 MHz

Below is the Radio Regulations (RR) table of allocations and associated footnotes for the band 117.975-137 MHz. It shows that services allocated in this band on a primary basis are:

– Aeronautical mobile (R) service throughout the entire frequency band.

– Aeronautical mobile (OR) service in the frequency bands 132-136 MHz and 136-137 MHz in certain countries listed respectively in RR Nos. **5.201** and **5.202**.

|  |  |  |
| --- | --- | --- |
| Allocation to Services | | |
| Region 1 | Region 2 | Region 3 |
| 117.975-137 AERONAUTICAL MOBILE (R)  5.111 5.200 5.201 5.202 | | |

5.111 The carrier frequencies 2 182 kHz, 3 023 kHz, 5 680 kHz, 8 364 kHz and the frequencies 121.5 MHz, 156.525 MHz, 156.8 MHz and 243 MHz may also be used, in accordance with the procedures in force for terrestrial radiocommunication services, for search and rescue operations concerning manned space vehicles. The conditions for the use of the frequencies are prescribed in Article **31**.

The same applies to the frequencies 10 003 kHz, 14 993 kHz and 19 993 kHz, but in each of these cases emissions must be confined in a band of  3 kHz about the frequency.     (WRC‑07)

5.200 In the band 117.975-137 MHz, the frequency 121.5 MHz is the aeronautical emergency frequency and, where required, the frequency 123.1 MHz is the aeronautical frequency auxiliary to 121.5 MHz. Mobile stations of the maritime mobile service may communicate on these frequencies under the conditions laid down in Article **31** for distress and safety purposes with stations of the aeronautical mobile service.     (WRC‑07)

5.201 *Additional allocation:*in Armenia, Azerbaijan, Belarus, Bulgaria, Estonia, the Russian Federation, Georgia, Hungary, Iran (Islamic Republic of), Iraq (Republic of), Japan, Kazakhstan, Mali, Mongolia, Mozambique, Uzbekistan, Papua New Guinea, Poland, Kyrgyzstan, Romania, Senegal, Tajikistan, Turkmenistan and Ukraine, the frequency band 132-136 MHz is also allocated to the aeronautical mobile (OR) service on a primary basis. In assigning frequencies to stations of the aeronautical mobile (OR) service, the administration shall take account of the frequencies assigned to stations in the aeronautical mobile (R) service.     (WRC‑19)

5.202 *Additional allocation:* in Saudi Arabia, Armenia, Azerbaijan, Bahrain, Belarus, Bulgaria, the United Arab Emirates, the Russian Federation, Georgia, Iran (Islamic Republic of), Jordan, Mali, Oman, Uzbekistan, Poland, the Syrian Arab Republic, Kyrgyzstan, Romania, Senegal, Tajikistan, Turkmenistan and Ukraine, the frequency band 136-137 MHz is also allocated to the aeronautical mobile (OR) service on a primary basis. In assigning frequencies to stations of the aeronautical mobile (OR) service, the administration shall take account of the frequencies assigned to stations in the aeronautical mobile (R) service.     (WRC‑19)

# Current Use of the frequency bands adjacent to 117.975-137 MHz

## Radiocommunication services operating in the 108-117.975 MHz frequency band based on the RR Table of Allocations

Below is the RR table of allocations and associated footnotes for the frequency band 108-117.975 MHz. It shows that services allocated in this band on a primary basis are:

– Aeronautical radio navigation service

– Aeronautical mobile (R) service.

|  |  |  |
| --- | --- | --- |
| Allocation to Services | | |
| Region 1 | Region 2 | Region 3 |
| 108-117.975 MHz AERONAUTICAL RADIONAVIGATION  5.197 5.197A | | |

5.197 *Additional allocation:* in the Syrian Arab Republic, the band 108-111.975 MHz is also allocated to the mobile service on a secondary basis, subject to agreement obtained under No. **9.21**. In order to ensure that harmful interference is not caused to stations of the aeronautical radionavigation service, stations of the mobile service shall not be introduced in the band until it is no longer required for the aeronautical radionavigation service by any administration which may be identified in the application of the procedures invoked under No. **9.21**.    (WRC‑12)

5.197A *Additional allocation:*  the band 108-117.975 MHz is also allocated on a primary basis to the aeronautical mobile (R) service, limited to systems operating in accordance with recognized international aeronautical standards. Such use shall be in accordance with Resolution **413 (Rev.WRC‑07)**\*. The use of the band 108-112 MHz by the aeronautical mobile (R) service shall be limited to systems composed of ground-based transmitters and associated receivers that provide navigational information in support of air navigation functions in accordance with recognized international aeronautical standards.     (WRC-07)

## Radiocommunication services operating in the frequency band 137‑143.6 MHz based on the Radio Regulations table of allocations

Below is the RR table of allocations and associated footnotes for the frequency band 137-143.6 MHz. It shows that services allocated in this band on a primary basis are:

Primary services in the frequency band 137-138 MHz:

– Aeronautical mobile (OR) service in certain countries under RR No. **5.206**

– Broadcasting service in Australia under RR No. **5.207**

– Fixed service in certain countries under RR No. **5.204** and No. **5.205**

– Meteorological satellite service (space-to-Earth)

– Mobile satellite service (space-to-Earth)

– Mobile service in certain countries under RR No. **5.204** and No. **5.205**

– Space operation service (space-to-Earth)

– Space research service (space-to-Earth)

Primary services in the frequency band 138-143.6 MHz:

– Aeronautical mobile (OR) service in Region 1

– Broadcasting service in Australia under RR No. **5.207**

– Fixed service in Region 2, Region 3, and certain countries in Region 1 under RR No. **5.212** and No. **5.214**

– Land mobile service in certain countries in Region 1 under RR No. **5.211**

– Mobile service in Region 2, Region 3, and certain countries in Region 1 under RR No. **5.212**

– Maritime mobile service in certain countries in Region 1 under RR No. **5.211**

– Radio location service in Region 2 and in China under RR No. **5.213**

|  |  |  |
| --- | --- | --- |
| Allocation to Services | | |
| Region 1 | Region 2 | Region 3 |
| 137-137.025 SPACE OPERATION (space-to-Earth) 5.203C  METEOROLOGICAL-SATELLITE (space-to-Earth)  MOBILE-SATELLITE (space-to-Earth) 5.208A 5.208B 5.209  SPACE RESEARCH (space-to-Earth)  Fixed  Mobile except aeronautical mobile (R)  5.204 5.205 5.206 5.207 5.208 | | | |
| 137.025-137.175 MHz SPACE OPERATION (space-to-Earth) 5.203C  METEOROLOGICAL-SATELLITE (space-to-Earth)  SPACE RESEARCH (space-to-Earth)  Fixed  Mobile except aeronautical mobile (R)  Mobile-satellite (space-to-Earth) 5.208A 5.208B 5.209  5.204 5.205 5.206 5.207 5.208 | | |
| 137.175-137.825 MHz SPACE OPERATION (space-to-Earth) 5.203C 5.209A  METEOROLOGICAL-SATELLITE (space-to-Earth)  MOBILE-SATELLITE (space-to-Earth) 5.208A 5.208B 5.209  SPACE RESEARCH (space-to-Earth)  Fixed  Mobile except aeronautical mobile (R)  5.204 5.205 5.206 5.207 5.208 | | |
| 137.825-138 MHz SPACE OPERATION (space-to-Earth) 5.203C  METEOROLOGICAL-SATELLITE (space-to-Earth)  SPACE RESEARCH (space-to-Earth)  Fixed  Mobile except aeronautical mobile (R)  Mobile-satellite (space-to-Earth) 5.208A 5.208B 5.209  5.204 5.205 5.206 5.207 5.208 | | |
| 138-143.6 MHz  AERONAUTICAL MOBILE (OR) | 138-143.6  FIXED  MOBILE  RADIOLOCATION  Space research (space-to-Earth) | 138-143.6  FIXED  MOBILE  Space research (space-to-Earth)  5.207 5.213 |
| 5.210 5.211 5.212 5.214 |

5.203C The use of the space operation service (space-to-Earth) with non-geostationary satellite short-duration mission systems in the frequency band 137-138 MHz is subject to Resolution **660 (WRC‑19)**.Resolution **32 (WRC‑19)** applies. These systems shall not cause harmful interference to, or claim protection from, the existing services to which the frequency band is allocated on a primary basis.     (WRC‑19)

5.204 *Different category of service:*in Afghanistan, Saudi Arabia, Bahrain, Bangladesh, Brunei Darussalam, China, Cuba, the United Arab Emirates, India, Indonesia, Iran (Islamic Republic of), Iraq, Kuwait, Montenegro, Oman, Pakistan, the Philippines, Qatar, Singapore, Thailand and Yemen, the frequency band 137-138 MHz is allocated to the fixed and mobile, except aeronautical mobile (R), services on a primary basis (see No. **5.33**).     (WRC-19)

5.205 *Different category of service:*in Israel and Jordan, the allocation of the band 137‑138 MHz to the fixed and mobile, except aeronautical mobile, services is on a primary basis (see No. **5.33**).

5.206 *Different category of service:*in Armenia, Azerbaijan, Belarus, Bulgaria, Egypt, the Russian Federation, Finland, France, Georgia, Greece, Kazakhstan, Lebanon, Moldova, Mongolia, Uzbekistan, Poland, Kyrgyzstan, the Syrian Arab Republic, Slovakia, the Czech Rep., Romania, Tajikistan, Turkmenistan and Ukraine, the allocation of the band 137-138 MHz to the aeronautical mobile (OR) service is on a primary basis (see No. 5.33).     (WRC‑2000)

5.207 *Additional allocation:*in Australia, the band 137-144 MHz is also allocated to the broadcasting service on a primary basis until that service can be accommodated within regional broadcasting allocations.

5.208 The use of the band 137-138 MHz by the mobile-satellite service is subject to coordination under No. **9.11A**.     (WRC-97)

5.208A In making assignments to space stations in the mobile-satellite service in the frequency bands 137-138 MHz, 387‑390 MHz and 400.15-401 MHz and in the maritime mobile-satellite service (space-to-Earth) in the frequency bands 157.1875-157.3375 MHz and 161.7875‑161.9375 MHz, administrations shall take all practicable steps to protect the radio astronomy service in the frequency bands 150.05-153 MHz, 322-328.6 MHz, 406.1-410 MHz and 608-614 MHz from harmful interference from unwanted emissions as shown in the most recent version of Recommendation ITU**‑**R RA.769-2.     (WRC‑19)

5.208B[[1]](#footnote-1)\* In the frequency bands:

137-138 MHz,  
 157.1875-157.3375 MHz,  
 161.7875-161.9375 MHz,  
 387-390 MHz,  
 400.15-401 MHz,  
 1 452-1 492 MHz,  
 1 525-1 610 MHz,  
 1 613.8-1 626.5 MHz,  
 2 655-2 690 MHz,  
 21.4-22 GHz,

Resolution **739** **(Rev.WRC-19)** applies.     (WRC‑19)

5.209 The use of the bands 137-138 MHz, 148-150.05 MHz, 399.9-400.05 MHz, 400.15‑401 MHz, 454‑456 MHz and 459-460 MHz by the mobile-satellite service is limited to non‑geostationary-satellite systems.     (WRC‑97)

5.209A The use of the frequency band 137.175-137.825 MHz by non-geostationary-satellite systems in the space operation service identified as short-duration mission in accordance with Appendix **4** is not subject to No. **9.11A**.     (WRC-19)

5.210 *Additional allocation:*in Italy, the Czech Rep. and the United Kingdom, the bands 138‑143.6 MHz and 143.65-144 MHz are also allocated to the space research service (space-to-Earth) on a secondary basis.     (WRC‑07)

5.211 *Additional allocation:* in Germany, Saudi Arabia, Austria, Bahrain, Belgium, Denmark, the United Arab Emirates, Spain, Finland, Greece, Guinea, Ireland, Israel, Kenya, Kuwait, Lebanon, Liechtenstein, Luxembourg, North Macedonia, Mali, Malta, Montenegro, Norway, the Netherlands, Qatar, Slovakia, the United Kingdom, Serbia, Slovenia, Somalia, Sweden, Switzerland, Tanzania, Tunisia and Turkey, the frequency band 138‑144 MHz is also allocated to the maritime mobile and land mobile services on a primary basis.    (WRC‑19)

5.212 *Alternative allocation:*in Angola, Botswana, Cameroon, the Central African Rep., Congo (Rep. of the), Eswatini, Gabon, Gambia, Ghana, Guinea, Iraq, Jordan, Lesotho, Liberia, Libya, Malawi, Mozambique, Namibia, Niger, Oman, Uganda, Syrian Arab Republic, the Dem. Rep. of the Congo, Rwanda, Sierra Leone, South Africa, Chad, Togo, Zambia and Zimbabwe, the frequency band 138-144 MHz is allocated to the fixed and mobile services on a primary basis.    (WRC‑19)

5.213 *Additional allocation:*in China, the band 138-144 MHz is also allocated to the radiolocation service on a primary basis.

5.214 *Additional allocation:* in Eritrea, Ethiopia, Kenya, North Macedonia, Montenegro, Serbia, Somalia, Sudan, South Sudan and Tanzania, the frequency band 138-144 MHz is also allocated to the fixed service on a primary basis.    (WRC‑19)

# Aircraft VHF transmitter and receiver characteristics

To address link budgets, this report considers the worldwide 25 kHz channelization of the VHF frequency band, the lowest assignable frequency being 118.000 MHz and the highest assignable frequency 136.975 MHz.

However, it can be noted that in order to address increasing demand for voice channels over particular regions, 8.33 kHz channel spacing has been implemented in these regions.

## Aircraft VHF transmitter characteristics

The same antenna pattern is considered for aircraft VHF transmitters and receivers.

### Aircraft VHF transmit power for voice application

In terms of transmitted power, the minimum aircraft transmit output powers for voice are 16 watts for 200 nautical miles maximum range, and 4 watts for 100 nautical miles maximum range. The first figure of 16 watts is retained in this report, as the range between aircraft and satellite will exceed 200 nautical miles as shown in next sections. ICAO has confirmed the relevance of this value.

### Aircraft VHF transmit power for data (VDL-Mode 2) application

In the same way, in terms of transmitted power, for data using VDL Mode 2, the RF output power, measured at the transmitter antenna port, on all frequencies for which the transmitter is designed, will be typically 15 watts for 200 nautical miles, and 4 watts for 100 nautical miles (EUROCAE ED-92C, section 2.2.1.3.2). The first figure of 15 watts is retained in this report for services using VDL Mode 2, as the range between aircraft and satellite will exceed 200 nautical miles as shown in next sections.

## Aircraft VHF receiver characteristics

### Aircraft VHF receiver antenna

Aircrafts are usually equipped with two or three VHF antennas, in which case at least one of them is located on top of the aircraft, and one on the bottom. In the case of three VHF antennas, their typical location installed on a generic aircraft is shown in Figure 2 below provided by ICAO.

Figure 2

Typical VHF antenna location on aircraft

Diagram

Description automatically generated with low confidence

The aircraft VHF receiving antenna pattern is obviously an essential element to consider in the studies. The performances of available products show that:

– Relatively low gains are achieved

– Radiation patterns are globally omni-directional, and more precisely

• omnidirectional in azimuth

• cosinusoidal in elevation, meaning a theoretical zero is achieved at aircraft zenith (90° elevation).

As a guide, ICAO provided the following general characteristics of the VHF antenna to be used as a baseline for ITU-R studies. ICAO has also confirmed the co-sinusoidal shape and consequential null at aircraft zenith, which has an important implication on the performance of the satellite VHF link: one can assume that the AMS(R)S downlink operation is expected to be ‘off-zenith’ between the aircraft and the satellite.

– Frequency band: 118-137 MHz

– Polarization: Vertical

– Radiation pattern: Omni directional

– Gain: −1 dBi

### Aircraft VHF receiver performance requirement

#### Voice application performance requirement

Regarding the aircraft VHF receiver sensitivity for voice application, ICAO Standards and Recommended Practices (SARPs) provide the following reference recommendation contained in Annex 10 Volume III (Communication System) Part II (Voice Communication Systems) of the Convention on International Civil Aviation:

|  |
| --- |
| Part II  Annex 10 – Aeronautical communications 2.3 System characteristics of the airborne installation […] 2.3.2 Receiving function […] 2.3.2.2 Sensitivity2.3.2.2.1 Recommendation After due allowance has been made for aircraft feeder mismatch, attenuation loss and antenna polar diagram variation, the sensitivity of the receiving function should be such as to provide on a high percentage of occasions an audio output signal with a wanted/unwanted ratio of 15 dB, with a 50per cent amplitude modulated (A3E) radio signal having a field strength of 75 microvolts per metre (minus 109 dBW/m2).  Note: For planning extended range VHF facilities, an airborne receiving function sensitivity of 30 microvolts per metre may be assumed. |

A satellite system relaying aeronautical VHF communications over oceanic and remote areas can be considered as part of “extended range VHF facilities”, hence the Note referring to a field strength of 30 microvolts per metre would be more relevant for the satellite case than the 75 microvolts per metre reference. Such a field strength corresponds to a sensitivity power flux density of −116.2 dBW/m². Indeed the relation between electric field strength and power flux density is given by:

Power flux density (dBW/m²) = 10log(electric field strength(V/m)² / 120)

ICAO recommends using the 30 microvolts per meter requirement, which becomes −90 dBm through an isotropic antenna @ 131 MHz. Indeed at 131 MHz, the aircraft VHF receiver effective aperture area (*A* = *Gr*.²/(4)) for an isotropic antenna (*Gr* = 0 dBi) is −3.8 dBm², hence with a power flux density of −116.2 dBW/m², corresponding received power is −120 dBW or −90 dBm at the aircraft antenna flange.

Feeder/cable losses on board aircraft should also be accounted for. It is proposed to consider 2 dB for voice applications in this study.

#### Aeronautical mobile satellite (route) service data (VDL Mode 2 modulation) application performance requirement

Regarding the aircraft VHF receiver sensitivity data using VDL Mode 2 modulation application, ICAO SARPs provide the following reference recommendation contained in Annex 10 Volume III (Communication System) Part I (Digital Data Communication Systems) of the Convention on International Civil Aviation:

|  |
| --- |
| PART I  Annex 10 – Aeronautical communications 6.3 System characteristics of the aircraft installation […] 6.3.5 Receiving function […] 6.3.5.2 *Sensitivity*. The receiving function shall satisfy the specified error rate with a desired signal strength of not more than 20 microvolts per metre (minus 120 dBW/m2). Note.— The required signal strength at the edge of the service volume takes into account the requirements of the system and signal losses within the system, and considers environmental noise sources. |

This sensitivity power flux density of −120 dBW/m² becomes −93.8 dBm through an isotropic antenna @ 131 MHz. Indeed at 131 MHz, the aircraft VHF receiver effective aperture area (*A* = *Gr*.²/(4)) for an isotropic antenna (*Gr* = 0 dBi) is −3.8 dBm², hence with a power flux density of −120 dBW/m², corresponding received power is −123.8 dBW or −93.8 dBm at the aircraft antenna flange. (Note: According to EUROCAE ED-92, Section 2.2.1.2.1 sensitivity “A signal level of minus 98dBm at the input of the receiver from a VDL Mode 2 signal source will produce an error rate that meets the requirements specified in Section 2.2.1.2”),

Feeder/cable losses on board aircraft should also be accounted for. It is proposed to consider 3 dB in this study, as specified in section 3.8.1 (“transmitter power”, page 241) of document RTCA DO-224C (Signal-in-Space Minimum Aviation System Performance Standards (MASPS) for Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques).

# Operational environment for the transmission and reception of satellite VHF

## Satellite-aircraft range

The effective path range is relative to the satellite altitude, and to the actual satellite and aircraft positions, which change continuously. Definition of the maximum range considered for satellite operation is helpful in the assessment of system performance and is an important assumption in the overall architecture design. Together with the targeted service area (FIR specific, regional, global) and the desired availability performance under given propagation conditions, this parameter directly impacts the number of satellites required in the satellite constellation.

Figure 3

Satellite-aircraft range



An assessment of satellite-to-aircraft link budget with a geostationary satellite (i.e. at around 36 000 km altitude) indicates that required power at satellite is out-of-reach. Indeed, Table 1 below provides an estimation of satellite power required in order to obtain the power-flux level of −116.2 dBW/m² for voice application specified in section 4.2.2 at 36 000 km distance, first with the typical assumption of a satellite transmitting gain of 3 dBi, second with the very optimistic assumption of a satellite transmitting gain of 20 dBi. Required satellite power is 155.5 kW and 3.1 kW respectively, which is either not achievable or not reasonable for a single 25 kHz carrier.

This leads to the conclusion that a geostationary AMS(R)S solution is not a workable architecture in order to address satellite VHF requirements. Hence only a non-geostationary case is considered in this report.

Table 1

Estimation of satellite RF power required for a geostationary satellite   
operating in the aeronautical mobile satellite (route) service

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | **Units** | **Satellite-to-aircraft link budget** | |
| **GSO with average VHF antenna gain** | **GSO with very high VHF antenna gain** |
| a. | Frequency | MHz | 137 | 137 |
| b. | Range | km | 36 000 | 36 000 |
| **Satellite transmitter** | | | | |
| c. | RF power required for 0dB link margin | W | 155 531 | 3 103 |
| d. | Satellite Tx antenna gain | dBi | 3 | 20 |
| e. | Feeder loss | dB | 1.0 | 1.0 |
| f. | Satellite E.I.R.P. (calculated from c, d and e) | dBW | 53.9 | 53.9 |
| **Signal propagation** | | | | |
| g. | Free space loss (calculated from a and b) | dB | 166.3 | 166.3 |
| h. | Additional propagation losses (scintillation) | dB | 5 | 5 |
| i. | Polarization losses to receive V polar | dB | 3 | 3 |
| **Receiver power flux at aircraft antenna input** | | | | |
|  | Effective received power flux density (calculated from a, f, g, h, i) | dBW/m2 | -116.2 | -116.2 |

The detailed definition of an AMS(R)S satellite constellation is out of the scope of this report. Several options are possible, and trade-offs are required on many elements such as the number of satellites in the constellation, their altitude, the desired coverage and number of simultaneously visible satellites (for redundancy), the presence or not of inter-satellite links, the number of VHF channels that can be addressed by each satellite, the desired quality of service, etc.

However, studies require certain assumptions to be made, and it is proposed to retain for this report a satellite altitude of 600 km, representative of typical low earth orbit (LEO) solutions. This altitude was for example considered in Recommendation ITU-R M.2092-0 related to the satellite component of a VHF data exchange system (VDES). Technical characteristics of the reference AMS(R)S system are detailed in Section 6. Of course, other orbital selections are also possible according to the overall system design consideration.

## Propagation

Satellite transmissions in the VHF range are known to be significantly affected by scintillation events that occur within the ionospheric layer. The ionosphere causes a delay proportional to the electron-density along the wave path, where the wave path passes patches of more or less dense ionosphere, scintillation occurs.

Scintillation is generally more pronounced at high latitudes and within ±20° of the geomagnetic equator. For much of the locations in mid-latitudes, propagation loss and phase changes due to scintillation will be less pronounced than those at high latitudes or near the geomagnetic equator. Notably, there are also areas which are not affected by ionospheric propagation loss. At this stage according to Recommendation ITU-R P.531-14, it is recommended that Global Ionospheric Scintillation Model is used to predict the effects of scintillation on a given link geometry. Careful consideration of the temporal, spatial and geomagnetic environment must be used to assess the range of ionospheric behaviour, noting that scintillation events last from 30 minutes to hours and commence after local ionospheric sunset. For every longitudinal position, the highest intensity of scintillation (if any) is observed for a period of time after sunset at 1800 (local time) and up to 0:00 at the equinox period, and for years of maximal solar activity (see in Figure 4, extracted from Recommendation ITU-R P.531-14, a representation at 1.5 GHz).

If qualitative effects are pretty well known, their accurate prediction is still challenging for the design of telecom systems. Given the limit of the current model accuracy, it is not possible yet to precisely quantify ionospheric propagation losses in relation to a given link availability for all ranges of latitude and aircraft station elevation.

Further work is required in order to appropriately take ionospheric losses into account in the design of an aeronautical VHF satellite system. A reference availability target should be identified so as to define the relevant attenuation margin, but considering the extent of the phenomenon and its variability against time and location, it may be appropriate to consider some splitting by region, and possibly between day and night period (for instance 1800-0000, and 0000-1800).

The three following reference ionospheric losses is given for different regions:

– A low level of 1 dB attenuation losses for medium latitude regions.

– A medium level of 5 dB attenuation losses for high latitude regions.

– A high level of 10 dB attenuation losses for low latitude regions.

ICAO has indicated that the levels of VHF service availability to be required will depend on the types of operations and airspace. Once a satellite system is designed, its availability performance will be evaluated, and will represent an important input for air navigation service providers (ANSPs) interested in the service. They will define a set of operational measures required to reach a given safety objective. Depending on satellite system design trade-offs, it may be of interest not to dimension the satellite system to account for the worst-case propagation loss, which is transient and highly dependent to time, weather and location, and to compensate with appropriate measures (like appropriate flight planning) over the concerned regions when affected.

ICAO also noted that, depending on ANSPs’ requirements and geographical constraints, both satellite and terrestrial systems may be used together to overcome the VHF scintillation trade-offs, to meet the service availability requirements. Moreover, the satellite system could also be designed with redundancies in place, an example would be to replicate the terrestrial VHF system setup to mount on different satellites.

An analysis is performed in Annex, based on existing bibliography, and provides the margin to take into account under favorable conditions (middle latitude of 51.5N, period of minimum solar activity between November 1971 and April 1972) for the link budget as a function of the selected probability of having fade higher than X dB.

Based on these considerations, it is proposed to retain in this report the assumptions corresponding to the low and medium levels of scintillation losses, i.e. 1 dB and 5 dB respectively, and to establish link budgets under both of these assumptions.

Figure 4

Ionospheric propagation loss at 1.5 GHz during solar maximum and minimum years  
(from Recommendation ITU-R P.531-14)



## Polarization

Emissions of standardised air-ground VHF communication systems are vertically polarized. Recommendation ITU-R P.531-14 identifies Faraday rotation as an effect on propagation for the proposed corresponding new satellite system. For systems that use linearly polarized antennas, potential phase rotation through the ionosphere depends on many factors such as location, time of year, time of day, solar cycle and geomagnetic conditions. It is therefore very difficult to predict the extent of associated polarization loss.

At satellite level, a setup with linear polarization, compatible with the vertical polarization used at aircraft would be preferable for link budget purposes. However, its design seems difficult to match in terms of alignment with aircraft antenna, taking into account the real-time link geometry between the transmitter and receiver, and Faraday rotation changing polarization angles. For this reason, circularly polarized receiving and transmitting antennas are assumed, mitigating by design against the Faraday effect, and leading to a polarization loss factor of 3 dB.

# Technical characteristics of the proposed reference system operating in the aeronautical mobile (route) service

Satellite link budgets are proposed at the upper edge of the considered AMS(R)S allocation, i.e. 136 or 137 MHz frequency. This is considered a worst case, as link budgets at 118 MHz is more favourable by 1.3 dB in terms of free space losses.

## Satellite transmission characteristics

The output of the link budget considered for satellite downlink will be the power required on-board the satellite. This power is another important driver of satellite system design, which cannot exceed a few hundred watts maximum to remain implementable.

Satellite antennas represent an essential element in any satellite system design. Their performance and pattern are main drivers in the overall system architecture, and in the compatibility of this system with its radio-frequency environment.

In our case of an AMS(R)S system within the band 117.975-137 MHz, an important consideration to take into account, outlined by ICAO, is that AMS(R)S operation is expected to be ‘off-zenith’ between the aircraft and the satellite, because of the co-sinusoidal shape of the aircraft VHF antenna pattern and consequential null at aircraft zenith (see Section 4.2.1). In that framework, the example of a satellite antenna described in Recommendation ITU-R M.2092-0 seem very much appropriate (see Section 2.1.5 and 2.1.6 of Annexes 4 and 5 respectively, which detail technical characteristics of the satellite downlink/uplink for the VDES operating around 160 MHz), because the main lobe is pointed towards the horizon of the Earth (similar as Figure 5 below). The communications coverage area is mainly around this main lobe, corresponding to low elevation angles, and high elevation angle (> 70°) coverage is sacrificed, corresponding to null at zenith of the aircraft VHF antenna pattern. It is therefore proposed to retain this example from Recommendation ITU-R M.2092-0 as reference satellite antenna pattern for our baseline satellite architecture.

Satellite gain example according to aircraft elevation angle (for a satellite at 600 km altitude) in shown in Table 2. This example is for a Yagi antenna but could be representative for a maximum antenna gain at 0 degrees angle for aircraft elevation, i.e. an Isoflux antenna with a maximum gain of 8 dBi at 66.1 Nadir offset degrees angle is feasible.

Table 2

Antenna gain pattern example of a satellite operating in the aeronautical mobile satellite (route) service

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Aircraft elevation angle (degrees)** | **Nadir offset angle (degrees)** | **Boresight offset angle (degrees)** | **Satellite-Aircraft range (km)** | **Satellite antenna Rx/Tx gain (dBi)** |
| 0 | 66.1 | 0 | 2831 | 8 |
| 10 | 64.2 | 1.9 | 1932 | 8 |
| 20 | 59.2 | 6.9 | 1392 | 8 |
| 30 | 52.3 | 13.8 | 1075 | 7.8 |
| 40 | 44.4 | 21.7 | 882 | 6.9 |
| 50 | 36 | 30.1 | 761 | 5.5 |
| 60 | 27.2 | 38.9 | 683 | 3.6 |
| 70 | 18.2 | 47.9 | 635 | 0.7 |
| 80 | 9.1 | 57 | 608 | −2.2 |
| 90 | 0 | 66.1 | 600 | −5.5 |

Figure 5 below provides an illustration of an antenna pattern example, showing its main lobe directed towards the low elevation angles and neglecting the satellite zenith region with high elevation angles.

Figure 5

Illustration of the proposed reference satellite antenna pattern

Diagram

Description automatically generated

Additional dynamic sharing and compatibility studies may be also carried out. As a reference example, a constellation using polar orbits with inclination of 90 degrees, 34 satellites per plane and 10 planes with equal spacing to achieve global coverage could be considered, as presented on figure below.

Figure X

Illustration of a reference satellite constellation coverage

Изображение выглядит как текст, наружный объект, паутина

Автоматически созданное описание

## Satellite Doppler and latency time

A LEO satellite will move at a speed of about 8 km/s and this will cause a Doppler of ±4 kHz maximum at VHF. The implementation a compensation mechanism on the satellite transmitter to mitigate Doppler effects at the aircraft receiver without making any modification on existing aircraft equipment is under study within ICAO, thus maintaining compliance with the existing aviation standards. In the uplink at satellite reception, this effect could be compensated.

Also, a LEO satellite at 600 km altitude will correspond to a latency time due to propagation comprised between 4 ms (at zenith) and 18.9 ms (at horizon). ICAO is of the view that no operational impact is expected, as the latency ranges expected from the AMS(R)S systems are compatible with existing aeronautical VHF systems.

## Satellite-to-aircraft (i.e. downlink) link budget example for voice application

AMS(R)S from a LEO constellation using VHF aeronautical band 117.975-137 MHz is feasible for the Space to Earth link communications. Table 3 provides an example of satellite-to-aircraft link budget, taking into account all considerations discussed in previous paragraphs (mainly satellite altitude of 600 km, satellite antenna pattern and gain corresponding to different elevations, aircraft VHF antenna gain of −1 dBi except for high elevation angles, etc). In this table, the satellite power required at each aircraft elevation angle is calculated in order to close the link budget under the assumption of 5 dB scintillation losses, i.e. to obtain a 0 dB margin on the satellite to aircraft forward link, taking into account the 30 µV/m requirement expressed by ICAO, equivalent to −116.2 dBW/m² power-flux.

Table 3

Example satellite-to-aircraft (downlink) link budget  
- satellite power required for different aircraft elevation angles

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FORWARD (To Aircraft) | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| AMS(R)S satellite altitude | km | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Elevation | (degrees) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Range | km | 2831 | 1932 | 1392 | 1075 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600 |
| **Transmitter** | | | | | | | | | | | |
| RF Power for 25 KHz channel | W | 304.1 | 141.7 | 73.6 | 45.9 | 38.1 | 39.1 | 48.8 | 82.2 | 147.1 | 305.9 |
| Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| Feeder loss | dBi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Satellite EIRP | dBW | 31.8 | 28.5 | 25.7 | 23.4 | 21.7 | 20.4 | 19.5 | 18.8 | 18.5 | 18.4 |
| **Signal Propagation** | | | | | | | | | | | |
| Free space path loss | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| Additional. propagation loss | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Effect received power flux density | dBW/m2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 |
| Recommended SAPRs power flux density | dBW/m2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 |
| Power flux margin | dB | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Receiver** | | | | | | | | | | | |
| Aircraft Rx Antenna Gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
| Feeder Losses | dBi | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Rx Signal power | dBm | -93.4 | -93.4 | -93.4 | -93.4 | -93.4 | -93.4 | -93.4 | -93.4 | -96.4 | -100.4 |

*[Chairman’s note: Table 3, 4, 5 and 6 are not easy to follow and appear to have inconsistencies with the VDL 2 case e.g. Aircraft feeder loss 2dB for AM 3 dB for VDL 2 is this correct?]*

A significant level of satellite power is required per channel to meet the aircraft receiver sensitivity requirement and the different losses. Under the assumptions mentioned above, it can be noted that, as an example, a satellite power of 85 watts per 25 kHz channel is compatible with aircraft elevation angles between 20° and 70°. It is proposed to consider this power level as a reference, and to establish the link budget contained in Table 4 as an example of satellite-to-aircraft link budget taken into account for studies in this report with 5 dB scintillation losses.

Table 4

Example satellite-to-aircraft (downlink) link budget  
with 5 dB scintillation losses

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FORWARD (To Aircraft) | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| AMS(R)S satellite altitude | km | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Elevation | (degrees) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Range | km | 2831 | 1932 | 1392 | 1075 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600 |
| **Transmitter** | | | | | | | | | | | |
| RF Power for 25 KHz channel | W | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 | 85 |
| Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| Feeder loss | dBi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Satellite EIRP | dBW | 26.3 | 26.3 | 26.3 | 26.1 | 25.2 | 23.8 | 21.9 | 19.0 | 16.1 | 12.8 |
| **Signal Propagation** | | | | | | | | | | | |
| Free space path loss | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| Additional. propagation loss | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Effect received power flux density | dBW/m2 | -121.7 | -118.4 | -115.6 | -113.5 | -112.7 | -112.8 | -113.8 | -116.1 | 118.6 | -121.8 |
| Recommended SAPRs power flux density | dBW/m2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 |
| Power flux margin | dB | -5.5 | -2.2 | 0.6 | 2.7 | 3.5 | 3.4 | 2.4 | 0.1 | -2.4 | -5.6 |
| **Receiver** | | | | | | | | | | | |
| Aircraft Rx Antenna Gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
| Feeder Losses | dBi | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Rx Signal power | dBm | -98.9 | -95.6 | -92.8 | -90.7 | -89.9 | -90.0 | -91.0 | -93.2 | -98.8 | -105.9 |
| Power flux density at Earth’s surface (taking only free space path loss into account) | dBm | -113.7 | -110.4 | -107.6 | -105.5 | -104.7 | -104.8 | -105.8 | -108.1 | -110.6 | -113.8 |

Under the assumption of the lower level of 1 dB scintillation losses corresponding to medium latitude regions, corresponding satellite power can be reduced by around 4 dB from 85W to 35W, and associated link budget becomes as shown in Table 5 below.

Table 5

Example satellite-to-aircraft (downlink) link budget  
with 1 dB scintillation losses

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FORWARD (To Aircraft) | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| AMS(R)S satellite altitude | km | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Elevation | (degrees) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Range | km | 2831 | 1932 | 1392 | 1075 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600 |
| **Transmitter** | | | | | | | | | | | |
| RF Power for 25 KHz channel | W | 35 | 35 | 5 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| Feeder loss | dBi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Satellite EIRP | dBW | 26.3 | 26.3 | 26.3 | 26.1 | 25.2 | 23.8 | 21.9 | 19.0 | 16.1 | 12.8 |
| **Signal Propagation** | | | | | | | | | | | |
| Free space path loss | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| Additional. propagation loss | dB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Effect received power flux density | dBW/m2 | -121.6 | -118.3 | -115.4 | -113.4 | -112.6 | -112.7 | -113.6 | -115.9 | 118.4 | -121.6 |
| Recommended SAPRs power flux density | dBW/m2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 |
| Power flux margin | dB | -5.4 | -2.1 | 0.8 | 2.8 | 3.6 | 3.5 | 2.6 | 0.3 | -2.2 | -5.4 |
| **Receiver** | | | | | | | | | | | |
| Aircraft Rx Antenna Gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
| Feeder Losses | dBi | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Rx Signal power | dBm | -98.8 | -95.5 | -92.6 | -90.6 | -89.7 | -89.9 | -90.8 | -93.1 | -98.6 | -105.8 |
| Power flux density at Earth’s surface (taking only free space path loss into account) | dBm | -117.6 | -114.3 | -111.4 | -109.4 | -108.6 | -108.7 | -109.6 | -111.9 | -114.4 | -117.6 |

Noteworthy, satellite power can be reduced appropriately in areas that are not affected by scintillation losses.

## Aircraft-to-satellite (i.e. uplink) link budget example for voice application

It is also interesting to consider an uplink link budget for the aircraft-to-satellite link, noting that this link does not introduce any new transmitting equipment. Aircraft VHF transmitter is assumed to have a power capability of 16 watts, as explained in Section 4.1.1.

Other assumptions regarding antenna patterns and losses (here 5 dB scintillation losses) are identical to the downlink link budget. A required satellite sensitivity level of −107 dBm is assumed taking into account state of the art technology, and there is some margin with that respect.

Table 6

Aircraft-to-satellite (uplink) link budget example  
with 5 dB scintillation losses

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| RETURN (From Aircraft) | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| AMS(R)S satellite altitude | km | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Elevation | (degrees) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Range | km | 2831 | 1932 | 1392 | 1075 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600 |
| **Transmitter** | | | | | | | | | | | |
| RF Power for 25 KHz channel | W | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 16 |
| Aircraft Tx gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
| Feeder loss | dBi | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Aircraft EIRP | dBW | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 6.0 | 2.0 |
| **Signal Propagation** | | | | | | | | | | | |
| Free space path loss | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| Additional. propagation loss | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Effect received power flux density | dBW/m2 | -139.0 | -135.7 | -132.8 | -130.6 | -128.9 | -127.6 | -126.6 | -126.0 | -128.6 | -132.5 |
| **Receiver** | | | | | | | | | | | |
| Satellite Rx Antenna Gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| Feeder Losses | dBi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Rx Signal power | dBm | -106.2 | -102.9 | -100.0 | -98.0 | -97.1 | -97.3 | -98.2 | -100.5 | -106.0 | -113.2 |
| Rx sensitivity target | dBm | -107 | -107 | -107 | -107 | -107 | -107 | -107 | -107 | -107 | -107 |
| Receiver link margin | dB | 0.8 | 4.1 | 7.0 | 9.0 | 9.9 | 9.7 | 8.8 | 6.5 | 1.0 | -6.2 |

For the uplink budget it shows also that the AMS(R)S is feasible in the Earth to Space link communications.

## Satellite-to-aircraft (i.e. downlink) link budget example for data (VDL-Mode 2) application

AMS(R)S from a LEO constellation using VHF aeronautical band 117.975-137 MHz is feasible for the Space to Earth link communications. Table 7 provides an example of satellite-to-aircraft link budget, taking into account all considerations discussed in previous paragraphs (mainly satellite altitude of 600 km, satellite antenna pattern and gain corresponding to different elevations, aircraft VHF antenna gain of −1 dBi except for high elevation angles, etc). In this table, the satellite power required at each aircraft elevation angle is calculated in order to close the link budget under the assumption of 5 dB scintillation losses, i.e. to obtain a 0 dB margin on the satellite to aircraft forward link, taking into account the 20 µV/m requirement expressed by ICAO, equivalent to −120 dBW/m² power-flux.

Note: a 0,2 dB have been assigned to the Power flux margin to fulfil the -98dBm sensitivity according to EUROCAE ED-92, section 2.2.1.2.1.

Table 7

Example satellite-to-aircraft (downlink) link budget (VHF data link mode 2 modulation)  
- satellite power required for different aircraft elevation angles assuming 5dB of scintillation loss-

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FORWARD (To Aircraft) | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| AMS(R)S satellite altitude | km | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Elevation | (degrees) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Range | km | 2831 | 1932 | 1392 | 1075 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600 |
| **Transmitter** | | | | | | | | | | | |
| RF Power for 25 KHz channel | W | 132.7 | 61.8 | 32.1 | 20.1 | 16.6 | 17.1 | 21.3 | 35.9 | 64.2 | 133.5 |
| Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| Feeder loss | dBi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Satellite EIRP | dBW | 28.2 | 24.9 | 22.1 | 19.8 | 18.1 | 16.8 | 15.9 | 15.2 | 14.9 | 14.8 |
| **Signal Propagation** | | | | | | | | | | | |
| Free space path loss | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| Additional. propagation loss | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Effect received power flux density | dBW/m2 | -119.8 | -119.8 | -119.8 | -119.8 | -119.8 | -119.8 | -119.8 | -119.8 | -119.8 | -119.8 |
| Recommended SAPRs power flux density | dBW/m2 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 |
| Power flux margin | dB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Receiver** | | | | | | | | | | | |
| Aircraft Rx Antenna Gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
| Feeder Losses | dBi | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Rx Signal power | dBm | -98.0 | -98.0 | -98.0 | -98.0 | -98.0 | -98.0 | -98.0 | -98.0 | -101.0 | -105.0 |

*[Chairman’s note: Table 7, 8 and 9 are not easy to follow]*

A level of satellite power is required per channel in order to meet the aircraft receiver sensitivity requirement and the different losses. Under the assumptions mentioned above, it can be noted that, as an example, a satellite power of 36 watts per 25 kHz channel is compatible with aircraft elevation angles between 20° and 70°. Following this example, it could be considered this power level as a reference, and to establish the link budget contained in Table 8 as an example of satellite-to-aircraft link budget taken into account for studies in this report with 5 dB scintillation losses.

Table 8

Example satellite-to-aircraft (downlink) link budget (VHF data link mode 2 modulation)  
with 5 dB scintillation losses

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FORWARD (To Aircraft) | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| AMS(R)S satellite altitude | km | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Elevation | (degrees) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Range | km | 2831 | 1932 | 1392 | 1075 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600 |
| **Transmitter** | | | | | | | | | | | |
| RF Power for 25 KHz channel | W | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 |
| Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| Feeder loss | dBi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Satellite EIRP | dBW | 22.6 | 22.6 | 22.6 | 22.4 | 21.5 | 20.1 | 18.2 | 15.3 | 12.4 | 9.1 |
| **Signal Propagation** | | | | | | | | | | | |
| Free space path loss | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| Additional. propagation loss | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Effect received power flux density | dBW/m2 | -125.5 | -122.2 | -119.3 | -117.3 | -116.4 | -116.6 | -117.5 | -119.8 | -122.3 | -125.5 |
| Recommended SAPRs power flux density | dBW/m2 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 |
| Power flux margin | dB | -5.5 | -2.2 | 0.7 | 2.7 | 3.6 | 3.4 | 2.5 | 0.2 | -2.3 | -5.5 |
| **Receiver** | | | | | | | | | | | |
| Aircraft Rx Antenna Gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
| Feeder Losses | dBi | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Rx Signal power | dBm | -103.7 | -100.3 | -97.5 | -95.4 | -94.6 | -94.7 | -95.7 | -98.0 | -103.5 | -110.7 |
| Power flux density at the earth surface | dBW/m2 | -117.5 | -114.2 | -111.3 | -109.3 | -108.4 | -108.6 | -109.5 | -111.8 | -114.3 | -117.5 |

Under the assumption of the lower level of 1 dB scintillation losses corresponding to medium latitude regions, corresponding satellite power can be reduced, as an example, by around 2,5 dB from 36W to 20W, and associated link budget becomes as shown in Table 9 below.

Table 9

Example satellite-to-aircraft (downlink) link budget (VHF data link mode 2 modulation)  
with 1 dB scintillation losses

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| FORWARD (To Aircraft) | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| AMS(R)S satellite altitude | km | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Elevation | (degrees) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Range | km | 2831 | 1932 | 1392 | 1075 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600 |
| **Transmitter** | | | | | | | | | | | |
| RF Power for 25 KHz channel | W | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| Feeder loss | dBi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Satellite EIRP | dBW | 20.0 | 20.0 | 20.0 | 19.8 | 18.9 | 17.5 | 15.6 | 12.7 | 9.8 | 6.5 |
| **Signal Propagation** | | | | | | | | | | | |
| Free space path loss | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| Additional. propagation loss | dB | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Effect received power flux density | dBW/m2 | -124.0 | -120.7 | -117.9 | -115.8 | -115.0 | -115.1 | -116.1 | -118.3 | -120.9 | -124.0 |
| Recommended SAPRs power flux density | dBW/m2 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 |
| Power flux margin | dB | -4.0 | -0.7 | 2.1 | 4.2 | 5.0 | 4.9 | 3.9 | 1.7 | -0.9 | -4.0 |
| **Receiver** | | | | | | | | | | | |
| Aircraft Rx Antenna Gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
| Feeder Losses | dBi | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Rx Signal power | dBm | -102.2 | -98.9 | -96.0 | -94.0 | -93.2 | -93.3 | -94.3 | -96.5 | -102.0 | -109.2 |
| Power flux density at the earth surface | dBW/m2 | -120 | -116.7 | -113.9 | -111.8 | -111.0 | 111.1 | -112.1 | -114.3 | -116.9 | -120.0 |

Noteworthy, satellite power can be reduced appropriately in areas that are not affected by scintillation losses.

## Aircraft-to-satellite (i.e. uplink) link budget example for data (VHF data link mode 2) application

It is also interesting to consider an uplink link budget for the aircraft-to-satellite link, noting that this link does not introduce any new transmitting equipment. Aircraft VHF transmitter is assumed to have a power capability of 15 watts as explained in Section 4.1.2 and detailed in EUROCAE ED-92C, section 2.2.1.3.2. Typical signal parameters.

Other assumptions regarding antenna patterns and losses (here 5 dB scintillation losses) are identical to the downlink link budget. A required satellite sensitivity level of −107 dBm is assumed taking into account state of the art technology, and there is some margin with that respect.

Table 10

Aircraft-to-satellite (uplink) link budget example for data (VHF data link mode 2 Modulation)  
with 5 dB scintillation losses

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| RETURN (From Aircraft) | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
|  | AMS(R)S satellite altitude | km | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
|  | Elevation | (degrees) | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|  | Range | km | 2831 | 1932 | 1392 | 1075 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600 |
|  | **Transmitter** | | | | | | | | | | | |
|  | RF Power for 25 KHz channel | W | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
|  | Aircraft Tx gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
|  | Feeder loss | dBi | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
|  | Aircraft EIRP | dBW | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 5 | 1 |
|  | **Signal Propagation** | | | | | | | | | | | |
|  | Free space path loss | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
|  | Additional. propagation loss | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
|  | Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
|  | Effect received power flux density | dBW/m2 | -140.3 | -137.0 | -134.1 | -131.9 | -130.1 | -128.9 | -127.9 | -127.3 | -129.9 | -133.8 |
|  | **Receiver** | | | | | | | | | | | |
|  | Satellite Rx Antenna Gain | dBi | 8 | 8 | 8 | 8 | 7 | 6 | 4 | 1 | -2 | -6 |
|  | Feeder Losses | dBi | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
|  | Rx Signal power level | dBm | -107.5 | -104.1 | -101.3 | -99.25 | -98.43 | -98.54 | -99.51 | -101.8 | -107.3 | -114.5 |
|  | Rx sensitivity target | dBm | -107 | -107 | -107 | -107 | -107 | -107 | -107 | -107 | -107 | -107 |
|  | Receiver link margin | dB | -0.5 | 2.9 | 5.7 | 7.8 | 8.6 | 8.5 | 7.5 | 5.2 | -0.3 | -7.5 |

For the uplink budget it shows also that the AMS(R)S is feasible in the Earth-to-space link communications.

# Technical parameters used in the sharing and compatibility studies

## Characteristics of spectral emissions of systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in the frequency band 117.975-136 MHz (voice applications)

### Spectrum mask

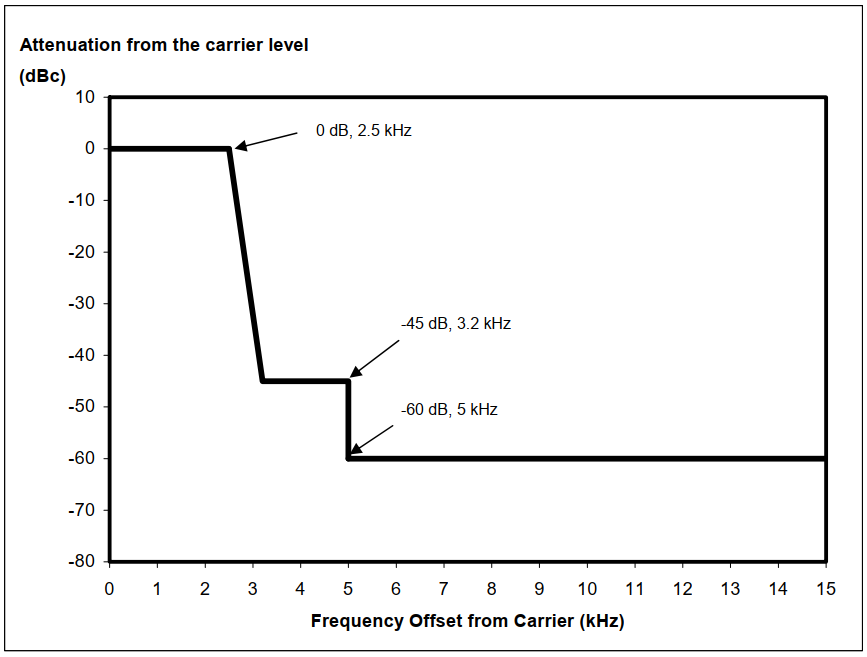
*[Editor’s note – While this mask is expected to be followed, there might be no requirement to use it. It should be also noted that while 8.33 kHz channel is mentioned below, -3 dB mask width is about 5 kHz and it would be good to clarify whether channels are expected to be adjacent or there is some guard band between them.]*

Document EUROCAE ED-23C provides the following emission mask for voice application (in the frame of 8.33 kHz channelization), showing a minimum attenuation of 60 dB for frequency offset greater than 5 kHz from the carrier centre frequency is. This value corresponds to the spectral roll-off of the voice signal.

From this figure, it can also be derived that a necessary bandwidth of 5 kHz can be considered for voice emission.

Figure XXX

Spectrum mask for voice emission (8.33 kHz channelization)



### Satellite on-board filtering

*[Editor’s note – While this filter might be used, there is no mandatory requirement to use it and system designers might ignore it for different purposes. It should be also noted that while 25 kHz channel is mentioned below, -3 dB level on figure gives approximately 83 kHz width.]*

A 25 kHz channel filter might provide additional rejection. In the VHF range, state-of-the art “surface acoustic wave” (SAW) can be used. The figure below provides the performance of such a filter, here for a centre frequency at 135.53 MHz. From this figure, it can be seen that a rejection of at least 52 dB is obtained through filtering at +/- 1 MHz.

Figure XXX

State-of-the-art VHF satellite filter

Chart, line chart

Description automatically generated

### Minimum expected attenuation from emissions of systems operating in the aeronautical mobile satellite (route) service (satellite-to-aircraft) operating in the frequency band 117.975-136 MHz (voice applications) above 137 MHz

*[Editor’s note: there is no enforcement to use above mentioned filter, so it is unsafe to account 112 dB attenuation]*

Considering spectrum emissions mask for systems operating in the AMS(R)S (minimum 60 dB, see 7.1.1) and state-of-the-art VHF satellite filters for 1 MHz offset (minimum 52 dB, see 7.1.2), it might be concluded that a minimum attenuation of 112 dB can be achieved. Therefore, emissions from systems operating in the AMS(R)S emission (satellite-to-aircraft) operating in the frequency band 117.975-136 MHz (voice applications) can be accounted for in the following sharing and compatibility studies with respect to systems operating above 137 MHz.

### Number of voice carriers considered in sharing studies per 25 kHz channel

*[Editor’s note: This section clearly indicates need for aggregated study from several space stations. It is also important to clarify whether there is any multi-carrier space stations]*

In order to extend the service area operated through one 25 kHz channel for voice application, a specific mechanism may be implemented, with several stations transmitting voice carriers within that same channel, but with an off-set of few kHz between them.

Such a mechanism may be used via satellite, and the assumption is therefore made in the following sections that two voice carriers are transmitted in the 25 kHz channel under consideration.

## Characteristics of spectral emissions of systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in the frequency band 136-137 MHz (data VDL Mode 2 channels)

The necessary bandwidth for the VDL-2 signal (worst case) is assumed to be 14.0 kHz corresponding to a 14K0G1DE class type signal (DO-224 Signal-In-Space Minimum Aviation System Performance Standards (MASPS) For Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques. 3.2.1.2.4, and Recommendation ITU-R SM.1138).

### Spectrum mask

The typical spectrum mask demonstrates that the spectral roll-off has an attenuation higher than 60 dBc. In Figure 7 below it is represented the case of the Common Signalling Channel (CSC) at 136.975 MHz, provides a rejection of 60 dB at a frequency separation that can accommodate even a potential worst case of +/-4 kHz frequency Doppler shift pre-compensation (-/+ 8 kHz frequency shift at receiver).

[Editor’s note: clarification is needed on necessary bandwidth]

FIGURE 7

Example of VHF data link mode 2 modulation spectral roll-off.   
D8PSK modulation with 10,5Ksymbols/s rate (Example of VHF Radio)

A screenshot of a computer

Description automatically generated with medium confidence

### Minimum expected attenuation from emissions of systems operating in the aweronautical mobile satellite (route) service (satellite-to-aircraft) in the frequency band 136-137 MHz (VDL Mode 2 applications) above 137 MHz

Considering a typical spectrum emission of AMS(R)S emission for VDL Mode 2 (minimum 60 dB, see 7.2.1) it can be concluded that such attenuation of 60 dB of AMS(R)S emission (satellite-to-aircraft) operating in the 136-137 MHz band (VDL Mode 2 applications) can be accounted for in following sharing and compatibility studies with respect to systems operating above 137 MHz.

### Number of VHF data link Mode 2 carriers considered in sharing studies per 25 kHz channel

Taking in to account the AMS(R)S channelling spacing of 25kHz and the necessary bandwidth of 14kHz for the VDL Mode 2 application, only one carrier can be transmitted within the 25kHz channel under consideration.

## Protection criteria considered for adjacent band systems operating in the frequency band 137-138 MHz

Adjacent band compatibility studies are conducted between systems operating in the AMS(R)S within 117.975-137 MHz and other satellite systems operating on a primary basis in the space-to-Earth direction in the frequency band 137-138 MHz, namely under allocations to the mobile-satellite service (MSS), the space operation service (SOS), the space research service (SRS) and the meteorological satellite service (MetSat). The following sections provide details on the protection criteria considered for these services.

### Protection criteria for the mobile satellite systems operating in the frequency band 137-137.025 MHz and 137.175-137.825 MHz

The frequency bands 137-137.025 MHz and 137.175-137.825 MHz are allocated to the mobile-satellite service (MSS) on a primary basis in the space-to-Earth direction.

Characteristics and protection criteria for MSS systems in the band 137-138 MHz can be found in Recommendations ITU-R M.1231 and ITU-R M.1232 entitled respectively “*Interference* (M.1231) / *sharing* (M.1232) *criteria for space-to-Earth links operating in the mobile-satellite service with non-geostationary satellites in the 137-138 MHz band*”. Two general types of modulation are considered for non-geostationary MSS systems, namely frequency division multiple access narrow-band modulation and spread spectrum wide-band modulation. However only narrow-band modulation systems have been implemented or are being deployed, for the provision of Internet of Things (IoT) and Machine-to-Machine (“M2M”) applications.

Recommendation ITU-R M.1232 provides single-entry interference levels to be used as sharing criteria for the protection of MSS. These levels are based on an assessment of the maximum possible aggregate interference level derived from typical link budgets detailed in Recommendation ITU-M.1231, and on an apportionment of this aggregate interference between terrestrial and satellite sources and between long-term and short-term. For the protection of subscriber terminals of narrow-band modulation MSS systems from unwanted emissions of AMS(R)S space-to-Earth links operating below 137 MHz, the following criteria should be applied:

Protection criteria for earth stations n the mobile satellite service to be applied to the unwanted emissions of systems operating in the aeronautical mobile satellite (route) service

|  |  |  |
| --- | --- | --- |
|  | Long-term | Short-term |
| Maximum interference level | −159.9 dBW | −144.7 dBW |
| Associated percentage of time | 20% of the time | 0.0625% of the time |
| Reference bandwidth | 19.2 kHz | 19.2 kHz |
| Propagation loss | 1 dB | 5 dB |
| MSS receiver antenna gain | −0.5 dB | 0 dB |
| Demodulator implementation loss | 3 dB | 3 dB |

### Protection criteria for systems operating in the space operations service (space-to-Earth) in the frequency band 137-138 MHz

The frequency band 137-138 MHz is allocated to the space operation service (SOS) on a primary basis in the space-to-Earth direction.

Characteristics and protection criteria for SOS systems in the frequency band 137-138 MHz can be found in Recommendation ITU-R SA.363-5 entitled “*Space operation systems*” and in Report ITU-R SA.2426 entitled “*Technical characteristics for telemetry, tracking and command in the space operation service below 1 GHz for non-GSO satellites with short duration missions*”. According to recommends 6 of this Recommendation, the aggregate interference criteria for earth station receivers in the SOS for frequencies above 1 GHz is a maximum interference power in each band 1 kHz wide of –184 dBW at the receiver input for more than 1% of the time each day. This value is increased by 20 dB per decreasing frequency decade, hence in our case at 137 MHz, a maximum interference power in each band 1 kHz wide of –164 dBW at the receiver input for more than 1% of the time each day is to be considered. There are two views provided in this report on adjacent-band apportionment of the protection criteria. View 1 distributes the arrival of the interference over time. View 2 assumes simultaneous arrival of the interference.

View 1

Recommendation ITU-R SA.1743, *recommends* 2.1 and 2.2, indicates that adjacent band interference from AMS(R)S belongs to “category 3”, for which an apportionment of 1% of the total allowable degradation should be applied. The SOS aggregate criteria in Recommendation ITU‑R SA.363-5 is for short-term interference, and the 1% apportionment to AMS(R)S is therefore to be applied on a percentage of time basis. This results in the following sharing criteria for AMS(R)S:

Protection of SOS : in each band 1 kHz wide above 137 MHz, the power level of AMS(R)S unwanted emissions must not exceed –164 dBW at the SOS receiver input for more than 0.01% of the time each day;

View 2

Recommendation ITU-R SA.1743 recommends 2.1 and 2.2 indicates that adjacent band interference from AMS(R)S belongs to “category 3”, for which an apportionment of 1% of the total allowable degradation should be applied. The SOS aggregate criteria in Recommendation ITU‑R SA.363-5 is for short-term interference, but considering global coverage interference from AMS(R)S, would be semi-constant and exist with other sources simultaneously. Therefore the 1% apportionment to AMS(R)S should be applied on a power level basis. This results in the following sharing criteria for AMS(R)S:

Protection of SOS : in each band 1 kHz wide above 137 MHz, the power level of AMS(R)S unwanted emissions must not exceed –184 dBW at the SOS receiver input for more than 1% of the time each day;

According to Table 2 of Report SA.2426, a typical value for the peak antenna gain of SOS earth stations at 137 MHz is 12 dBi (Yagi-Uda or parabolic type antenna, conforming to Rec. ITU-R F.699-7 antenna pattern). Table 2 also indicates that SOS receiving earth stations polarisation is circular.

### Protection criteria for systems operating in the Space research service (space-to-Earth) in the frequency band 137-138 MHz

The frequency band 137-138 MHz is allocated to the space research service (SRS) on a primary basis in the space-to-Earth direction.

Protection criteria for SRS systems in the frequency band 137-138 MHz can be found in Recommendation ITU-R SA.609-2 entitled “*Protection criteria for radiocommunication links for manned and unmanned near-Earth research satellites*”. According to recommends 1.1 of this Recommendation, the protection criteria for earth station receivers in the SRS for frequencies in the 1-20 GHz frequency range is -216 dB(W/Hz). For frequencies below 1 GHz, the permissible interference may be increased at the rate of 20 dB per decreasing frequency decade. In our case around 137 MHz, a protection of ‑196 dB(W/Hz) is therefore to be considered. According to recommends 1.2 of this Recommendation, calculation of interference that may result from atmospheric and precipitation effects should be based on weather statistics for 0.001% of the time for manned missions and for 0.1% of the time for unmanned missions. There are two views provided in this report on adjacent-band apportionment of the protection criteria. View 1 distributes the arrival of the interference over time. View 2 assumes simultaneous arrival of the interference.

View 1

Similarly to SOS in section 0 above, Recommendation ITU-R SA.1743 applies and results in an apportionment of 1% of the total allowable degradation to be applied to AMS(R)S. The SRS criteria in Recommendation ITU‑R SA.609-2 is for short-term interference, and the 1% apportionment to AMS(R)S is therefore to be applied on a percentage of time basis. This results in the following sharing criteria for AMS(R)S:

Protection of SRS : in each band 1 Hz wide above 137 MHz, the power level of AMS(R)S unwanted emissions must not exceed -196 dBW at the SRS receiver input for more than 10‑5 % of the time for manned missions and for more than 10‑3 % of time for unmanned missions;

View 2

Similarly to SOS in section 0 above, Recommendation ITU-R SA.1743 applies and results in an apportionment of 1% of the total allowable degradation to be applied to AMS(R)S. The SRS criteria in Recommendation ITU‑R SA.609-2 is for short-term interference, but, similarly, considering global coverage interference from AMS(R)S would be semi-constant and exist with other sources simultaneously. Therefore the 1% apportionment to AMS(R)S is therefore to be applied on a power level basis. This results in the following sharing criteria for AMS(R)S:

Protection of SRS : in each band 1 Hz wide above 137 MHz, the power level of AMS(R)S unwanted emissions must not exceed -216 dBW at the SRS receiver input for more than 10‑3 % of the time for manned missions and for more than 10‑1 % of time for unmanned missions;

### Protection criteria for systems operating in the meteorological satellite service (space-to-Earth) in the frequency band 137-138 MHz

The frequency band 137-138 MHz is allocated to the meteorological satellite service (MetSat) on a primary basis in the space-to-Earth direction.

Aggregate protection criteria for MetSat systems in the frequency band 137-138 MHz are given in Recommendation ITU-R SA.1026-5 (“*Aggregate interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit*”). These criteria are derived from performance analyses of systems described in Table 2 of this recommendation, using methodology described in Recommendation ITU-R SA.1022-1.

Summary of protection criteria for MetSat earth stations to be applied to the unwanted emissions of AMS(R)S (as per ITU-R SA.1026-5)[[2]](#footnote-2)

|  |  |  |
| --- | --- | --- |
| Frequency band (MHz) | Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time | Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than p% of the time |
| 137-138 | –142 dBW per 150 kHz | –136 dBW per 150 kHz(1)  p = 0.0125 |

View 1

MetSat single-entry protection criteria are derived from MetSat aggregate criteria, using Recommendation ITU-R SA 1023-0 methodology for apportionment of aggregate interference criteria between space-to-Earth and Earth-to-space links, as well as multiple sources of interference. These can then be found in Recommendation ITU-R SA.1027-6 entitled “*Sharing criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit*”, and are summarized in the following Table :

Protection criteria for MetSat earth stations to be applied to the unwanted emissions of AMS(R)S

|  |  |  |
| --- | --- | --- |
| Frequency band (MHz) | Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time | Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than p% of the time |
| 137-138 | –147 dBW per 150 kHz(1) | –137 dBW per 150 kHz(1)  p = 0.0031 |

(1) The interfering signal powers (dBW) in the reference bandwidths are specified for reception at elevation angles ≥ 25°.

View 2

MetSat single-entry protection criteria are derived from MetSat aggregate criteria, using Recommendation ITU-R SA 1023-0[[3]](#footnote-3) methodology for apportionment of aggregate interference criteria between space-to-Earth and Earth-to-space links, as well as multiple sources of interference. Reverse calculations show that approximately three sources of interference were used to obtain criteria found in Recommendation ITU-R SA.1027-6 entitled “*Sharing criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit*” . Based on 7.1.4 there would be at least two extra sources, while taking into account unwanted emissions domain, this value might increase. It should be also noted that recommends 3 of SA.1027-6 imply using 1% apportionment for systems with lower status (including newcomers). Therefore, considering current usage of 137-138 MHz by other systems, least restrictive protection criteria is summarized in the following Table :

Protection criteria for MetSat earth stations to be applied to the unwanted emissions of AMS(R)S

|  |  |  |
| --- | --- | --- |
| Frequency band (MHz) | Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time | Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than p% of the time |
| 137-138 | –177 dBW per 150 kHz(1) | –157 dBW per 150 kHz(1)  p = 0.0031 |

(1) The interfering signal powers (dBW) in the reference bandwidths are specified for reception at elevation angles ≥ 25°.

According to Annex 1/Section 2 of Recommendation ITU-R SA.1027-6, SRS earth stations use either low antenna gains of 2 dBi or higher antenna gains of 10 dBi.

*[Chairman’s note: I have reviewed down to this point or the rest of the text. I would note, which should be considered in further editing of the document that tables should be editable and not pictures and you do not have compatibility between services but between systems operating in or under a service(s)]*

# Sharing and compatibility studies related to applications of the aeronautical mobile (route) service in the frequency band 117.975-136 MHz for voice application

ICAO has recommended to take into account the fact that there are existing AM(R)S application(s) that are mainly operated in sub-bands (for example, typical terrestrial VHF voice links within the frequency band 117.975-136 MHz, typical terrestrial VDL Mode 2 within the sub-band 136-137 MHz), by dividing the analysis of the AMS(R)S allocation into two parts:

– Firstly to consider the frequency band 117.975-136 MHz for the new AMS(R)S allocation, noting that the 1 MHz guard band in 136-137 MHz will ease compatibility with non-ICAO services above 137 MHz. This range is considered in this section 7 for AMS(R)S voice application. According to ICAO SARPs, it is possible to also establish data links using DSB-AM modulation, with the same performance requirement as voice, hence identical RF parameters and link budgets.  In terms of in-band and adjacent band sharing within 117.975-136 MHz, the conclusions are therefore identical for voice and DSB-AM data applications.

– Secondly, to consider the sub-band 136-137 MHz for the new AMS(R)S allocation, which sharing and compatibility analysis are provided in chapter 9.

## In-band sharing between systems operating in the aeronautical mobile satellite (route) and aeronautical mobile (route) services

ICAO has outlined that even though AM(R)S and AMS(R)S would represent two different ITU-R services within the frequency band 117.975-137 MHz, the same on-board cockpit avionics system (for VHF communications) would be used for ground and satellite communications. Indeed, AMS(R)S would not correspond to a new aeronautical service but would relay VHF communications operating under the AM(R)S over oceanic and remote areas, without modification to aircraft equipment. AMS(R)S would therefore not trigger new compatibility issue with aircraft system.

ICAO is of the position that if there is any potential interference between AM(R)S and AMS(R)S, it would be resolved by the ICAO through conventional frequency planning exercise, assigning frequencies to the satellite system over interested regions, to ensure compatibility between ground and satellite facilities. Therefore, from an ICAO perspective there is no need to perform a comprehensive compatibility study within ITU-R between these two different services, that cover the same system on-board the aircraft. Both are technically similar services as the same on-board cockpit avionics system (for VHF communications) would be used for ground and satellite communications.

## In-band sharing between systems operating in the aeronautical mobile satellite (route) and aeronautical mobile (off-route) services

As indicated in Section 2, the bands 132-136 MHz and 136-137 MHz are allocated to the Aeronautical mobile (OR) service on a primary basis in 24 and 22 countries respectively, listed in RR Nos. **5.201** and **5.202**.

Currently, compatibility between AM(R)S and AM(OR)S is ensured through a kind of planning mechanism, with administrations taking account of AM(R)S assignments when assigning frequencies to AM(OR)S stations. The introduction of AMS(R)S in the band is not expected to significantly impact this mechanism. Provided AM(OR)S assignments are known, they could be taken into account by ICAO when introducing AMS(R)S in its frequency planning exercise.

Although there are no available characteristics for AM(OR)S systems, they should be close to that of AM(R)S, since AM(OR)S is also intended for aeronautical communications, including those relating to flight coordination, but is operated in a different framework primarily outside national or international civil air routes.

AM(OR)S systems operate in channels within national assignments, which themselves are managed by ICAO [on a regional basis]. Compatibility between AMS(R)S and AM(OR)S assignments should be resolved by the ICAO through their conventional frequency planning exercise. It is anticipated that, in the event that a new allocation is made to AMS(R)S in this band, ICAO will develop a corresponding channel plan for use of AMS(R)S frequencies to ensure compatibility between the satellite and terrestrial uses of the band. By protecting existing terrestrial assignments, this plan should protect any assignments to AM(OR)S. National Administrations are encouraged to liaise with ICAO on the frequency planning and coordination work, since the AM(OR)S systems are understood to operate in channels within national assignments.

## Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service above 117.975 MHz and systems operating in the aeronautical radionavigation service below 117.975 MHz

Similarly, ICAO has outlined that there is also no need to perform a comprehensive compatibility study within ITU-R between the AMS(R)S and aeronautical radionavigation services. The same frequency planning and coordination works on-going within ICAO will be performed to ensure compatibility between AMS(R)S and aeronautical radionavigation services.

## Adjacent band compatibility with non-ICAO services above 137 MHz

### General consideration

It is to be noted that, although the possible primary new AMS(R)S allocation within the band 117.975-137 MHz would be both in the Earth-to-space and space-to-Earth directions, related sharing and adjacent band compatibility studies should be conducted only with respect to AMS(R)S (space-to-Earth). Indeed, transmitting earth stations in the AMS(R)S (Earth-to-space) would correspond to the AM(R)S aircraft station already in place.

### Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) below 136 MHz and systems operating in the mobile satellite service (space-to-Earth) above 137 MHz

Characteristics and protection criteria for MSS systems in the range 137-138 MHz used in this compatibility study are given in section 7.3.1.

Table 11 below is a rough calculation of the maximum power level per 19.2 kHz above 137 MHz at the MSS receiver input resulting from AMS(R)S emissions in 117.975-136 MHz. It takes into account:

– The reference downlink AMS(R)S link budget in Table 4, with only 1 dB propagation loss on the path towards the MetSat earth station (instead of 5 dB towards aircraft).

– The 5 kHz necessary bandwidth considered for voice emission in section 7.1.1.

– The minimum attenuation of 112 dB calculated in section 7.1.3 for the level of unwanted emissions above 137 MHz resulting from AMS(R)S satellite in-band emissions below 136 MHz.

– MSS long-term protection criteria from section 7.3.1, as it is more stringent than the short-term criteria in the frame of such a static analysis.

Table 11

Assessment of the maximum power levels in 19.2 kHz at mobile satellite service subscriber terminal receiver inputs of the unwanted emission levels above 137 MHz resulting from systems operating in the aeronautical mobile satellite (route) service below 136 MHz



The 65.4 dB minimum margin obtained through Table 11 is to be lowered:

– by 3 dB in order to account for two voice carriers being possibly transmitted simultaneously in the 25 kHz channel under consideration, as indicated in section 7.1.4, and received in the 19.2 kHz MSS receiver.

– by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the MSS earth station (perhaps 6dB). The margin would remain huge even with several satellites in visibility.

Even allowing for these factors, the minimum margin remains above 55 dB. This shows that protection of MSS above 137 MHz from AMS(R)S satellite emissions in 117.975-136 MHz is ensured even under worst case assumptions.

### Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) below 136 MHz and systems operating in the space operations service (space-to-Earth) above 137 MHz

*[Editor’s note: further discussion required on information provided by 7B in 5B/383 regarding protection criterion of SOS until next WP5 meeting considering 7B has provided protection criterion for total interference which require justified apportionment and proper simulation of interfering system(s)]*

[Characteristics and protection criteria for space operation systems in the band 137-138 MHz used in this compatibility study are given in section 0.

Table 12 below is a rough calculation of the maximum power level per 1 kHz above 137 MHz at the SOS receiver input resulting from AMS(R)S single space station with single carrier emissions in 117.975-136 MHz. It takes into account:

– The worst case assumption of the SOS antenna pointing towards the AMS(R)S satellite.

– The reference downlink AMS(R)S link budget in Table 4, with only 1 dB propagation loss on the path towards the SOS earth station (instead of 5 dB towards aircraft).

– The 5 kHz necessary bandwidth considered for voice emission in section 7.1.1.

– The attenuation of 112 dB calculated in section 7.1.3 for the level of unwanted emissions above 137 MHz resulting from AMS(R)S satellite in-band emissions below 136 MHz.

Table 12

Assessment of the maximum power level per 1 kHz at space operation service receiver input of the unwanted emissions above 137 MHz resulting from aeronautical mobile satellite (route) service satellite emissions in 117.975-136 MHz



There are two views provided in this report on adjacent-band apportionment of the protection criteria. View 1 distributes the arrival of the interference over time. View 2 assumes simultaneous arrival of the interference. The summaries of the results of the study of each view are as follows:

View 1

The 52.8 dB minimum margin obtained through Table 12 is to be lowered by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the SOS earth station. The margin would remain huge even with several tens of satellites in visibility.

This shows that protection of SOS above 137 MHz from AMS(R)S satellite emissions in 117.975-136 MHz is ensured during 100% of the time even under worst case assumptions.

View 2

The 52.8 dB minimum margin obtained through Table 12 is to be lowered by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the SOS earth station and apportionment. The margin is expected to stay positive even with several single-carrier satellites in visibility, subject to confirmation based on dynamic studies.

]

### Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) below 136 MHz and systems operating in the space research service (space-to-Earth) above 137MHz

*[Editor’s note: further discussion required on information provided by 7B in 5B/383 regarding protection criterion of SRS until next WP5 meeting considering 7B has provided protection criterion for total interference which require justified apportionment and proper simulation of interfering system(s)]*

[Characteristics and protection criteria for space research systems in the band 137-138 MHz used in this compatibility study are given in section 7.3.3.

Table 13 below is a rough calculation of the maximum power level per Hz above 137 MHz at the SRS receiver input resulting from AMS(R)S single space station with single carrier emissions in 117.975-136 MHz. It takes into account:

– The worst case assumption of the SRS antenna pointing towards the AMS(R)S satellite.

– The value of 3.2 dBi for the peak antenna gain of SRS earth stations at 137 MHz, as recommended by ITU-R Working Party 7B responsible for this service.

– The reference downlink AMS(R)S link budget in Table 4, with only 1 dB propagation loss on the path towards the SRS earth station (instead of 5 dB towards aircraft).

– The 5 kHz necessary bandwidth considered for voice emission in section 7.1.1.

– The attenuation of 112 dB calculated in section 7.1.3 for the level of unwanted emissions above 137 MHz resulting from AMS(R)S satellite in-band emissions below 136 MHz.

Table 13

Assessment of the maximum power level per Hz at space research service receiver input of the unwanted emissions above 137 MHz resulting from aeronautical mobile satellite (route) service satellite emissions in 117.975-136 MHz



There are two views provided in this report on adjacent-band apportionment of the protection criteria. View 1 distributes the arrival of the interference over time. View 2 assumes simultaneous arrival of the interference. The summaries of the results of the study of each view are as follows:

View 1

The 59.6 dB minimum margin obtained through Table 13 is to be lowered by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the SRS earth station. The margin would remain huge even with several tens of satellites in visibility.

This shows that protection of SRS above 137 MHz from AMS(R)S satellite emissions in 117.975-136 MHz is ensured even under worst case assumptions.

View 2

The 59.6 dB minimum margin obtained through Table 13 is to be lowered by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the SRS earth station and apportionment. The margin is expected to stay positive even with several single-carrier satellites in visibility, subject to confirmation based on dynamic studies.

### ]Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) below 136 MHz and systems operating in the meteorological satellite service (space-to-Earth) operating above 137 MHz

*[Editor’s note: further discussion required on information provided by 7B in 5B/383 regarding protection criterion of MetSat until next WP5 meeting considering 7B has provided protection criterion for total interference which require justified apportionment and proper simulation of interfering system(s)]*

[

The frequency band 137-138 MHz is allocated to the meteorological satellite service (MetSat) on a primary basis in the space-to-Earth direction.

Characteristics and protection criteria for meteorological satellite systems in the band 137-138 MHz used in this compatibility study are given in section 7.3.4.

Table 14 below is a rough calculation of the maximum power level per 150 kHz above 137 MHz at the MetSat receiver input resulting from AMS(R)S single space station with single carrier emissions in 117.975-136 MHz. It takes into account:

– The worst case assumption of the MetSat antenna pointing towards the AMS(R)S satellite.

– The value of 10 dBi for the peak antenna gain of MetSat earth stations at 137 MHz. This represents a worst case from the sharing point of view under this static analysis, the alternative being the lower 2 dBi antenna gain.[Editor’s note: Under dynamic analysis this might change with number of satellites in the main beam.]

– The reference downlink AMS(R)S link budget in Table 4, with only 1 dB propagation loss on the path towards the MetSat earth station (instead of 5 dB towards aircraft).

– The minimum attenuation of 112 dB calculated in section 7.1.3 for the level of unwanted emissions above 137 MHz resulting from AMS(R)S satellite in-band emissions below 136 MHz.

– MetSat long-term protection criteria from section 7.3.4, as it is more stringent than the short-term criteria in the frame of such a static analysis.

[Editor’s note: considering 25 kHz channels and unwanted emission domain, below assumption needs clarification as all 721 channel’s unwanted emissions might be received in the 150 kHz bandwidth of MetSat receiving earth station. However it doesn’t seem justified to consider the addition of unwanted emissions in the spurious domain]

– The worst case assumption that up to 6 channels of 25 kHz may be contained in the 150 kHz bandwidth of MetSat receiving earth station.

Table 14

Assessment of the maximum power level per 150 kHz at MetSat receiver input (with high antenna gain antenna) of the unwanted emissions above 137 MHz resulting from aeronautical mobile satellite (route) service satellite emissions in 117.975-136 MHz



View 1

The 57 dB minimum margin obtained through Table 14 is to be lowered:

– by 3 dB in order to account for two voice carriers being possibly transmitted simultaneously in the 25 kHz channel under consideration, as indicated in section 7.1.4

– by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the MetSat earth station. The margin would remain huge even with several tens of satellites in visibility.

This shows that protection of MetSat above 137 MHz from AMS(R)S satellite emissions in 117.975-136 MHz is ensured even under worst case assumptions.

View 2

The 57 dB minimum margin obtained through Table 14 is to be lowered:

– by 3 dB in order to account for two voice carriers being possibly transmitted simultaneously in the 25 kHz channel under consideration, as indicated in section 7.1.4. It should be noted that this could be further lowered in case of multi-carrier space stations

– by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the MetSat earth station and apportionment. The margin is expected to stay positive even with several single-carrier satellites in visibility, subject to confirmation based on dynamic studies.

]

### Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) below 136 MHz and systems operating in the radioastronomy service in the frequency band 150.05-153 MHz

MSS (space-to-Earth) systems in the frequency bands 137-137.025 MHz and 137.175-137.825 MHz must comply with the effective power flux density (EPFD) limits provided in Resolution **739** **(Rev WRC-19)** to protect the radio astronomy service in certain adjacent and nearby frequency bands.

More specifically, Table 2 of Resolution **739 (Rev.WRC-19)** contains an epfd limit of ‑238 dBW/m² in a reference bandwidth of 2.95 MHz for the protection of radio astronomy in the band 150.05-153 MHz by MSS (space-to-Earth) in 137‑138 MHz.

Regarding the Earth-to-space direction (the AMS(R)S allocation would be both in the Earth-to-space and space-to-Earth directions), since transmitting AMS(R)S earth stations correspond to the AM(R)S aircraft station already in place, which are not known to cause any difficulty to radio astronomy observations in 150.05-153 MHz, there is no need for specific limit on AMS(R)S Earth-to-space.

Regarding the AMS(R)S space-to-Earth direction, it is noted that:

– Certain space services in 137-138 MHz allocated in the space-to-Earth direction, which correspond to narrow band emissions, are not subject to the Resolution **739 (Rev.WRC‑19)** epfd limit.

– The frequency separation between the possible AMS(R)S allocation within 117.975-137 MHz and the radio astronomy allocation in the band 150.05-153 MHz would be 13.05 MHz or more.

– Studies conducted in the framework of the introduction of the SOS allocation in 137-138 MHz by WRC-19, which are reported in ITU-R Report SA.2427, resulted in the need for a guard band of at least 1.5 MHz for the protection of radio astronomy in 150.05-153 MHz, which was largely existing.

For these reasons, taking into account the fact that AMS(R)S emissions are also narrow band, it does not appear necessary to mandate that the epfd limit in Resolution **739 (Rev.WRC-19)** applies to the space-to-Earth AMS(R)S allocation.

## Summary of sharing and compatibility studies related to applications of the aeronautical mobile (route) service in the frequency band 117.975-136 MHz for voice application

Main conclusion of studies conducted in section 8 on the basis of voice application is that an AMS(R)S system operating in the band 117.975-136 MHz might be compatible with primary services in this frequency band and in adjacent frequency bands under certain assumptions. In particular:

– Protection of in-band systems operating under AM(R)S and AM(OR)S, and of adjacent band systems below 117.975 MHz under ARNS would be resolved through conventional frequency planning exercise, involving the relevant aeronautical authorities including ICAO, and assigning frequencies to the satellite system over interested regions in a manner that ensures compatibility between ground and satellite facilities.

– Protection of adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth), Space operation service (space-to-Earth), Space research service (space-to-Earth), and Meteorological satellite service (space-to-Earth) would be ensured by a 1 MHz guard band in 136-137 MHz.

# Sharing and compatibility studies related to applications of the aeronautical mobile (route) service operating in the band 136-137 MHz for VDL mode 2 application

The sharing and compatibility context is already explained in section 8

## In-band sharing between systems operating in the aeronautical mobile satellite (route) and aeronautical mobile (route) services

Refer to section 8.1. Considerations developed in this section for AMS(R)S voice application in 117.975-136 MHz are also relevant for AMS(R)S VDL mode 2 application in 136-137 MHz.

## In-band sharing between systems operating in the aeronautical mobile satellite (route) and aeronautical mobile (off-route) services

Refer to section 8.2. Considerations developed in this section for AMS(R)S voice application in 117.975-136 MHz are also relevant for AMS(R)S VDL mode 2 application in 136-137 MHz.

## Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service above 117.975 MHz and systems operating in the aeronautical radionavigation service below 117.975 MHz

Refer to section 8.3. Considerations developed in this section for AMS(R)S voice application in 117.975-136 MHz are also relevant for AMS(R)S VDL mode 2 application in 136-137 MHz.

## Adjacent band compatibility with non-ICAO services above 137 MHz

### General consideration

Refer to section 8.4.1 General considerations contained in that section for AMS(R)S voice application in 117.975-136 MHz are also relevant for AMS(R)S VDL Mode 2 application in 136-137 MHz.

Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in the band 136-137 MHz and systems operating in the mobile satellite service (space-to-Earth) above 137 MHz

Characteristics and protection criteria for MSS systems in the range 137-138 MHz used in this compatibility study are given in section 7.3.1.

The following table provides an assessment of the received power at subscriber terminals in the mobile satellite service from unwanted emission levels above 137 MHz from systems operating in the aeronautical mobile satellite (route) service in the band 136-137 MHz, taking into account:

* The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the SOS earth station (instead of 5 dB towards aircraft).
* The 14kHz necessary bandwidth considered for VDL Mode 2 emission in section 7.2.
* AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2 .2) is 60 dB.
* MSS long-term protection criteria from section 7.3.1, as it is more stringent than the short-term criteria in the frame of such a static analysis.

Table 16

Assessment of the maximum power levels in 19.2 kHz at mobile satellite service subscriber terminal receiver inputs of the unwanted emission levels above 137 MHz resulting from systems operating in the aeronautical mobile satellite (route) service in the band 136-137 MHz

|  |  |  |  |
| --- | --- | --- | --- |
|  | | | |
|  |  |  |  |
|  |  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  | | | |
|  |  |  |  |
|  |  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |



The 17.2 dB minimum margin obtained (Table 16) is to be lowered by a factor of 3 dB assuming a typical simultaneous operation of 2 AMS(R)S space stations using VDL Mode 2, as visible from the MSS earth station.

This shows that protection of MSS above 137 MHz from AMS(R)S satellite emissions in 136-137 MHz is ensured even under worst case assumptions.

### Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in 136-137 MHz and systems operating in the space operations service (space-to-Earth) above 137 MHz

*[Editor’s note: further discussion required on information provided by 7B in 5B/383 regarding protection criterion of SOS until next WP5 meeting considering 7B has provided protection criterion for total interference which require justified apportionment and proper simulation of interfering system(s)]*

[Characteristics and protection criteria for space operation systems in the band 137-138 MHz used in this compatibility study are given in section 0.

Table 18 below provides an assessment of the maximum power level per 1 kHz above 137 MHz at the SOS receiver input resulting from AMS(R)S single space station with single carrier emissions in 136-137 MHz, taking into account:

– The worst case assumption of the SOS antenna pointing towards the AMS(R)S satellite.

– The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the SOS earth station (instead of 5 dB towards aircraft).

* The 14kHz necessary bandwidth considered for VDL Mode 2 emission in section 7.2.

– AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2.2) is 60 dB.

Table 18

Assessment of the maximum power level per 1 kHz at space operation service receiver input of the unwanted emissions above 137 MHz resulting from aeronautical mobile satellite (route) service satellite emissions in 136-137 MHz

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | | | | |
|  |  |  |  | |
|  |  |  |  | |
|  |  |  | |
|  |  |  | |
|  |  |  |  |
|  |  |  |
|  |  |  |  | |
|  |  |  | |
|  |  |  |  | |
|  |  |  |  | |
|  |  |  |  | |
|  |  |  |  | |



The 9.1 dB minimum margin obtained (Table 18) is to be lowered by a factor of 3 dB assuming a typical simultaneous operation of 2 AMS(R)S space stations using VDL Mode 2, as visible from the SOS earth station.

This shows that protection of SOS above 137 MHz from AMS(R)S satellite emissions in 136-137 MHz is ensured even under worst case assumptions.

]

### Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in 136-137 MHz and systems operating in the space research service (space-to-Earth) above 137MHz

*[Editor’s note: further discussion required on information provided by 7B in 5B/383 regarding protection criterion of SRS until next WP5 meeting considering 7B has provided protection criterion for total interference which require justified apportionment and proper simulation of interfering system(s)]*

[Characteristics and protection criteria for space research systems in the band 137-138 MHz used in this compatibility study are given in section 7.3.3.

Table 19 below provides an assessment of the maximum power level per Hz above 137 MHz at the SRS receiver input resulting from AMS(R)S single space station with single carrier emissions in 136-137 MHz, taking into account:

– The worst case assumption of the SRS antenna pointing towards the AMS(R)S satellite.

– The value of 3.2 dBi for the peak antenna gain of SRS earth stations at 137 MHz, as recommended by ITU-R Working Party 7B responsible for this service.

– The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the SRS earth station (instead of 5 dB towards aircraft).

* The 14kHz necessary bandwidth considered for VDL Mode 2 emission in section 7.2.

– AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2.2) is 60 dB.

TABLE 19

Assessment of the maximum power level per Hz at space research service receiver input of the unwanted emissions above 137 MHz resulting from aeronautical mobile satellite (route) service satellite emissions in 136-137 MHz

|  |  |  |  | |
| --- | --- | --- | --- | --- |
|  |  |  |  | |
|  |  |  | |
|  |  |  | |
|  |  |  |  |
|  |  |  |  | |
|  |  |  |  | |
|  |  |  | |
|  |  |  |  | |
|  |  |  |  | |
|  |  |  |  | |
|  |  |  |  | |



The 15.9 dB minimum margin obtained (Table 19) is to be lowered by a factor of 3 dB assuming a typical simultaneous operation of 2 AMS(R)S space stations using VDL Mode 2, as visible from the SRS earth station.

This shows that protection of SRS above 137 MHz from AMS(R)S satellite emissions in 136-137 MHz is ensured even under worst case assumptions.]

### Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in 136-137 MHz and systems operating in the meteorological satellite service (space-to-Earth) operating above 137 MHz

The analysis of adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in 136-137 MHz and systems operating in the meteorological satellite service (space-to-Earth) operating above 137 MHz is presented here below with respect to the applicacations of either Recommendation ITU-R SA.1026-5 and ITU-R SA. 1027-6.

*[Editor’s note: further discussion required on information provided by 7B in 5B/383 regarding protection criterion of MetSat until next WP5 meeting considering 7B has provided protection criterion for total interference which require justified apportionment and proper simulation of interfering system(s)]*

**Analysis for Recommendation ITU-R SA.1026-5**

The frequency band 137-138 MHz is allocated to the meteorological satellite service (MetSat) on a primary basis in the space-to-Earth direction.

Recommendation ITU-R-SA.1026-5 “Aggregate interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit”, Table 1 provides the Interference protection criteria for meteorological satellite earth stations using spacecraft in low-earth orbits and Table 2 provides the Type of Earth Stations for different systems with the typical MetSat earth stations parameters.

Characteristics and protection criteria for meteorological satellite systems in the band 137-138 MHz used in this compatibility study are given in section 7.3.4.

Table 20 below provides an assessment of the maximum power level per 150 kHz above 137 MHz at the MetSat receiver input resulting from AMS(R)S single space station with single carrier emissions in 136-137 MHz, taking into account:

– The worst case assumption of the MetSat antenna pointing towards the AMS(R)S satellite.

– The value of 10 dBi for the peak antenna gain of MetSat earth stations at 137 MHz. This represents a worst case from the sharing point of view under this static analysis, the alternative being the lower 2 dBi antenna gain.

– The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the SRS earth station (instead of 5 dB towards aircraft).

– AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2.2) is 60 dB.

– MetSat long-term protection criteria from section 7.3.4, as it is more stringent than the short-term criteria in the frame of such a static analysis.

– The worst case assumption is for ten simultaneous AMS(R)S carriers (14 kHz necessary bandwidth each) within the 150 kHz bandwidth of MetSat receiving earth station.

Table 20

Assessment of the maximum power level per 150 kHz at MetSat receiver input (with high antenna gain antenna) of the unwanted emissions above 137 MHz resulting from aeronautical mobile satellite (route) service satellite emissions in 136-137 MHz



The 11.3 dB minimum margin obtained (Table 20) is to be lowered by a factor of 3 dB assuming a typical simultaneous operation of 2 AMS(R)S space stations using VDL Mode 2, as visible from the MetSat earth station.

This shows that protection of MetSat above 137 MHz from AMS(R)S satellite emissions in 136-137 MHz is ensured even under worst case assumptions.

**Analysis for Recommendation ITU-R SA.1027-6**

The frequency band 137-138 MHz is allocated to the meteorological satellite service (MetSat) on a primary basis in the space-to-Earth direction.

Considering Recommendation ITU-R SA.1027-6 “Sharing criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in low Earth orbit”, Table 1 provides the Interference protection criteria for meteorological satellite earth stations using spacecraft in low-earth orbits and ITU-R SA.1026-5 Table 2 provides the Type of Earth Stations for different systems with the typical MetSat earth stations parameters. Not should be taken Recommendation ITU-R SA.1027-6 provides aggregated interference levels in a sharing scenario (preferably on a co-channel basis).

Characteristics and protection criteria for meteorological satellite systems in the band 137-138 MHz used in this compatibility study are given in section 7.3.4.

Table 21 below is a rough calculation of the maximum power level per 150 kHz above 137 MHz at the MetSat receiver input resulting from AMS(R)S emissions in 136-137 MHz. It takes into account:

– The worst case assumption of the MetSat antenna pointing towards the AMS(R)S satellite.

– The value of 10 dBi for the peak antenna gain of MetSat earth stations at 137 MHz. This represents a worst case from the sharing point of view under this static analysis, the alternative being the lower 2 dBi antenna gain.

– The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the SRS earth station (instead of 5 dB towards aircraft).

– AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2.2) is 60 dB.

– MetSat long-term protection criteria from section 7.3.4, as it is more stringent than the short-term criteria in the frame of such a static analysis.

– The worst case assumption is for ten simultaneous AMS(R)S carriers (14kHz necessary bandwidth each) within the 150kHz bandwidth of MetSat receiving earth station.

Table 21

Assessment of the maximum power level per 150 kHz at MetSat receiver input (with high antenna gain antenna) of the unwanted emissions above 137 MHz resulting from aeronautical mobile satellite (route) service satellite emissions in 136-137 MHz



The 6.3 dB minimum margin obtained (Table 20) is to be lowered by a factor of 3 dB assuming a typical simultaneous operation of 2 AMS(R)S space stations using VDL Mode 2, as visible from the MetSat earth station.

This shows that protection of MetSat above 137 MHz from AMS(R)S satellite emissions in 136-137 MHz is ensured even under worst case assumptions.

]

### Adjacent band compatibility between systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in 136-137 MHz and systems operating in the radioastronomy service in the frequency band 150.05-153 MHz

Refer to section 8.4.6. Considerations developed in this section for AMS(R)S voice application in 117.975-136 MHz are also relevant for AMS(R)S VDL mode 2 application in 136-137 MHz.

## Summary of adjacent band compatibility with non-ICAO services

[Editor’s note: further discussion required on information provided by 7B in 5B/383 regarding protection criterion of SOS, SRS and MetSat until next WP5 meeting considering 7B has provided protection criterion for total interference which require justified apportionment and proper simulation of interfering system(s).]~~[~~

Main conclusion of studies conducted in section 9 on the basis of VDL Mode 2 application is that an AMS(R)S system operating in the band 136-137 MHz would be compatible with primary services in this frequency band and in adjacent frequency bands. In particular:

– Protection of in-band systems operating under AM(R)S and AM(OR)S, and of adjacent band systems below 117.975 MHz under ARNS would be resolved through conventional frequency planning exercise, involving the relevant aeronautical authorities including ICAO, and assigning frequencies to the satellite system over interested regions in a manner that ensures compatibility between ground and satellite facilities.

– Protection of adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth), would be ensured with respect to tupical AMS(R)S systems operating with VDL Mode 2 in the band 136-137MHz while guarantee the protection criteria defined in section 7.

[Editor’s note: information above may be revised if additional dynamic studies would be carried out and additional information on protection criteria application would be received]

]

# Summary

In the framework of the consideration of a possible new allocation to the AMS(R)S within the aeronautical frequency band 117.975-137 MHz, this report defines the relevant technical characteristics of a reference satellite system that would relay VHF voice communications operating today under the Aeronautical Mobile (Route) Service (AM(R)S), and complement terrestrial communications infrastructures for the coverage of oceanic and remote areas.

This report also reviews existing primary services in-band and in adjacent bands, and studies compatibility between systems operated under these services and the reference AMS(R)S system. Main conclusions are as follows:

– Protection of in-band systems operating under AM(R)S and AM(OR)S, and of adjacent band systems below 117.975 MHz under ARNS would be resolved through conventional frequency planning exercise, involving the relevant aeronautical authorities including ICAO, and assigning frequencies to the satellite system over interested regions in a manner that ensures compatibility between ground and satellite facilities.

– For an AMS(R)S system operating in the band 117.975-136 MHz, studies conducted on the basis of voice application show that protection of adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth), Space operation service (space-to-Earth), Space research service (space-to-Earth), and Meteorological satellite service (space-to-Earth) would be ensured by a 1 MHz guard band in 136-137 MHz.

For an AMS(R)S system operating in the band 136-137 MHz, and using VDL Mode 2 application, sharing and compatibility studies show that the protection of adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth), Space operation service (space-to-Earth), Space research service (space-to-Earth), and Meteorological satellite service (space-to-Earth) might be ensured by limiting a maximum emission above 137 MHz not more:

* + - than –[156.3] dB(W/(m2 · 14 kHz)) or the equivalent –[197.7] dB(W/(m2 · Hz)) when using the protection criteria set forth by Recommendation ITU-R SA. 1026-5. This approach would imply using full aggregate criteria and revoke other possible interferers like MSS allocation in 137-138 MHz.
    - than –[161.6] dB(W/(m2 · 14 kHz)) or the equivalent –[203.1] dB(W/(m2 · Hz)). when using the protection criteria set forth by Recommendation ITU-R SA. 1027-6.

[Editor’s note: to check above values in line with appropriate apportionment etc and to define limit – per system, per station or other]

– These analyses have been conducted assuming two simultaneous space stations contributing to interference signals into the victim receiver, and still with a resulting margin of [3.3 to 8.3 dB – exact value TBD], depending on the protection criteria. Whether the constellation could require more space stations contributing simultaneously to generate interference into one single receiver of the victim services, the AMS(R)S constellation should be designed to respect the resulting maximum aggregated levels of interference signals, thus guaranteeing the protection of the victim services.

Annex

Assessment of fading due to ionospheric scintillation

# 1 Scope

The scope of this annex is the analysis of the Scintillation occurring in the Ionosphere layers which may cause fades in the VHF signal to be transmitted to/from the satellite.

The idea behind the study is to model this effect as a probability of having a fade higher than X dB, which at the end it is going to provide the availability of the link and a corresponding margin to be considered in the link budgets.

# 2 Scintillation mathematical model an input data

During a scintillation level about 50% of the time the signal is higher than the nominal level and the other 50% is below the nominal level (fade)

According to RD.06, the Nakagami density function is believed to be adequately close for describing the statistics of the instantaneous variation of amplitude. Being the Nakagami “m-coefficient” related to S4 as:



Provided we can mathematically model the event by a distribution function, we can represent the event as a probability of having a fade of X dB:



Where , *x* is the Fade in dB and P2 computes the fraction of time that the signal is above or below given threshold during an ionospheric event. It represents in %, the probability of having a fade higher than X dB.

As an example, in the following plot, four different curves corresponding to 4 scintillation levels are depicted. They correspond to the distribution of the probability that the fade will be higher than X (dB) during the corresponding scintillation level.

Chart

Description automatically generated

The probability is provided from low (0.1) to strong (0.7) scintillation level.

The scintillation event above modelled depends on the S4 index, which is an indication of the magnitude of the solar effect in the total electron content within the atmosphere. This index depends on:

Time of day

In the equatorial zone, scintillation effects are generally worst from sunset to about midnight.

Season

Scintillation effects also show a seasonal distribution.

Latitude

Signal degradation due to scintillation is most significant within 20 deg of the magnetic equator and at high latitudes (above 60 deg).

Solar cycle

Scintillation magnitude depends strongly on solar cycle. At solar maximum, when the number of sunspots is greatest and solar activity is highest, scintillation effects are the worst. Solar maxima occur approximately every 11 years.

Once the relationship between fade and its probability is provided for a scintillation event, the next step is to provide the frequency of occurrence (with respect to the total time) of these scintillations in percentage (%) to the total time.

At the end of the day, this is resumed in a percentage of occurrence of the scintillation event. According to RD.06, this frequency of occurrence should be also considered in such a way that the global probability that one Scintillation event, with a fade higher than X dB, will occur in a given time and position can be considered as the product of all the Scintillations events multiplied by its frequency of occurrence,

 (1)

According to ICAO answer to ITU (RD.02):

“... it may be of interest not to dimension the satellite system to account for the worst-case propagation loss, which is transient and highly dependent to time, weather and location, and to compensate with appropriate measures (like appropriate flight planning) over the concerned regions when affectedˮ.

The ionospheric scintillation should not be considered as the worst-case scenario (which is the case for equatorial and aurorally areas), hence the statistical data of interest is focused on availability of data recorded for mid latitude stations.

Bibliography available regarding statistical collection on ionospheric scintillation provides frequency of occurrence of these fades in these areas.

This is the case of referenced at RD.07, where fluctuations in amplitude of 136 MHz signals received from a Geostationary satellite have been recorded for 6 months (from November 1971 to April 1972, corresponding to a period of minimum solar activity) at Slough (51.5°N, 0.6°W).

From this document an analysis of the percentage of occurrence of an ionospheric event was evaluated (Fig. 5 of the document). The averaged value of the probability of having a scintillation event having a peak to peak maximum value of 1.5 dB is 12%. For the remaining 88% of the time it is considered that there are not any scintillation event.

Diagram

Description automatically generated

According to the RD.04 paper, S4 index is determined by *N*/25, where *N* is the maximum Peak to peak signal fade. As explained before, the scintillations are recorded for maximum peaks of 1.5 dB, hence the Scintillation index S4 is 0.06.

However (as it is a more pessimistic case), we refer to RD.06 for calculating the S4 level 

According to this reference the S4 = 0.099

According to formula (1) above and weighting the Nakagami distribution for the S4 = 0.099 for the 12% of the time with the remaining 88% being free of Scintillation event, we would have a cumulative distribution function as shown below:



Table

Description automatically generated

And,

|  |  |
| --- | --- |
| Ionospheric fading probability  (wrt time) | Fading |
| 99% | < 0.63 dB |
| 99.9% | < 1.09 dB |
| 99.99% | < 1.45 dB |

These values should be considered as an input for the consideration of the Ionospheric fading in the Link budget analysis.

According to WP 3L response to WP 5B question, Document [5B/372](https://www.itu.int/md/meetingdoc.asp?lang=en&parent=R19-WP5B-C-0372):

*1)* *The value of 1 dB seems to be appropriate for middle latitude regions, but the study was done in Solar Minimum (November 1971 to April 1972) conditions. It could be expected that for Solar Maximum conditions this value may change. In this regard, it is suggested to change one of the assumptions presented in Document* [*3L/43*](https://www.itu.int/dms_ties/itu-r/md/19/wp3l/c/R19-WP3L-C-0043!!MSW-E.docx) *by:*

*–* *frequency of occurrence of Scintillation event at the different solar activity levels*

From [Solar Cycle Progression | NOAA / NWS Space Weather Prediction Center](https://www.swpc.noaa.gov/products/solar-cycle-progression), historical reference it is possible to see that the SSN for the year considered is about 100, which is not certainly a maximum value, but it is not also a minimum value.

In fact, according to RD.08 [Solar Cycle Progression | NOAA / NWS Space Weather Prediction Center](https://www.swpc.noaa.gov/products/solar-cycle-progression), the maximum predicted SSN for the next 19 years is 115.2 (in 2025 year).

Chart

Description automatically generated

The comparison can be seen in the same web page. Below is an image of a zoom covering both the 1971/1972 year and the predicted maximum one, showing similar levels of SSN.

Chart, histogram

Description automatically generated

On the other hand, additional references like RD.09, predicts solar cycle progressions estimation up to year 2500. According to this reference we can trace and compare the Maximum at 2025 with next maximums. The plot below shows that a similar maximum is predicted by about 2140 and the SSN level will be maintained low up to about year 2350.

Chart

Description automatically generated

From all the data compiled and shown, it seems reasonable to consider the data recorded in RD.07 as a representative value for mid latitude areas and hence the analysis of the scintillation fade probability performed within this annex may be considered valid once the new definition of Nakagami coefficient “m” has been taken into account.

Reference documents

RD.01 International Civil Aviation Organization Volume III. Communication Systems. Part II.

RD.02 International Civil Aviation Organization. Reply liaison statement to ITU-R Working Party 5B – WRC-23 agenda item 1.7 – Questions on a space-based aeronautical VHF communications system in 117.975-137 MHz frequency band.

RD.03 International Civil Aviation Organization. FSMP-WG07-FLIMSY2 APC VHF AM(R)S.

RD.04 International Civil Aviation Organization. Document 5B/225 (Annex 26 to Working Party 5B Chairman’s Report) – Working document towards a preliminary draft new Report ITU-R M.(SPACE-VHF) – Space-based aeronautical VHF communications in 117.975-137 MHz frequency band.

RD.05 Aviation Spectrum Resources INC. VHF Air/ground radio installation guidelines introduction/overview.

RD.06 Ionospheric propagation data and prediction methods required for the design of satellite networks and systems. Recommendation ITU-R P.531-14.

RD.07 Fluctuations in direction and amplitude of 136 MHz signals from a geostationary satellite – Journal of atmospheric and terrestrial physics 1974 Vol. 36, pp. 1503-1513. Pergamon Press. Printed in Northern Ireland. E. N. Bramley, S.R.C., Appleton Laboratory, Ditton Park, Slough SL3 9JX, Bucks., England.

RD.08 [Solar Cycle Progression | NOAA / NWS Space Weather Prediction Center](https://www.swpc.noaa.gov/products/solar-cycle-progression). <https://www.swpc.noaa.gov/products/solar-cycle-progression>.

RD.09 [Prediction of solar activity for the next 500 years - Steinhilber - 2013 - Journal of Geophysical Research: Space Physics - Wiley Online Library](https://agupubs.onlinelibrary.wiley.com/doi/10.1002/jgra.50210), Friedhelm Steinhilber and Jurg Beer.

1. \* This provision was previously numbered as No. **5.347A**. It was renumbered to preserve the sequential order. [↑](#footnote-ref-1)
2. The protection criteria of this recommendation is also used in the analysis contained in chapter 9.4.5. [↑](#footnote-ref-2)
3. Note that the Document 5B/383 (LS from WP 7B on applicable protection criteria) does not mention ITU-R SA 1023-0. [↑](#footnote-ref-3)