SRWG/6 – **IP/02**
**Agenda Item 7**
1-3/03/22

*International Civil Aviation Organization*

**SIXTH MEETING OF SPECTRUM REVIEW WORKING GROUP (SRWG/6)**

Video Teleconference, 1 – 3 March 2022

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**Agenda Item 7:** State and regional updates

## UPDATE ON SPACE-BASED VHF

(Presented by Singapore)

**SUMMARY**

As requested by the secretary of this meeting, this paper is to update the meeting on the progress of Space-based VHF discussions at International Telecommunications Union (ITU) Working Party 5B (WP 5B) and ICAO Frequency Spectrum Management Panel (FSMP) working group meetings.

## 1. BACKGROUND

1.1 With the support of ICAO and the different Regional Groups of the ITU, the space-based VHF frequency allocation was formally accepted as an agenda item for World Radiocommunication Conference 2023 (WRC-23).

1.2 ITU WP5B is the responsible group for this agenda item. Currently, the space-based VHF frequency compatibility study is still ongoing in ITU WP 5B meetings, and the FSMP is the designated ICAO point of liaison with ITU WP 5B.

## 2. UPDATE

2.1 In the recent ITU WP 5B meeting held from 29 November to 10 December 2021, the following documents were updated:

a) Liaison Statement (LS) to ICAO to update the progress of space-based VHF studies and to seek clarifications, in particular, on VHF data link (VDL) Mode 2;

| | |
|---|---|
| LIAISON STATEMENT TO ICAO | R19-WP5B-C-0481!N36!MSW-E.pdf |

b) Working document towards a Preliminary Draft New Report (PDNR) detailing the technical studies and assessments of space-based studies; and

| | |
|---|---|
| WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW REPORT ITU-R M.[SPACE-VHF] | PDF<br>R19-WP5B-C-0481!N33!MSW-E.pdf |

c) Working document towards a Draft Conference Preparatory Meeting (CPM) report that details the proposed regulatory changes for WRC-23.

| | |
|---|---|
| WORKING DOCUMENT TOWARDS A DRAFT CPM TEXT | PDF<br>R19-WP5B-C-0481!N03!MSW-E.pdf |

2.2 The thirteenth meeting of the working group of Frequency Spectrum Management Panel (FSMP WG/13) was held from 21 to 25 February 2022. At the FSMP meeting, several contributions on space-based VHF were presented and the LS from WP 5B was discussed.

2.3 In one of the contributions to FSMP WG/13, ENAIRE, Indra, SITA and EUROCONTROL had jointly updated the meeting regarding about the European initiative called VOICE. The objective of that project is to perform a proof of concept (POC) for a satellite-based CNS technology in a real operational environment. The POC will also include satellite relay of VHF voice and data.

2.4 The initial outcomes of the technical studies and test/validations performed by VOICE as well as a section on frequently asked questions (FAQs) were provided in the attachment below.

| | |
|---|---|
| FSMP-WG13-IP06_Attachment (including a section on FAQs) | PDF<br>FSMP-WG13-IP06_Attachment_ICAO-FS |

2.5 The meeting agreed that the FAQs listed in the above FSMP WG/13 IP06 have answered many queries raised at ITU WP5B, and ICAO FSMP and FVSG (Future VHF Sub-Group). Correspondingly, a new satellite VHF coordination group (CG-SV) would be formed to continue the development of the questions and responses.

## 3. ACTION BY THE MEETING

3.1 The activities within the ITU WP5B and the FSMP are intensifying as WRC23 draws nearer. To ensure aviation interests are safeguard, the meeting is invited to:

a) note the information contained within this paper;

b) support the agenda items as advised by ICAO Assembly Resolution A38-6 (*Support of the ICAO Policy on radio frequency spectrum matters*); and

c) submit additional questions, if any, to FSMP through ICAO Regional Office.

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**Radiocommunication Study Groups**

Source: Document 5B/TEMP/196

Subject: WRC-23 agenda item 1.7
Resolution **428 (WRC-19)**

**Annex 36 to**
**Document 5B/481-E**
**23 December 2021**
**English only**

# Annex 36 to Working Party 5B Chairman's Report

## INITIAL REPLY LIAISON STATEMENT TO ICAO

## Studies on WRC-23 agenda item 1.7

Working Party (WP) 5B would like to thank ICAO for its liaison statement contained in Document 5B/403 related to studies under WRC-23 agenda item 1.7 on space-based aeronautical VHF communications system within the 117.975-137 MHz frequency band. In this document, ICAO provides information and comments for WP 5B's consideration on the working document under development by WP 5B.

At its meeting in November-December 2021, WP 5B has further progressed in its studies and has amended its working document, taking into account all material provided by ICAO.

In addition, regarding adjacent band compatibility with services above 137 MHz, the case of the AMS(R)S allocation in 117.975-136 MHz (voice application, and possibly data link under DSB-AM modulation in accordance with SARPs with identical RF parameters) is considered separately from the case of the AMS(R)S allocation in 136-137 MHz (voice and VDL Mode 2 applications). Studies are in progress within WP 5B, in particular on the space operation service (space-to-Earth), the space research service (space-to-Earth) and the meteorological satellite service (space-to-Earth) to ensure proper protection of these services.

The latest version of WP 5B's working document can be found in Attachment to this document for review and comments, in particular on VDL Mode 2 performance requirement in section 4.2.2.2.

Working Party 5B looks forward to continued fruitful cooperation with ICAO regarding this work.

**Status:** For information, and action, if any

**Deadline:** 22 March 2022

**Contact:** Mr Loftur JONASSON **E-mail:** ljonasson@icao.int

**Attachment:** Working document towards a preliminary draft new Report ITU-R M.[Space-VHF] (Annex 33 to WP 5B Chairman's Report, Doc. 5B/481)

R19-WP5B-C-0481!
N33!MSW-E.docx

**Radiocommunication Study Groups**

Source: Document 5B/TEMP/198

Subject: WRC-23 agenda item 1.7
Resolution **428 (WRC-19)**

**Annex 33 to**
**Document 5B/481-E**
**23 December 2021**
**English only**

# Annex 33 to Working Party 5B Chairman's Report

## 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

*Editor's note there are alternative texts/ suggestions/views in this document which need to be reconsidered and agreed.*

### 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 |
| SOS: | Space operation service |
| SRS: | Space research service |
| VDES: | VHF data exchange system |

**Relevant ITU-R Recommendations and Reports**

*Recommendations*

| | |
|---|---|
| ITU-R M.1231-0 | 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 | 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 | Technical characteristics for a VHF data exchange system in the VHF maritime mobile band |
| ITU-R P.531-14 | 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 | 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 | 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 Technical characteristics for telemetry, tracking and command in the space operation service below 1 GHz for non-GSO satellites with short duration missions

# 1 Description of space-based VHF communications concept

## 1.1 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.

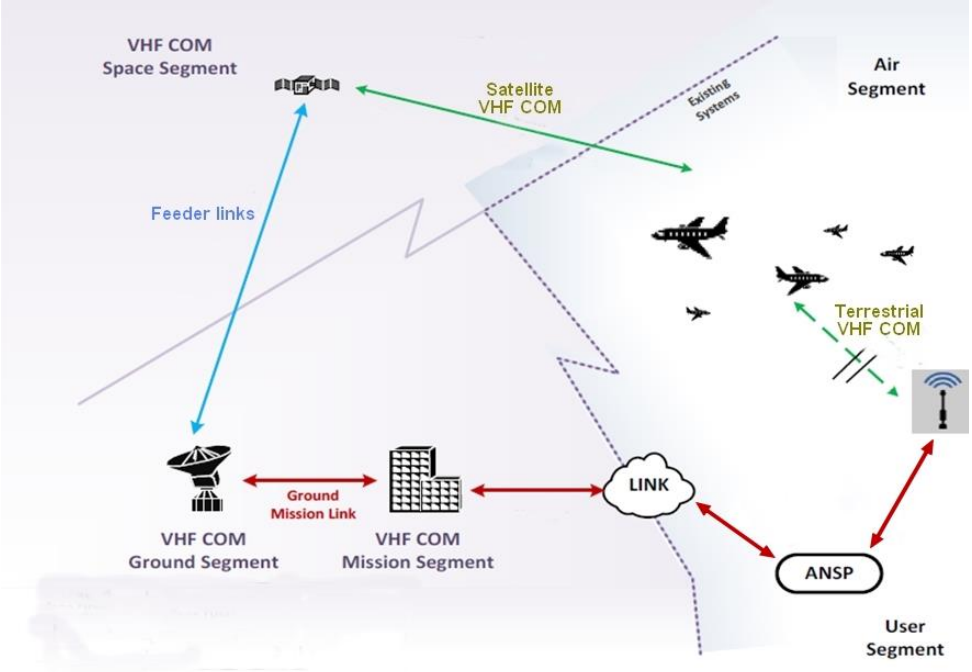
This concept, when implemented, is expected to enhance air traffic management and flight operations in oceanic and remote airspace and will complement current aviation use of satellite-based navigation and surveillance technologies.

While currently there are other long-range communication systems, such as HF and SATCOM, available to facilitate communications between aircraft to 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 on board 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**



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 provision of 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 band and may be accommodated in the fixed-satellite service, therefore are out of scope of this Report.

## 1.2 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 [and 136-137] MHz.
  - VHF data-link (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 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), with the repartition between voice and data applications as mentioned above, and existing primary in-band and adjacent band services considering existing and planned systems.

– 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 new AMS(R)S and existing aeronautical systems, and other relevant available operational characteristics.

## 2 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 all the band.

– Aeronautical mobile (OR) service in the 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)<br>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)

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

## 3.1 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 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<br>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)

## 3.2 Radiocommunication services operating in the 137-143.6 MHz frequency bands based on the Radio Regulations table of allocations

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

*Primary services in 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 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**

<table>
<tr><th colspan="3">Allocation to Services</th></tr>
<tr><th>Region 1</th><th>Region 2</th><th>Region 3</th></tr>
<tr><td><b>137-137.025</b></td><td colspan="2">SPACE OPERATION (space-to-Earth) 5.203C<br>METEOROLOGICAL-SATELLITE (space-to-Earth)<br>MOBILE-SATELLITE (space-to-Earth) 5.208A 5.208B 5.209<br>SPACE RESEARCH (space-to-Earth)<br>Fixed<br>Mobile except aeronautical mobile (R)<br>5.204 5.205 5.206 5.207 5.208</td></tr>
<tr><td><b>137.025-137.175 MHz</b></td><td colspan="2">SPACE OPERATION (space-to-Earth) 5.203C<br>METEOROLOGICAL-SATELLITE (space-to-Earth)<br>SPACE RESEARCH (space-to-Earth)<br>Fixed<br>Mobile except aeronautical mobile (R)<br>Mobile-satellite (space-to-Earth) 5.208A 5.208B 5.209<br>5.204 5.205 5.206 5.207 5.208</td></tr>
<tr><td><b>137.175-137.825 MHz</b></td><td colspan="2">SPACE OPERATION (space-to-Earth) 5.203C 5.209A<br>METEOROLOGICAL-SATELLITE (space-to-Earth)<br>MOBILE-SATELLITE (space-to-Earth) 5.208A 5.208B 5.209<br>SPACE RESEARCH (space-to-Earth)<br>Fixed<br>Mobile except aeronautical mobile (R)<br>5.204 5.205 5.206 5.207 5.208</td></tr>
<tr><td><b>137.825-138 MHz</b></td><td colspan="2">SPACE OPERATION (space-to-Earth) 5.203C<br>METEOROLOGICAL-SATELLITE (space-to-Earth)<br>SPACE RESEARCH (space-to-Earth)</td></tr>
</table>

<table>
<tr><td colspan="3">Fixed<br>Mobile except aeronautical mobile (R)<br>Mobile-satellite (space-to-Earth) 5.208A 5.208B 5.209<br>5.204 5.205 5.206 5.207 5.208</td></tr>
<tr><td>**138-143.6 MHz**<br>AERONAUTICAL MOBILE (OR)<br>5.210 5.211 5.212 5.214</td><td>**138-143.6**<br>FIXED<br>MOBILE<br>RADIOLOCATION<br>Space research (space-to-Earth)</td><td>**138-143.6**<br>**FIXED**<br>**MOBILE**<br>**Space research (space-to-Earth)**<br>**5.207 5.213**</td></tr>
</table>

**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**[*] In the frequency bands:

137-138 MHz,
157.1875-157.3375 MHz,
161.7875-161.9375 MHz,
387-390 MHz,
400.15-401 MHz,

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[*] This provision was previously numbered as No. **5.347A**. It was renumbered to preserve the sequential order.

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)

# 4 Aircraft VHF transmitter and receiver characteristics

## 4.1 Aircraft VHF transmitter characteristics

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

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.

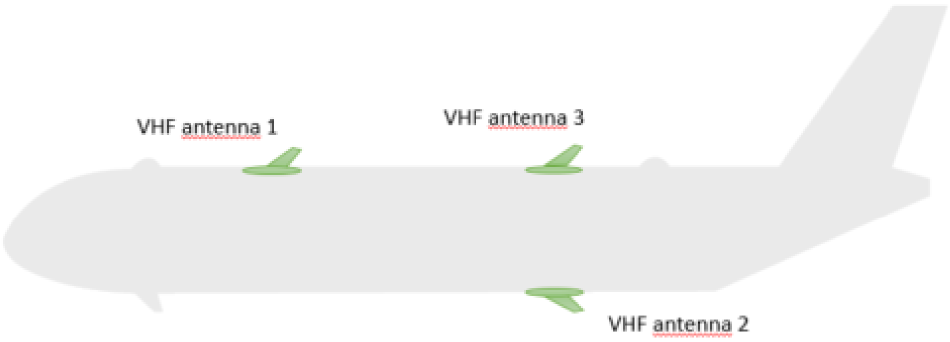
## 4.2 Aircraft VHF receiver characteristics

### 4.2.1 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**



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 range: 118-137 MHz
- Polarization: Vertical
- Radiation pattern: Omni directional
- Gain: −1 dBi

### 4.2.2 Aircraft VHF receiver performance requirement

#### 4.2.2.1 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 Sensitivity

### 2.3.2.2.1 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 50 per cent amplitude modulated (A3E) radio signal having a field strength of 75 microvolts per metre (minus 109 dBW/m$^2$).

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 of −116.2 dBW/m². Indeed the relation between field strength and power flux is given by:

$$\text{Power Flux (dBW/m}^2\text{)} = 10\log(\text{Field Strength(V/m)}^2 / 120\pi)$$

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 ($A = G_r.\lambda^2/(4\pi)$) for an isotropic antenna ($G_r$ = 0 dBi) is −3.8 dBm², hence with a power flux of −116.2 dBW/m², corresponding received power is −120 dBW or −90 dBm.

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

### 4.2.2.2 AMS(R)S Data (VDL Mode 2 modulation) application performance requirement

[*Editor´s note: This section has been elaborated during WP 5B December 2021 session, following suggestions to re-structure the document as per input from ICAO document 403. It introduces the performance requirement for VDL Mode 2, which has been used in the study contained in doc 419. Confirmation of the representativeness of these parameters against international standardized system will be required.*]

Regarding the aircraft VHF receiver sensitivity data using VDL Mode 2 modulation application, ICAO Standards and Recommended Practices (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/m$_2$).**

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 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 ($A = G_r.\lambda^2/(4\pi)$) for an isotropic antenna ($G_r$ = 0 dBi) is −3.8 dBm², hence with a power flux of −120 dBW/m², corresponding received power is −123.8 dBW or −93.8 dBm.

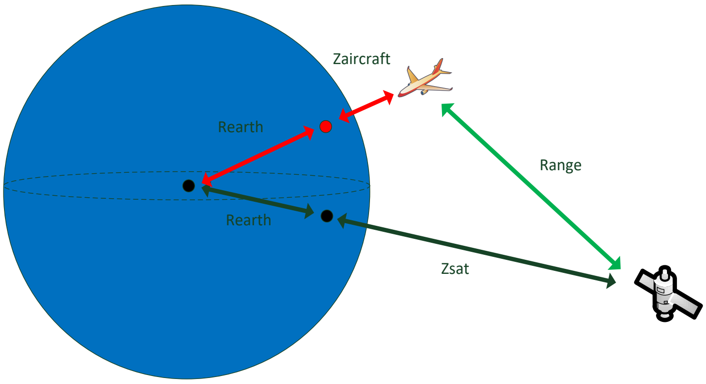
# 5 Operational environment for the transmission and reception of satellite VHF

## 5.1 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**

| | | | **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 | 36000 | 36000 |
| | **Satellite transmitter** | | | |
| c | **RF power required for 0 dB link margin** | **W** | **155531** | **3103** |
| d | Satellite Tx antenna gain | dBi | 3 | **20** |
| e | Feeder losses | dB | 1.0 | 1.0 |
| f | Satellite EIRP (calculated from c, d and e) | dBW | 53.9 | 53.9 |
| | **Signal propagation** | | | |
| g | Free space losses (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 |
| | **Received power flux at aircraft antenna input** | | | |
| | Effective received power flux (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.

## 5.2 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.

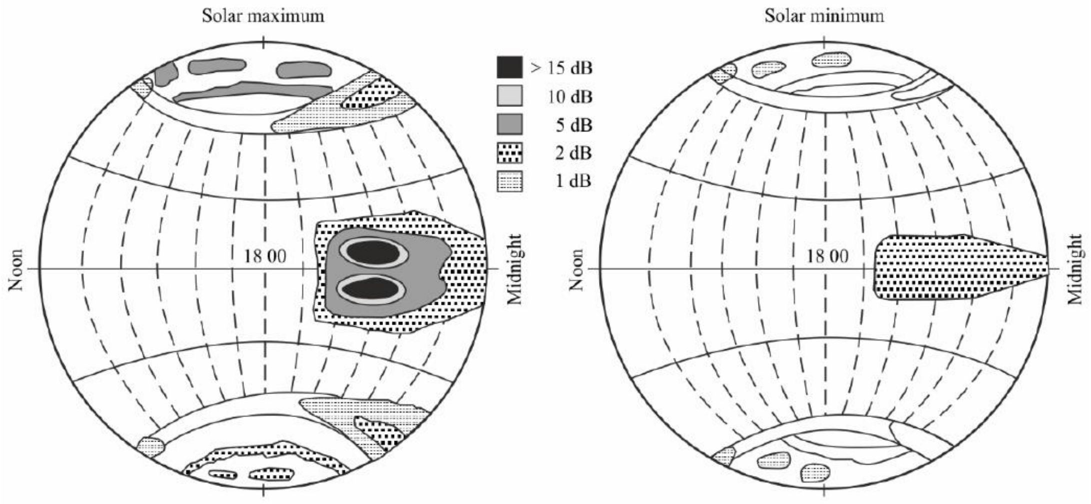
An analysis is performed in Annex, based on existing bibliography, and provides the margin to take into account under favorable conditions (middle latitude of 51.5N, period of minimum solar activity between November 1971 and April 1972) for the link budget as a function of the selected probability of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



## 5.3 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.

# 6 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.

## 6.1 Satellite transmitter 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 8dBi at 66.1 Nadir offset degrees angle is feasible.

TABLE 2

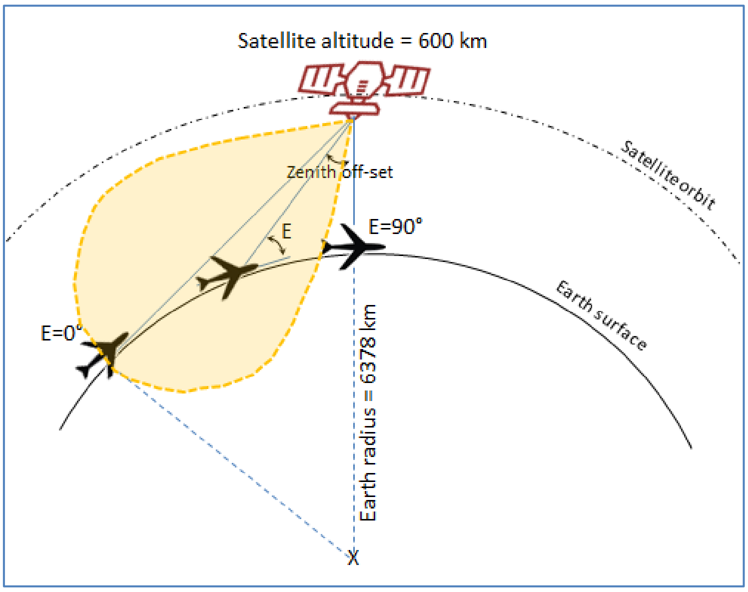
**Antenna gain pattern example of a satellite operating in the aeronautical mobile satellite (route) service**

| 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**



## 6.2 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.

## 6.3 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 | 2830.8 | 1932.2 | 1392.4 | 1075.2 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600.0 |
| | **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 | dB | 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 losses | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| | Add. propagation losses | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Effective received power flux | dBW/m$^2$ | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 | -116.2 |
| | Recommended SARPs power-flux | dBW/m$^2$ | -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 | dB | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Rx signal power level | dBm | -93.4 | -93.4 | -93.4 | -93.4 | -93.4 | -93.4 | -93.4 | -93.4 | -96.4 | -100.4 |

A significant 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 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 | 2830.8 | 1932.2 | **1392.4** | **1075.2** | **882.4** | **760.8** | **683.2** | **634.9** | 608.4 | 600.0 |
| | **Transmitter** | | | | | | | | | | | |
| | RF Power for 25 kHz channel | W | 85.0 | 85.0 | **85.0** | **85.0** | **85.0** | **85.0** | **85.0** | **85.0** | 85.0 | 85.0 |
| | Sat Tx gain | dBi | 8 | 8 | **8** | **7.8** | **6.9** | **5.5** | **3.6** | **0.7** | -2.2 | -5.5 |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.9 | **138.1** | **135.8** | **134.1** | **132.8** | **131.9** | **131.2** | 130.9 | 130.7 |
| | Add. propagation losses | dB | 5 | 5 | **5** | **5** | **5** | **5** | **5** | **5** | 5 | 5 |
| | Polarization losses | dB | 3 | 3 | **3** | **3** | **3** | **3** | **3** | **3** | 3 | 3 |
| | Effective received power flux | dBW/m$^2$ | -121.7 | -118.4 | **-115.6** | **-113.5** | **-112.7** | **-112.8** | **-113.8** | **-116.1** | -118.6 | -121.8 |
| | Recommended SARPs power-flux | dBW/m$^2$ | -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 | dB | 2 | 2 | **2** | **2** | **2** | **2** | **2** | **2** | 2 | 2 |
| | Rx signal power level | dBm | -98.9 | -95.6 | **-92.8** | **-90.7** | **-89.9** | **-90.0** | **-91.0** | **-93.2** | -98.8 | -105.9 |
| | PFD at Earth's surface (taking only free space loss into account) | dBW/m$^2$/25kHz | -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 | 2830.8 | 1932.2 | 1392.4 | 1075.2 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600.0 |
| | **Transmitter** | | | | | | | | | | | |
| | RF Power for 25 kHz channel | W | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 | 35.0 |
| | Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| | Feeder loss | dB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Satellite EIRP | dBW | 22.4 | 22.4 | 22.4 | 22.2 | 21.3 | 19.9 | 18.0 | 15.1 | 12.2 | 8.9 |
| | **Signal propagation** | | | | | | | | | | | |
| | Free space losses | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| | Add. propagation losses | dB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Effective received power flux | dBW/m$^2$ | -121.6 | -118.3 | -115.4 | -113.4 | -112.6 | -112.7 | -113.6 | -115.9 | -118.4 | -121.6 |
| | Recommended SARPs power-flux | dBW/m$^2$ | -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 | dB | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Rx signal power level | dBm | -98.8 | -95.5 | -92.6 | -90.6 | -89.7 | -89.9 | -90.8 | -93.1 | -98.6 | -105.8 |
| | PFD at Earth's surface (taking only free space loss into account) | dBW/m$^2$/25kHz | -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.

## 6.4 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.

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 | 2830.8 | 1932.2 | 1392.4 | 1075.2 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600.0 |
| | **Transmitter** | | | | | | | | | | | |
| | RF Power for 25 kHz channel | W | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| | Aircraft Tx gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -4 | -8 |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| | Add. propagation losses | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Effective received power flux | dBW/m$^2$ | -139.0 | -135.7 | -132.8 | -130.6 | -128.9 | -127.6 | -126.6 | -126 | -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 | dB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Rx signal power level | 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.

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

*[Editor´s note: This section has been elaborated during WP 5B December 2021 session, following suggestions to re-structure the document as per input from ICAO document 403. It introduces the performance requirement for VDL Mode 2, which has been used in the study contained in doc 419. Confirmation of the representativeness of these parameters against international standardized system will be required.]*

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.

TABLE 7

**Example satellite-to-aircraft (downlink) link budget (VHF data link mode 2 modulation)**
**- 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 | 2830,8 | 1932,2 | 1392,4 | 1075,2 | 882,4 | 760,8 | 683,2 | 634,9 | 608,4 | 600 |
| | Transmitter | | | | | | | | | | | |
| | RF Power for 25 KHz channel | W | 126,8 | 59,1 | 30,7 | 19,2 | 15,9 | 16,3 | 20,3 | 34,2 | 61,3 | 127,5 |
| | 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 | 28,0 | 24,7 | 21,9 | 19,6 | 17,9 | 16,6 | 15,7 | 15,0 | 14,7 | 14,6 |
| | Signal Propagation | | | | | | | | | | | |
| | Free SPACE Losses | dB | 144,2 | 140,9 | 138,1 | 135,8 | 134,1 | 132,8 | 131,9 | 131,2 | 130,9 | 130,7 |
| | Add. Propagation Losses | 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 | dBW/m$^2$ | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 | -120 |
| | Recommended SAPRs Power flux | dBW/m$^2$ | -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 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Rx Signal power | dBm | -97,2 | -97,2 | -97,2 | -97,2 | -97,2 | -97,2 | -97,2 | -97,2 | -100,2 | -104,2 |

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 35 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 | 2830,8 | 1932,2 | 1392,4 | 1075,2 | 882,4 | 760,8 | 683,2 | 634,9 | 608,4 | 600 |
| | Transmitter | | | | | | | | | | | |
| | RF Power for 25 KHz channel | W | 35,0 | 35,0 | 35,0 | 35,0 | 35,0 | 35,0 | 35,0 | 35,0 | 35,0 | 35,0 |
| | 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 | 22,4 | 22,4 | 22,4 | 22,2 | 21,3 | 19,9 | 18,0 | 15,1 | 12,2 | 8,9 |
| | Signal Propagation | | | | | | | | | | | |
| | Free SPACE Losses | dB | 144,2 | 140,9 | 138,1 | 135,8 | 134,1 | 132,8 | 131,9 | 131,2 | 130,9 | 130,7 |
| | Add. Propagation Losses | 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 | dBW/m$^2$ | -125,6 | -122,3 | -119,4 | -117,4 | -116,6 | -116,7 | -117,6 | -119,9 | -122,4 | -125,6 |
| | Recommended SAPRs Power flux | dBW/m$^2$ | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 |
| | Power flux margin | dB | -5,6 | -2,3 | 0,6 | 2,6 | 3,4 | 3,3 | 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 | -102,8 | -99,5 | -96,6 | -94,6 | -93,7 | -93,9 | -94,8 | -97,1 | -102,6 | -109,8 |
| | PFD at the earth surface FSL | dBW/m2/25 KHz | -117,6 | -114,3 | -111,4 | -109,4 | -108,6 | -108,7 | -109,6 | -111,9 | -114,4 | -117,6 |

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 2,4 dB from 35W 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 | 2830,8 | 1932,2 | 1392,4 | 1075,2 | 882,4 | 760,8 | 683,2 | 634,9 | 608,4 | 600 |
| | Transmitter | | | | | | | | | | | |
| | RF Power for 25 KHz channel | W | 20,0 | 20,0 | 20,0 | 20,0 | 20,0 | 20,0 | 20,0 | 20,0 | 20,0 | 20,0 |
| | 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 Losses | dB | 144,2 | 140,9 | 138,1 | 135,8 | 134,1 | 132,8 | 131,9 | 131,2 | 130,9 | 130,7 |
| | Add. Propagation Losses | 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 | dBW/m$^2$ | -124,0 | -120,7 | -117,9 | -115,8 | -115,0 | -115,1 | -116,1 | -118,3 | -120,9 | -124,0 |
| | Recommended SAPRs Power flux | dBW/m$^2$ | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 | -120,0 |
| | 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 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Rx Signal power | dBm | -101,2 | -97,9 | -95,0 | -93,0 | -92,2 | -92,3 | -93,3 | -95,5 | -101,0 | -108,2 |
| | PFD at the earth surface FSL | dBW/m2/25 KHz | -120,0 | -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.

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

*[Editor´s note: This section has been elaborated during WP 5B December 2021 session, following suggestions to re-structure the document as per input from ICAO document 403. It introduces the performance requirement for VDL Mode 2, which has been used in the study contained in doc 419. Confirmation of the representativeness of these parameters against international standardized system will be required.]*

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 and detailed in ICAO Doc. 9718, ICAO Handbook on Radio Frequency Spectrum Requirements for Civil Aviation, Volume II Frequency assignment planning criteria for aeronautical radio communication and navigation systems, 2.3.2 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 | 2830.8 | 1932.2 | 1392.4 | 1075.2 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600.0 |
| | **Transmitter** | | | | | | | | | | | |
| | RF Power for 25 kHz channel | W | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| | Aircraft Tx gain | dBi | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | **-4** | **-8** |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| | Add. propagation losses | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Polarization losses | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Effective received power flux | dBW/m² | -139.0 | -135.7 | -132.8 | -130.6 | -128.9 | -127.6 | -126.6 | -126 | -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 | dB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Rx signal power level | 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.

## 7 Sharing and compatibility studies related to applications of the aeronautical mobile (route) service in the frequencyband 117.975-136 MHz

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 [and data using DSB-AM modulation] 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 117.975-136MHz, the conclusions are therefore identical for voice and DSB-AM data applications.

– Secondly, to include the sub-band 136-137 MHz for the new AMS(R)S allocation, after both the in-band compatibility studies within ICAO and the adjacent band compatibility studies by the ITU with non-ICAO services above 137 MHz are completed and agreed. This is addressed in section 8.

### 7.1 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.

### 7.2 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.

There are no available characteristics for AM(OR)S systems. However 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.

### 7.3 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.

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

#### 7.4.1 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.

### 7.4.2 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

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:

- Long-term: −159.9 dBW in a reference bandwidth of 19.2 kHz, to be exceeded for no more than 20% of the time.
- Short-term: −144.7 dBW in a reference bandwidth of 19.2 kHz, to be exceeded for no more than 0.0625% of the time.

These criteria have been derived under certain assumptions detailed in Table 2 of recommendation M.1231. The following of these assumptions are retained in Table 11 below for the assessment of the attenuation level required to ensure that AMS(R)S unwanted emissions do not exceed the required level.

- Long term: propagation loss of 1 dB, MSS receiver antenna gain of −0.5 dB, demodulator implementation loss of 3 dB.
- Short term: propagation loss of 5 dB, MSS receiver antenna gain of 0 dB, demodulator implementation loss of 3 dB.

TABLE 11

**Assessment of the attenuation required to ensure that unwanted emission levels above 137 MHz from systems operating in the aeronautical mobile satellite (route) service below 136 MHz are compliant with the protection levels of subscriber terminals for systems operating in the mobile satellite service operating above 137 MHz**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Long-term protection of MSS subscriber receiver** | 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 | 2830.8 | 1932.2 | 1392.4 | 1075.2 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600.0 |
| | **AMS(R)S Transmitter** | | | | | | | | | | | |
| | Frequency | MHz | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 |
| | RF Power for 25 kHz channel | W | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| | Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| | Add. propagation losses | dB | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | Polarization losses | dB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **MSS Receiver (see M.1231 Table 2)** | | | | | | | | | | | |
| | Frequency | MHz | 137.0 | 137.0 | 137.0 | 137.0 | 137.0 | 137.0 | 137.0 | 137.0 | 137.0 | 137.0 |
| | MSS Rx antenna gain | dBi | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 | -0.5 |
| | Demodulator implementation loss | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Rx signal power level in 19.2 kHz | dBW | -123.6 | -120.2 | -117.4 | -115.4 | -114.5 | -114.7 | -115.6 | -117.9 | -120.4 | -123.6 |
| | M.1232 **long term** protection requirement in 19.2 kHz | dBW | -159.9 | -159.9 | -159.9 | -159.9 | -159.9 | -159.9 | -159.9 | -159.9 | -159.9 | -159.9 |
| | Required signal attenuation/filtering | dB | **36.3** | **39.7** | **42.5** | **44.5** | **45.4** | **45.2** | **44.3** | **42.0** | **39.5** | **36.3** |
| **Short-term protection of MSS subscriber receiver** | 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 | 2830.8 | 1932.2 | 1392.4 | 1075.2 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600.0 |
| | **AMS(R)S Transmitter** | | | | | | | | | | | |
| | Frequency | MHz | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 |
| | RF Power for 25 kHz channel | W | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| | Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.9 | 138.1 | 135.8 | 134.1 | 132.8 | 131.9 | 131.2 | 130.9 | 130.7 |
| | Add. propagation losses | dB | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| | Polarization losses | dB | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **MSS Receiver (see M.1231 Table 2)** | | | | | | | | | | | |
| | Frequency | MHz | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| | MSS Rx antenna gain | dBi | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Demodulator implementation loss | dB | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Rx signal power level in 19.2 kHz | dBW | -127.1 | -123.7 | -120.9 | -118.9 | -118.0 | -118.2 | -119.1 | -121.4 | -123.9 | -127.1 |
| | M.1232 **short term** protection requirement in 19.2 kHz | dBW | -144.7 | -144.7 | -144.7 | -144.7 | -144.7 | -144.7 | -144.7 | -144.7 | -144.7 | -144.7 |
| | Required signal attenuation/filtering | dB | **17.6** | **21.0** | **23.8** | **25.8** | **26.7** | **26.5** | **25.6** | **23.3** | **20.8** | **17.6** |

This analysis shows that in order to ensure protection of systems operating in the MSS, the unwanted emission level above 137 MHz of a system operating in the AMS(R)S below 136 MHz would have to be attenuated by 45 dB compared to its maximum in-band level.

This attenuation will be obtained by a combination of spectral roll-off and filtering. The amount of required filtering would depend on the exact extent of the AMS(R)S allocation.

For an AMS(R)S allocation in 117.975-136 MHz, the guard band of at least 1 MHz in 136-137 MHz, corresponding to 40 channels of 25 kHz, is sufficient to ensure that this attenuation will be respected. Indeed, according to RR Appendix 3, AMS(R)S unwanted emissions falling above 137 MHz would correspond to spurious emissions, and would have to comply with the maximum permitted power level for space services of "43 + 10 log (P), or 60 dBc, whichever is less stringent, in a 4 kHz reference bandwidth". Taking into account the 85 W / 19.3 dBW satellite power mentioned in the table above per 25 kHz channel:

– Minimum attenuation in dBc for resulting spurious emissions is: min (43 + 19.3; 60) dBc = 60 dBc in a 4 kHz reference bandwidth.

– Converting to an absolute level yields for the maximum level of spurious emissions: 19.3 – 60 dBc = - 40.7 dBW in a 4 kHz bandwidth, or -32.7 dBW/25 kHz.

– Corresponding attenuation relative to in-band satellite level is therefore 19.3 – (-32.7) = 52 dB, to be compared with the required 45 dB attenuation for MSS protection.

In can therefore be concluded that protection of MSS above 137 MHz from AMS(R)S satellite emissions in 117.975-136 MHz is ensured.

### 7.4.3 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)]*

[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 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 protection 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. And 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.

Table 8 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 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 minimum attenuation of 52 dB calculated in section 7.4.2 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**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMS(R)S satellite downlink into SOS earth station receiver | Frequency | MHz | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 |
| | 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 | 2830.8 | 1932.2 | 1392.4 | 1075.2 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600.0 |
| | **Transmitter** | | | | | | | | | | | |
| | RF Power for 25 kHz channel | W | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| | Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.8 | 138.0 | 135.7 | 134.0 | 132.7 | 131.8 | 131.2 | 130.8 | 130.7 |
| | Additional propagation losses | dB | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| | **Receiver** | | | | | | | | | | | |
| | SOS Rx antenna gain | dBi | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | Rx signal power level per 1 kHz | dBW | -120.8 | -117.5 | -114.7 | -112.6 | -111.8 | -111.9 | -112.9 | -115.2 | -117.7 | -120.9 |
| | Minimum attenuation level above 137 MHz | dB | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| | Maximum power level per 1 kHz at SOS receiver input | dBW | -172.8 | -169.5 | -166.7 | -164.6 | -163.8 | -163.9 | -164.9 | -167.2 | -169.7 | -172.9 |
| | SOS protection criteria: max. interference power in 1 kHz | dBW | -164 | -164 | -164 | -164 | -164 | -164 | -164 | -164 | -164 | -164 |
| | Margin | dB | 8.8 | 5.5 | 2.7 | 0.6 | -0.2 | -0.1 | 0.9 | 3.2 | 5.7 | 8.9 |

Table 12 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.

### 7.4.4 ]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)]*

[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 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.

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 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 minimum attenuation of 52 dB calculated in section 7.4.2 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**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMS(R)S satellite downlink into SRS earth station receiver | Frequency | MHz | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 | 136 |
| | 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 | 2830.8 | 1932.2 | 1392.4 | 1075.2 | 882.4 | 760.8 | 683.2 | 634.9 | 608.4 | 600.0 |
| | **Transmitter** | | | | | | | | | | | |
| | RF Power for 25 kHz channel | W | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| | Sat Tx gain | dBi | 8 | 8 | 8 | 7.8 | 6.9 | 5.5 | 3.6 | 0.7 | -2.2 | -5.5 |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.8 | 138.0 | 135.7 | 134.0 | 132.7 | 131.8 | 131.2 | 130.8 | 130.7 |
| | Additional propagation losses | dB | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| | **Receiver** | | | | | | | | | | | |
| | SRS Rx antenna gain | dBi | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| | Rx signal power level per 1 Hz | dBW | -159.6 | -156.3 | -153.5 | -151.4 | -150.6 | -150.7 | -151.7 | -154 | -156.5 | -159.7 |
| | Minimum attenuation level above 137 MHz | dB | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |
| | Maximum power level per 1 Hz at SRS receiver input | dBW | -211.6 | -208.3 | -205.5 | -203.4 | -202.6 | -202.7 | -203.7 | -206 | -208.5 | -211.7 |
| | SRS protection criteria: max. interference power in 1 Hz | dBW | -196 | -196 | -196 | -196 | -196 | -196 | -196 | -196 | -196 | -196 |
| | Margin | dB | 15.6 | 12.3 | 9.5 | 7.4 | 6.6 | 6.7 | 7.7 | 10.0 | 12.5 | 15.7 |

Table 13 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.

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### 7.4.5 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.

Protection criteria for MetSat systems in the band 137-138 MHz can 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". According to Table 1 of this Recommendation, the most dimensioning protection criteria for earth station receivers in the MetSat at 137-138 GHz is -147 dBW per 150 kHz, and these earth stations use either low antenna gains of 2 dBi or higher antenna gains of 10 dBi.

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 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 2 dBi for the peak antenna gain of MetSat earth stations at 137 MHz.

– 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 52 dB calculated in section 7.4.2 for the level of unwanted emissions above 137 MHz resulting from AMS(R)S satellite in-band emissions below 136 MHz.

TABLE 14

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

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AMS(R)S satellite downlink into MetSat earth station receiver** | Frequency | MHz | 136 | 136 | **136** | **136** | **136** | **136** | **136** | **136** | 136 | 136 |
| | 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 | 2830.8 | 1932.2 | **1392.4** | **1075.2** | **882.4** | **760.8** | **683.2** | **634.9** | 608.4 | 600.0 |
| | **Transmitter** | | | | | | | | | | | |
| | RF Power for 25 kHz channel | W | 85.0 | 85.0 | **85.0** | **85.0** | **85.0** | **85.0** | **85.0** | **85.0** | 85.0 | 85.0 |
| | Sat Tx gain | dBi | 8 | 8 | **8** | **7.8** | **6.9** | **5.5** | **3.6** | **0.7** | -2.2 | -5.5 |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.8 | **138.0** | **135.7** | **134.0** | **132.7** | **131.8** | **131.2** | 130.8 | 130.7 |
| | Additional propagation losses | dB | 1.0 | 1.0 | **1.0** | **1.0** | **1.0** | **1.0** | **1.0** | **1.0** | 1.0 | 1.0 |
| | **Receiver** | | | | | | | | | | | |
| | MetSat Rx antenna gain | dBi | 2 | 2 | **2** | **2** | **2** | **2** | **2** | **2** | 2 | 2 |
| | Rx signal power level per 150 kHz | dBW | -109.1 | -105.8 | **-102.9** | **-100.9** | **-100** | **-100.2** | **-101.1** | **-103.4** | -105.9 | -109.1 |
| | Minimum attenuation level above 137 MHz | dB | 52 | 52 | **52** | **52** | **52** | **52** | **52** | **52** | 52 | 52 |
| | Maximum power level per 150 kHz at MetSat receiver input | dBW | -161.1 | -157.8 | **-154.9** | **-152.9** | **-152** | **-152.2** | **-153.1** | **-155.4** | -157.9 | -161.1 |
| | MetSat protection criteria: max. interference power in 150 kHz | dBW | -147 | -147 | **-147** | **-147** | **-147** | **-147** | **-147** | **-147** | -147 | -147 |
| | Margin | dB | 14.1 | 10.8 | **7.9** | **5.9** | **5.0** | **5.2** | **6.1** | **8.4** | 10.9 | 14.1 |

Table 14 shows that protection of MetSat above 137 MHz from AMS(R)S satellite emissions in 117.975-136 MHz is ensured, for MetSat earth stations using low antenna gains of 2 dBi. For MetSat earth stations using higher antenna gains of 10 dBi, the calculation will be identical, except that the received power level will be increased by 8 dB. Table 15 below provides the associated calculation.

TABLE 15

**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**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **AMS(R)S satellite downlink into MetSat earth station receiver** | Frequency | MHz | 136 | 136 | **136** | **136** | **136** | **136** | **136** | **136** | 136 | 136 |
| | 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 | 2830.8 | 1932.2 | **1392.4** | **1075.2** | **882.4** | **760.8** | **683.2** | **634.9** | 608.4 | 600.0 |
| | **Transmitter** | | | | | | | | | | | |
| | RF Power for 25 kHz channel | W | 85.0 | 85.0 | **85.0** | **85.0** | **85.0** | **85.0** | **85.0** | **85.0** | 85.0 | 85.0 |
| | Sat Tx gain | dBi | 8 | 8 | **8** | **7.8** | **6.9** | **5.5** | **3.6** | **0.7** | -2.2 | -5.5 |
| | Feeder loss | dB | 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 losses | dB | 144.2 | 140.8 | **138.0** | **135.7** | **134.0** | **132.7** | **131.8** | **131.2** | 130.8 | 130.7 |
| | Additional propagation losses | dB | 1.0 | 1.0 | **1.0** | **1.0** | **1.0** | **1.0** | **1.0** | **1.0** | 1.0 | 1.0 |
| | **Receiver** | | | | | | | | | | | |
| | MetSat Rx antenna gain | dBi | 10 | 10 | **10** | **10** | **10** | **10** | **10** | **10** | 10 | 10 |
| | Rx signal power level per 150 kHz | dBW | -101.1 | -97.76 | **-94.91** | **-92.87** | **-92.05** | **-92.16** | **-93.13** | **-95.39** | -97.92 | -101.1 |
| | Minimum attenuation level above 137 MHz | dB | 52 | 52 | **52** | **52** | **52** | **52** | **52** | **52** | 52 | 52 |
| | Maximum power level per 150 kHz at MetSat receiver input | dBW | -153.1 | -149.8 | **-146.9** | **-144.9** | **-144** | **-144.2** | **-145.1** | **-147.4** | -149.9 | -153.1 |
| | MetSat protection criteria: max. interference power in 150 kHz | dBW | -147 | -147 | **-147** | **-147** | **-147** | **-147** | **-147** | **-147** | -147 | -147 |
| | Margin | dB | 6.1 | 2.8 | **-0.1** | **-2.1** | **-3.0** | **-2.8** | **-1.9** | **0.4** | 2.9 | 6.1 |

This results logically in negative margin in certain cases where the margin in Table 15 is lower than 8dB, the worst case being a margin of -3 dB at 40° elevation. However, this has to be put in perspective with the fact that several worst case assumptions have been added in this static calculation. Namely:

- The MetSat earth station is assumed to permanently point towards the satellite with its maximum gain, which will not be the case in the reality.
- The highest value of 85W from Table 4 is considered for satellite power, rather than the 35W level from Table 5, which is 4 dB lower.
- A low level of 1 dB propagation loss is considered for the satellite-MetSat earth station link.
- The minimum attenuation level of 52 dB for unwanted emissions is considered, based on RR Appendix 3, while spurious emissions from satellite will be even more attenuated.
- The possible excess of the protection criterion for “no more than 20% of the time” is not considered here.

It can therefore be concluded that this negative margin of -3 dB is not significant, and that protection of MetSat above 137 MHz from AMS(R)S satellite emissions in 117.975-136 MHz is ensured.

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### 7.4.6 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.

# 8 Sharing and compatibility studies related to applications of the aeronautical mobile (route) service operating in the band 136-137 MHz

*[Editor´s note: This section has been elaborated during WP 5B December 2021 session, following suggestions to re-structure the document as per input from ICAO document 403. It introduces the performance requirement for VDL Mode 2, which has been used in the study contained in doc 419. Confirmation of the representativeness of these parameters against international standardized system will be required.]*

Refer to section 7

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

Refer to section 7.1

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

Refer to section 7.2

## 8.3 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 7.3

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

### 8.4.1 General consideration

To reference values for the compatibility studies, it is assumed that the minimum power flux value to establish the link space-to-Earth is, according to previous section 4.2.2.2, −120 dBW/m². In addition, as mentioned in TABLES 2, 3, 4 and 5 in section 6, it could be assumed a maximum effective received power flux at surface level of -115 dBW/m$^2$ (@20W; 1 dB scintillation).

### 8.4.2 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 mobile satellite service (space-to-Earth) above 137 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:

– Long-term : −159.9 dBW in a reference bandwidth of 19.2 kHz, to be exceeded for no more than 20% of the time.

– Short-term: −144.7 dBW in a reference bandwidth of 19.2 kHz, to be exceeded for no more than 0.0625% of the time.

These criteria have been derived under certain assumptions detailed in Table 2 of recommendation M.1231. The following of these assumptions are retained in Table 16 below for the assessment of the attenuation level required to ensure that AMS(R)S unwanted emissions do not exceed the required level.

– Long term: propagation loss of 1 dB, MSS receiver antenna gain of −0.5 dB, demodulator implementation loss of 3 dB.

– Short term: propagation loss of 5 dB, MSS receiver antenna gain of 0 dB, demodulator implementation loss of 3 dB.

TABLE 16

**Assessment of the attenuation required to ensure that unwanted emission levels above 137 MHz from systems operating in the aeronautical mobile satellite (route) service below 137 MHz are compliant with the protection levels of subscriber terminals for systems operating in the mobile satellite service operating above 137 MHz**

| **AMS(R)S Interference Into MSS (Spectral OoB Characteristics)<br>Long Term** | | | |
|---|---|---|---|
| **Input Source** | **Parameter** | **Value** | **Unit** |
| AMS(R)S | Frequency | 137,00 | MHz |
| | Lambda | 2,19 | m |
| | Max PFD | -115,00 | dBW/m$^2$ |
| | G Iso Antenna | 0,38 | m2 |
| | Expected AMS(R)S Interf. Level | -119,18 | dBW |
| ITU.R M 1231 | Propagation Loss (Rec.1231) | 1,00 | dB |
| | MSS Rx antenna Gain | -0,50 | dBi |
| | Dem. Impl. Loss | 3,00 | dB |
| ITU-R-SM-1541 | OoB attenuation Mask at 137 MHz | 35,00 | dB |
| ITU-R.M1232 | M1232 Long Term Protection | -159,90 | dBW |
| | Expected AMS(R)S OoB Interf. Level | -158,68 | dBW |
| | **Margin** | -1,22 | **dB** |

| **AMS(R)S Interference Into MSS (Spectral OoB Characteristics)<br>Short Term** | | | |
|---|---|---|---|
| **Input Source** | **Parameter** | **Value** | **Unit** |
| AMS(R)S | Frequency | 137,00 | MHz |
| | Lambda | 2,19 | m |
| | Max PFD | -115,00 | dBW/m$^2$ |
| | G Iso Antenna | 0,38 | m2 |
| | Expected AMS(R)S Interf. Level | -119,18 | dBW |

| | | | |
|---|---|---|---|
| ITU.R M 1231 | Propagation Loss (Rec.1231) | 5,00 | dB |
| | MSS Rx antenna Gain | 0,00 | dBi |
| | Dem. Impl. Loss | 3,00 | dB |
| ITU-R-SM-1541 | OoB attenuation Mask at 137 MHz | 35,00 | dB |
| ITU-R.M1232 | M1232 Long Term Protection | -144,70 | dBW |
| | Expected AMS(R)S OoB Interf. Level | -162,18 | dBW |
| | **Margin** | 17,48 | **dB** |

This analysis shows that in order to ensure protection of systems operating in the MSS, the unwanted emission level above 137 MHz of a system operating in the AMS(R)S in the frequency band 136-137 MHz would have to be attenuated by 36.22 dB compared to its maximum in-band level.

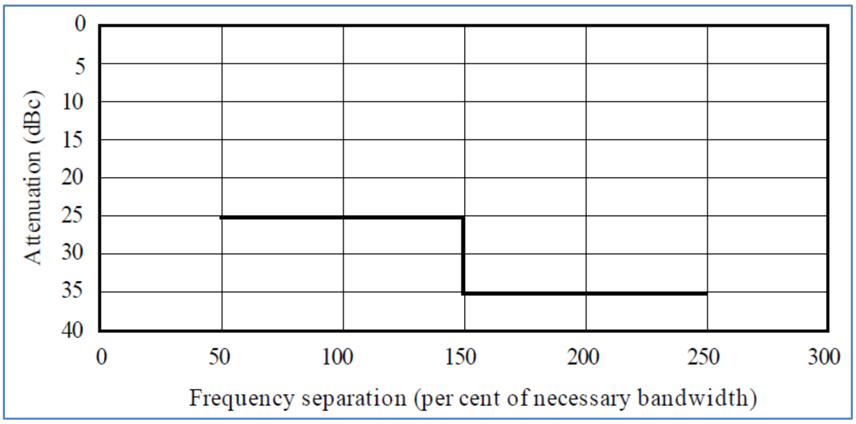
For the sake of comparison, it is interesting to consider the out-of-band emission mask for the aeronautical mobile service provided in Recommendation ITU-R SM.1541 (Annex 11) on “unwanted emissions in the out-of-band domain”.

Considering that,

- 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 R-REC-SM.1138).
- The estimated very worst case of frequency deviation with the main contribution coming from the Satellite-Aircraft Doppler, 8 kHz (4 kHz * 2 if some Doppler correction is implemented in the satellite that will affect two time the aircrafts in the opposite direction), which shifts the centre frequency to 136.983 MHz.
- The applicable Recommendation ITU-R-SM.1541 Unwanted emissions in the Out-of-Band Domain states in Figure 44 for aeronautical transmitters, that the following mask is applicable:

FIGURE 6

**Out-of-band mask in Recommendation ITU-R SM.1541
for the aeronautical mobile service (Figure 44)**



*[**Chairman’s note**: This figure from ITU-R SM.1541 doesn’t seem to be consistent with the definition of the necessary bandwidth unless the necessary bandwidth of an aeronautical mobile service is the -25 dBc points which I do not believe to be true]*

At 137.0 MHz, the spectral roll-off is required to be at least 35 dBc from the carrier power (Frequency separation=150% of necessary bandwidth).

TABLE 17

| **Fo** | **Necessary Bandwidth** | **0%** | **50%** | **100%** | **150%** | **200%** | **250%** |
|---|---|---|---|---|---|---|---|
| 136.975 MHz | 14 kHz | 136.975 MHz<br>0 dBc | 136.982 MHz<br>25 dBc | 136.989 MHz<br>25 dBc | 136.996 MHz<br>35 dBc | 137.003 MHz<br>35 dBc | 137.010 MHz<br>35 dBc |
| 136.983 MHz | 14 kHz | 136.983 MHz<br>0 dBc | 136.990 MHz<br>25 dBc | 136.997 MHz<br>25 dBc | 137.004 MHz<br>35 dBc | 137.011 MHz<br>35 dBc | 137.018 MHz<br>35 dBc |

### 8.4.3 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)]*

[According to Recommendation ITU-R SA.363-5, “space Operation Systems" the protection level of the earth station receivers is defined as -214 dBW/Hz, however the permissible interference level may be raised by 20 dB per decade below 1 GHz. This would result in -194 dBW/Hz PFD level:

– Worst case for Data (BW 14.0 kHz)- max allowed level at SOS receiver is -152.54 dBW / 14 kHz.

In order to evaluate the interference from the AMS(R)S service, the following assumptions were made:

– Maximum effective received power flux at surface level of -115 dBW/m$^2$.

– The out-of-band emission mask for the aeronautical mobile service provided in Recommendation ITU-R SM.1541 (Annex 11) on “unwanted emissions in the out-of-band domain” (as used in 7.3.1).

– Typical SOS earth station parameters:
  - Antenna Gain: 12 dBi
  - Polarization + Tracking losses: 4 dB
  - The short term protection.

Having into account estimated values for SOS earth stations and the out-of-band emission mask for the aeronautical mobile service provided in Recommendation ITU-R SM.1541 (Annex 11) on “unwanted emissions in the out-of-band domain” (as used in 7.3.1).

TABLE 18

| AMS(R)S Interference Into SOS (Spectral characteristics) | | | |
|---|---|---|---|
| **Input Source** | **Parameter** | **Value** | **Unit** |
| AMS(R)S | Frequency | 137,00 | MHz |
| | Lambda | 2,19 | m |
| | Max PFD | -115,00 | dBW/m$^2$ |
| | G Iso Antenna | 0,38 | m2 |
| | Expected AMS(R)S Interf. Level | -119,18 | dBW |
| ITU-R SA.2426-0 (Table 6) | Polarization and Tracking Loss | 4,00 | dB |
| | MSS Rx antenna Gain | 12,00 | dBi |
| ITU-R-SM-1541 | OoB attenuation Mask at 137 MHz | 35,00 | dB |
| REC-SA-363-5 | Protection Criteria | -152,54 | dBW/14kHz |
| Expected AMS(R)S level For 14 KHz BW (spectral) | OoB Interf. Level | -146,18 | dBW/14kHz |
| | **Margin** | **-6,35** | **dB** |

This analysis shows that in order to ensure protection of systems operating in the SOS, the unwanted emission level above 137 MHz of a system operating in the AMS(R)S in the frequency band 136-137 MHz would have to be attenuated by 41.35 dB (35+6.35) compared to its maximum in-band level.]

### 8.4.4 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: This section has been elaborated during WP 5B December 2021 but will require further consideration at next WP 5B 2022 meeting]*

*[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)]*

[According to Recommendation ITU-R SA-609-1, the permissible interference is defined as −216 dBW/Hz, however the permissible interference level may be raised by 20 dB per decade below 1 GHz. This would result in -196 dBW/Hz PFD level.

- Worst case for Data (BW 14 kHz)- max allowed level at SRS receiver is -154.54 dBW within 14 kHz.

Considering relevant data for SRS typical station at VHF frequencies as recommended by Working party 7B responsible a typical antenna gain data of 3.2 dBi.

TABLE 19

**Spectral characteristics of systems operating in the aeronautical mobile satellite (route) service and space research service used in compatibility studies**

| Input source | Parameter | Case 1 | Unit |
|---|---|---|---|
| AMS(R)S | Frequency | 137,00 | MHz |

| | | | |
|---|---|---|---|
| | Lambda | 2,19 | m |
| | Max PFD | -115,00 | dBW/m2 |
| | G Iso Antenna | 0,38 | m2 |
| | Expected AMS(R)S Interf. Level | -119,18 | dBW |
| SRS Services earth station<br>Estimated Values | SRS Rx antenna Gain | 3,2 | dBi |
| | Add propagation Losses | 1 | dB |
| Spectral ITU-1541 | Attenuation | 35 | dB |
| ITU-R SA-609-2 | Protection Criteria | -154,54 | dBW/14kHz |
| | Expected AMS(R)S Interf. Level | -151,98 | dBW |
| | Margin | -2,55 | dB |

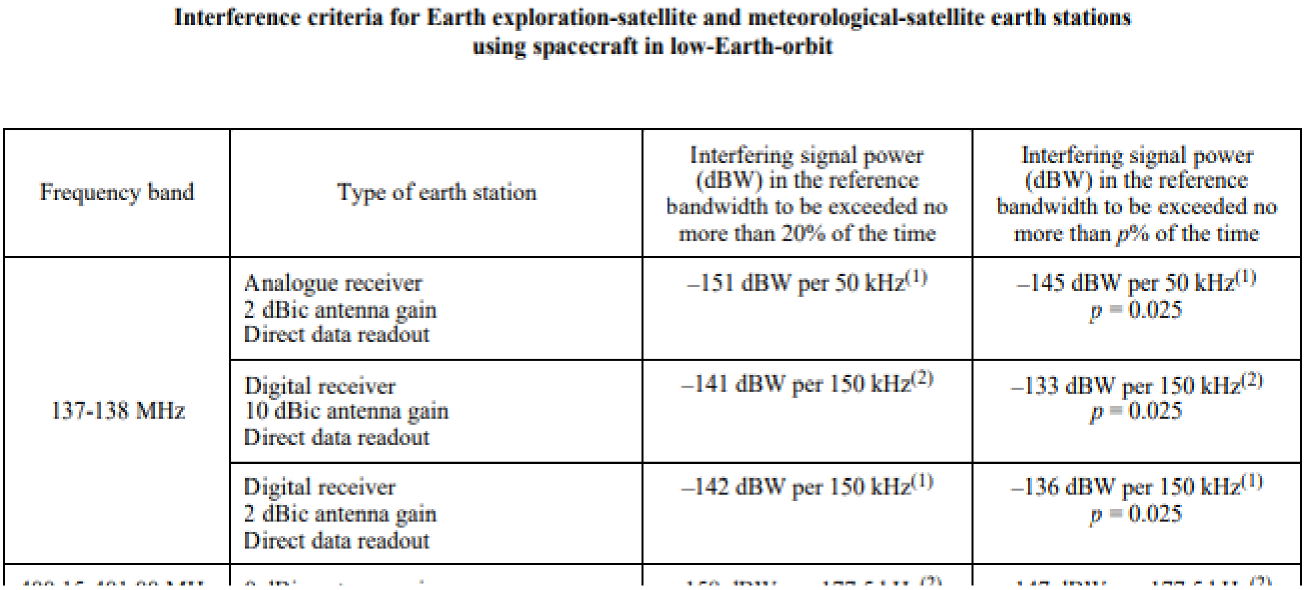
This analysis shows that in order to ensure protection of systems operating in the SRS, the unwanted emission level above 137 MHz of a system operating in the AMS(R)S in the frequency band 136-137 MHz would have to be attenuated by 37.55 dB (35+2.55) compared to its maximum in-band level.]

### 8.4.5 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

*[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)]*

[Recommendation ITU-R-SA.1026-3 provides the Interference protection criteria for meteorological –satellite earth stations using spacecraft in low-earth orbits as well as the typical MetSat earth stations parameters.

TABLE 20



**Interference criteria for Earth exploration-satellite and meteorological-satellite earth stations using spacecraft in low-Earth-orbit**

| Frequency band | Type of earth station | 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 MHz | Analogue receiver<br>2 dBic antenna gain<br>Direct data readout | –151 dBW per 50 kHz(1) | –145 dBW per 50 kHz(1)<br>$p$ = 0.025 |
| | Digital receiver<br>10 dBic antenna gain<br>Direct data readout | –141 dBW per 150 kHz(2) | –133 dBW per 150 kHz(2)<br>$p$ = 0.025 |
| | Digital receiver<br>2 dBic antenna gain<br>Direct data readout | –142 dBW per 150 kHz(1) | –136 dBW per 150 kHz(1)<br>$p$ = 0.025 |

Following the same logic as in 8.4.3, the link budget provides:

TABLE 21

**Spectral characteristics of systems operating in the aeronautical mobile satellite (route) service and meteorological service used in compatibility studies**

| **Input Source** | **Parameter** | **Case 1** | **Case 2** | **Case 3** | **Unit** |
|---|---|---|---|---|---|
| AMS(R)S | Frequency | 137,00 | 137,00 | 137,00 | MHz |
| | Lambda | 2,19 | 2,19 | 2,19 | m |
| | Max PFD | -115,00 | -115,00 | -115,00 | dBW/m$^2$ |
| | G Iso Antenna | 0,38 | 0,38 | 0,38 | m2 |
| | Expected AMS(R)S Interf. Level | -119,18 | -119,18 | -119,18 | dBW |
| MET Services earth station<br>Estimated Values | MET Rx antenna Gain | 2 | 10 | 2 | dBi |
| | | | | | |
| | Feeder Losses | 3 | 3 | 3 | dB |
| Spectral ITU-1541 | Attenuation | 35 | 35 | 35 | dB |
| REC-SA-1026-3 | Protection Criteria | -156,53 | -151,30 | -152,30 | dBW/14kHz |
| | Expected AMS(R)S Interf. Level | -155,18 | -147,18 | -155,18 | dBW |
| | **Margin** | **-1,34** | **-4,12** | **2,88** | **dB** |

In the worst case:

– Maximum Interfering power to be exceeded not more than 20% of time: -141 dBW/150 kHz (-151.3/14 kHz), and Rx antenna gain of 10 dBi.

This analysis shows that in order to ensure protection of systems operating in the meteorological satellite services, the unwanted emission level above 137 MHz of a system operating in the frequency band 136-137 MHz within the AMS(R)S allocation would have to be attenuated by 39.2 dB (35+4.2) compared to its maximum in-band level.]

### 8.4.6 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 7.4.6

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

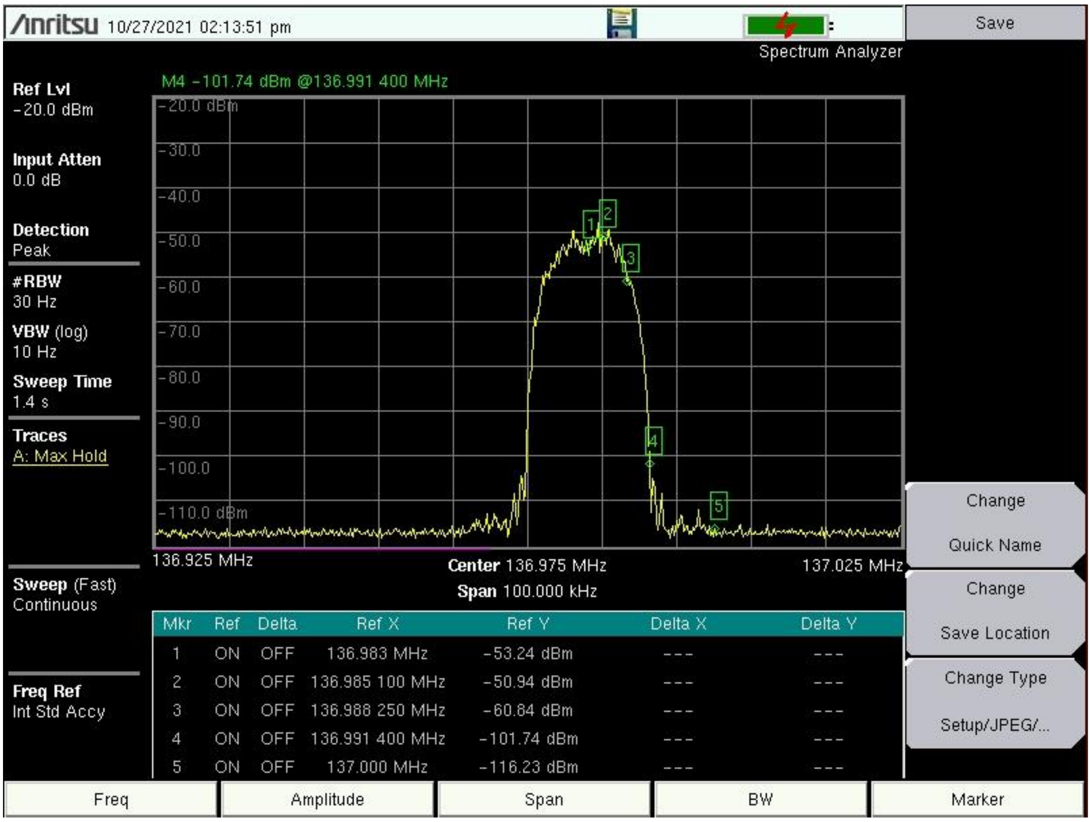
*[Editor’s note: further discussion required on information provided by 7B in 5B/383 regarding protection criterion of SOS, SRS and MetSat until next WP5 meeting considering 7B has provided protection criterion for total interference which require justified apportionment and proper simulation of interfering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

[These technical and compatibility studies show that in order to ensure protection of other services operating in the band above 137 MHz, the unwanted emission level of a system operating in the AMS(R)S VDL-Mode 2 in the frequency band 136-137 MHz would have to be attenuated (worst case) by 41.35 dB compared to its maximum in-band level.

The current state-of-the art demonstrates that the required attenuation can be obtained only with spectral roll-off without the need of additional filtering, even for the Common Signalling Channel (CSC) at 136.975 MHz and in the potential worst case of using a +/-4 kHz frequency Doppler shift pre-compensation (-/+ 8 kHz frequency shift at receiver). The spectral roll-off has an attenuation higher than 60 dBc within 25 kHz at 137 MHz as shows in Figure 7 below.

FIGURE 7

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



Ref Lvl
-20.0 dBm

Input Atten
0.0 dB

Detection
Peak

#RBW
30 Hz

VBW (log)
10 Hz

Sweep Time
1.4 s

Traces
A: Max Hold

Sweep (Fast)
Continuous

Freq Ref
Int Std Accy

M4 -101.74 dBm @136.991 400 MHz

Center 136.975 MHz
Span 100.000 kHz

| Mkr | Ref | Delta | Ref X | Ref Y | Delta X | Delta Y |
|---|---|---|---|---|---|---|
| 1 | ON | OFF | 136.983 MHz | -53.24 dBm | --- | --- |
| 2 | ON | OFF | 136.985 100 MHz | -50.94 dBm | --- | --- |
| 3 | ON | OFF | 136.988 250 MHz | -60.84 dBm | --- | --- |
| 4 | ON | OFF | 136.991 400 MHz | -101.74 dBm | --- | --- |
| 5 | ON | OFF | 137.000 MHz | -116.23 dBm | --- | --- |

]

# 9 Summary

[*Editor´s note: This section has been re-structured during WP 5B December 2021 session to be coherent with previous analysis and document structure*]

## 9.1 Summary of aeronautical mobile satellite (route) service VHF communications operating in the frequency band 117.975-136 MHz

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 conclusion is that such an AMS(R)S system operating in the band 117.975-136 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.

*[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)]*

– [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, thanks to the 1 MHz guard band in 136-137 MHz.]

### 9.2 Summary of aeronautical mobile satellite (route) service VHF communications operating in the frequency band 136-137 MHz

Main conclusion is that such 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.

*[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)]*

– [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 spectrum roll-off in order to achieve a maximum emission above 137 MHz not more than -156.3 dB(W/(m$^2$ · 14 kHz)) or the equivalent -197.7 dB(W/(m$^2$ · Hz)).]

### 9.3 T

### 9.4 S

# 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:

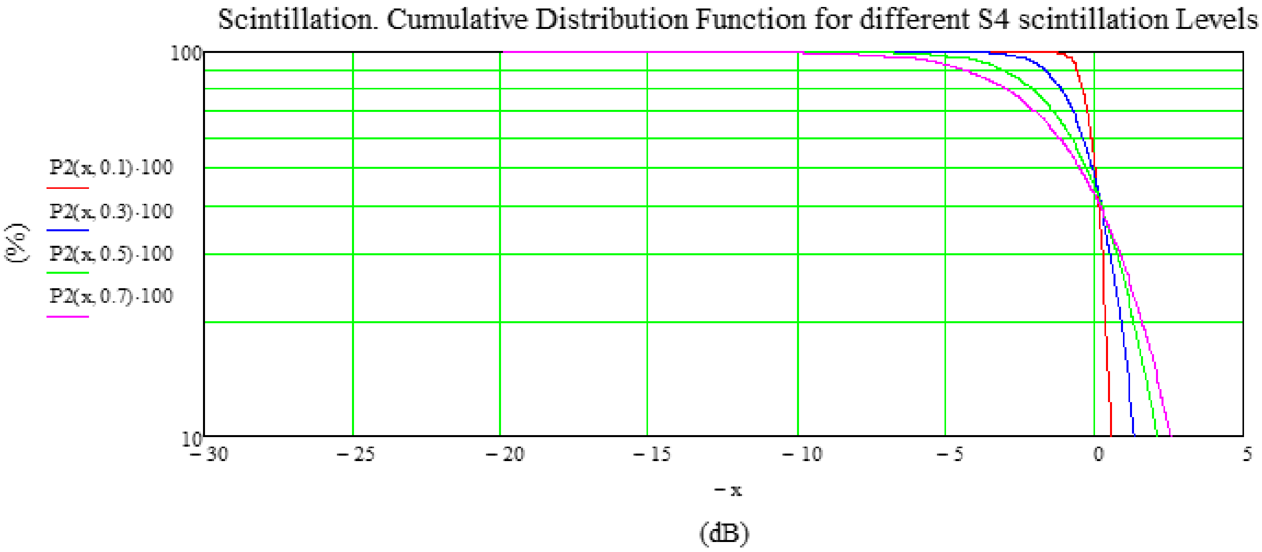
$$m(s4) := e^{5.69 \cdot e^{(-3.055 \cdot s4)} + 0.292 \cdot e^{(0.344 \cdot s4)}}$$

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:

$$P2(x, s4) := \frac{\Gamma(m(s4), m(s4) \cdot I2(x))}{\Gamma(m(s4))}$$

Where $I2(x) := 10^{\frac{-x}{10}}$, *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.



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,

$$Pt(n,x) := \sum_{n=0}^{n} \left[ f_n(s4) \cdot P2(x, s4) \right] \tag{1}$$

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 affected".

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.

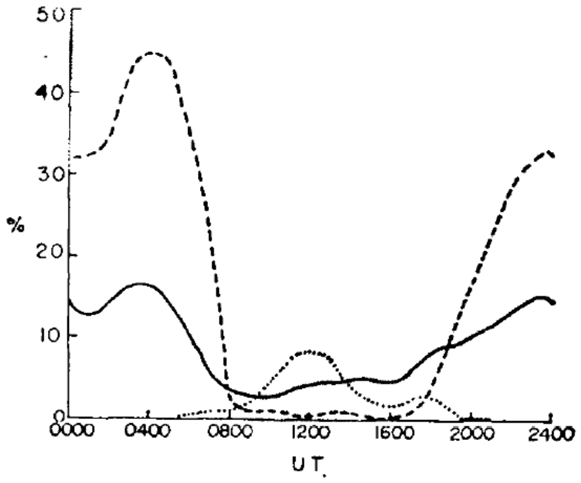


**Fig. 5.** Diurnal variation of scintillation, spread-*F* and high *foEs* at Slough
——— Percentage occurrence of scintillation;
– – – – Percentage of ionograms showing spread-*F*;
. . . . Percentage of ionograms showing *foEs* > 4 MHz.

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.

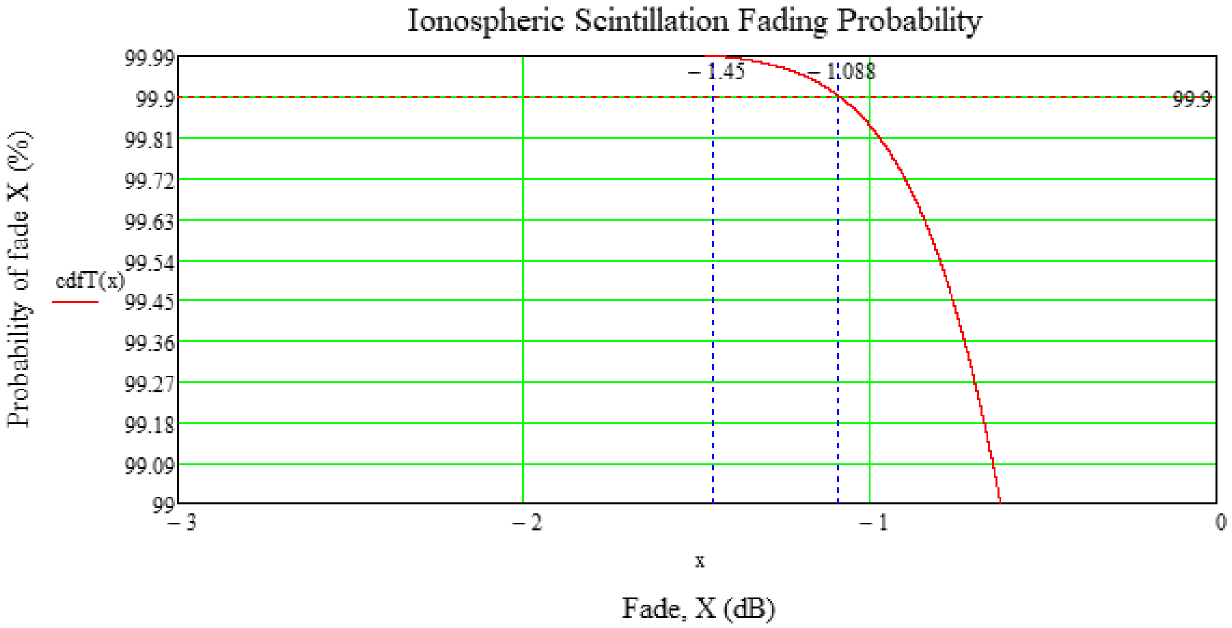
However (as it is a more pessimistic case), we refer to RD.06 for calculating the S4 level

$$\mathrm{Pscint}(s4) := 27.5 \cdot s4^{1.26}$$

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:

$$\mathrm{Ptotal}(x) := f(s4)_0 \cdot P2(x, s4\_0) + f(s4)_1 \cdot P2(x, s4\_1)$$



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.

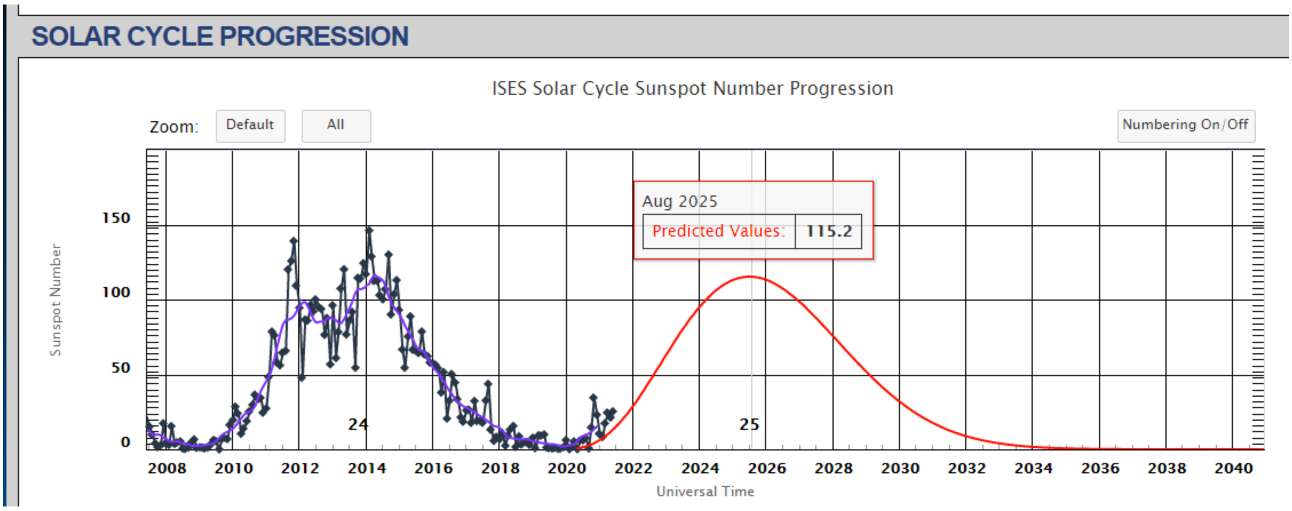
According to WP 3L response to WP 5B question, R19-WP5B-C-0372:

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 by:*

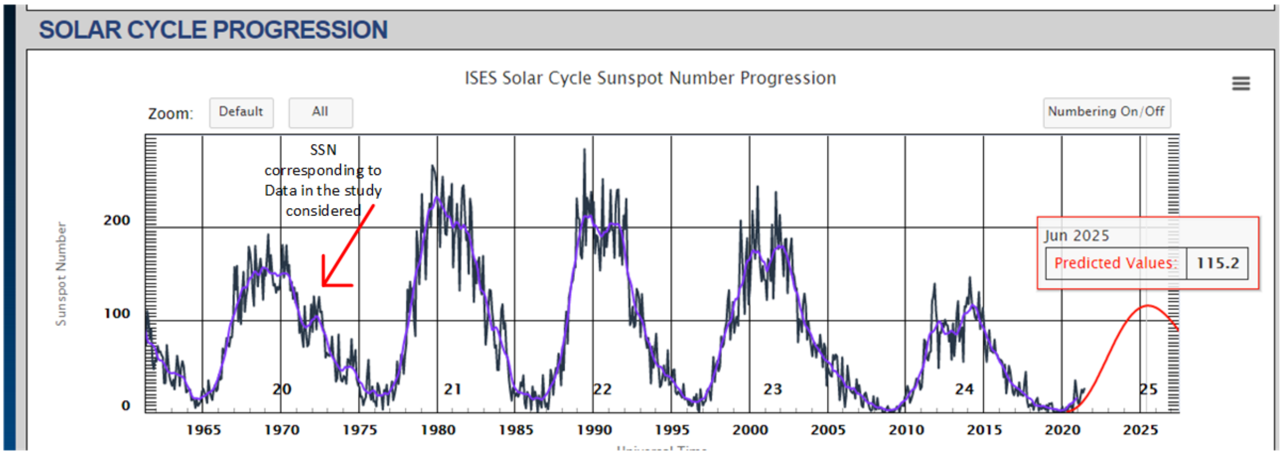
   – *frequency of occurrence of Scintillation event at the different solar activity levels*

From Solar Cycle Progression | NOAA / NWS Space Weather Prediction Center, 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, the maximum predicted SSN for the next 19 years is 115.2 (in 2025 year).

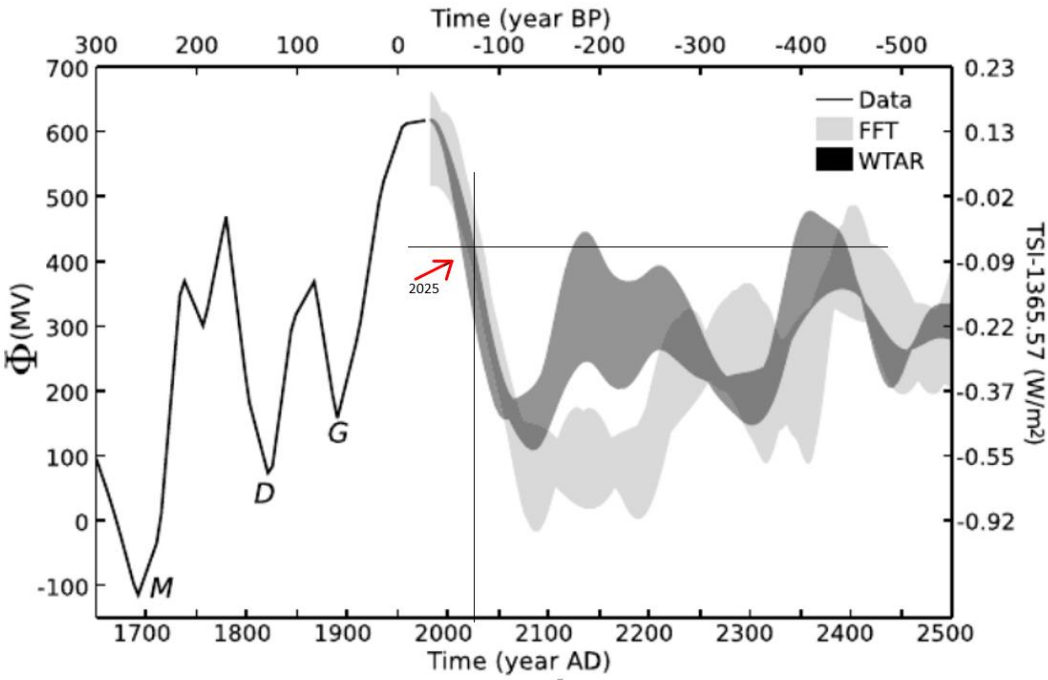


The comparison can be seen in the same web page. Below is an image of a zoom covering both the 1971/1972 year and the predicted maximum one, showing similar levels of SSN.



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.

STEINHILBER AND BEER: PREDICTION OF SOLAR ACTIVITY



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.

RD.09 Prediction of solar activity for the next 500 years - Steinhilber - 2013 - Journal of Geophysical Research: Space Physics - Wiley Online Library, Friedhelm Steinhilber and Jurg Beer.

**Radiocommunication Study Groups**

| | | |
|---|---|---|
| Source: | Documents 5B/TEMP/195 | **Annex 3 to**<br>**Document 5B/481-E**<br>**17 December 2021**<br>**English only** |
| Subject: | WRC-23 AI 1.7 Draft CPM Text | |

## Annex 3 to Working Party 5B Chairman's Report

## WORKING DOCUMENT TOWARDS A DRAFT CPM TEXT FOR WRC-23 AGENDA ITEM 1.7

# CHAPTER 2

## Aeronautical and maritime issues

(Agenda items 1.6, 1.7, 1.8, 1.9, 1.10, 1.11)

### Agenda item 1.7

**(WP 5B[*] / WP 3M, WP 4C, WP 7B)**

*1.7 to consider a new aeronautical mobile-satellite (R) service (AMS(R)S) allocation in accordance with Resolution* ***428 (WRC-19)*** *for both the Earth-to-space and space-to-Earth directions of aeronautical VHF communications in all or part of the frequency band 117.975-137 MHz, while preventing any undue constraints on existing VHF systems operating in the AM(R)S, the ARNS, and in adjacent frequency bands;*

Resolution **428 (WRC-19)** – *Studies on a possible new allocation to the aeronautical mobile satellite (R) service within the frequency band 117.975-137 MHz in order to support aeronautical VHF communications in the Earth-to-space and space-to-Earth directions*

## 2/1.7/1 Executive summary

*[Text of the executive summary, not more than half a page of text to describe briefly the purpose of the agenda item, summarize the results of the studies carried out and, most importantly, provide a brief description of the method(s) identified that may satisfy the agenda item. See also § A2.1 of Annex 2 to Resolution ITU-R 2-8]*

To address this agenda item, ITU-R has undertaken studies, pursuant to Resolution **428 (WRC-19)**, on a possible new AMS(R)S allocation in order to accommodate the relay of VHF communications, towards the development of an ITU-R Report (see section 2/1.7/3).

---

[*] Note: See relevant text in CPM23-1 meeting report (Annex 4 to BR Administrative Circular CA/251) on how to facilitate the work related to satellite.

Four methods are considered to answer this agenda item:

– Method A: NOC

– Method B proposes to add a new allocation to the aeronautical mobile-satellite (R) service (AMS(R)S) in the frequency band 117.975-136 MHz.

– Method C proposes to add a new allocation to the aeronautical mobile-satellite (R) service (AMS(R)S) in the frequency band 117.975-[136/137] MHz.

– Method D proposes to add a new allocation to the aeronautical mobile-satellite (R) service (AMS(R)S) in the frequency band 117.975-137 MHz.

Under all methods, use of AMS(R)S would be limited to internationally standardized aeronautical systems.

Further discussions are ongoing towards possible reconciliation of the three last methods into a single method, depending upon the results of the technical compatibility studies

## 2/1.7/2 Background

*[Text of the background, not more than half a page of text to provide general information in a concise manner, in order to describe the rationale of the agenda items (or issue(s)). See also § A2.2 of Annex 2 to Resolution ITU-R 2-8]*

The level of aircraft traffic and separation in oceanic and remote areas remains limited due to the difficulty of providing and maintaining suitable terrestrial communication, navigation and surveillance (CNS) means. Progress has been made over the last years in the areas of navigation and surveillance, with the existing availability of global navigation satellite systems (GNSS) and reception by satellite of automatic dependent surveillance-broadcast (ADS-B) signals in the frequency band 1 087.7-1 092.3 MHz.

WRC-23 agenda item 1.7 deals with a possible new allocation to the aeronautical mobile-satellite (R) service (AMS(R)S) within the frequency band 117.975-137 MHz, to relay standard VHF communications operating under the aeronautical mobile (R) Service (AM(R)S), and to complement terrestrial infrastructures over oceanic and remote areas. This would not require modification to aircraft equipment, as the space segment would be able to receive and transmit to standard VHF radios already installed on board aircraft.

The services using the in-band and adjacent bands allocations were identified and technical and compatibility analysis were carried out to determine the operating conditions for the new AMS(R)S. This is to ensure the protection to services operating in-band and the adjacent bands from the likelihood of interference from the introduction of an AMS(R)S allocation in this band.

## 2/1.7/3 Summary and analysis of the results of ITU-R studies

*[This section should contain a summary of the technical and operational studies performed within ITU-R, including a list of relevant ITU-R Recommendations. Depending on the agenda item, this section could be divided in two parts, one part dealing with the summary and the other part dealing with the analysis. The results of the ITU-R studies should also be analysed with respect to the possible methods of satisfying the agenda item and presented in a concise manner.]*

Analysis was made of a possible deployment of a satellite-based VHF system using existing aircraft terminals communicating with satellites in low-Earth orbit, which confirmed the technical feasibility of such operation. It was assumed that aircraft would use the existing VHF radio equipment to avoid the need to refit aircraft with specific satellite-based AMS(R)S equipment. Communications with satellites in the geostationary orbit is currently not-considered feasible.

*[Editor's note: The reason of [] is that the arrangement for a system which is not ICAO standard yet to be described]*

Article **35** of the Radio Regulations provides special arrangements to be concluded amongst the interested parties. In this connection, the International Civil Aviation Organization (ICAO) has agreed upon standards and recommended practices adapted to the needs of aircraft operation which have been proven in practice and are well established in current use. [Therefore, the frequency planning, and compatibility between AM(R)S and AMS(R)S operating in this band could be managed by the ICAO through existing procedures, assigning channels to a satellite system(s) over specific regions to ensure compatibility between ground and satellite facilities.]The same on-board aircraft VHF cockpit avionics system would be used for both ground and satellite communications, ensuring that compatibility of aircraft transmissions (in the Earth-to-space direction for AMS(R)S) with existing adjacent band services would remain unchanged.

### 2/1.7/3.1 Summary of technical and operational studies

In liaison with ICAO, ITU-R has first studied the architecture, parameters, and baseline link budgets of a reference AMS(R)S system for the provision of voice communications for air traffic management, without modification to aircraft equipment. Considering the different elements provided by ICAO regarding antenna pattern for aircraft VHF equipment, performance requirement for this equipment, and overall availability considerations, ITU-R has determined that an AMS(R)S system would have to rely on non-geostationary satellites. Reference link budgets for satellite-to-aircraft (downlink) and aircraft-to-satellite (uplink) VHF links have been defined, on the basis of propagation considerations discussed with Working Party 3L as the ITU-R expert group.

Maximum Doppler shift and latency times associated with the AMS(R)S system were discussed with ICAO. It is envisaged to implement a compensation mechanism on the satellite transmitter to mitigate Doppler effects at the aircraft receiver without making any modification on existing aircraft equipment. And no operational impact would be expected, as the latency ranges from the AMS(R)S systems are compatible with existing aeronautical VHF systems.

Compatibility with existing primary services in-band and in adjacent bands has been assessed in close liaison with:

- ICAO for the AM(R)S in 117.975-137 MHz and in adjacent band below 117.975 MHz, and for the Aeronautical Radionavigation service (ARNS) in adjacent frequency band below 117.975 MHz.
- ITU-R Working Party 4C for the mobile-satellite service (space-to-Earth) in adjacent frequency band above 137 MHz.
- ITU-R Working Party 7B for the space operation service (space-to-Earth), space research service (space-to-Earth), and meteorological satellite service (space-to-Earth) in adjacent frequency band above 137 MHz.
- ITU-R Working Party 7D for the protection of radio astronomy in the frequency band 150.05-153 MHz.

In addition, consideration has been given to the in-band compatibility between AMS(R)S and the aeronautical mobile (off-route) service (AM(OR)S) which is allocated on a primary basis under RR Nos. **5.201** and **5.202**, respectively in the band 132-136 MHz (24 countries) and in the frequency band 136-137 MHz (22 countries).

### 2/1.7/3.2 Relevant ITU-R Recommendations and Reports

The relevant ITU-R Recommendations are: M.1231-0, M.1232-0, M.2092-0, P.531-14, SA.363-5, SA.609-2 and SA.1027-6 [and SA.1743].

To perform studies required under agenda item 1.7 and Resolution **428 (WRC-19)**, developed Report ITU-R M.[SPACE-VHF].

### 2/1.7/3.3 Analysis of the results of studies

The result of studies conducted under WRC-23 agenda item 1.7 is that an AMS(R)S system operating pursuant to Resolution **428 (WRC-19)** in the band 117.975-136 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.

*[Editor's note: The text below in this section needs to be revisited to remove any apparent ambiguity.]*

– [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, due to the existence of 1 MHz guard band in 136-137 MHz.

In addition to the above, 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) would be ensured, from emissions from AMS(R)S operating in the sub-band 136-137 MHz taking account of limits of radiation in the adjacent bands, due to frequency separation and AMS( R)S signal roll-off mask.]

The required protection criteria applicable for adjacent band services need to be clarified and addressed due to the fact that the protection criteria in band and in adjacent band may be different.

The case of an AMS(R)S system operating in the frequency band 136-137 MHz for voice applications requires further studies.

*[Editor's note: The text below contains technical conclusion which need to be updated after the consideration of performance requirements and link budgets associated to VHF Data Link (VDL) Mode 2 application]*

For the cases of adjacent band compatibility between AMS(R)S and mobile satellite service (space-to-Earth), space operations service (space-to-Earth), and meteorological satellite service (space-to-Earth) above 137 MHz, the analysis show that it is possible to ensure protection of non- aeronautical services operating in adjacent band based on the unwanted emission level above 137 MHz of a system operating in the AMS(R)S below 137 MHz when reducing its adjacent band emissions 45.7 dB compared to its maximum in-band level to limit a maximum power flux density of ($-156.3$ dB(W/(m$^2$ · 14 kHz)) above 137 MHz.

Further studies are ongoing for the cases of adjacent band compatibility between AMS(R)S and space research service (space-to-Earth) above 137 MHz and radioastronomy service in 150.05-153 MHz.]

## 2/1.7/4 Methods to satisfy the agenda item

*[This section should contain the brief description of the Method or Methods to satisfy the agenda item as per Section A2.4 of Annex 2 to Resolution ITU-R 2-8]*

### 2/1.7/4.1 Method A: No change

### 2/1.7/4.2 Method B: New AMS(R)S allocation in the band 117.975-136 MHz

Method B proposes to add a new allocation to the aeronautical mobile-satellite (R) service (AMS(R)S) in the frequency band 117.975-136 MHz, limited to internationally standardized aeronautical systems.

### 2/1.7/4.3 Method C: Allocation of AMS(R)S in the band 117.975-[136/137] MHz

Create a new co-primary allocation for the AMS(R)S service in the frequency band 117.975-[136/137] MHz limiting to systems that operate in accordance with international Standards and Recommended Practices and procedures established in accordance with the Convention on International Civil Aviation.

### 2/1.7/4.4 Method D: Allocation of AMS(R)S in the band 117.975-137 MHz

Create a new co-primary allocation for the AMS(R)S service in the frequency band 117.975-137 MHz on the condition that maximum power flux density radiated over the Earth above 137 MHz is limited to [$-197.7$ dB(W/(m$^2$ · Hz))] and limited to internationally standardized aeronautical systems.

## 2/1.7/5 Regulatory and procedural considerations

*[To be populated later]*

# Space Based VHF Studies

## VOICE project: outcomes of technical studies and test/validations

ICAO-FSMP-PT-T
22/2/2022

# Contents

# Introduction.

- The objective of this presentation is to present the results of the technical studies and laboratory tests performed by VOICE project in support of the SB-CNS concept.
- ICAO FMSP and PT-T members are invited to:
  - take note regarding the activities that are performed and are planned in the future under the umbrella of this project.
  - discuss and agree about the response to ITU-R 5B considering all potential services voice and data provided in the whole or parts of the whole band.
  - receive a feedback about next actions proposed in this paper.

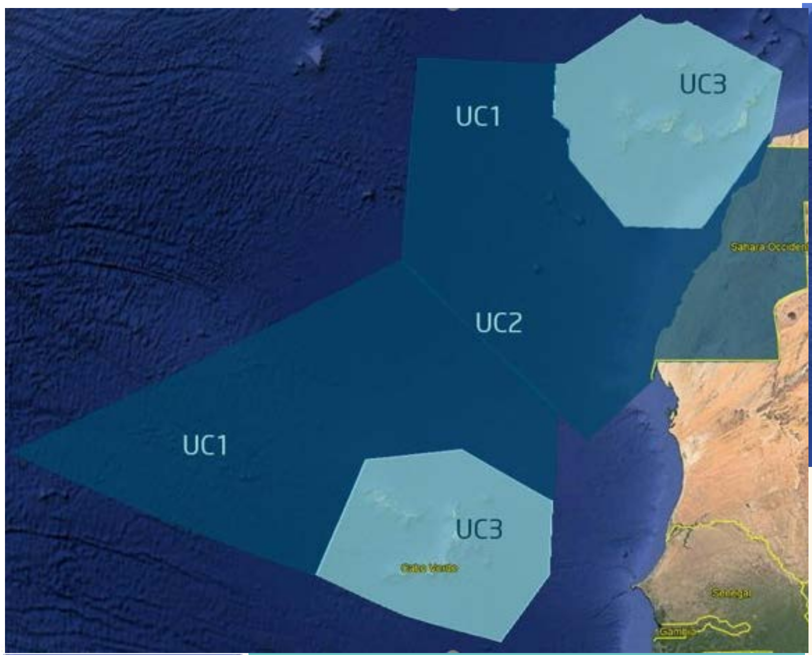
# Contents

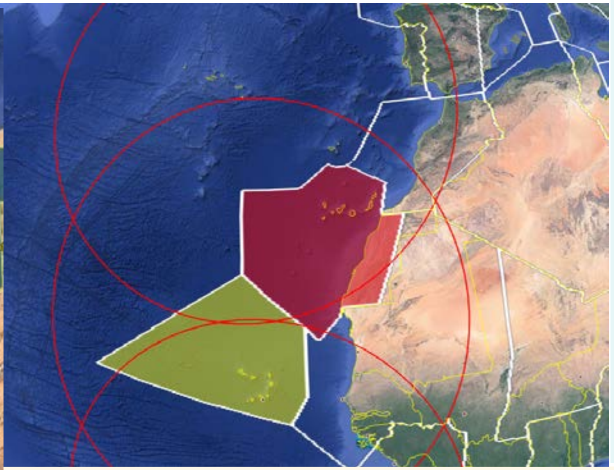
# VOICE Project – Validation approach

- **Objective:**
  - Evaluate the feasibility of Space based VHF communications in oceanic and remote airspaces in order to provide VHF voice and Data services and ensure the possibility to provide complementary and continuous coverage for VHF voice and Data services from Continental to oceanic Airspaces.
- **Validation approach:**
  - Aircrafts in the area of interest of the exercise will be asked to communicate using pre-assigned frequencies (1 for VHF voice and 1 for Data) in areas where normally no VHF coverage is available.
  - Communication with ATCO from Canarias and SAL FIRs will be stablished using assigned VHF frequencies.
  - No operational instructions will be given during this demonstration.
- **Technical aspects:**
  - VHF frequencies for VHF voice and data has been selected considering that they are not repeated in the affected envelope of the possible satellite positions used for Tx.
  - Transmitted power in Satellite is dynamically configurable based on satellite position (LAT-LONG) and based in command and control orders, in order to ensure that there´s no impact outside the exercise envelope.
  - Satellite is configured in Rx mode as default, and will switch to Tx mode only when commanded by the system and with the power levels in order to ensure there´s no impact outside the exercise envelope.

# VOICE Project – End to End Test

## Reduced separations and improved efficiency based on Vhf cOmmunICations over LEO satEllites





### Objectives

The main objective of this project is to perform a proof of concept for this technology in real environment by end 2022.

- Demonstrate that use of VHF comms with LEO satellites is successful and does not interfere with existing installations.
- Provide real data for approval of use of VHF in LEO satellites in the next WRC2023

### Consortium partners

- **Indra (consortium leader)**
  - Subcontractors: SITA, INTA, UPM
- **Enaire**
  - LTP: CRIDA, ASA-Cape Verde
- **GomSpace**
  - GomSpace A/S
  - GomSpace Lux
- **Eurocontrol**

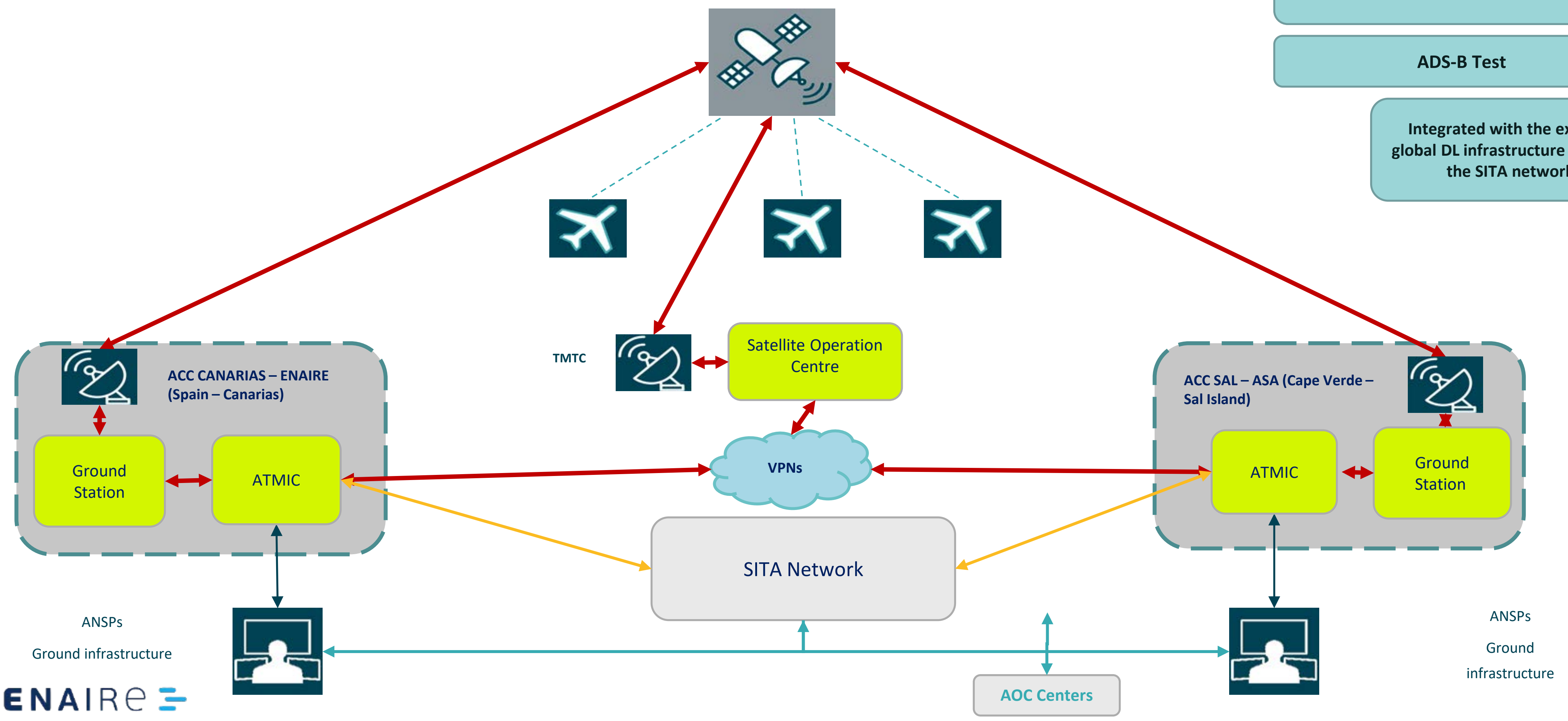
### Advisory Board

- Air Europa
- IATA
- AESA
- JOTRON

This project has received EUR 3.989.808,75 funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101017688.

# VOICE Project – Infrastructure

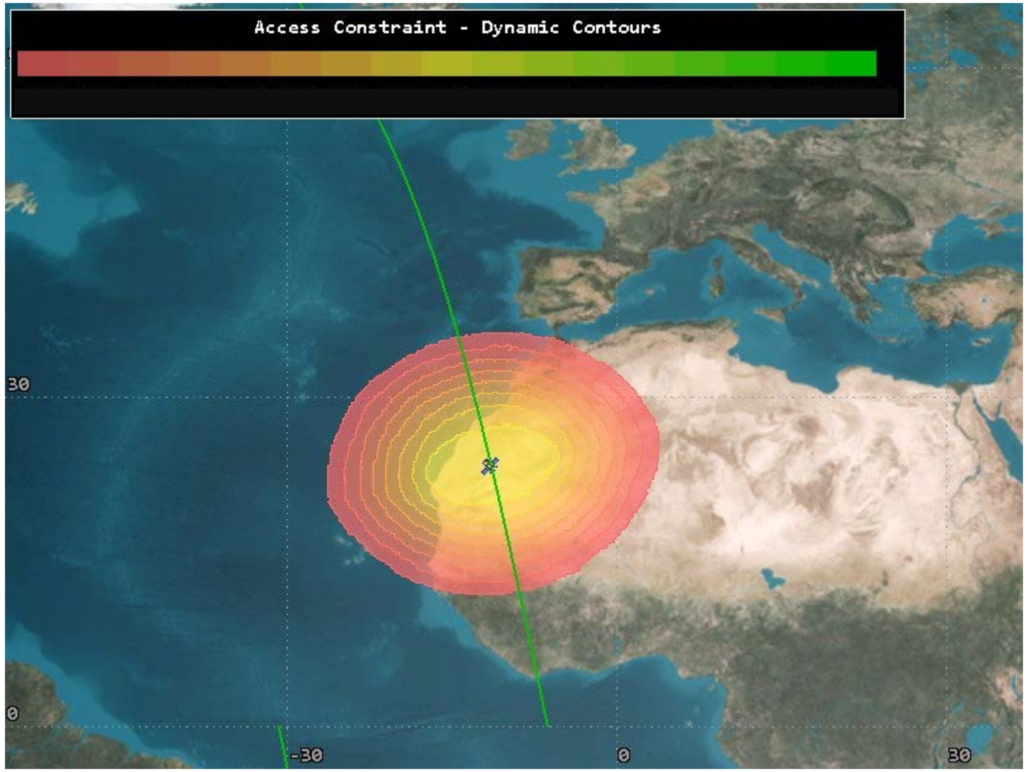
## VHF – Data and Voice - System Definition for VOICE project



# VOICE Project – Theoretical Coverage

**Orbit Type: Sun-Synchronous 550 km**

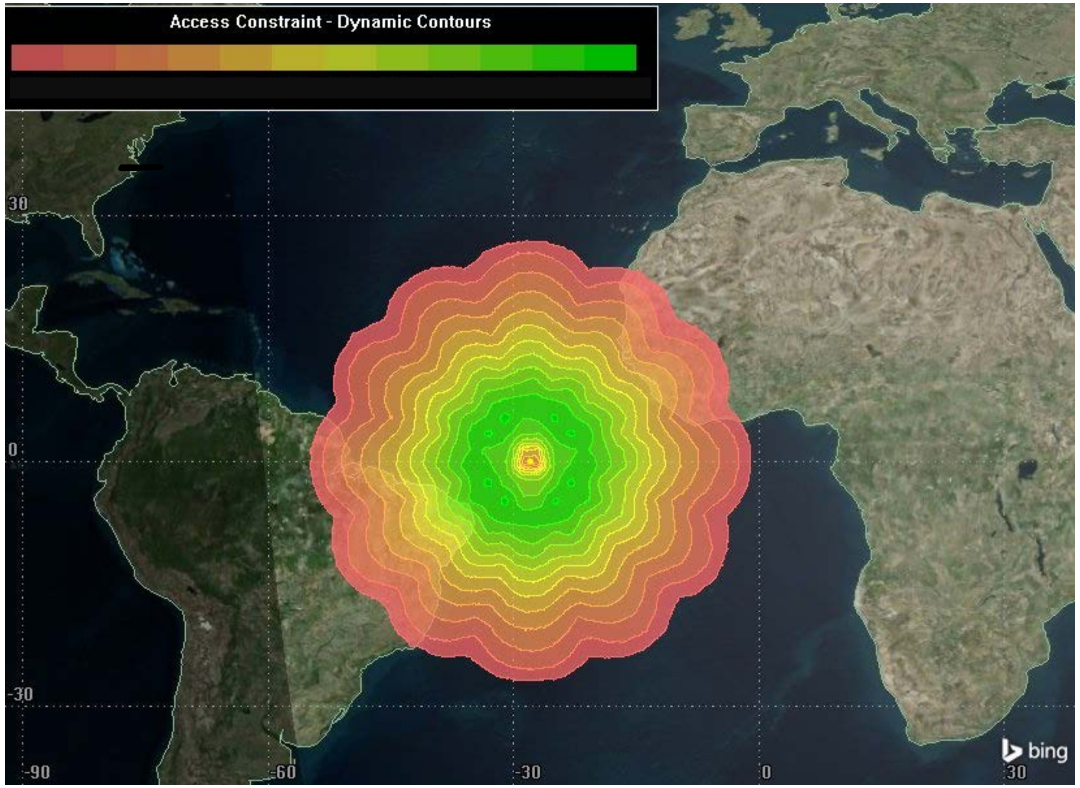
**VHF Antenna Type: Isoflux Nadir pointing**
**VHF Tx Coverage (configurable): Maximum 1500 km**



**VHF link budget for Data and Voice Satellite to Aircraft**

**(PFD, Scintillation, Doppler, Faraday, Antenna …. )**

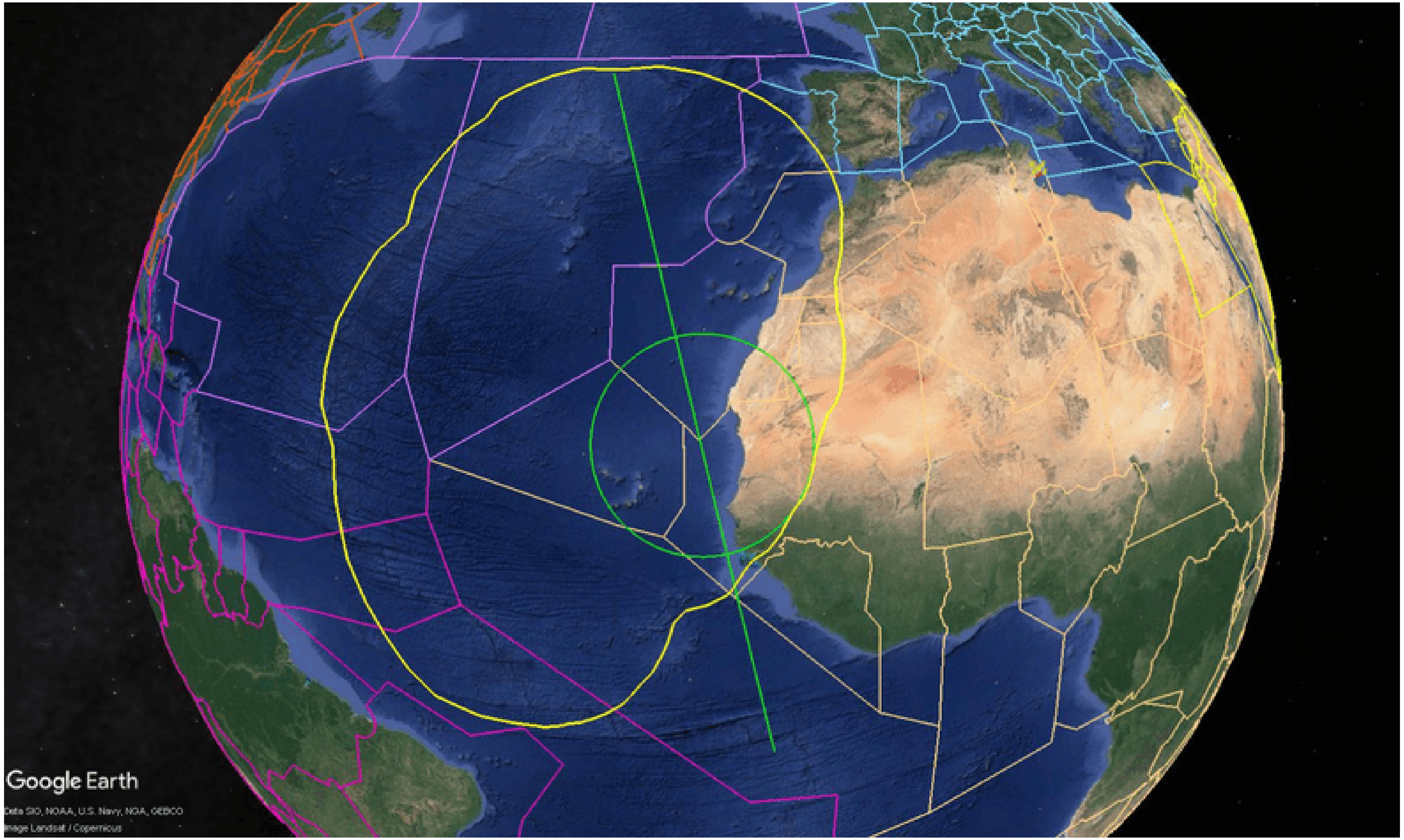
**ADS-B Antenna type patch**



**ADS-B - Aircraft to Satellite (Rx) Coverage**

**(S/N, Detectability, Antenna ….)**

# VOICE Project – Technical Test



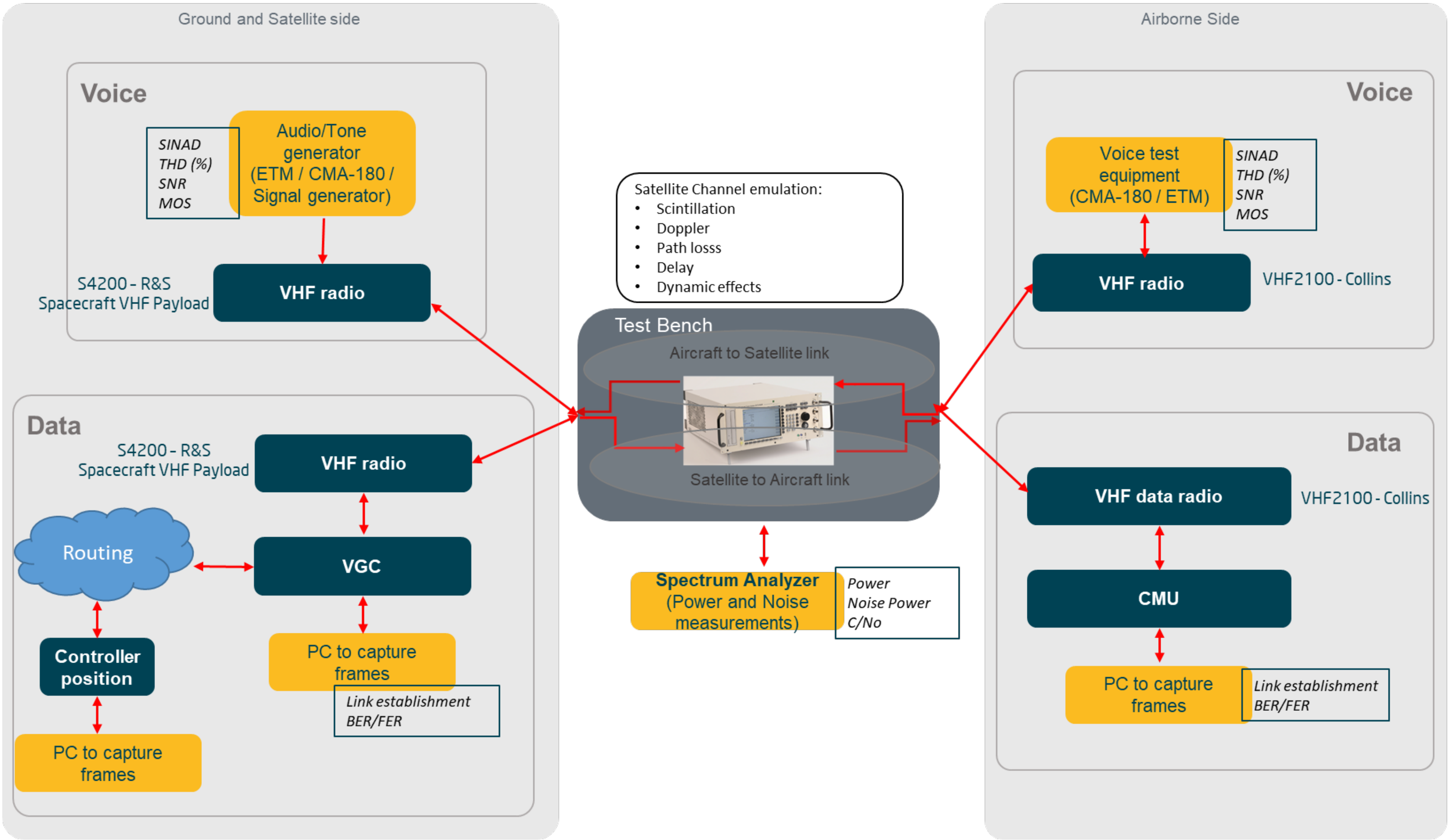
N-S passes marked in red.

S-N passes marked in green

Satellite Footprint is dynamically configurable based on satellite position (LAT-LONG) and based in command and control orders, in order to ensure that there´s no impact outside the exercise envelope.

# Contents

# Test Bench for global communications



Ground and Satellite side

**Voice**

*SINAD*
*THD (%)*
*SNR*
*MOS*

Audio/Tone generator (ETM / CMA-180 / Signal generator)

S4200 - R&S
Spacecraft VHF Payload

**VHF radio**

**Data**

S4200 - R&S
Spacecraft VHF Payload

**VHF radio**

Routing

**VGC**

**Controller position**

PC to capture frames

PC to capture frames

*Link establishment*
*BER/FER*

Satellite Channel emulation:
- Scintillation
- Doppler
- Path losss
- Delay
- Dynamic effects

Test Bench

Aircraft to Satellite link

Satellite to Aircraft link

**Spectrum Analyzer** (Power and Noise measurements)

*Power*
*Noise Power*
*C/No*

Airborne Side

**Voice**

Voice test equipment (CMA-180 / ETM)

*SINAD*
*THD (%)*
*SNR*
*MOS*

**VHF radio**

VHF2100 - Collins

**Data**

**VHF data radio**

VHF2100 - Collins

**CMU**

PC to capture frames

*Link establishment*
*BER/FER*

# Contents

# Signal propagation - impact on VHF link

- **Objective:** Evaluate impact of higher satellite channel propagation attenuation and scintillation effect to verify PFDs and SNRs for VHF Voice and VHF Data links requested in ICAO SARPS.
- **Studies / Analysis:**
  - Analysis considering variable propagation conditions, scintillation and the typical aircraft antennas characteristics and by taking into account the relevant ITU-R Recommendations/Reports for these studies

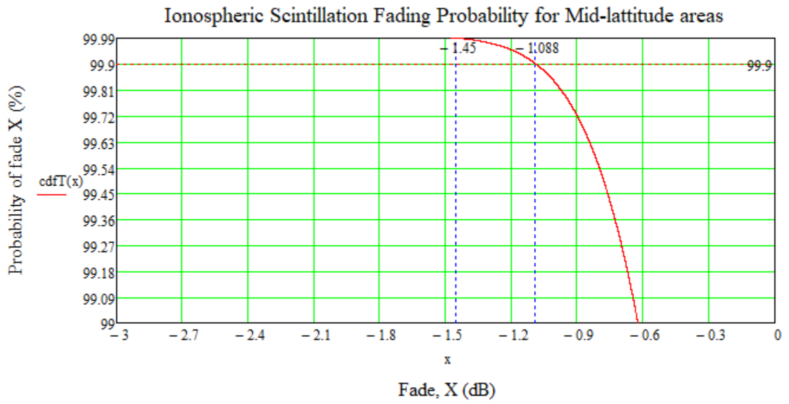
- **Tests / Measurement:**
  - Laboratory Test environment
    - Composed of commercial VHF equipment (both airborne from Collins and ground sides ) deployed in ENAIRE test facilities.
    - Satellite Channel Emulator to introduce representative attenuation patterns and scintillation effect.
    - Scintillation emulated based on ITU-R models and generated through computed time series.

  - SESAR VOICE project to carry out flight tests with a LEO satellite.

# Signal propagation -Impact of satellite channel propagation on VHF links. Scintillation Analysis

## ITU 5B group Inputs

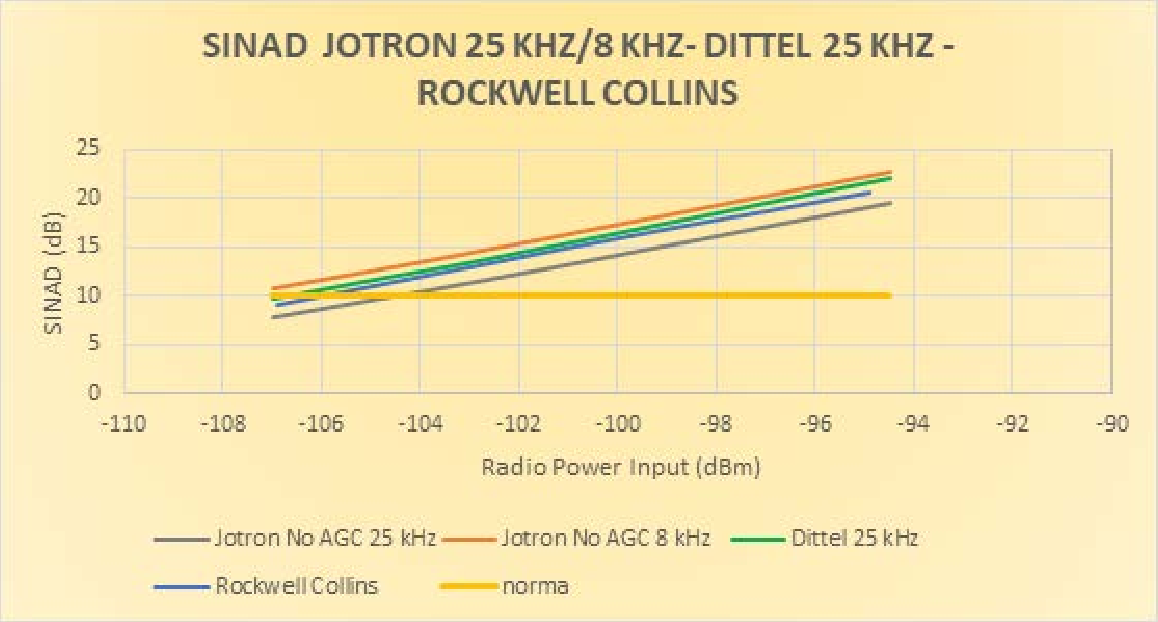
- **Document 5B/112-E – ITU-R WP 3L**
  - **link to ITU-R  P.531-14:** Ionospheric propagation data and prediction methods required for the design of satellite networks and systems.
- **Annex 29 to Document 5B/355-E:**
  - "…. Depending on satellite system design trade-offs, **it may be of interest not 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. "
  - "…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."
- **Document 5B/372-E – WP 3L**
  - "… The value of 1 dB seems to be appropriate for middle latitude regions…".

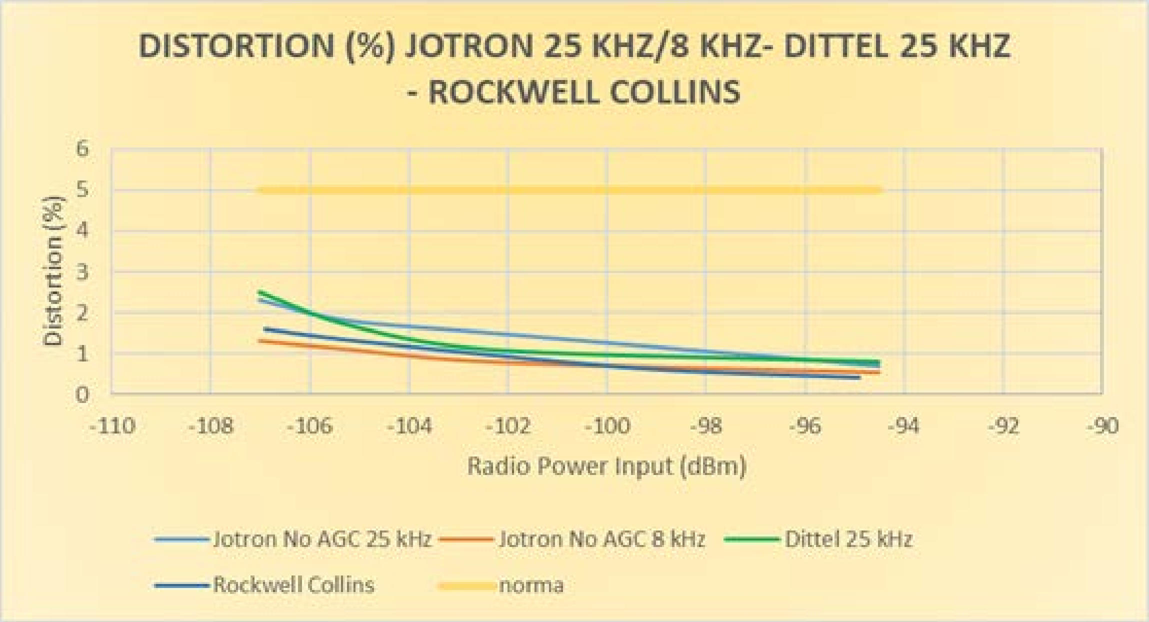


## Outcomes:

- Using Nakagami formulation we can mathematically model the event can be mathematically modeled by a distribution function for middle latitudes areas considering existing scintillation bibliography and statistical data around 138MHz. Therefore, as was discussed with ITU-R Working Party 3L and according to Nakagami model, **1 dB of fading effect for 99,9% of cases in middle latitudes is considered**.

# Signal propagation - Impact of satellite channel propagation on VHF links. Voice Calibration Tests: C/No and sensitivity

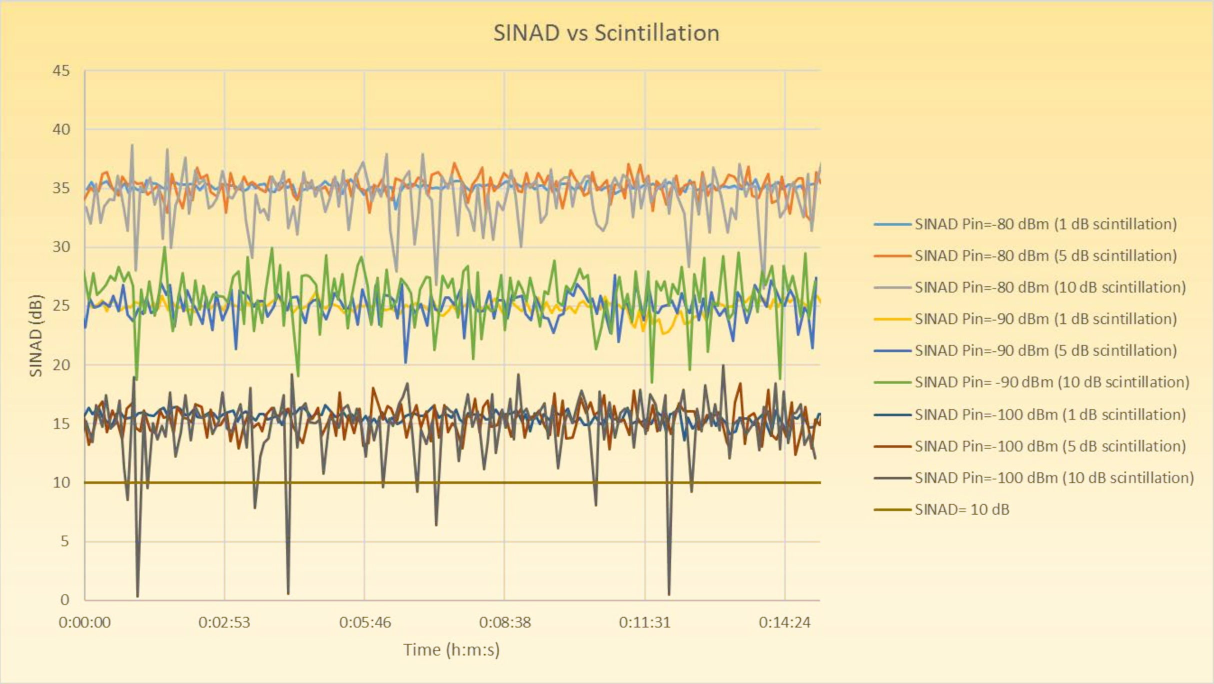


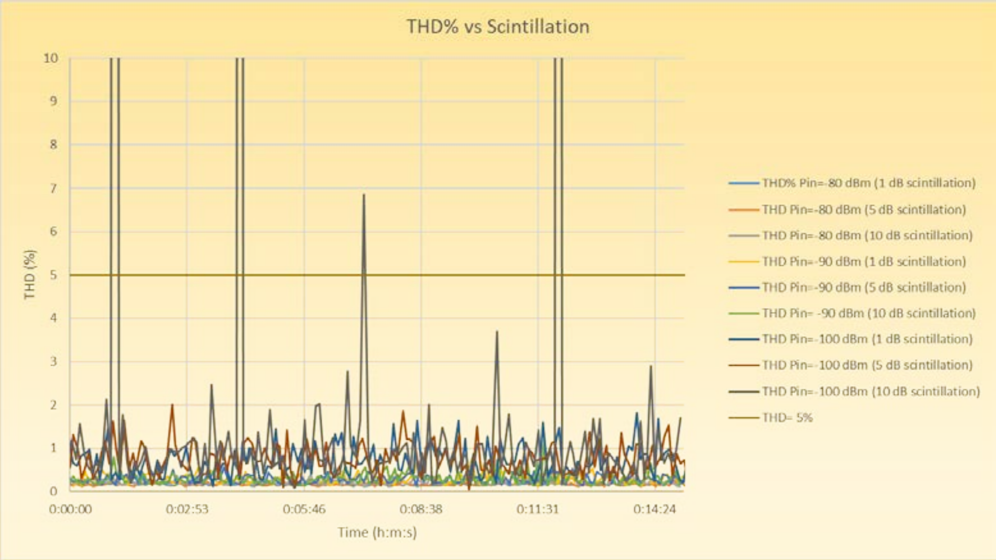


- Calibration based on power levels from Link budget computation. Reference results to compare with the ones when satellite channel effects are introduced.
- **Performance of demodulated audio is above the values specified** in ICAO SARPS (SINAD >10 dB and THD<5%) for the expected range of input powers.

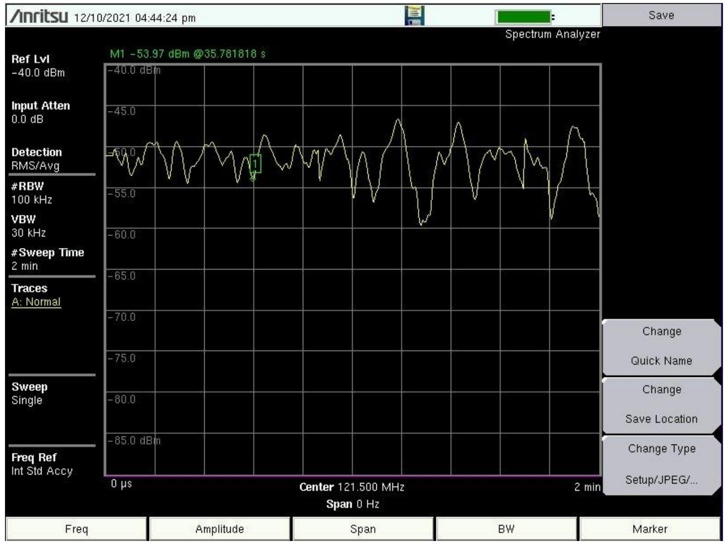
*SINAD: Signal-to-noise and distortion ratio*

# Signal propagation - Impact of satellite channel propagation on VHF links. Voice Tests: Scintillation





- Tests of 3 scintillation time series with different attenuations (1 dB middle latitudes, 5 dB high latitudes) and 10 dB (equatorial)
- **SINAD and THD% are over values specified** in ICAO SARPS (SINAD >10 dB and THD<5%) when scintillation is applied, except a few instants for the 10 dB scintillation case.


Anritsu 12/10/2021 04:44:24 pm

Spectrum Analyzer

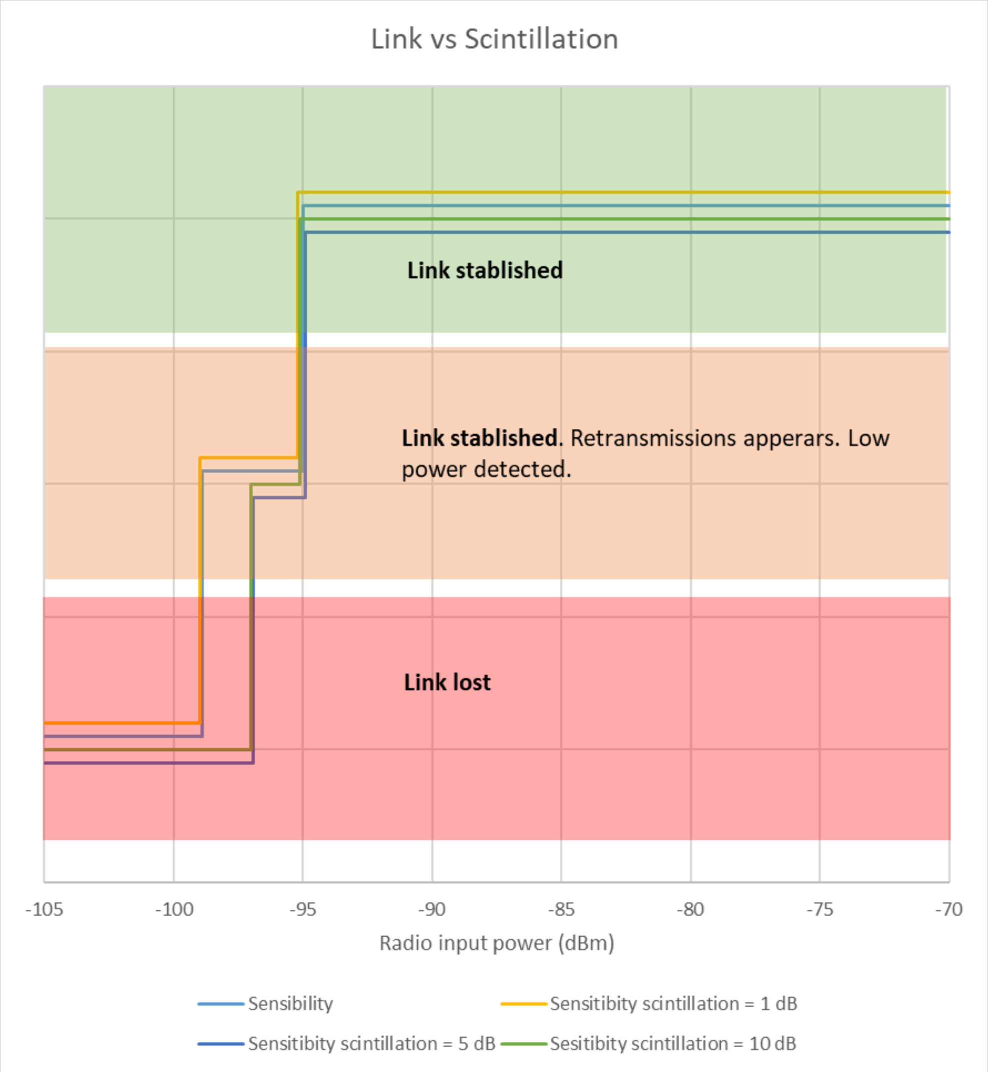
M1 -53.97 dBm @35.781818 s

Ref Lvl -40.0 dBm
Input Atten 0.0 dB
Detection RMS/Avg
#RBW 100 kHz
VBW 30 kHz
#Sweep Time 2 min
Traces A: Normal
Sweep Single
Freq Ref Int Std Accy

Center 121.500 MHz
Span 0 Hz

*SINAD: Signal-to-noise and distortion ratio*

# Signal propagation - Impact of satellite channel propagation on VHF links. Preliminary DATA link Tests: sensitivity & Scintillation



- Calibration was done with power level from Link budget computation. **Data link was established until a power level of –99 dBm**.
- VDLM2 retransmissions avoid some scintillation effects minimizing its effects in the link behaviour.
- No degradation is observed for 1 dB scintillation case with respect no scintillation. For 5 dB and 10 dB cases, there is no degradation for inputs levels higher than -97 dBm.

# Contents

# Doppler effect on VHF link

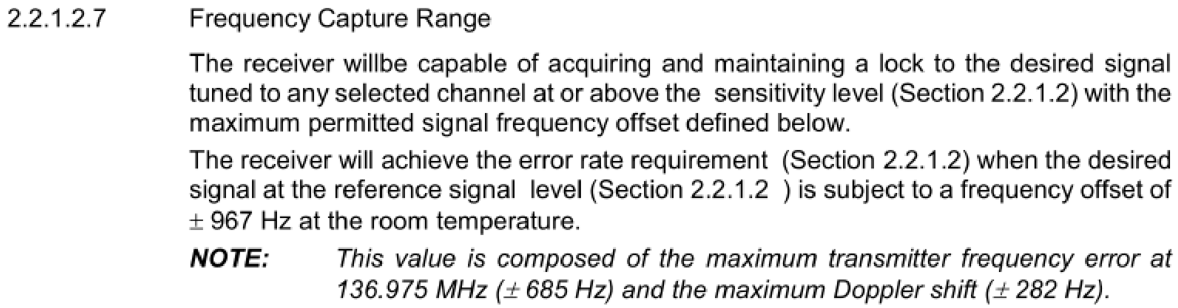
- **Objective:** Evaluate the impact of the satellite Doppler effect in airborne VHF radios, taking into account currently defined ICAO SARPS specification for carrier frequency acquisition range. To be assessed for VHF Voice and VHF Data (focus on VDLm2).

- **Studies / Analysis:**
  - Computation of the aggregated frequency offset over the Satellite footprint with the main contribution of the Satellite Doppler shift.
  - Study of the impact on VHF Data reception and assess the necessity of a pre-compensation mechanism.
  - Study of the impact on VHF Voice reception for 25 kHz channel.

- **Tests / Measurement:**
  - Laboratory Test environment
    - Composed of commercial VHF equipment (both airborne and ground sides ) deployed in ENAIRE test facilities.
    - Representative satellite Doppler effect profiles introduced in the VHF links by a Satellite Channel Emulator.
    - Evaluate the maximum Doppler shift tolerated, both for voice and data that a commercial airborne VHF radio.
  - SESAR VOICE project to carry out flight tests with a LEO satellite.

# Doppler effect on VHF link –
# Analysis Spacecraft -> Aircraft Doppler effect

- **VDL Mode 2 Standards Specifications**
- **ED-92C** Minimum Operational performance standard for **an airborne VDL Mode-2 system** operating in the frequency range 118-136.975 MHz



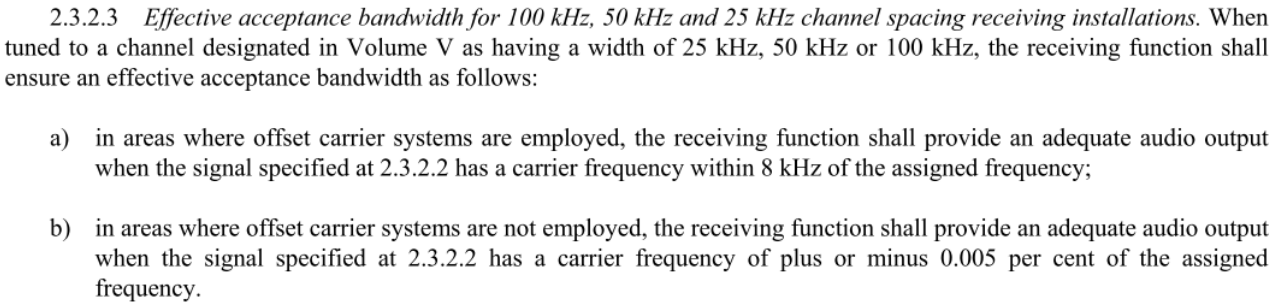
2.2.1.2.7 Frequency Capture Range

The receiver willbe capable of acquiring and maintaining a lock to the desired signal tuned to any selected channel at or above the sensitivity level (Section 2.2.1.2) with the maximum permitted signal frequency offset defined below.

The receiver will achieve the error rate requirement (Section 2.2.1.2) when the desired signal at the reference signal level (Section 2.2.1.2 ) is subject to a frequency offset of ± 967 Hz at the room temperature.

**NOTE:** *This value is composed of the maximum transmitter frequency error at 136.975 MHz (± 685 Hz) and the maximum Doppler shift (± 282 Hz).*

- **VHF Voice Standards Specifications**
- **Annex 10:** Volume III Communications Systems Part II – Voice Communication Systems
- Effective **acceptance bandwidth for 25 kHz** channel spacing (including Doppler shift)



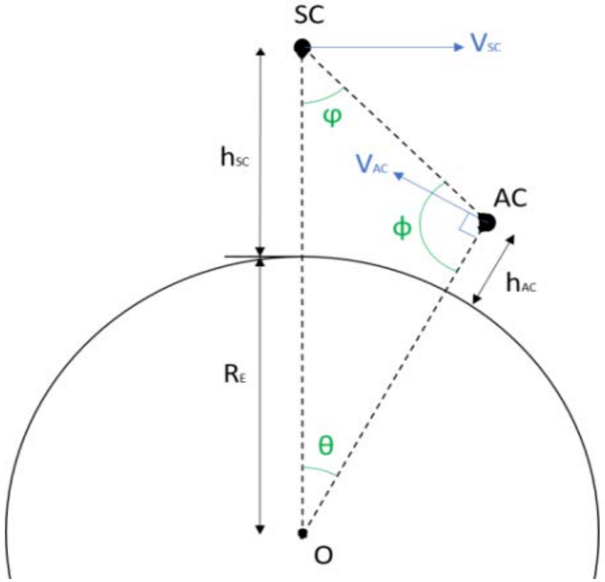
2.3.2.3 *Effective acceptance bandwidth for 100 kHz, 50 kHz and 25 kHz channel spacing receiving installations.* When tuned to a channel designated in Volume V as having a width of 25 kHz, 50 kHz or 100 kHz, the receiving function shall ensure an effective acceptance bandwidth as follows:

a) in areas where offset carrier systems are employed, the receiving function shall provide an adequate audio output when the signal specified at 2.3.2.2 has a carrier frequency within 8 kHz of the assigned frequency;

b) in areas where offset carrier systems are not employed, the receiving function shall provide an adequate audio output when the signal specified at 2.3.2.2 has a carrier frequency of plus or minus 0.005 per cent of the assigned frequency.

| | VDLM2 (Hz) | Voice 25 kHz offset carrier | Voice 25 kHz no offset carrier |
|---|---|---|---|
| Frequency stability [ppm] | ±5 | ±30 | ±5 |
| Frequency stability [Hz] | ±685 | ±4110 | ±685 |
| **Acceptance bandwidth [ppm]** | **±7** | **±58** | **±50** |
| **Acceptance bandwidth [Hz]** | **±967** | **±8000** | **±6850** |

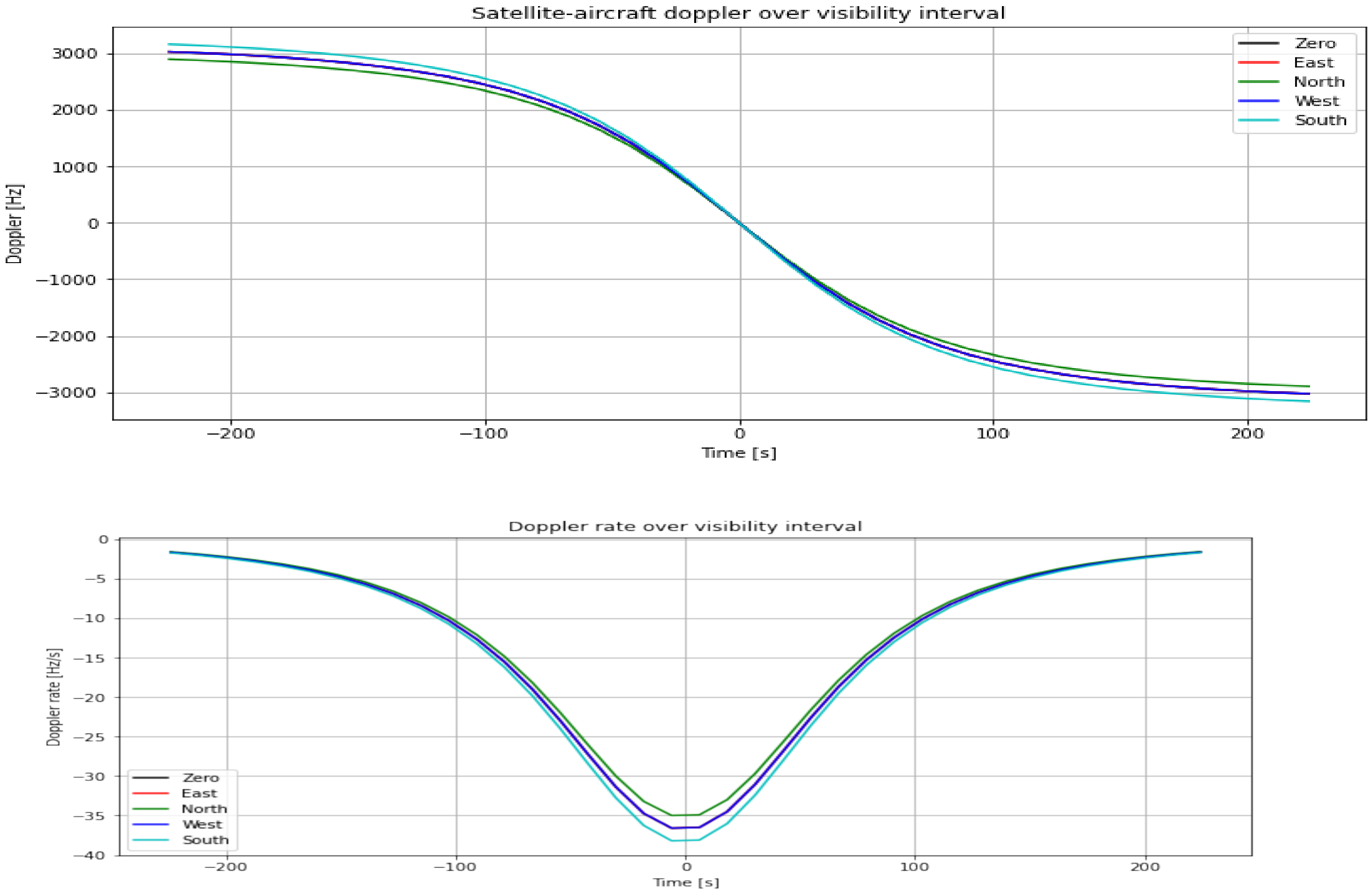
# Doppler effect on VHF link- Analysis Spacecraft -> Aircraft Doppler effect



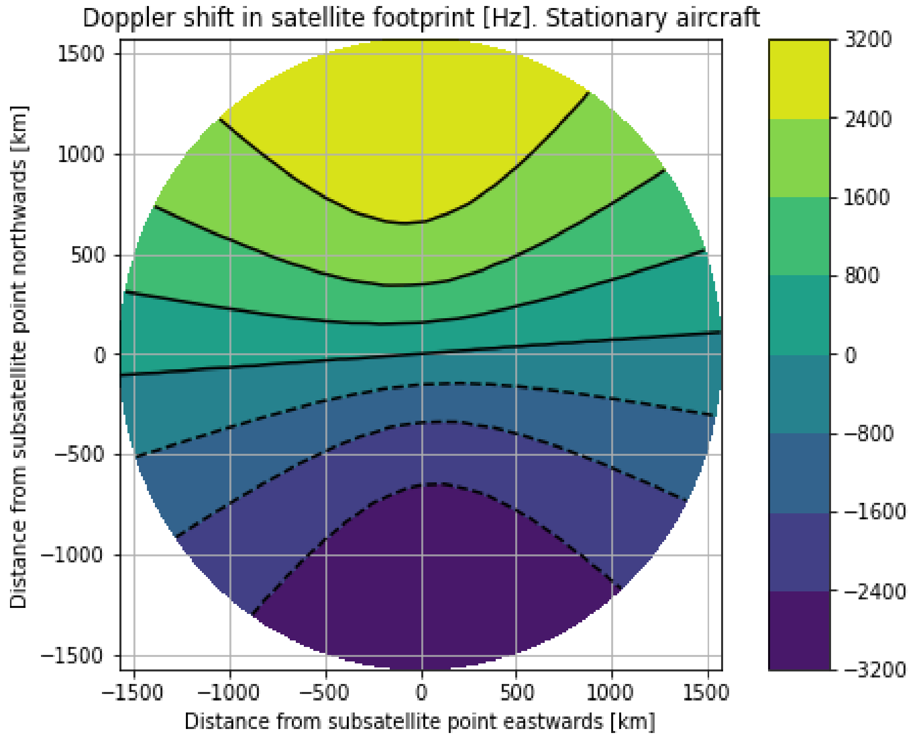
- **Frequency error budget computation**
- Maximum expected shift ±3.2 kHz
- Maximum Doppler shift experienced with a direct overflight
- Doppler shift attenuated as maximum spacecraft elevation decreases
- Clock relativistic effect is negligible
- Possibility to pre-compensate the Doppler shift based on known spacecraft-aircraft position/velocity (uncertainties in the computation of around 60 Hz)

| | Frequency error [Hz] | Comments |
|---|---|---|
| Spacecraft oscillator | ±15 | |
| Spacecraft-aircraft velocity | ±3170 | It can be estimated |
| Aircraft oscillator | ±685 | Not to be considered |
| Uncertainty in aircraft & spacecraft position / velocity | ±60 | |
| | | |

# Doppler effect on VHF link- Analysis Spacecraft -> Aircraft Doppler effect

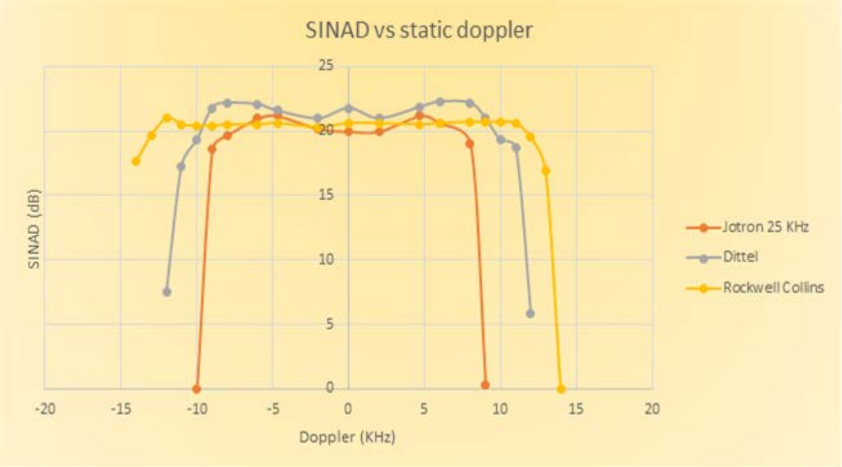


Doppler shift and Doppler rate experienced by an aircraft as function of time in a spacecraft overflight when flying from North to South



Doppler shift experienced by an aircraft in the footprint

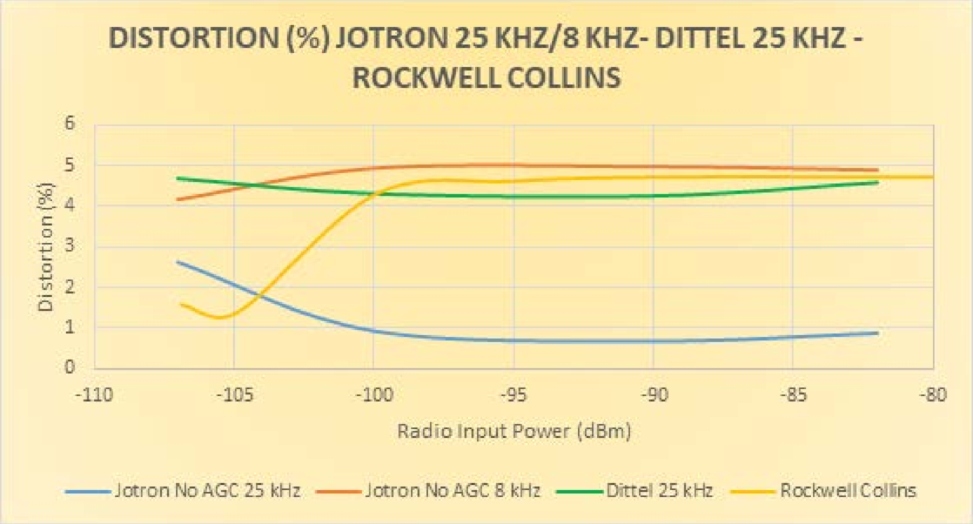
# Doppler effect on VHF link- Impact of satellite channel Doppler on VHF links. VHF Voice Tests: Static Doppler



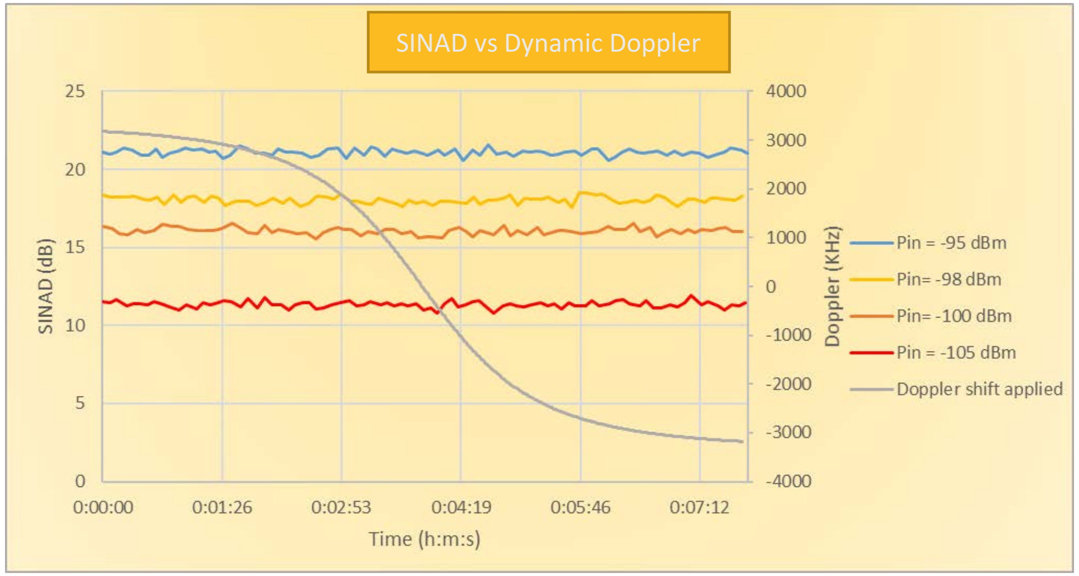
SINAD vs Doppler for fix radio input power

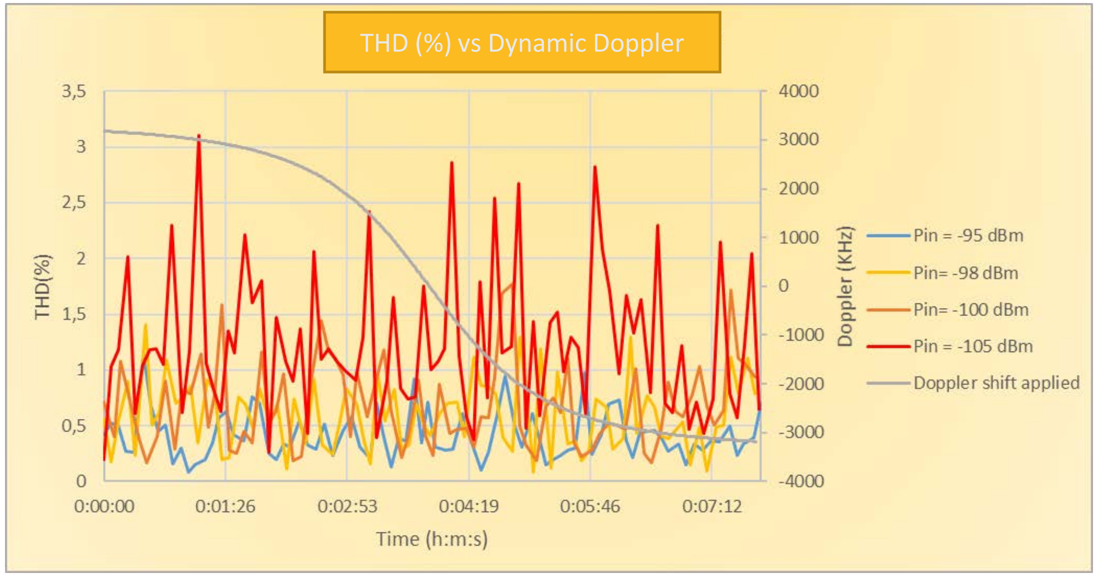
- In the radio tested, **25 KHz channels support Doppler shifts higher than the maximum Doppler shift expected** due to satellite movement (3.2 kHz).
- The behavior of the **audio demodulated when Doppler is applied is within the limits specified** in ICAO SARPS (SINAD >10 dB and THD<5%).

Maximum Doppler shift for a SINAD> 10 dB and THD<5%



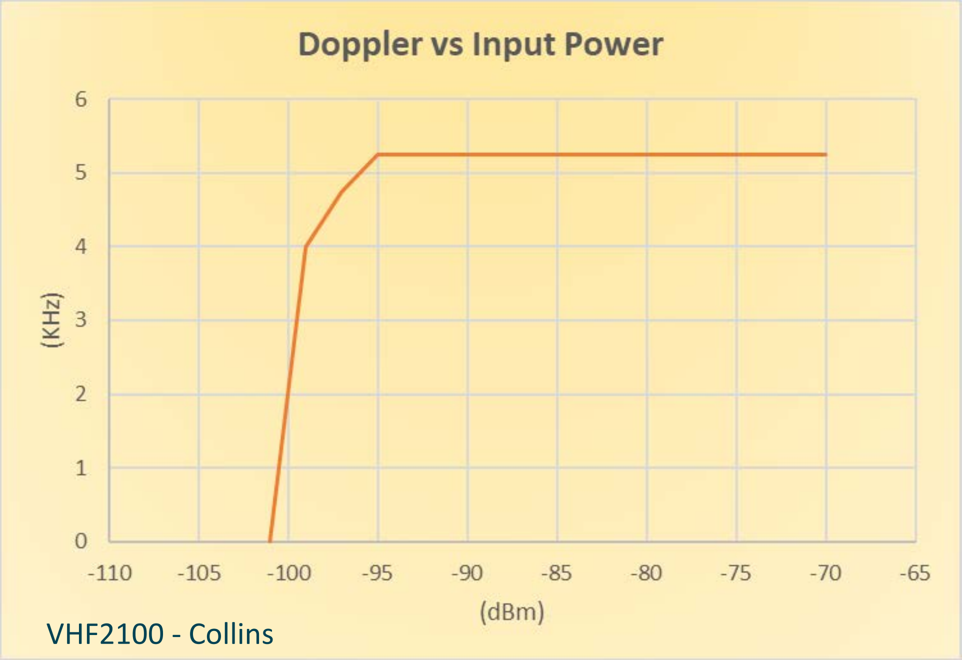
# Doppler effect on VHF link- Impact of satellite channel Doppler on VHF radio. VHF Voice Tests: Dynamic Doppler





- Radio behaviour is not affected by dynamic Doppler shift.
- The performance of the audio demodulate when Doppler is applied is above the values specified in ICAO SARPS (SINAD >10 dB and THD<5%)

# Doppler effect on VHF link - Impact of satellite channel Doppler on VHF radio. Data Link Tests: Doppler



VHF2100 - Collins

- Airborne Radio tested **(Collins VHF2100) supports Doppler shifts** due to satellite movement (3.2 kHz) that produces a **maximum frequency offset higher** than specified (ED-92C: 967 Hz).
- The Airborne radio behavior is the same when introducing dynamic Doppler effect (one satellite overflight)
- This Airborne radio is one of the most commonly installed on board aircraft

# Contents

# Spectrum compatibility

- **Objective:** Study the compatibility between the space-based VHF system and systems operating inside the band 117.975-137MHz, below the band <117.975MHz and above the band >137MHz. The considered channels will be both, 25 kHz channels with AM Voice Signal and D8PSK Data Signal. The interference levels at different bands will be studied at aircraft and ground levels transmitting VHF carriers and measuring in band and out of band interference levels. Power Flux Density (PFD) and absolute value (dBW) on ground will be the key parameters involved.

- **Studies / Analysis:**
  - Analysis of ITU-R regulations affecting the harmful interference protection and determine the required level of protection to be implemented if required.
  - Analyze interference over adjacent channels coming from spectrum shift due to satellite Doppler.
- **Tests / Measurement:**
  - Test in the lab transmitter spectrum mask behavior using a real VHF amplifier.

# Spectrum compatibility – Below 117.975MHz

Compatibility of Unwanted AMS(R)S Out-Of-Band and spurious emissions below 117.975 MHz to be ensured by ICAO Frequency management

**ITU-R Draft Report for AI 1.7, paragraph 7.3:** "… 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."

# Spectrum compatibility – In band 117.975MHz-137 MHz

According to the summary in ITU-R Draft Report for AI 1.7 of ITU-R WP5B November meeting:

- Section 9.1 for in the frequency band 117.975-136 MHz  and Section 9.2 for in the frequency band 136-137 MHz :

“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.”

# Spectrum compatibility above 137MHz

Based on the summary in Draft Report for AI 1.7 of ITU-R WP5B November meeting:

- Section 9.1 for operating of the space-based VHF system in the frequency band 117.975-136 MHz:

“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, thanks to the 1 MHz guard band in 136-137 MHz.”

- Section 9.2 for operation of the space-based VHF system in the frequency band 136-137 MHz:

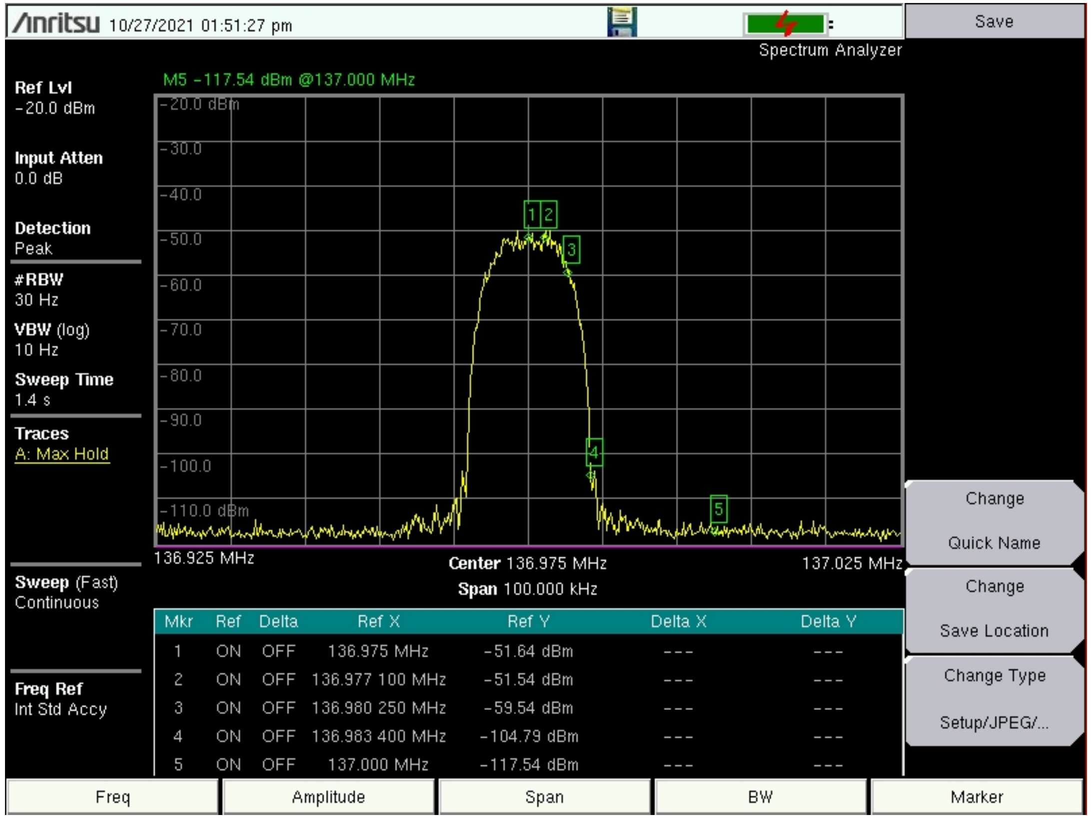
“Protection of adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth), Space operation service (space-to-Earth), Space research service (space-to-Earth), and Meteorological satellite service (space-to-Earth) would be ensured by a spectrum roll-off in order to achieve a maximum emission above 137 MHz not more than -156.3 dB(W/(m$^2$ · 14 kHz)) or the equivalent -197.7 dB(W/(m$^2$ · Hz)).”

# Spectrum compatibility above 137MHz

**Actual VHF radio measurements on a VHF D8PSK frequency modulation 10,5Ksymbols/s**

## Without Doppler

- **@136.975MHz**
- **Out of Band power < -60dBc spurious**



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Spectrum Analyzer

M5 -117.54 dBm @137.000 MHz

Ref Lvl -20.0 dBm

Input Atten 0.0 dB

Detection Peak

#RBW 30 Hz

VBW (log) 10 Hz

Sweep Time 1.4 s

Traces A: Max Hold

Sweep (Fast) Continuous

Freq Ref Int Std Accy

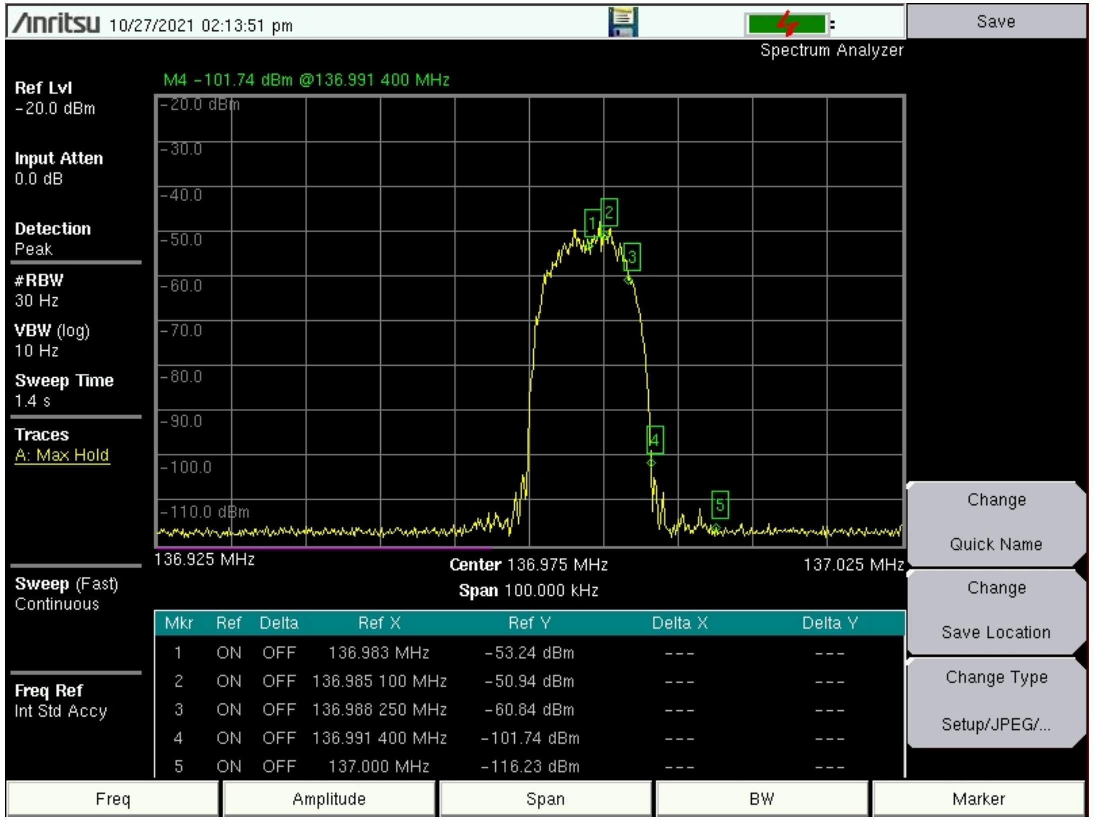
Center 136.975 MHz

Span 100.000 kHz

| Mkr | Ref | Delta | Ref X | Ref Y | Delta X | Delta Y |
|---|---|---|---|---|---|---|
| 1 | ON | OFF | 136.975 MHz | -51.64 dBm | --- | --- |
| 2 | ON | OFF | 136.977 100 MHz | -51.54 dBm | --- | --- |
| 3 | ON | OFF | 136.980 250 MHz | -59.54 dBm | --- | --- |
| 4 | ON | OFF | 136.983 400 MHz | -104.79 dBm | --- | --- |
| 5 | ON | OFF | 137.000 MHz | -117.54 dBm | --- | --- |

## With Worst case Doppler

- **@136.975MHz+8KHz Doppler shift**
- **Out of Band power < -60dBc spurious**



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Spectrum Analyzer

M4 -101.74 dBm @136.991 400 MHz

Ref Lvl -20.0 dBm

Input Atten 0.0 dB

Detection Peak

#RBW 30 Hz

VBW (log) 10 Hz

Sweep Time 1.4 s

Traces A: Max Hold

Sweep (Fast) Continuous

Freq Ref Int Std Accy

Center 136.975 MHz

Span 100.000 kHz

| Mkr | Ref | Delta | Ref X | Ref Y | Delta X | Delta Y |
|---|---|---|---|---|---|---|
| 1 | ON | OFF | 136.983 MHz | -53.24 dBm | --- | --- |
| 2 | ON | OFF | 136.985 100 MHz | -50.94 dBm | --- | --- |
| 3 | ON | OFF | 136.988 250 MHz | -60.84 dBm | --- | --- |
| 4 | ON | OFF | 136.991 400 MHz | -101.74 dBm | --- | --- |
| 5 | ON | OFF | 137.000 MHz | -116.23 dBm | --- | --- |

**Out of Band (OoB) power at 137 MHz is attenuated higher than 60 dB from the In band AMS(R)S signal**

# Contents

# Compatibility to use VDL-Mode 2 from Space

- **Objective:** analysis of compatibility for the operation of space-based stations in the 136 – 137 MHz frequency band with ground stations.

- **Studies / Analysis:**
  - Analysis of the compatibility of the use of the VHF datalink from satellite system.
  - Identification of any technical and operational constraint and their impact on the satellite services.

- **Tests / Measurement:**
  - SESAR VOICE Very Large Demonstration activity: an operational infrastructure will be deployed in the Gran Canary Island between the ENAIRE ATC system, the SITA network and initial assets (Ground Segment and first satellite).
  - VOICE project aims to demonstrate that, with the use of Satellite based VHF systems providing Voice and Datalink ATS, traffic in remote and oceanic airspace can be handled as in a continental, and current aircraft separation could be reduced without compromising safety.

# Compatibility to use VDL-Mode 2 from Space

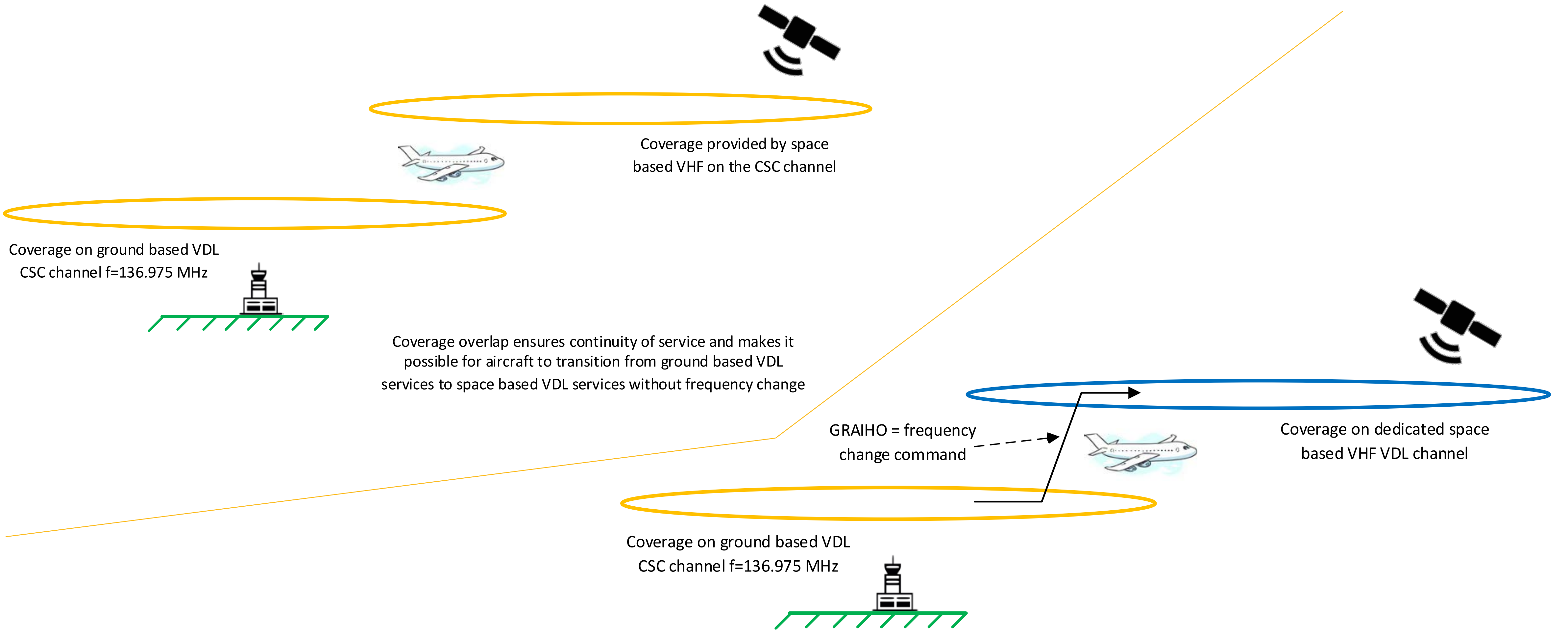
**Operation of space-based VDLm2 system**

- The satellite system is similar to the ground station in term of behaviour :
  - CSMA protocol
  - D8PSK modulation
  - CVME to assign to the radio a dedicated channel as specified by ICAO
  - The ground stations and the space-based VHF system will be visible each other. As a result, this will avoid the issue of the hidden transmitters in the event that they use the same channel (CSC)

- To assess the impact of unwanted emissions of the space-based VHF system onto the ground-based radio operating in the adjacent channel

- Satellite coverage over oceanic and remote areas:
  - Satellite is complementary component to the ground-based VDL network
  - Channel to be assigned by ICAO
  - Other specific channels to be considered depending on the traffic
  - Minimum overlaps with ground stations operating close to the coastline to ensure continuity of service
  - Seamlessly transition from a ground station to the satellite component
  - No impact on ground stations

# Compatibility to use VDL-Mode 2 from Space



Coverage provided by space based VHF on the CSC channel

Coverage on ground based VDL CSC channel f=136.975 MHz

Coverage overlap ensures continuity of service and makes it possible for aircraft to transition from ground based VDL services to space based VDL services without frequency change

GRAIHO = frequency change command

Coverage on dedicated space based VHF VDL channel

Coverage on ground based VDL CSC channel f=136.975 MHz

Coverage overlap ensures continuity of service and makes it possible to operate the space based service on a dedicated channel different from ground based VDL services

# Contents

# Technical Summary

**VHF Voice. Initial results show that:**

- actual aircraft radios exhibit performances as specified in ICAO for the Sensitivity and SNR range of the satellite channel and also for several cases of scintillation.
- radios tested, working in a 25 KHz channel, can manage the Doppler effect added to the VHF link due to satellite movement. Pre-compensation can be applied if needed.

**VHF Data. Initial results show that:**

- actual aircraft radios behaves as expected in terms of Sensitivity for the expected satellite channel range. In addition, preliminary tests with scintillation show good behaviour for moderate cases.
- the radio tested (Collins VHF2100) shows very good performances when Doppler is applied, behaving better than the specified requirement in ICAO SARPS. A pre-compensation mechanism can be used if needed.

**Spectrum. Initial results show that :**

- outcomes of the compatibility studies demonstrate that the space-based VHF satellite does not create harmful interference to services operating above 137 MHz.
- Compatibility of Unwanted AMS(R)S Out-of-Band and spurious emission below 117.975 MHz and compatibility in the frequency band of 117.975 MHz-137MHz is ensured by ICAO Frequency management.

**VDL-Mode 2**

- Compatibility between AMS(R)S and AM(R)S is accomplished by frequency allocation for the operation of the space-based VHF system.
- The Space-based VHF system will be complementary component to the actual terrestrial networks, providing seamlessly transition from a ground station to the satellite component.
- To address sharing studies under ICAO umbrella, but not under ITU-R.

# General Summary

- **WRC-19 approved the Resolution 428:** *"Studies on a possible new allocation to the aeronautical mobile-satellite (R) service within the frequency band 117.975-137 MHz in order to support aeronautical VHF communications in the Earth-to-space and space-to-Earth directions***"**

- **Resolution 428 noting b):** *"that the development of compatibility criteria between new AMS(R)S systems proposed for operations in the frequency band 117.975-137 MHz and ICAO-standardized aeronautical systems in this frequency band* ***is the responsibility of ICAO*** *"*

- **Resolution 428 invites ITU-R:** *"to take into account the results of the studies to provide technical and regulatory recommendations relative to a possible new AMS(R)S allocation within the frequency band 117.975- 137 MHz, taking into consideration the responsibility of ICAO referred to in noting b)"*
- **Resolution 428 invites ICAO:** *"to participate in the studies by providing aeronautical operational requirements and relevant available technical characteristics to be taken into account in ITU Radiocommunication Sector (ITU-R) studies and to take into account the sharing and compatibility conclusions reached at ITU-R in the SARPs to be developed for the AMS(R)S,"*

Considering outcomes from works done concludes that the new allocation of AMS(R) are:

  - Technically feasible.
  - Operationally feasible.
  - Compatible with services in adjacent band.

ICAO and their States members should promote and support the activities in ITU-R and ICAO in order to achieve the new allocation for all AMS(R)S in the whole VHF aeronautical band 117.975-137MHz, under ICAO responsibility, AI 1.7 at WRC-2023.

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1. **Introduction**
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3. **Test Bench Architecture**
4. **Signal propagation**
5. **Doppler effect on VHF link**
6. **Spectrum Compatibility**
7. **Compatibility to use VDL-Mode 2 from Space**
8. **Technical Summary**
9. **Questions and Answers**

# Question #1 - Regulation

➢ **Should we resolve all the technical and operational questions of a potential space-based AMS(R) service before achieving the allocation of that service at WRC-23?**

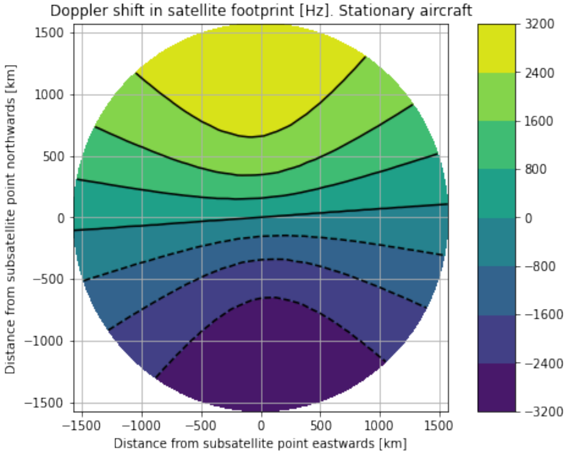
This is an important point as some of the apparent discrepancies are due to the understanding that ITU-R would be deciding on assignments for AMS(R )S, while ITU is just deciding on allocation. The ITU step is crucial and is required before any further assignment or operational conditions are decided by ICAO. The reasons:

- The allocation to AMS(R )S would be made by ITU at the light of the interference scenarios with respect to other services. It is assumed that the management of the assignments within the AMS(R )S band will be made by ICAO and will not be an ITU issue. Therefore, the interference assessment has to be made with respect to adjacent band services. This ITU decision will set the restrictions and conditions to use the AMS(R )S in order to protect adjacent band services.
- It is reasonable and convenient to develop a typical reference AMS(R )S scenario of using the band by AMS(R )S, to have it as reference of typical AMS(R )S parameters for the purpose of interference analysis. This is typical way of conducting interference studies by ITU: develop parameters typical for sharing studies; these parameters do not need being standardized, or being confirmed as the mandatory parameters.
- The final design or conditions to use the AMS(R )S band (and associated ICAO standards or ICAO operational procedures) will depend upon the final restrictions to use the band due to requirements to protect adjacent band services as decided by ITU-R.
- Consequently, the ITU work should be distinguished from ICAO work. ITU should take decisions on the way AMS(R)S would use the whole band 117.975 – 137 MHz. Whether ICAO will define standards in the short term for use of the sub-band 117.975-136 MHz and other standards for 136-137 MHz at later stage is purely a matter of strategy or internal needs from ICAO, but it is not a matter of ITU.
- The decisions at ITU level imply a high cost of studies and are adopted only every 4 years involving resources from all ITU Community. Therefore, ICAO should ensure firstly the AMS(R )S allocation in the whole band, as per already decided by WRC19, ensuring the whole band is studied by WRC 23. Then, once conditions to use the band (or different conditions for each sub-band, as appropriate) are decided by WRC23, ICAO can develop a strategy on standardization, operational aspects for the use of the allocation and adopt/recommend assignment procedures to civil aviation authorities.

# Question #2a – Doppler compensation

- **Preliminary ITU studies have shown that it will be necessary to use LEO satellites which will result in a Doppler effect of +/-4kHz, which is incompatible with the Eurocae ED92C standards and therefore not consistent with considering (a) of Res 428 (…without modification to aircraft equipment).**

- A key driver of the design of the LEO satellite system is that it has to behave in such a way that not any modification will be required in the aircraft equipment. In this sense, and concerning the 4kHz Doppler, a Doppler pre-compensation mechanism is being defined to guarantee the compatibility of the satellite transmissions with the specified maximum frequency error. Basically, the transmissions from the satellite will be shifted in frequency in order to compensate the Doppler shift for the targeted aircraft (and a large area around it) in order to comply with the standards and messages can be received without modification to aircraft equipment.
- The Doppler introduced by the satellite varies from -3.2 kHz to 3.2 kHz in the satellite footprint and in the direction of the satellite movement, that is in latitude.  On the other hand, the variation for the same latitude is much lower (see figure). It is then clear that aircrafts located in front or behind will be affected by a Doppler with a different sign, being necessary to apply a Doppler pre-compensation mechanism to guarantee that the aircraft receives correctly (for the case of VDL2).
- Several potential solutions are possible to do that, avoiding entering in technical details to save Intellectual Properties:
  - Using beam forming footprint radiation adapted to the Doppler effect observed by the aircraft. i.e, the satellite could radiate only in forward o rear direction with a pre-compensated shifted frequency, the satellite could radiate only perpendicular to the movement. Alternatively, a combined solution.
  - Omnidirectional radiation with multiple pre-compensated shift frequencies.
  - Above are for omnidirectional radiation, for point-to-point connection, the needed shifted frequency could be calculated using several solutions.



# Question #2b – Doppler compensation

- **If you looked at the TSO for VHF comm there are different TSO classes for radios that support or do not support offset carrier.**

- For Voice service could be not necessary to apply a pre-compensation based on the effective acceptance bandwidth specification of ICAO Annex X, Volume III section 2.3.2.3. From the specification, the effective bandwidth is higher than the maximum Doppler for both with offset carrier (8 kHz) and without offset carrier (6.8 kHz).
- In addition, the VHF voice radios must support the operation in CLIMAX for continental area, implementing the offset carrier operation.

- **The voice and data issues with the compensation how this is resolved?**

- For the voice service, based on ICAO Annex X, it is more tolerant to Doppler shift and could work without pre-compensation. For the data service, a pre-compensation mechanism will be implemented.

- **If the satellite shifts its transmit frequency to compensate for Doppler shift for aircraft in front of the satellite, won't that make it more problematic for aircraft behind the satellite to correctly receive the signal, since they would require a frequency shift in the opposite direction?**

- refer to question #2a.

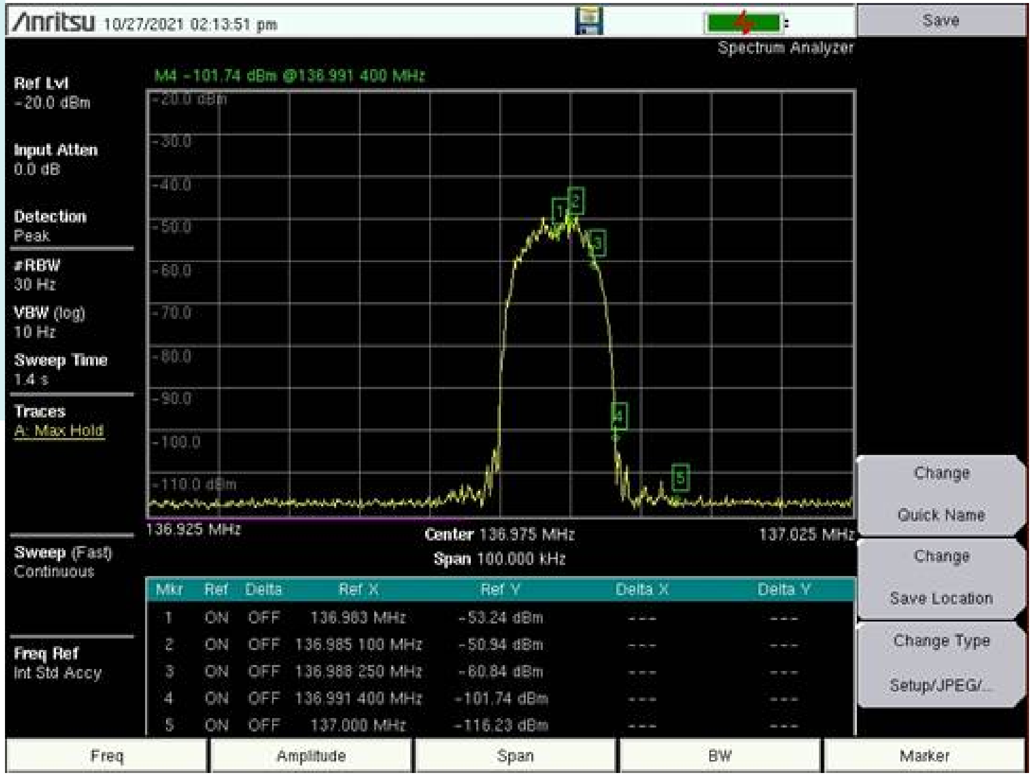
- **CSMA behavior when applying Doppler pre-compensation: if a pre-compensation is applied addressed to one specific aircraft, would other aircrafts with different Doppler be able to detect the channel busy even in case of not being able to decode the packet?**

- The Doppler pre-compensation is valid for an area around the specific aircraft. Aircraft for which the pre-compensation is not valid are far away. For those aircraft, even if their CSMA did not detect the channel as busy and decided to transmit, their transmissions are unlikely to affect the original transmission (because of the distance) and will be received normally by the satellite receiver.

# Question #2c – Doppler Spectrum assessment

- **An aircraft needs to the last channel 136.975Mhz (CSC) to get into the VDL2 Network, a possible compensation of the Doppler effect on emission would make the emission of the VDL2 CSC channel (136.975MHz) closer to the edge of the band (137MHZ).**

- The satellite transmitter mask is designed to comply with the out of band emissions taking into account the Doppler shift. We presented the transmitted signal of a COTS equipment with a shift of two time the Doppler and there was not emission in the adjacent band. In the worst case it will be shifted 8 kHz (two times the Doppler shift). This moves the last channel to 136.983 MHz max, still more than 60 dBc of out of band attenuation. We presented plots of COTS equipment exhibiting this out of band level. See Figure 7 in the ITU-R PNDR for AI 1.7.
- Note that 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 section 3.2.1.2.4) and R-REC-SM.1138.



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Spectrum Analyzer

M4 -101.74 dBm @136.991 400 MHz

Ref Lvl: -20.0 dBm
Input Atten: 0.0 dB
Detection: Peak
#RBW: 30 Hz
VBW (log): 10 Hz
Sweep Time: 1.4 s
Traces: A: Max Hold
Sweep (Fast): Continuous
Freq Ref: Int Std Accy

Center 136.975 MHz
Span 100.000 kHz

| Mkr | Ref | Delta | Ref X | Ref Y | Delta X | Delta Y |
|---|---|---|---|---|---|---|
| 1 | ON | OFF | 136.983 MHz | -53.24 dBm | --- | --- |
| 2 | ON | OFF | 136.985 100 MHz | -50.94 dBm | --- | --- |
| 3 | ON | OFF | 136.988 250 MHz | -60.84 dBm | --- | --- |
| 4 | ON | OFF | 136.991 400 MHz | -101.74 dBm | --- | --- |
| 5 | ON | OFF | 137.000 MHz | -116.23 dBm | --- | --- |

# Question #3a – Testing Details

- **Which radios did you test for the Doppler shift as there are different radios.?**
  - Voice: Collins VHF 2100; Jotron TR-7750(ground radio), Dittel; Data: Collins VHF-2100, IDTS MTP-200; Jotron TR-7750(ground radio)

- **Need to hear from avionics manufacturers**
  - In contact with Honeywell, Collins and Thales, and also with the collaboration of SITA as part of the VOICE project.

- **What assumptions of the bands did you use for these tests, etc.**
  - The tests will use a frequency for voice and frequency for data inside the AM(R)S band (117.975 to 137 MHz). A frequency coordination analysis has been carried out to select VHF frequencies not currently used in the demonstration region.

- **Error rate over Doppler calculation are not available and similarly many calculation are missing, power, etc.**
  - It is understood that the question is asking for BER or FER measurements when Doppler is introduced. Such measurements are on going, as they take some time to be carried out due to its statistical nature. However, it has been monitored the link status while Doppler is present, both a fix one and a Doppler variation and the link is not lost with the VHF2100 radios. The test carried out have been for different receiver input power.

# Question #4a – Operational Details

- **Is it required that all aircrafts receive the packets addressed to all aircrafts? This is obvious for broadcast packets but may not be needed for unicast ones.?**
  - This situation will happen when the aircrafts are flying in regions located very far from each other, To note that in terrestrial networks the situation is equivalent, aircrafts located in places that are far from each other will not listen among them due to terrestrial coverage limits.

- **What will be the coverage/signal strength over land for administrations that are not using the system in terrestrial airspace (i.e. if it only operates in neighboring oceanic areas)?**
  - The satellite system will be deployed guaranteeing its compatibility with terrestrial networks, not impacting the ones not using it even being under the satellite coverage. This will be achieved with proper frequency coordination as it is done for terrestrial networks.

- **What antenna characteristic is used for the space segment to ensure a stable uplink from the AC to space?. What coverage is given for the downlink if the “uplink characteristic” of the receive antenna is also used for transmit into the downlink?**
  - There are several solutions for the satellite antenna. To guarantee a stable solution the antenna just shall guarantee enough gain in all the defined coverage. It can be achieve using omnidirectional antennas, isoflux antennas, or more complex antennas like array or reconfigurable antennas. The purpose of this study is not to define the technological solution of the antenna but to evaluate the feasibility of establishing communication with the required parameters. The final solution will depend on each manufacturer and will be a solution that combines the satellite solution with the satellite constellation solution that guarantees continuity of coverage and service.

# Question #4b – Operational Details

- ➢ **Given that the VHF analog voice use case assumes a "party line" for flight crew situational awareness in a particular airspace sector, and VDL Mode 2 utilizes Carrier Sense Media Access (CSMA) to minimize data packet collisions, any Doppler compensation by the satellite would have to ensure that all aircraft in the intended coverage area would still be able to correctly receive the satellite signal on the intended frequency.**

- For CSMA / VDL2, refer to question #4a. For VHF voice, party line, no Doppler pre-compensation could be implemented, refer to question #2b.

- ➢ **How is ensured that a 24/7 operation is possible for any sector by just selecting one frequency mapped to this sector?**

- Satellite coverage will be overlapped up to a certain area, so a collateral sat could service just in case. Moreover, there will be a number of backup satellites. Space-Earth links will be at least duplicated.
- By the frequency management point of view, there will be several different channels to be assigned to collateral sectors. Then at a certain distance, channels will be reused

- ➢ **How is it managed to monitor also the guard channel 121,5Mhz within the sector?**

- the satellite payload receiver will have the capability to listen to several voice channels simultaneously.

# Question #4c – Operational Details

- **Can the current avionics work without modification?**

- This is a key design driver for the satellite system, it will be designed and implemented to guarantee that no any modification is needed in the avionics. As examples:
    - The satellite EIRP will guarantee the minimum power flux density at the aircraft VHF antenna input for both voice and data services.
    - As answered in question #2, Doppler effect will be pre-compensated

- **How is it managed to operate also at least on backup frequency within the sector?**

- Each satellite will handle several frequencies.

# Question #5a – VDL Compatibility

## ➢ Compatibility between terrestrial VDL and satellite VDL

- Complete compatibility at the air-ground protocol layer. Exactly the same protocol stack is used..
- On the co-channel operation, it should be seen the space-based VHF system as a complementary component to the ground-based VDL station. It means that in area where it is impossible to deploy a ground-based VDL station, hence no coverage from the ground, the space-based VHF station will take the hand-over. As both system are similar (same modulation, same CSMA protocol), both system will co-exist as it is already the case for the ground-based VDL stations which use the same channel. It should be noted that the impact is greater if considering only the ground component as there is the issue of the hidden transmitter. In the case between the space-based VDL system and the ground-based VDL station, this issue does not exist as both are in line-of-sight.
- It is important to ensure that the unwanted emissions of the space-based VHF system (in the out-of-band and spurious domain) do not affect the operation of the ground-based VDL station in the adjacent channel. The initial analysis made based on the typical out-of-band mask and on the typical spurious values shows that the operation of the space-based VHF would not affect the operation of the ground-based VDL station operating in the adjacent channel (50 kHz, 100 kHz frequency separation). See attachment for details.

## ➢ Ensuring that CSMA will work fine and that we will avoid specific issues that we find for terrestrial VDL, like, for instance the "hidden transmitter" issue.

- The satellite-based VDL station covers a very wide area, hence by design there are no hidden transmitters. The reason being that the satellite will be in light-of-sight with ground-based VDL station. In the event, the ground-based VDL station transmits, the space-based VHF station would not transmit unless the signal received is below the detection threshold.

# Question #5b – VDL Compatibility

- **A few scenarios to consider for space-based VDL OPS, notably the switchover mechanism between space-based VDL and ground-based VDL:**
- **1. Aircraft from Europe to USA are on different channels.**
- **2. Aircraft up to within 250nm from a terrestrial VDL system**
- **3. If VDL are different service providers**
- **4. GRAIHO**

1. Aircraft flying between Europe and USA operate on exactly the same VDL CSC channel but with large gaps in coverage. Satellite-based VDL can fill the gaps in coverage. The underlying principle of the space-based VDL is that it appears to the aircraft as “just another VDL station” hence all the same, existing handoff mechanisms apply.

   In case of oceanic coverage, it should be mentioned that as this area is considered as international, an alternate frequency can be different to the one used in the USA and Europe.
2. For coverage near the coasts of continents the space-based VDL station allows the VDL service to be extended out to the oceanic region in a seamless fashion. The space-based VDL service can be provided on the same frequency as the terrestrial-based VDL stations or it can be provided on an alternate frequency to which the aircraft would be commanded to switch by the CVME, as it is done currently in the scope of VDL multi-frequency management.
3. Terrestrial-based and space-based VDL services can be provided using the same DSP ID or a different DSP ID. The “same DSP ID” approach is preferred because it does not require any changes in avionics configuration (no software modifications would ever be needed in the avionics)
4. Space-based VDL stations will be managed by the CVME just as the existing terrestrial-based VDL stations are already managed. The space-based VDL stations will be simply added to the inventory of VDL stations managed by the CVME with their own, appropriate coverage maps.

# Question #5c – VDL Compatibility

- **Handover from the terrestrial VDL network to the satellite VDL network through the CVME (Central VHF Management Entity) and vice versa. How this will happen seamlessly for the aircrafts?.**

- The aircraft only receives and processes VDL frames and it cannot tell the difference between VDL frames originating from a ground-based VDL station and a satellite-based VDL station. Handoff between a ground-based VDL station and a satellite-based VDL station is identical to a handoff between two ground-based VDL stations. In the CVME, the space-based VDL station is simply just another station that it is managing, albeit with a much larger coverage map.

- **In a multi service providers how the transferring of frequencies will work between those entering oceanic and coming into terrestrial between service providers, and what are the conditions under that is initiated.**

- If the space-based VDL service was required to operate with its own DSP ID that is different from the existing DSP IDs then the transfer from satellite-based to terrestrial based would happen exactly the same way as transfers which occur currently when an aircraft that is configured to be allowed to access the VDL service of different service providers, for example ARINC and SITA, loses datalink service when it flies outside the coverage area of one service provider but then detects the availability of VDL service from the other service provider. This mechanism is already actively being used on the current aircraft fleet.

- **Even if the aircraft does not detect the busy channel state, could it cause a significate increase of collisions?**

- If they occur, transmissions from the aircraft performed while the channel is being used by another transmitter are likely to increase the level of collision. It is important however to mitigate this by the fact that, as highlighted in previous answers, the broadcast nature of the satellite signal transmission and the low blockage of the Line of Sight of the satellite signal for aircrafts in flight lowers the probability of such events where an aircraft is transmitting while the channel is busy. The increase in collisions, if any, will thus likely not be significant.
- An aircraft (a2) may not detect packets with a Doppler pre-compensation addressed to another aircraft (a1), not detecting a busy channel state. In this situation this aircraft (a2) may transmit, but it will not affect the aircraft (a1) caption from the satellite as they will be far from each other. On the other hand, aircraft (a2) could transmit to the satellite as it sees the channel free, but it would be received by the satellite always listening.

# Question #5d – VDL Compatibility

- **Is it required that all aircrafts receive the packets addressed to all aircrafts? This is obvious for broadcast packets but may not be needed for unicast ones.?**
  - It is not necessary that all unicast transmissions be received by all aircrafts in the coverage area for the system to function. However, the reception of the signal by a subset of the aircrafts could lead the transmitters of the aircrafts not receiving the transmission to believe the channel is not busy and initiating a transmission themselves, which could result in collisions lowering the overall offered capacity of the VHF service volume. It is thus desirable that all aircrafts are able to sense the presence of energy on the channel for CSMA purposes.

- **What protocol will SATCOM VDLM2 use (FANS/ATN?). If ATN, how will the network avoid aircraft attempting to connect on their own initiative?**
  - The Space Based VHF is agnostic to the protocols running on top of the AVLC layer. Space Base VHF will use the same AVLC protocol as Ground Based VDLm2, the protocols that will be used on top of this are transparent (just as they are for Ground VDL). GSIF will indicate the available services (AOA and/or ATN) over Space Based VDL.

- **How will assignments to SATCOM stations be coordinated with terrestrial channel plans?**
  - Coordination of the channel assignments for Space Based VHF (either dedicated or shared) are expected to be performed through the existing mechanisms for frequency management for VHF spectrum.

- **What requirements will be placed on planning criteria for new or modified terrestrial assignments?**
  - Current proposal is to handle satellite frequency assignments like any other, thus a study will be made for each channel-region assignment considering adjacent frequencies.

# Question #5e – VDL Compatibility

- **What is the function that moves an aircraft from a terrestrial to a SATCOM network (and vice versa) when each network is a different CSP? Both on entering and exiting oceanic regions.**
- **1. What are the technical and operational conditions that would initiate such a move?**
- **2. What agreements will operators need to have in place, if any?**

- If the space-based VDL service was required to operate with its own DSP ID that is different from the existing DSP IDs then the transfer from satellite-based to terrestrial based would happen exactly the same way as transfers which occur currently when an aircraft that is configured to be allowed to access the VDL service of different service providers, for example ARINC and SITA, loses datalink service when it flies outside the coverage area of one service provider but then detects the availability of VDL service from the other service provider. This mechanism is already actively being used on the current aircraft fleet

- **If the SATCOM and GS appear to be same CSP to the aircraft, does this introduce a risk with the current VDLM2 connection orientated protocol letting an aircraft potentially jump between sub-optimal stations as seen on terrestrial networks?**

- The risk already exists in existing networks either given to specific user terminals behavior or in areas where two or more stations (either two GS or one GS and the Space Station) appear to have similar signal quality from an aircraft terminal point of view. Geographical areas in which this can happen are limited. The addition of Space Based VHF, given the high coverage areas that the satellite radio will have, is likely not to increase this situation. The areas in which special attention should be taken are the boundaries of the satellite transmitters and the terrestrial transmitters coverage respectively.

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