



ICAO

International Civil Aviation Organization

SEVENTH MEETING OF SPECTRUM REVIEW WORKING GROUP (SRWG/7)

Bangkok, Thailand, 15-17 February 2023

Agenda Item 9: 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. INTRODUCTION

- 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 the Agenda Item 1.7 for World Radiocommunication Conference 2023 (WRC-23).
- 1.2 ITU WP5B is the responsible group for this agenda item and the FSMP is the designated ICAO point of liaison with ITU WP 5B.

2. DISCUSSION

2.1 ITU-R STUDIES

- 2.1.1 ITU-R has studied the architecture, parameters, and baseline link budgets of a reference aeronautical mobile satellite (route) service “AMS(R)S” system for the provision of standardized communications for air traffic management, without modification to aircraft equipment.
- 2.1.2 To support compatibility studies, examples of the link budgets for satellite-to-aircraft (downlink) and aircraft-to-satellite (uplink) VHF links have been developed, based on propagation considerations adopted by ITU-R.
- 2.1.3 Compatibility studies of new AMS(R)S with existing primary services operating in-band/adjacent bands have been conducted with inputs from the relevant ITU-R Working Parties to ensure the protection of existing systems from possible interference resulting from the introduction of a new AMS(R)S.

Agenda Item 9

15-17/02/23

2.1.4 Analysis of the results of ITU-R studies has been divided into five sub-sections as follows:

- a) In-band sharing between the systems operating in the AMS(R)S and AM(R)S
- b) Adjacent band compatibility between AMS(R)S above 117.975 MHz & ARNS below 117.975 MHz
- c) Adjacent band compatibility with systems operating above 137MHz
- d) In-band sharing with other services
- e) Compatibility between systems operating in the AMS(R)S from different Administrations

2.1.5 The Preliminary Draft New Report (PDNR) detailing the technical studies and assessments of space-based VHF studies was progressed at the ITU WP 5B meeting held on 14-25 November 2022. The report is attached below for reference.

PRELIMINARY DRAFT NEW REPORT ITU-R M.[SPACE-VHF]	 R19-WP5B-C-0731! N09!MSW-E.pdf
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2.1.6 The Draft Conference Preparatory Meeting (CPM) report detailing the proposed regulatory changes for WRC-23 was completed at the ITU WP 5B meeting held on 11-22 July 2022. The report is attached below for reference.

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2.2 ICAO FSMP Working Group

2.2.1 The sixteenth meeting of the working group of Frequency Spectrum Management Panel (FSMP WG/16) will be held from 15 to 24 February 2023 and several contributions on space-based VHF have been received. The papers and topics for discussion are summarised in the table below.

FSMP WG/16 papers	Description
WP/08, WP/09	Proposed protection criteria, guard band, threshold
WP/10, WP/11, WP/20, WP/23	Proposed changes to Draft ICAO Position for WRC-23
WP/18	Concept of operations for VHF datalink
WP08, WP/19, WP/24	Frequency assignment, planning, coordination and regulatory affairs
IP/05	Proof of concept and satellite launch

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

- a) note the information contained within this paper for WRC-23 Agenda Item 1.7; and
- b) support the ICAO Positions for WRC-23.

Source: Document 5B/TEMP/298
Subject: WRC-23 agenda item 1.7
Resolution **428 (WRC-19)**

**Annex 9 to
Document 5B/731-E
14 December 2022
English only**

Annex 9 to Working Party 5B Chairman's Report

PRELIMINARY DRAFT NEW REPORT ITU-R M.[SPACE-VHF]

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

(202X)

Scope

In preparation for WRC-23 Agenda Item 1.7 and pursuant to Resolution 428 (WRC-19), ITU-R was invited to define relevant technical characteristics and to study compatibility between possible AMS(R)S satellite systems within the band 117.975-137 MHz and existing primary services in-band and in adjacent bands, taking into account RR No. **5.200** and RR No. **5.111**. Such satellite systems would relay aeronautical VHF communications over oceanic and remote areas and complement terrestrial communication infrastructures without modification to aircraft equipment. This Report is the response from ITU-R to that invitation.

Glossary of abbreviations

AM(OR)S	Aeronautical mobile (off-route) service
AM(R)S	Aeronautical mobile (route) service
AMS(R)S	Aeronautical mobile satellite (route) service
ANSP	Air navigation service provider
ATC	Air traffic control
epfd	Effective power flux density
FIR	Flight information region
ICAO	International Civil Aviation Organization
IoT	Internet of things
LEO	Low earth orbit
MASPS	Minimum aviation system performance standards
MSS	Mobile satellite service
M2M	Machine to machine
pfd	Power flux density
RR:	Radio Regulations
SARPs:	Standards and Recommended Practices

SATCOM	Satellite communications
SOS	Space operation service
SRS	Space research service
VDES	VHF data exchange system
VDL	VHF data link
VHF	Very high frequency

Relevant ITU-R Recommendations and Reports

Recommendations

ITU-R M.1231	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	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	Technical characteristics for a VHF data exchange system in the VHF maritime mobile band
ITU-R P.531	Ionospheric propagation data and prediction methods required for the design of satellite networks and systems
ITU-R SA.363	Space Operation Systems
ITU-R SA.609	Protection criteria for radiocommunication links for manned and unmanned near-Earth research satellites
ITU-R SA.1026	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	Sharing criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit
ITU-R SA.1743	Maximum allowable degradation to radiocommunication links of the space research and space operation services arising from interference from emissions and radiations from other radio sources

Reports

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
ITU-R SA.2488	Characteristics to be used for assessing interference to systems operating in the Earth exploration-satellite and meteorological-satellite services, and for conducting sharing studies

1 Description of space-based VHF communications concept

1.1 General concept

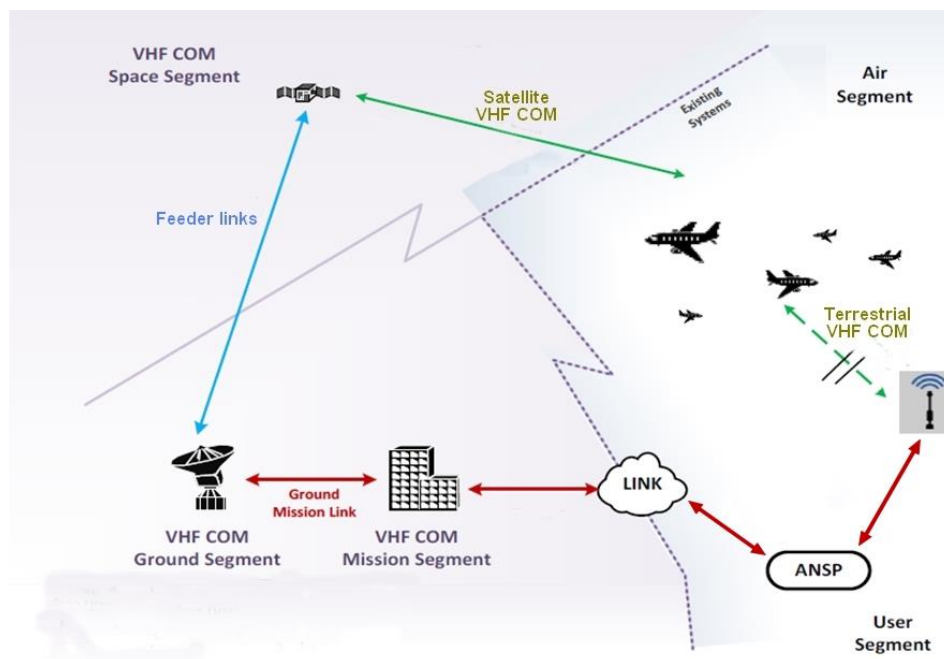
Space-based VHF communication is a concept in which aircraft operating in remote regions and oceanic areas provide communications from the aircraft to air traffic control (ATC) via satellite using VHF frequencies within the 117.975-137 MHz frequency range.

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

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

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

FIGURE 1
The space-based VHF communication concept



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 systems within the frequency band 117.975-137 MHz, currently allocated to the aeronautical mobile (Route) service (AM(R)S), aims to utilize existing on-board VHF radios used for terrestrial-based VHF communications.

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

AMS(R)S links between aircraft and satellite (shown as “Satellite VHF COM” in Figure 1) will operate within the frequency band 117.975-137 MHz and are the subject of considerations contained in this Report. Feeder links of AMS(R)S systems between earth station and satellite are not implemented within the VHF frequency band and may be accommodated in the fixed-satellite service, therefore consideration of feeder links is out of the 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.
 - VHF datalink (VDL) Mode 2 is studied within the sub-band 136-137 MHz, as channels currently assigned worldwide to this application are within this range.
- No change is made on:
 - aircraft avionic equipment.
 - terrestrial base stations specifications, and configuration of base stations located in flight information regions (FIRs) which do not make use of the space-based VHF service.
- No or minimal change would be made on:
 - operational aspects for pilots and controllers.
 - terrestrial base stations configuration in FIRs with space-based VHF service.

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

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

- ITU-R carried out sharing and compatibility studies for the co-existence between potential new AMS(R)S systems operating in the frequency band 117.975-137 MHz (Earth-to-space and space-to-Earth), providing voice and data applications as mentioned above, and existing primary in-band and adjacent band services.
- Based on the outcome of the studies, technical and regulatory proposals are provided in the summary section towards a possible new AMS(R)S allocation within the frequency band 117.975-137 MHz.
- ICAO participation was beneficial in ITU-R sharing and compatibility studies to provide aeronautical operational requirements, between the new AMS(R)S systems and the existing aeronautical systems, and other relevant available operational characteristics.

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

Below is the Radio Regulations (RR), (Edition of 2020) table of allocations and associated footnotes for the band 117.975-137 MHz. It shows that services allocated in this band on a primary basis are:

- Aeronautical mobile (R) service throughout the entire frequency band.
- Aeronautical mobile (OR) service (AM(OR)S) in the frequency bands 132-136 MHz and 136-137 MHz in certain countries listed respectively in RR Nos. **5.201** and **5.202**.

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

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

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

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

5.201 *Additional allocation:* in Armenia, Azerbaijan, Belarus, Bulgaria, Estonia, the Russian Federation, Georgia, Hungary, Iran (Islamic Republic of), Iraq (Republic of), Japan, Kazakhstan, Mali, Mongolia, Mozambique, Uzbekistan, Papua New Guinea, Poland, Kyrgyzstan, Romania, Senegal, Tajikistan, Turkmenistan and Ukraine, the frequency band 132-136 MHz is also allocated to the AM(OR)S on a primary basis. In assigning frequencies to stations of the AM(OR)S, 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 AM(OR)S on a primary basis. In assigning frequencies to stations of the AM(OR)S, 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 (Edition of 2020) table of allocations and associated footnotes for the frequency band 108-117.975 MHz. It shows that services allocated in this band on a primary basis are:

- Aeronautical radio navigation service
- Aeronautical mobile (R) service.

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

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

5.197A *Additional allocation:* the band 108-117.975 MHz is also allocated on a primary basis to the aeronautical mobile (R) service, limited to systems operating in accordance with recognized international aeronautical standards. Such use shall be in accordance with Resolution 413 (Rev.WRC-07)*. The use of the band 108-112 MHz by the aeronautical mobile (R) service shall be limited to systems composed of ground-

based transmitters and associated receivers that provide navigational information in support of air navigation functions in accordance with recognized international aeronautical standards. (WRC-07)

3.2 Radiocommunication services operating in the frequency band 137-143.6 MHz based on the Radio Regulations Table of Allocations

Below is the RR (Edition of 2020) table of allocations and associated footnotes for the frequency band 137-143.6 MHz. It shows that services allocated in this band on a primary basis are:

Primary services in the frequency band 137-138 MHz:

- AM(OR)S in certain countries under RR No. **5.206**
- Broadcasting service in Australia under RR No. **5.207**
- Fixed service in certain countries under RR No. **5.204** and No. **5.205**
- Meteorological satellite service (space-to-Earth)
- Mobile satellite service (space-to-Earth)
- Mobile service in certain countries under RR No. **5.204** and No. **5.205**
- Space operation service (space-to-Earth)
- Space research service (space-to-Earth).

Primary services in the frequency band 138-143.6 MHz:

- AM(OR)S in Region 1
- Broadcasting service in Australia under RR No. **5.207**
- Fixed service in Region 2, Region 3, and certain countries in Region 1 under RR No. **5.212** and No. **5.214**
- Land mobile service in certain countries in Region 1 under RR No. **5.211**
- Mobile service in Region 2, Region 3, and certain countries in Region 1 under RR No. **5.212**
- Maritime mobile service in certain countries in Region 1 under RR No. **5.211**
- Radio location service in Region 2 and in China under RR No. **5.213**.

Allocation to Services		
Region 1	Region 2	Region 3
137-137.025	SPACE OPERATION (space-to-Earth) 5.203C METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) 5.208A 5.208B 5.209 SPACE RESEARCH (space-to-Earth) Fixed Mobile except aeronautical mobile (R) 5.204 5.205 5.206 5.207 5.208	
137.025-137.175 MHz	SPACE OPERATION (space-to-Earth) 5.203C METEOROLOGICAL-SATELLITE (space-to-Earth) SPACE RESEARCH (space-to-Earth) Fixed Mobile except aeronautical mobile (R) Mobile-satellite (space-to-Earth) 5.208A 5.208B 5.209 5.204 5.205 5.206 5.207 5.208	

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

5.203C 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,
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

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

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

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

4.1 Aircraft VHF transmitter characteristics

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

4.1.1 Aircraft VHF transmit power for voice application

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

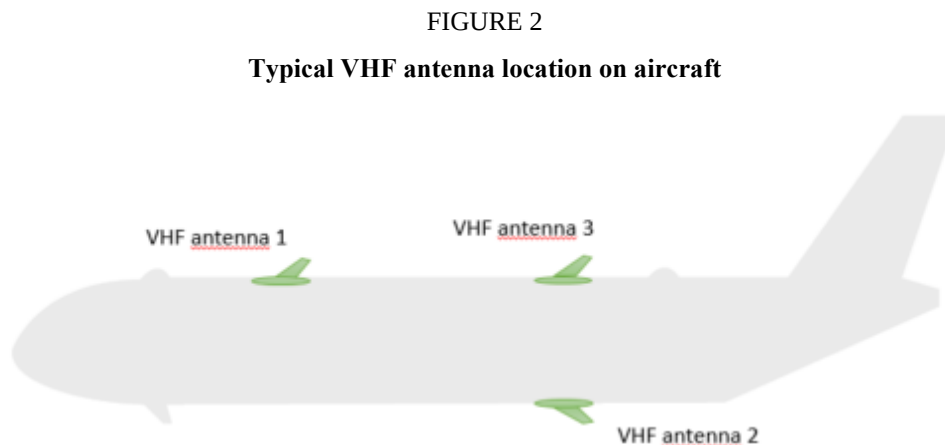
4.1.2 Aircraft VHF transmit power for data application

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

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.



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

- Relatively low gains are achieved
- Radiation patterns are globally omni-directional, and more precisely
 - omnidirectional in azimuth
 - cosinusoidal in elevation, meaning a theoretical zero is achieved at aircraft zenith (90° elevation).

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

- Frequency band: 117.975-137 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 density of –116.2 dB(W/m²). Indeed the relation between electric field strength and power flux density is given by:

$$\text{Power flux density (dB(W/m}^2\text{))} = 10\log(\text{electric field strength(V/m)}^2 / 120\pi)$$

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 density of -116.2 dB(W/m²), corresponding received power is -120 dBW or -90 dBm at the aircraft antenna flange.

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

4.2.2.2 Aeronautical mobile satellite (route) service data application performance requirement

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

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

This sensitivity power flux density of -120 dB(W/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 density of -120 dB(W/m²), corresponding received power is -123.8 dBW or -93.8 dBm at the aircraft antenna flange. (Note: According to EUROCAE ED-92, Section 2.2.1.2.1 sensitivity “A signal level of minus 98 dBm at the input of the receiver from a VDL Mode 2 signal source will produce an error rate that meets the requirements specified in Section 2.2.1.2”),

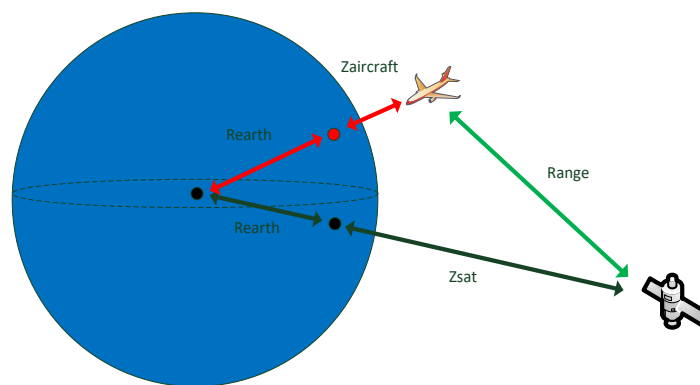
Feeder/cable losses on board aircraft should also be accounted for. It is proposed to consider 3 dB in this study, as specified in section 3.8.1 (“transmitter power”, page 241) of document RTCA DO-224C (Signal-in-Space minimum aviation system performance standards (MASPS) for Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques). The 1 dB difference with the 2 dB feeder loss figure considered for voice application is due to different typical locations on the aircraft for corresponding antenna.

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 $-116.2 \text{ dB(W/m}^2\text{)}$ for voice application specified in section 4.2.2 at 36 000 km distance, first with the typical assumption of a satellite transmitting gain of 3 dBi, second with the very optimistic assumption of a satellite transmitting gain of 20 dBi. Required satellite power is 155.5 kW and 3.1 kW respectively, which is either not achievable or not reasonable for a single 25 kHz carrier.

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

TABLE 1
Estimation of satellite RF power required for a geostationary satellite
operating in the aeronautical mobile satellite (route) service

		Units	Satellite-to-aircraft link budget	
			GSO with average VHF antenna gain	GSO with very high VHF antenna gain
a.	Frequency	MHz	137	137
b.	Range	km	36 000	36 000
Satellite transmitter				
c.	RF power required for 0 dB link margin	W	155 531	3 103

d.	Satellite Tx antenna gain	dBi	3	20
e.	Feeder loss	dB	1.0	1.0
f.	Satellite e.i.r.p. (calculated from c, d and e)	dBW	53.9	53.9
Signal propagation				
g.	Free space loss (calculated from a and b)	dB	166.3	166.3
h.	Additional propagation losses (scintillation)	dB	5	5
i.	Polarization losses to receive V polar	dB	3	3
Receiver power flux at aircraft antenna input				
	Effective received power flux density (calculated from a, f, g, h, i)	dBW/m ²	-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 0. 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 $\pm 20^\circ$ 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.

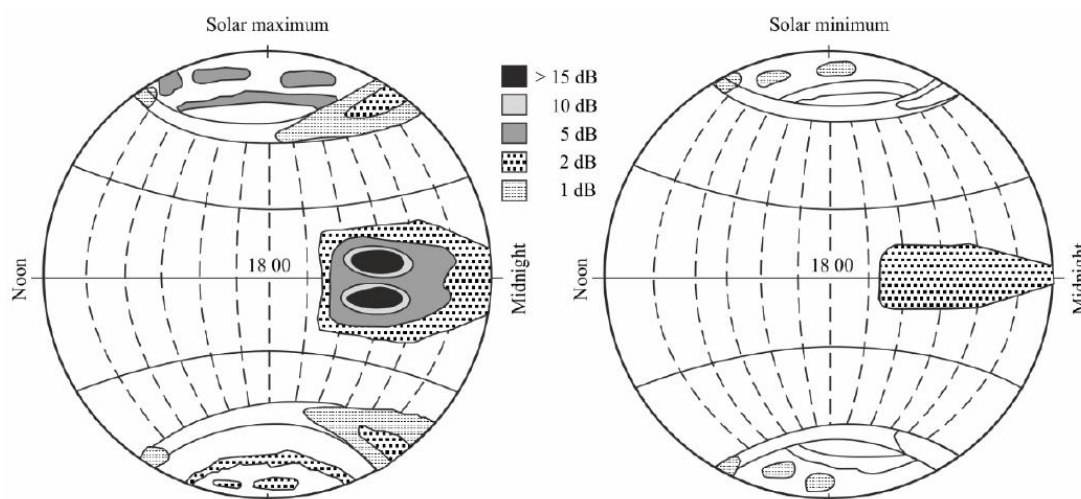
ICAO also noted that, depending on ANSPs' requirements and geographical constraints, both satellite and terrestrial systems may be used together to overcome the VHF scintillation trade-offs, to meet the service availability requirements. Moreover, the satellite system could also be designed with redundancies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

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.

It is important to note that the phenomena leading to higher attenuation loss due to scintillation can be predicted. Consequently, it is possible for aviation competent authority to decide in advance to not operate in area and in the period of time where and when ionospheric propagation would preclude the use of satellite VHF link; it is similar situation that can be met for HF links.

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 transmission characteristics

The output of the link budget considered for satellite downlink determines 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). An antenna pattern defined within ITU-R Recommendation for a different purpose was considered relevant for the study and was taken into account. In that framework, the example of a satellite antenna described in Recommendation ITU-R M.2092-1 seems appropriate (see Sections 2.2 and 2.3 of Annexe 5, 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 ($> 70^\circ$) coverage is sacrificed, corresponding to null at zenith of the aircraft VHF antenna pattern. It is therefore proposed to retain for the present study this example from Recommendation ITU-R M. 2092-1 as reference satellite antenna pattern for our baseline satellite architecture.

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

TABLE 2

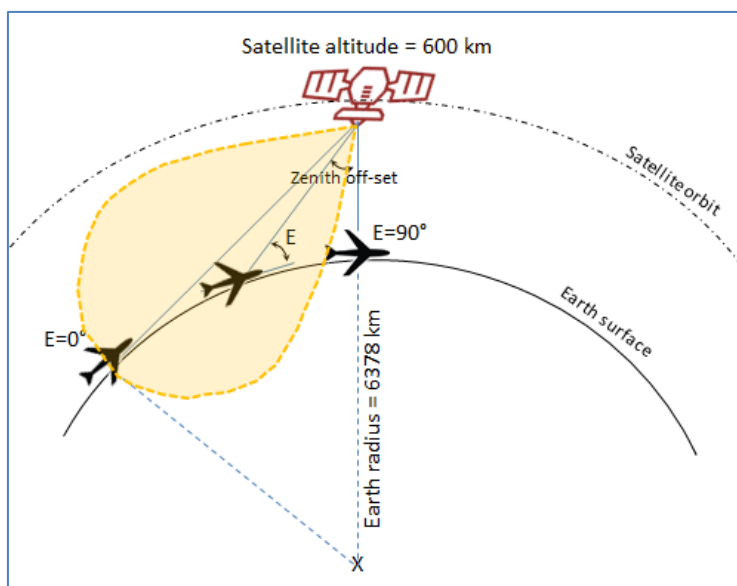
Antenna gain pattern example of a satellite operating in the aeronautical mobile satellite (route) service

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

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

FIGURE 5

Illustration of the proposed reference satellite antenna pattern



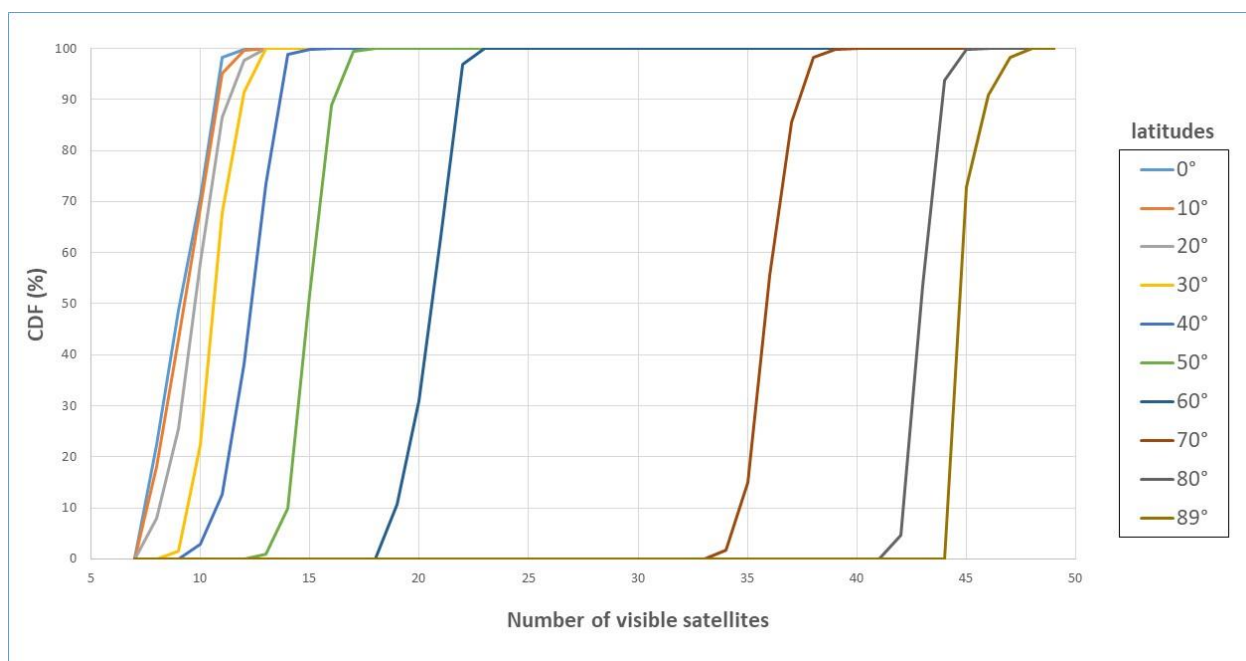
Additional dynamic sharing and compatibility studies may be also carried out for cases where static worst-case analyses don't lead to a firm conclusion. As a reference example, a constellation using polar orbits with 600 km altitude, inclination of 90 degrees, 34 satellites per plane and 10 planes with equal spacing to achieve global coverage could be considered, as presented on Figure 6 below. The number of planes and satellites is determined so as to ensure global coverage, taking into account the 20°-70°E operational elevation range considered later in section 6.3.

FIGURE 6
Illustration of a reference satellite constellation



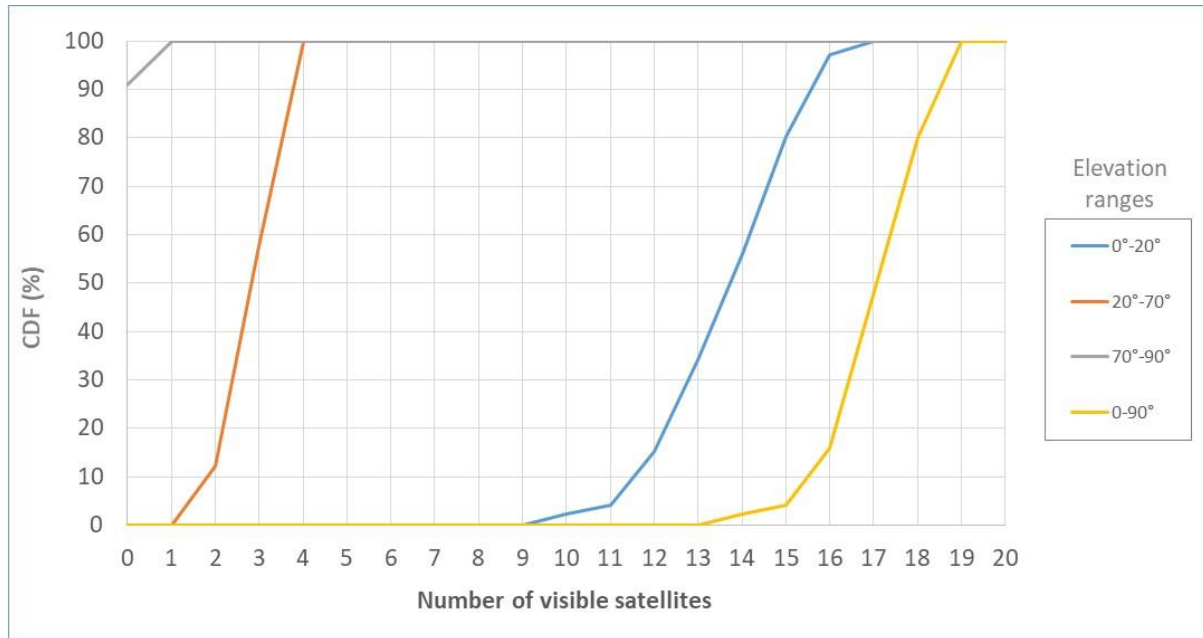
With such a constellation, the number of satellites visible from a given point on the Earth will depend on the latitude of this point. Figure 7 below provides the associated statistic:

FIGURE 7
Statistic of the number of visible satellites function of latitude



Only few (possibly only one) of the visible satellites will be within the 20°-70°E operational elevation range considered in section 6.3. As an illustration, Figure 8 below provides the statistic of the elevation ranges for satellites visible from a given point at 55° latitude. The difference is made between satellites visible within the 20°-70° elevation range, those which are seen with an elevation below 20°, and those with an elevation greater than 70°.

FIGURE 8
Statistic of the number of visible satellites per elevation range at 55° latitude



It is important to note that not all satellites which are visible from a given point will be active on the same channel, this would generate intra-system self-interference. As a result of frequency planning exercises assigning frequencies to the satellite system over interested regions, the satellite system would therefore be operationally controlled so as to ensure that, for any point on the Earth, 2 satellites maximum are active on the same channel, irrespective of the elevation at which these satellites are seen. This operational mechanism is an important assumption with respect to co-frequency sharing. Different assumptions on the number of satellites operating on the same channel could be considered.

For adjacent band compatibility, studies consider some assumptions on attenuation level for unwanted emissions. It should depend on the spurious and out-of-band of emissions. The number of frequency carriers transmitted simultaneously by satellites and taken into account at the receiver of an adjacent band earth station needs further investigations.

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 $\mu\text{V/m}$ requirement expressed by ICAO, equivalent to -116.2 dB(W/m²) power-flux.

TABLE 3
Example satellite-to-aircraft (downlink) link budget
- satellite power required for different aircraft elevation angles

FORWARD (To Aircraft)	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											
	RF Power for 25 KHz channel	W	304.1	141.7	73.6	45.9	38.1	39.1	48.8	82.2	147.1	305.9
	Sat Tx gain	dBi	8	8	8	7.8	6.9	5.5	3.6	0.7	-2.2	-5.5
	Feeder loss	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 path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
	Additional. propagation loss	dB	5	5	5	5	5	5	5	5	5	5
	Polarization losses	dB	3	3	3	3	3	3	3	3	3	3
	Effective received power flux density	dBW/m ²	-116.2	-116.2	-116.2	-116.2	-116.2	-116.2	-116.2	-116.2	-116.2	-116.2
	Recommended SAPRs power flux density	dBW/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	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 to meet the aircraft receiver sensitivity requirement and the different losses. Under the assumptions mentioned above, it can be noted that, as an example, a satellite power of 85 watts per 25 kHz channel is compatible with aircraft elevation angles between 20° and 70°. It is proposed to consider this power level as a reference, and to establish the link budget contained in Table 4 as an example of satellite-to-aircraft link budget taken into account for studies in this report with 5 dB scintillation losses.

TABLE 4
Example satellite-to-aircraft (downlink) link budget
with 5 dB scintillation losses

FORWARD (To Aircraft)	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											
	RF Power for 25 KHz channel	W	85	85	85	85	85	85	85	85	85	85
	Sat Tx gain	dBi	8	8	8	7.8	6.9	5.5	3.6	0.7	-2.2	-5.5
	Feeder loss	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 path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
	Additional. propagation loss	dB	5	5	5	5	5	5	5	5	5	5
	Polarization losses	dB	3	3	3	3	3	3	3	3	3	3
	Effective received power flux density	dBW/m ²	-121.7	-118.4	-115.6	-113.5	-112.7	-112.8	-113.8	-116.1	-118.6	-121.8
	Recommended SAPRs power flux density	dBW/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	dBi	2	2	2	2	2	2	2	2	2	2
	Rx Signal power	dBm	-98.9	-95.6	-92.8	-90.7	-89.9	-90.0	-91.0	-93.2	-98.8	-105.9
Power flux density at Earth’s surface (taking only free space path loss into account)	dBW/m ²	-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

[illegible]

Polarization losses	dB	3	3	3	3	3	3	3	3	3	3
Effective received power flux density	dBW/m ²	-121.6	-118.3	-115.4	-113.4	-112.6	-112.7	-113.6	-115.9	-118.4	-121.6
Recommended SAPRs power flux density	dBW/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	dBi	2	2	2	2	2	2	2	2	2	2
Rx Signal power	dBm	-98.8	-95.5	-92.6	-90.6	-89.7	-89.9	-90.8	-93.1	-98.6	-105.8
Power flux density at Earth's surface (taking only free space path loss into account)	dBW/m ²	-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 0.

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

TABLE 6
Aircraft-to-satellite (uplink) link budget example
with 5 dB scintillation losses

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

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

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

AMS(R)S from a LEO constellation using VHF aeronautical band 117.975-137 MHz is feasible for the Space to Earth link communications. Table 7 provides an example of satellite-to-aircraft link budget, taking into account all considerations discussed in previous paragraphs (mainly satellite altitude of 600 km, satellite antenna pattern and gain corresponding to different elevations, aircraft VHF antenna gain of -1 dBi except for high elevation angles, etc). In this table, the satellite power required at each aircraft elevation angle is calculated in order to close the link budget under the assumption of 5 dB scintillation losses, i.e. to obtain a 0 dB margin on the satellite to aircraft forward link, taking into account the $20 \mu\text{V/m}$ requirement expressed by ICAO, equivalent to $-120 \text{ dB(W/m}^2\text{)}$ power-flux.

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

TABLE 7

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

FORWARD (To Aircraft)	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											
	RF Power for 25 KHz channel	W	132.7	61.8	32.1	20.1	16.6	17.1	21.3	35.9	64.2	133.5
	Sat Tx gain	dBi	8	8	8	7.8	6.9	5.5	3.6	0.7	-2.2	-5.5
	Feeder loss	dB	1	1	1	1	1	1	1	1	1	1
	Satellite EIRP	dBW	28.2	24.9	22.1	19.8	18.1	16.8	15.9	15.2	14.9	14.8
	Signal Propagation											
	Free space path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
	Additional. propagation loss	dB	5	5	5	5	5	5	5	5	5	5
	Polarization losses	dB	3	3	3	3	3	3	3	3	3	3
	Effective received power flux density	dBW/m ²	-119.8	-119.8	-119.8	-119.8	-119.8	-119.8	-119.8	-119.8	-119.8	-119.8
	Recommended SAPRs power flux density	dBW/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	dB	3	3	3	3	3	3	3	3	3	3
	Rx Signal power	dBm	-98.0	-98.0	-98.0	-98.0	-98.0	-98.0	-98.0	-98.0	-101.0	-105.0

A level of satellite power is required per channel in order to meet the aircraft receiver sensitivity requirement and the different losses. Under the assumptions mentioned above, it can be noted that, as an example, a satellite power of 36 watts per 25 kHz channel is compatible with aircraft elevation angles between 20° and 70° . Following this example, it could be considered this power level as a

reference, and to establish the link budget contained in Table 8 as an example of satellite-to-aircraft link budget taken into account for studies in this report with 5 dB scintillation losses.

TABLE 8

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

FORWARD (To Aircraft)	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											
	RF Power for 25 KHz channel	W	36	36	36	36	36	36	36	36	36	36
	Sat Tx gain	dBi	8	8	8	7.8	6.9	5.5	3.6	0.7	-2.2	-5.5
	Feeder loss	dB	1	1	1	1	1	1	1	1	1	1
	Satellite EIRP	dBW	22.6	22.6	22.6	22.4	21.5	20.1	18.2	15.3	12.4	9.1
	Signal Propagation											
	Free space path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
	Additional. propagation loss	dB	5	5	5	5	5	5	5	5	5	5
	Polarization losses	dB	3	3	3	3	3	3	3	3	3	3
	Effective received power flux density	dBW/m ²	-125.5	-122.2	-119.3	-117.3	-116.4	-116.6	-117.5	-119.8	-122.3	-125.5
	Recommended SAPRs power flux density	dBW/m ²	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120
	Power flux margin	dB	-5.5	-2.2	0.7	2.7	3.6	3.4	2.5	0.2	-2.3	-5.5
	Receiver											
	Aircraft Rx Antenna Gain	dBi	-1	-1	-1	-1	-1	-1	-1	-1	-4	-8
	Feeder Losses	dBi	3	3	3	3	3	3	3	3	3	3
	Rx Signal power	dBm	-103.7	-100.3	-97.5	-95.4	-94.6	-94.7	-95.7	-98.0	-103.5	-110.7
Power flux density at the earth surface	dBW/m ²	-117.5	-114.2	-111.3	-109.3	-108.4	-108.6	-109.5	-111.8	-114.3	-117.5	

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

TABLE 9

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

FORWARD (To Aircraft)	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											
	RF Power for 25 KHz channel	W	20	20	20	20	20	20	20	20	20	20
	Sat Tx gain	dBi	8	8	8	7.8	6.9	5.5	3.6	0.7	-2.2	-5.5
	Feeder loss	dB	1	1	1	1	1	1	1	1	1	1
	Satellite EIRP	dBW	20.0	20.0	20.0	19.8	18.9	17.5	15.6	12.7	9.8	6.5

	Signal Propagation											
	Free space path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
	Additional. propagation loss	dB	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Polarization losses	dB	3	3	3	3	3	3	3	3	3	3
	Effective received power flux density	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 density	dBW/m ²	-120	-120	-120	-120	-120	-120	-120	-120	-120	-120
	Power flux margin	dB	-4.0	-0.7	2.1	4.2	5.0	4.9	3.9	1.7	-0.9	-4.0
	Receiver											
	Aircraft Rx Antenna Gain	dB _i	-1	-1	-1	-1	-1	-1	-1	-1	-4	-8
	Feeder Losses	dB _i	3	3	3	3	3	3	3	3	3	3
	Rx Signal power	dB _m	-102.2	-98.9	-96.0	-94.0	-93.2	-93.3	-94.3	-96.5	-102.0	-109.2
	Power flux density at the earth surface	dBW/m ²	-120	-116.7	-113.9	-111.8	-111.0	111.1	-112.1	-114.3	-116.9	-120.0

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

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

It is also interesting to consider an uplink link budget for the aircraft-to-satellite link, noting that this link does not introduce any new transmitting equipment. Aircraft VHF transmitter is assumed to have a power capability of 15 watts as explained in Section 0 and detailed in EUROCAE ED-92C, section 2.2.1.3.2. Typical signal parameters.

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

TABLE 10
Aircraft-to-satellite (uplink) link budget example for data (VHF data link mode 2 modulation)
with 5 dB scintillation losses

[illegible]

Rx Signal power level	dBm	-107.5	-104.1	-101.3	-99.25	-98.43	-98.54	-99.51	-101.8	-107.3	-114.5
Rx sensitivity target	dBm	-107	-107	-107	-107	-107	-107	-107	-107	-107	-107
Receiver link margin	dB	-0.5	2.9	5.7	7.8	8.6	8.5	7.5	5.2	-0.3	-7.5

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

7 Technical parameters used in the sharing and compatibility studies related to emissions in the aeronautical mobile satellite (route) service (space-to-Earth)

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

7.1.1 Spectrum mask

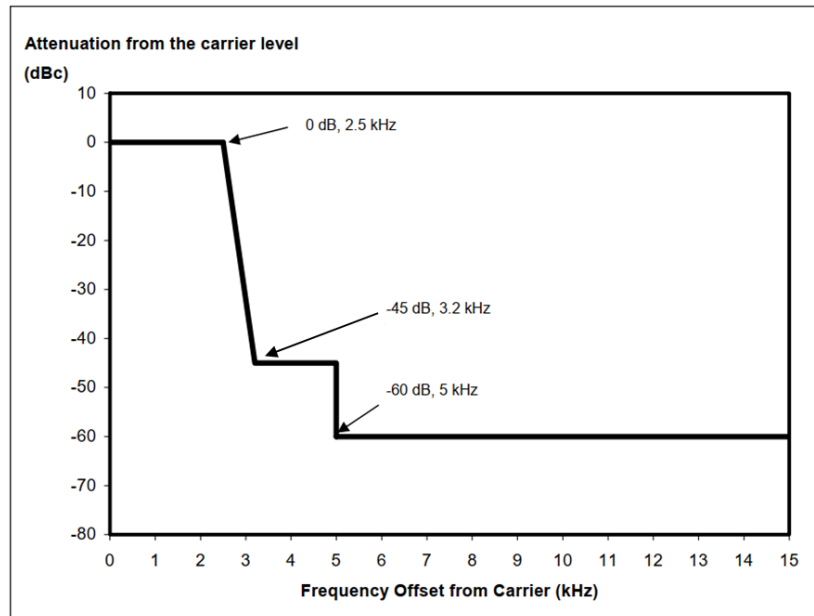
A necessary bandwidth of 5 kHz is considered for voice emission. This value is relevant worldwide, irrespective of the 25 kHz or 8.33 kHz channelization of the VHF band mentioned at the beginning of Section 4.

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

It can be noted that, according to Appendix 3 of the Radio Regulations, the minimum attenuation for AMS(R)S spurious emission is 60 dBc (“ $43 + 10 \log (P)$, or 60 dBc, whichever is less stringent”) in 4 kHz reference bandwidth. Therefore, for the spurious emission domain (i.e. for frequency offset greater than 200% = 10 kHz from the carrier centre frequency), Appendix 3 represents a regulatory requirement to follow this mask with its 60 dB roll-off.

FIGURE 9

Spectrum mask considered for voice emission



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

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

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

7.2 Characteristics of spectral emissions of systems operating in the aeronautical mobile satellite (route) service (space-to-Earth) in the frequency band 136-137 MHz

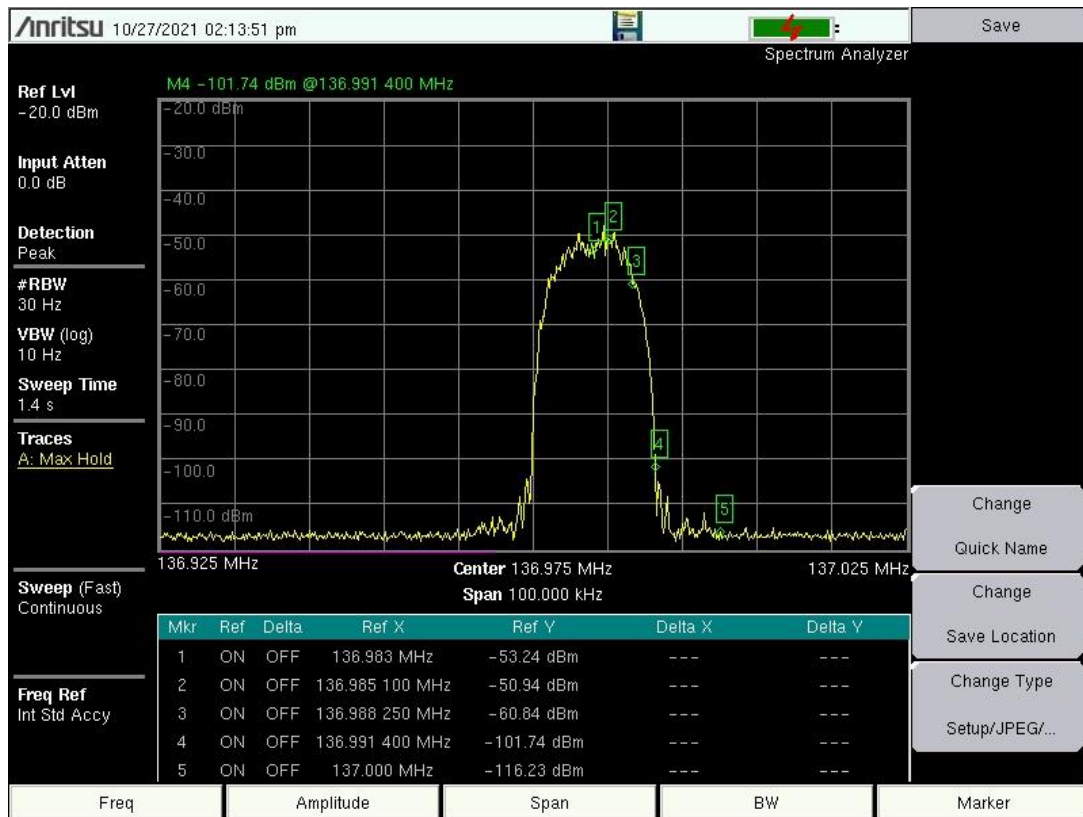
The necessary bandwidth for the VDL-2 signal (worst case) is assumed to be 14.0 kHz corresponding to a 14K0G1DE class type signal (DO-224 Signal-In-Space Minimum Aviation System Performance Standards (MASPS) For Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques.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

7.2.1 Spectrum mask

The typical spectrum mask demonstrates that the spectral roll-off has an attenuation higher than 60 dB. Figure 10 below represents the case of the Common Signalling Channel (CSC) at 136.975 MHz, with a rejection of 60 dB at a frequency separation that can accommodate even a potential worst case of +/-4 kHz frequency Doppler shift pre-compensation (-/+ 8 kHz frequency shift at receiver).

FIGURE 10

**Example of VHF data link mode 2 modulation spectral roll-off.
differential 8-phase shift keying modulation with 10,5 Ksymbols/s rate (Example of VHF Radio)**



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

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

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

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

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

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

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

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

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

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

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

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

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

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

Characteristics and protection criteria for SOS systems in the frequency band 137-138 MHz can be found in Recommendation ITU-R SA.363-5 entitled “*Space operation systems*” and in Report ITU-R SA.2426 entitled “*Technical characteristics for telemetry, tracking and command in the space operation service below 1 GHz for non-GSO satellites with short duration missions*”. According to recommends 6 of this Recommendation, the aggregate interference criteria for earth station receivers in the SOS for frequencies above 1 GHz is a maximum interference power in each frequency 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 frequency band 1 kHz wide of −164 dBW at the receiver input for more than 1% of the time each day is to be considered. Recommendation ITU-R SA.1743, recommends 2.1 and 2.2, indicates that adjacent band interference from AMS(R)S belongs to “category 3”, for which an apportionment of 1% of the total allowable degradation should be applied. There are two

understandings provided in this report on adjacent-band apportionment of the total allowable degradation.

One understanding assumes uncorrelated interference events distributed over time and, considering that the SOS aggregate criteria in Recommendation ITU-R SA.363-5 is short-term, applies the 1% apportionment to AMS(R)S on a percentage of time basis. This results in the following sharing criteria for AMS(R)S:

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

Another understanding assumes constant interference and possible simultaneous arrival from different sources. Therefore the 1% apportionment to AMS(R)S is applied on a power level basis. This results in the following sharing criteria for AMS(R)S:

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

NOTE : subject to the result of pending discussions within ITU-R on Recommendation ITU-R SA.1743, this Report might be revised in the future.

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

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

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

Protection criteria for SRS systems in the frequency band 137-138 MHz can be found in Recommendation ITU-R SA.609-2 entitled “*Protection criteria for radiocommunication links for manned and unmanned near-Earth research satellites*”. According to *recommends* 1.1 of this Recommendation, the protection criteria for earth station receivers in the SRS for frequencies in the 1-20 GHz frequency range is -216 dB(W/Hz). For frequencies below 1 GHz, the permissible interference may be increased at the rate of 20 dB per decreasing frequency decade. In our case around 137 MHz, a protection of -196 dB(W/Hz) is therefore to be considered. According to *recommends* 1.2 of this Recommendation, calculation of interference that may result from atmospheric and precipitation effects should be based on weather statistics for 0.001% of the time for manned missions and for 0.1% of the time for unmanned missions. Similarly, to SOS, Recommendation ITU-R SA.1743 applies and results in an apportionment of 1% of the total allowable degradation to be applied to AMS(R)S. There are two understandings provided in this report on adjacent-band apportionment of the total allowable degradation.

One understanding assumes uncorrelated interference events distributed over time and, considering that the SRS criteria in Recommendation ITU-R SA.609-2 is short-term, applies the 1% apportionment to AMS(R)S on a percentage of time basis. This results in the following sharing criteria for AMS(R)S:

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

Another understanding assumes constant interference and possible simultaneous arrival from different sources. Therefore the 1% apportionment to AMS(R)S is applied on a power level basis. This results in the following sharing criteria for AMS(R)S:

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

NOTE : subject to the result of pending discussions within ITU-R on Recommendation ITU-R SA.1743, this Report might be revised in the future.

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

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

Aggregate protection criteria for MetSat systems in the frequency band 137-138 MHz are given in Recommendation ITU-R SA.1026-5 (*“Aggregate interference criteria for space-to-Earth data transmission systems operating in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit”*). In addition, MetSat single-entry protection criteria are derived from MetSat aggregate criteria, using Recommendation ITU-R SA.1023-0 methodology for apportionment of aggregate interference criteria between space-to-Earth and Earth-to-space links, as well as multiple sources of interference. These can then be found in Recommendation ITU-R SA.1027-6 entitled *“Sharing criteria for space-to-Earth data transmission systems in the Earth exploration-satellite and meteorological-satellite services using satellites in low-Earth orbit”*.

Recommends 2 of Recommendation ITU-R SA.1027-6 indicates that the assumptions under which these single entry criteria are derived from Recommendation ITU-R SA.1026-5 should be periodically revisited in order to determine whether the typical interference environment and consequential sharing criteria should be revisited. The ITU expert group for the meteorological-satellite service was therefore consulted in the particular framework of the need for protection criteria in relation to an adjacent-band services, and provided the following values to consider specifically to this context:

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

Frequency band (MHz)	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than p% of the time
137-138	–151 dBW per 150 kHz	–137 dBW per 150 kHz ⁽¹⁾ p = 0.0013

According to Annex 1/Section 2 of Recommendation ITU-R SA.1027-6, MetSat earth stations use either low antenna gains of 2 dBi or higher antenna gains of 10 dBi. For the latter, the ITU expert group for the meteorological-satellite service indicated that the antenna pattern given in RR Appendix 8 could be considered.

7.3.5 Summary of protection criteria considered for MSS, MetSat, SOS and SRS (space-to-Earth) in the frequency band 137-138 MHz

As detailed in sections 7.3.2 and 7.3.3 above, there are two understandings on adjacent-band apportionment of the total allowable degradation to be used for the protection of SOS and SRS operating in the frequency band 137-138 MHz from adjacent band emissions below 137 MHz : One understanding distributes the arrival of the interference over time, whereas another understanding assumes simultaneous arrival of the interference.

Though they correspond to widely different applications, with different requirements in terms of quality of service, it is of interest to make a summary between the protection criteria associated to MSS, MetSat, SOS and SRS.

In order to compare power spectral density levels associated with the long term and short-term protection criteria of these services, these levels are translated into the same bandwidth of 1 kHz, as shown in the table below.

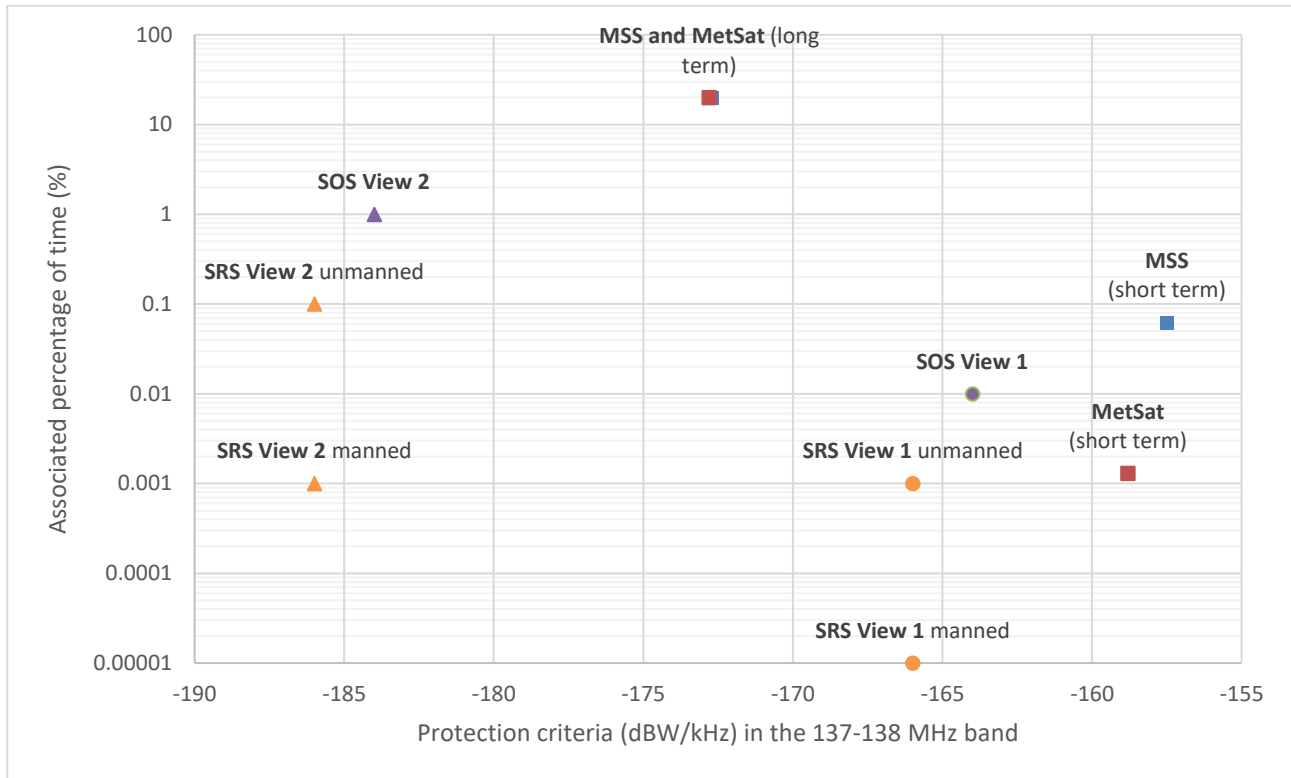
TABLE 11
Comparison of the different understandings on apportionment of protection criteria for SRS and SOS

		MSS	MetSat	SOS	SRS
Reference bandwidth for protection criteria (kHz)		19.2	150	1	0.001
Long-term protection level at receiver input	in reference bandwidth (dBW)	-159.9	-151	N/A	N/A
	in 1 kHz (dBW)	-172.7	-172.8	N/A	N/A
Short-term protection level at receiver input	in reference bandwidth (dBW)	-144.7	-137	-164	-196
	in 1 kHz (dBW)	-157.5	-158.8	View 1: -164 View 2: -184	View 1: -166 View 2: -186
	associated % of time (%)	0.0625	0.0013	View 1: 0.01 View 2: 1	View 1: 10^{-3} ; 10^{-5} View 2: 10^{-1} ; 10^{-3}

These values and associated percentages of time are illustrated in the figure below.

FIGURE 11

Comparison of the different understandings on apportionment of protection criteria for SRS and SOS



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

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

- Firstly to consider the frequency band 117.975-136 MHz for the new AMS(R)S allocation, noting that the 1 MHz guard band (136-137 MHz) will ease compatibility with non-ICAO services above 137 MHz. This range is considered in this section 8 for AMS(R)S voice application. According to ICAO SARPs, it is possible to also establish data links using DSB-AM modulation, with the same performance requirement as voice, hence identical RF parameters and link budgets. In terms of in-band and adjacent band sharing within 117.975-136 MHz, the conclusions are therefore identical for voice and DSB-AM data applications.
- Secondly, to consider the sub-band 136-137 MHz for the new AMS(R)S allocation, which sharing and compatibility analysis are provided in Chapter 9.

8.1 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 space stations, 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.

Terrestrial out of band and spurious limits exists to ensure that adjacent and near adjacent channels can coexist when a distant wanted channel is adjacent in the band to an unwanted channel and the unwanted transmitter is substantially nearer to the victim receiver than the wanted transmitter.

AMS(R)S signals will always be subject to a spreading loss in the range of 130-135 dB which exceeds the spreading loss of operation AM(R)S signals by at least 10-15 dB.

Therefore, terrestrial equipment standards intended to minimise the probability of adjacent and near adjacent channel interference are not needed for AMS(R)S equipment installed on a satellite as this form of interference will not occur as a result of an AMS(R)S signal.

The detailed ITU regulatory framework associated with AMS(R)S is outside the scope of this technical report. Article 9 coordination procedures may complement the ICAO framework in order to ensure full compatibility between AM(R)S and AMS(R)S systems.

A coordination process as defined in RR Article 9 could be considered for a new AMS(R)S allocation in all or part of the frequency band 117.975-137 MHz. An example of coordination threshold that could be used for coordination between AMS(R)S transmitting space stations and AM(R)S under RR No. 9.11A is provided in Table 12:

TABLE 12
Coordination Threshold to protect AM(R)S in all of part of the frequency band 117.975-137 MHz

	Units	Aircraft
$k = 1.38064852 \times 10^{-23}$ (J/K)	dBW/K/Hz	-228.60
Standard room temperature, $T_0 = 290$ K	dB-K	24.62
Rx noise figure, NF,	dB	6
Noise density, $N_0 = kT_0 + NF$	dB(W/Hz)	-197.98
Protection criteria, I/N	dB	-10
Max RFI power density at receiver input	dBW/Hz	-207.98
Max RFI power density at receiver input	dBW/4 kHz	-172
Feeder loss	dB	2
Receiver antenna gain	dB _i	-1
dBW to dBW/m ² (RR IV Rec. ITU-R P.525 section 2.3: $10 \log(4\pi/\lambda^2)$)	dB	4.18
Polarization mismatch loss	dB	3
Max AMS(R)S power flux-density at antenna input	dB(W/(m ² · 4 kHz))	-161.8

An important assumption in the application of the coordination threshold is that it is applied at the antenna input of an AM(R)S receiver onboard an aircraft operating at the edge of a terrestrial service volume, as defined by 250 nmi in range and at 40,000 feet above mean sea level.

[Editor's note : other ways to address the threshold for coordination are under consideration. In particular, characteristics in Table 12 are still under consideration.]

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

As indicated in Section 0, the frequency 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 frequency band is not expected to significantly impact this mechanism. Provided AM(OR)S assignments are known, they could be taken into account by ICAO when introducing AMS(R)S in its frequency planning exercise.

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

AM(OR)S systems operate in channels within national assignments, which themselves are managed by ICAO, regional organizations and national regulators. Compatibility between AMS(R)S and AM(OR)S assignments should be resolved through their conventional frequency planning exercise. It is anticipated that, in the event that a new allocation is made to AMS(R)S in this frequency band, the corresponding responsible organization will develop a corresponding channel plan for use of AMS(R)S frequencies to ensure compatibility between the satellite and terrestrial uses of the frequency band. By protecting existing terrestrial assignments, this plan should protect any assignments to AM(OR)S.

The detailed ITU regulatory framework associated with AMS(R)S is outside the scope of this technical report. Article 9 coordination procedures may also provide a complementary mechanism to ensure full compatibility between AM(OR)S and AMS(R)S systems.

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

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.

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

8.4.1 General consideration

It is to be noted that, although the possible primary new AMS(R)S allocation within the frequency 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.

8.4.2 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

Characteristics and protection criteria for MSS systems in the range 137-138 MHz used in this compatibility study are given in section 0.

Table 13 below is an assessment of the maximum power level per 19.2 kHz above 137 MHz at the MSS receiver input resulting from AMS(R)S emissions in 117.975-136 MHz. It takes into account:

- The reference downlink AMS(R)S link budget in Table 4, with only 1 dB propagation loss on the path towards the MSS earth station (instead of 5 dB towards aircraft).
- The 5 kHz necessary bandwidth considered for voice emission in section 0.
- The minimum attenuation of 60 dB specified in section 0 for the level of spurious emissions above 137 MHz resulting from AMS(R)S satellite in-band emissions below 136 MHz.
- MSS long-term protection criteria from section 0, as it is more stringent than the short-term criteria in the frame of such a static analysis.

TABLE 13

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

Long-term protection of MSS subscriber 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	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	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 path loss	dB	144.2	140.8	138.0	135.7	134.0	132.7	131.8	131.2	130.8	130.7
	Additional. propagation loss	dB	1	1	1	1	1	1	1	1	1	1
	Polarization losses	dB	0	0	0	0	0	0	0	0	0	0
	Receiver											
	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
	Minimum attenuation above 137 MHz	dB	60	60	60	60	60	60	60	60	60	60
	Rx signal power level in 19.2 kHz	dBW	-182.4	-179	-176.2	-174.1	-173.3	-173.4	-174.4	-176.7	-179.2	-182.4
	MSS long-term protection requirement	dBW	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9
	Margin	dB	22.5	19.1	16.3	14.2	13.4	13.5	14.5	16.8	19.3	22.5

The 13.4 dB minimum margin obtained through Table 13 is to be lowered:

- by 3 dB in order to account for two voice carriers being possibly transmitted simultaneously in the 25 kHz channel under consideration, as indicated in section 7.1.4, and received in the 19.2 kHz MSS receiver.
- by an additional 3 dB factor to account for two active satellites possibly visible from the MSS earth station (see section 0).

Even with these additional factors, the margin remains positive. This shows that, based on assumptions considered in studies, protection criteria for MSS above 137 MHz is met from AMS(R)S satellite emissions in 117.975-136 MHz.

8.4.3 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

Static study

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

Table 14 below is an assessment of the maximum power level per 1 kHz above 137 MHz at the SOS receiver input resulting from AMS(R)S single space station with single carrier emissions in 117.975-136 MHz. It takes into account:

- The worst case assumption of the SOS antenna pointing towards the AMS(R)S satellite.
- The reference downlink AMS(R)S link budget in Table 4, with only 1 dB propagation loss on the path towards the SOS earth station (instead of 5 dB towards aircraft).
- The 5 kHz necessary bandwidth considered for voice emission in section 0.
- The attenuation of 60 dB specified in section 0 for the level of spurious 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 1 kHz at space operation service receiver input of the spurious emissions above 137 MHz resulting from aeronautical mobile satellite (route) service satellite emissions in 117.975-136 MHz

[illegible]

Rx signal power level per 1 kHz	dBW	-113.8	-110.5	-107.7	-105.6	-104.8	-104.9	-105.9	-108.2	-110.7	-113.9
Minimum attenuation above 137 MHz	dB	60	60	60	60	60	60	60	60	60	60
Maximum power level per 1 kHz at SOS receiver input	dBW	-173.8	-170.5	-167.7	-165.6	-164.8	-164.9	-165.9	-168.2	-170.7	-173.9
SOS protection criteria: max. interference power in 1 kHz	dBW	-164	-164	-164	-164	-164	-164	-164	-164	-164	-164
Margin	dB	9.8	6.5	3.7	1.6	0.8	0.9	1.9	4.2	6.7	9.9

There are two understandings provided in this report on adjacent-band apportionment of the protection criteria. One understanding assumes uncorrelated interference events distributed over time. Another understanding assumes constant interference and possible simultaneous arrival from different sources. The summaries of the results of the study under each understanding are described hereafter.

The minimum margin obtained through Table 14 is 0.8 dB under the first understanding, when the protection criteria for SOS is assumed to be -164 dBW for more than 0.01% of the time from section 0. This margin is to be lowered by a factor of 3 dB maximum to account for two active satellites possibly visible from the SOS earth station. As the resulting margin would become negative, it is interesting to consider dynamic studies, which results are more accurate as they take into account the antenna pattern of the SOS earth station, and the fact that his earth station tracks its own satellite.

Dynamic studies

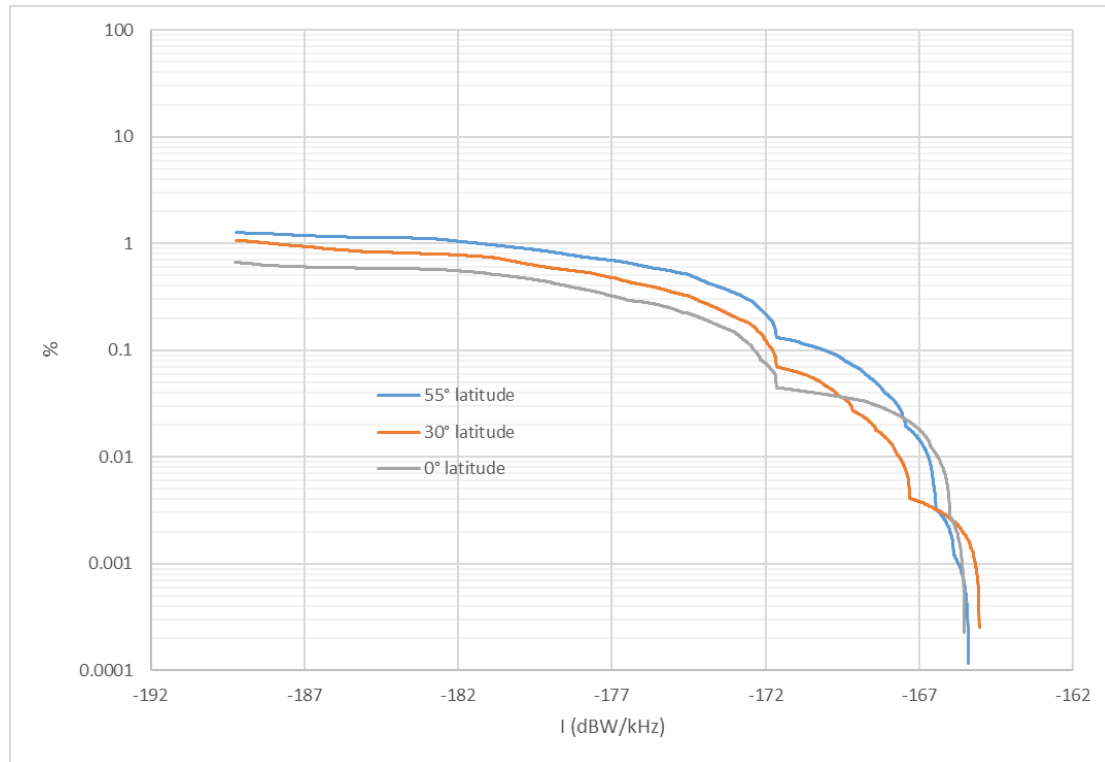
Based on information provided by the ITU expert group responsible for the space operation service, the following parameters have been considered for the SOS system:

- 1 satellite at 835 km altitude in a sun-synchronous orbit with 98.85° inclination;
- 12 dBi receiving earth station with an antenna pattern compliant with Recommendation ITU-R F.699-8, located at 0°, 30° and 55° latitude. The earth station tracks the satellite with a minimum elevation angle of 5°.

With parameters for the complete AMS(R)S constellation taken from section 6.1, a simulation was run for 365 days with time-steps of 1 second. The power level received at the SOS receiving earth station was assessed, respectively with only one AMS(R)S satellite always active within the 20°-70° operational elevation range, and with possibly two AMS(R)S satellites always active in this range.

FIGURE 12

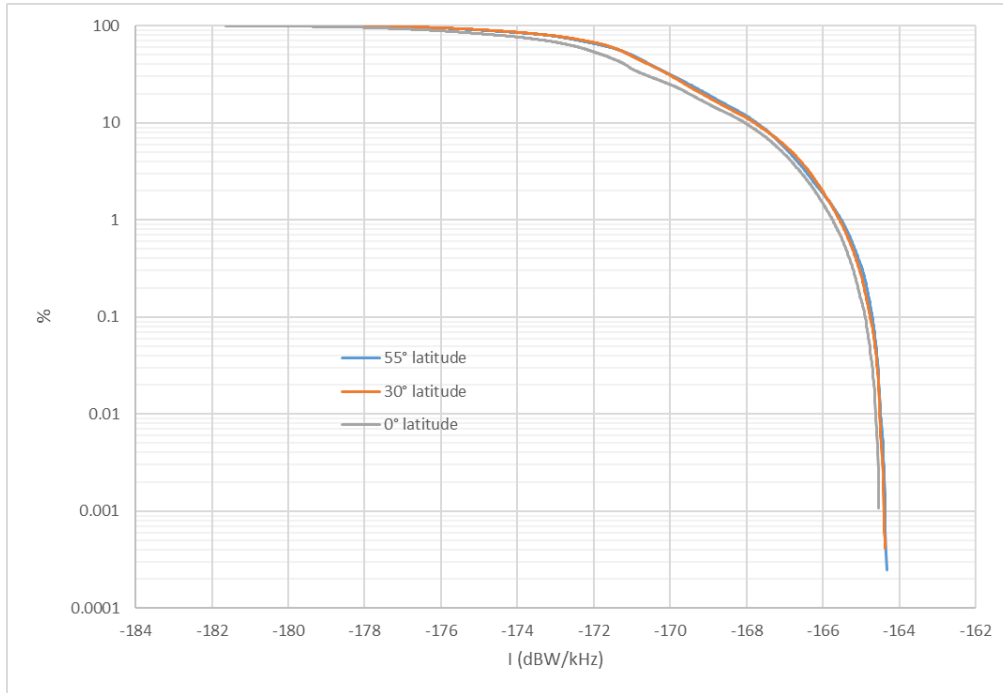
Dynamic study with only one satellite operating in the aeronautical mobile satellite (route) service always active within the 20°-70° operational elevation range. Assessment of the maximum power level per 1 kHz at receiver input operating in the space operations service for the spurious emissions above 137 MHz resulting from emissions of stations operating in the aeronautical mobile satellite (route) service in 117.975-136 MHz



This study with only one active satellite within the 20°-70° operational elevation range provides a maximum of -165.0 dBW/kHz for the spurious emission power level at the receiver input of systems operating in the space operation service. This compares very well with the level of -164.8 dBW/kHz which was determined in the table above on the basis of worst case assumptions.

FIGURE 13

Dynamic study with two AMS(R)S satellites maximum always active within the 20°-70° operational elevation range Assessment of the maximum aggregate power level per 1 kHz at SOS receiver input for the spurious emissions above 137 MHz resulting from AMS(R)S emissions in 117.975-136 MHz



This study with up to two active satellites within the 20°-70° operational elevation range provides a maximum of -164.3 dBW/kHz for the emission power level at SOS receiver input. Hence, even when considering the aggregate effect of two active satellites, the margin remains positive with respect to the protection criteria of -164 dBW/kHz.

This shows that, based on assumptions considered in studies, protection criteria for SOS above 137 MHz is met from AMS(R)S satellite emissions in 117.975-136 MHz.

Another understanding of the protection criteria is also considered as follows. The minimum margin obtained through Table 14 is -19.2 dB under this understanding, when the protection criteria for SOS is assumed to be -184 dBW for more than 1% of the time from section 0. This margin is to be lowered by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the SOS earth station.

This shows that, based on assumptions considered in studies, protection criteria for SOS above 137 MHz could not be met from AMS(R)S satellite emissions in 117.975-136 MHz, unless there is a limit, yet to be defined, to the level of AMS(R)S spurious emissions.

It is also possible to define maximum pfd limit at Earth surface as alternative to spurious emission limit. Considering protection criterion “in each frequency band 1 kHz wide above 137 MHz, the power level of AMS(R)S unwanted emissions must not exceed -184 dBW at the SOS receiver input for more than 1% of the time each day” and possible isotropic SOS antenna maximum interference would be -184 dBW. Based on ITU-R P.525 it is possible to conclude that pfd limit could be calculated as:

$$S = I_{max} + 20\log_{10}f + 21.4$$

Which leads to maximum pfd value of -179.93 dB ($W/(m^2 \cdot kHz)$) at Earth surface for the 1% of time. This limit could be used as maximum aggregate pfd value for all AMS(R)S systems combined. For higher SOS antenna gains this value would be lowered by relevant gain value.

8.4.4 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

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

Table 15 below is an assessment of the maximum power level per Hz above 137 MHz at the SRS receiver input resulting from AMS(R)S single space station with single carrier emissions in 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 the ITU-R expert group responsible for this service.
- The reference downlink AMS(R)S link budget in Table 4, with only 1 dB propagation loss on the path towards the SRS earth station (instead of 5 dB towards aircraft).
- The 5 kHz necessary bandwidth considered for voice emission in section 0.
- The attenuation of 60 dB specified in section 0 for the level of spurious emissions above 137 MHz resulting from AMS(R)S satellite in-band emissions below 136 MHz.

TABLE 15

Assessment of the maximum power level per Hz at space research service receiver input of the spurious 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	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	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 path loss	dB	144.2	140.8	138.0	135.7	134.0	132.7	131.8	131.2	130.8	130.7
	Additional. propagation loss	dB	1	1	1	1	1	1	1	1	1	1
	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	-152.6	-149.3	-146.5	-144.4	-143.6	-143.7	-144.7	-147	-149.5	-152.7
	Minimum attenuation above 137 MHz	dB	60	60	60	60	60	60	60	60	60	60
	Maximum power level per 1 Hz at SRS receiver input	dBW	-212.6	-209.3	-206.5	-204.4	-203.6	-203.7	-204.7	-207	-209.5	-212.7
	SRS protection criteria: max. interference power in 1 Hz	dBW	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196
	Margin	dB	16.6	13.3	10.5	8.4	7.6	7.7	8.7	11.0	13.5	16.7

There are two understandings provided in this report on adjacent-band apportionment of the protection criteria. One understanding assumes uncorrelated interference events distributed over time.

Another understanding assumes constant interference and possible simultaneous arrival from different sources. The summaries of the results of the study under each understanding are described hereafter.

The minimum margin obtained through Table 15 is 7.6 dB under the first understanding, when the protection criteria for SRS is assumed to be -196 dBW for more than 10^{-5} % of the time for manned missions and for more than 10^{-3} % of time for unmanned missions from section 0. This margin is to be lowered by a factor of 3 dB to account for two active satellites possibly visible from the SRS earth station (see section 6.1). Even with this additional factor, the margin remains positive.

This shows that, based on assumptions considered in studies, protection criteria for SRS above 137 MHz is met from AMS(R)S satellite emissions in 117.975-136 MHz.

Another understanding of the protection criteria is also considered as follows. The minimum margin obtained through Table 15 is -12.4 dB under this understanding, when the protection criteria for SRS is assumed to be -216 dBW for more than 10^{-3} % of the time for manned missions and for more than 10^{-1} % of time for unmanned missions from section 0. This margin is to be lowered by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the SRS earth station.

This shows that, based on assumptions considered in studies, protection criteria for SRS above 137 MHz could not be met from AMS(R)S satellite emissions in 117.975-136 MHz, unless there is a limit, yet to be defined, to the level of AMS(R)S spurious emissions.

It is also possible to define maximum pfd limit at Earth surface as alternative to spurious emission limit. Considering protection criterion “Protection of SRS: in each frequency band 1 Hz wide above 137 MHz, the power level of AMS(R)S unwanted emissions must not exceed -216 dBW at the SRS receiver input for more than 10^{-3} % of the time for manned missions and for more than 10^{-1} % of time for unmanned missions” and possible isotropic SRS antenna, this leads to maximum tolerable interference of -216 dBW. Based on ITU-R P.525 it is possible to conclude that pfd limit could be calculated as:

$$S = I_{max} + 20 \log_{10} f + 21.4$$

Which leads to maximum pfd value of -211.93 dB (W/(m²·Hz)) at Earth surface for 10^{-3} % of the time. This limit could be used as maximum aggregate pfd value for all AMS(R)S systems combined. For higher SRS antenna gains this value would be lowered by relevant gain value.

8.4.5 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

Static study

Characteristics and protection criteria for meteorological satellite systems in the frequency band 137-138 MHz used in this compatibility study are given in section 0.

Table 16 below is an assessment of the maximum power level per 150 kHz above 137 MHz at the MetSat receiver input resulting from AMS(R)S single space station with single carrier emissions in 117.975-136 MHz. It takes into account:

- The worst case assumption of the MetSat antenna pointing towards the AMS(R)S satellite.
- The value of 10 dBi for the peak antenna gain of MetSat earth stations at 137 MHz. This represents a worst case from the sharing point of view under this static analysis, the alternative being the lower 2 dBi antenna gain.

- 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 60 dB specified in section 0 for the level of spurious emissions above 137 MHz resulting from AMS(R)S satellite in-band emissions below 136 MHz.
- MetSat long-term protection criteria from section 0, as it is more stringent than the short-term criteria in the frame of such a static analysis.
- The worst case assumption that up to 6 channels of 25 kHz may be contained in the 150 kHz bandwidth of MetSat receiving earth station.

TABLE 16

Assessment of the maximum power level per 150 kHz at MetSat receiver input (with high antenna gain antenna) of the spurious 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	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	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 path loss	dB	144.2	140.8	138.0	135.7	134.0	132.7	131.8	131.2	130.8	130.7
	Additional, propagation loss	dB	1	1	1	1	1	1	1	1	1	1
	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 above 137 MHz	dB	60	60	60	60	60	60	60	60	60	60
	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	-151	-151	-151	-151	-151	-151	-151	-151	-151	-151
	Margin	dB	10.1	6.8	3.9	1.9	1.0	1.2	2.1	4.4	6.9	10.1

The 1 dB minimum margin obtained through Table 16 is to be lowered:

- by 3 dB in order to account for two voice carriers being possibly transmitted simultaneously in the 25 kHz channel under consideration, as indicated in section 7.1.2.
- by a factor of 3 dB maximum to account for two active satellites possibly visible from the MetSat earth station.

As the resulting margin would become negative, it is interesting to consider dynamic studies, which results are more accurate as they take into account the antenna pattern of the MetSat earth station, and the fact that his earth station tracks its own satellite. Furthermore, dynamic studies enable the consideration of the percentages of time associated with protection criteria.

Dynamic studies

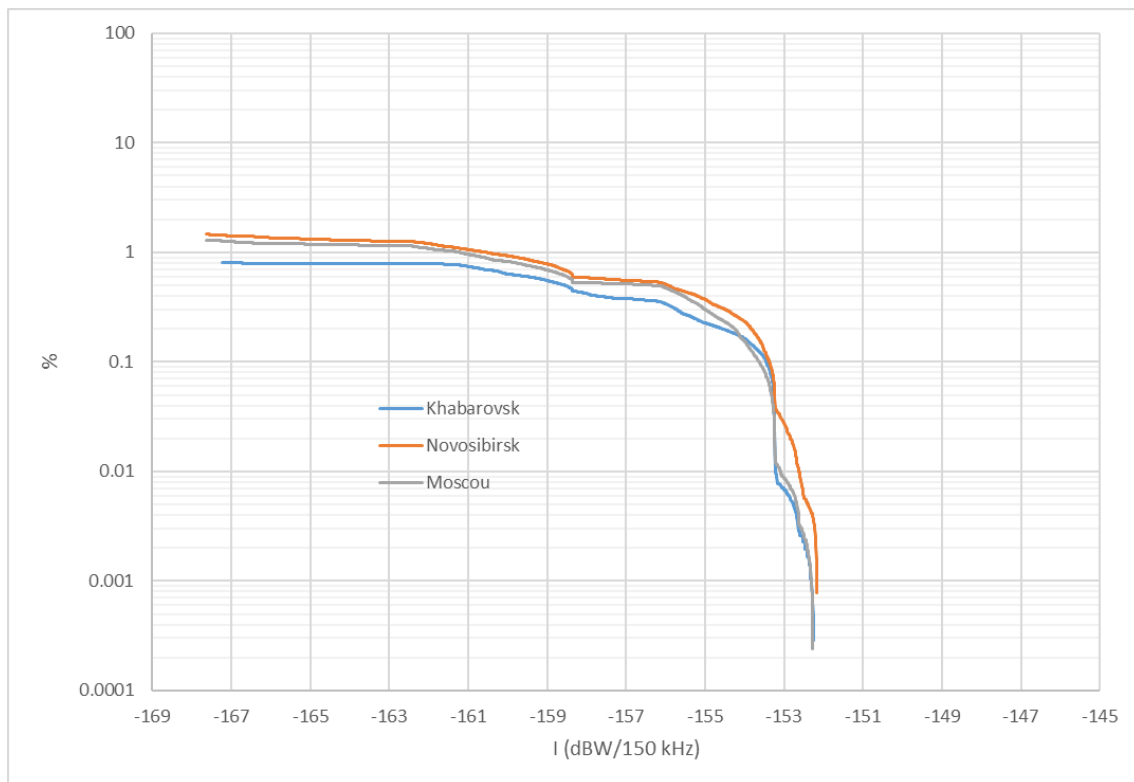
Based on information provided by the ITU expert group responsible for the meteorological-satellite service, the following parameters corresponding to the METEOR-3M system have been considered for the MetSat system:

- 2 equidistant satellites at 835 km altitude with 98.85° inclination;
- 10 dBi receiving earth stations with an antenna pattern compliant with Appendix 8, located in Moscow, Novosibirsk and Khabarovsk. Earth stations track satellites with a minimum elevation angle of 25° as mentioned in Recommendation ITU-R SA.1027.

With parameters for the complete AMS(R)S constellation taken from section 0, a simulation was run for 365 days with time-steps of 1 second. The power level received at the MetSat receiving earth stations was assessed, respectively with only one AMS(R)S satellite always active within the 20° - 70° operational elevation range, and with possibly two AMS(R)S satellites always active in this range.

FIGURE 14

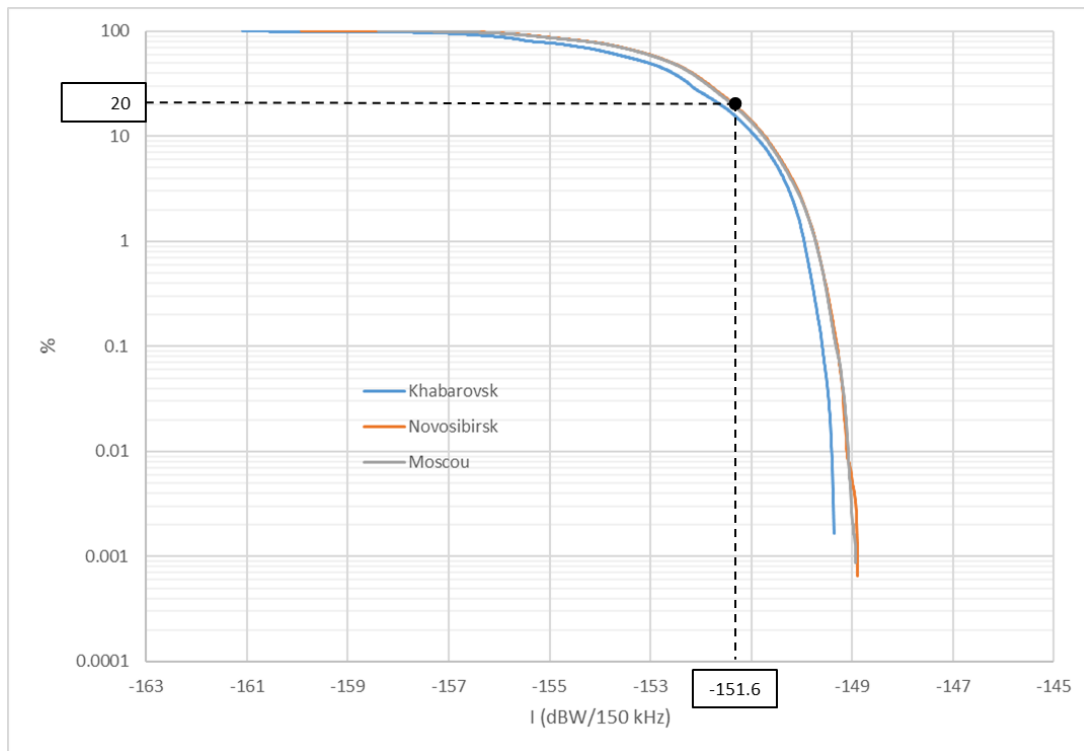
Dynamic study with only one AMS(R)S satellite always active within the 20° - 70° operational elevation range
Assessment of the maximum power level per 150 kHz at MetSat receiver input for the spurious emissions above 137 MHz resulting from AMS(R)S emissions in 117.975-136 MHz



This study with only one active satellite within the 20° - 70° operational elevation range provides a maximum of -152.2 dB(W/150 kHz) for the spurious emission power level at MetSat receiver input. This compares very well with the level of -152 dB(W/150 kHz) which was determined in the table above on the basis of worst case assumptions. Here both the long-term criteria (-151 dB(W/150 kHz), 20% of time possible exceedance) and the short-term criteria (-137 dB(W/150 kHz), 0.0013% of time possible exceedance) are met.

FIGURE 15

Dynamic study with two AMS(R)S satellites maximum always active within the 20°-70° operational elevation range Assessment of the maximum aggregate power level per 150 kHz at MetSat receiver input for the spurious emissions above 137 MHz resulting from AMS(R)S emissions in 117.975-136 MHz



This study with up to two active satellites within the 20°-70° operational elevation range provides the following outcome:

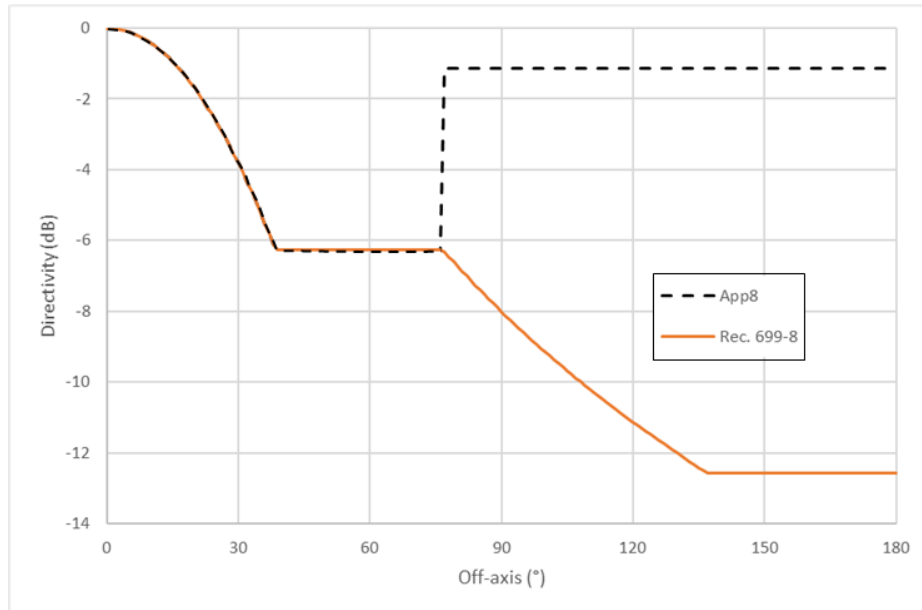
- the maximum emission power level at MetSat receiver input is -148.9 dB(W/150 kHz). This value is to be compared with the short term criteria -137 dB(W/150 kHz).
- the maximum emission power level at MetSat receiver input exceeded not more than 20% of time is -151.6 dB(W/150 kHz). This value is to be compared with the long term criteria -151 dB(W/150 kHz).

This shows that the meeting the long term criteria is the driving element. The apparent 0.6 dB margin is to be lowered by 3 dB in order to account for two voice carriers being possibly transmitted simultaneously in the 25 kHz channels under consideration, as indicated in section 0. This results in a negative margin of -2.6 dB.

It is therefore interesting to investigate the RR Appendix 8 antenna pattern associated with the 10 dBi MetSat earth station. Figure 16 below shows that, according to this pattern, the gain for off-axis angles greater than 70° rises at a level close to the maximum gain, which is not physically possible. This obviously has a relatively strong impact on the result of dynamic studies, and it is therefore interesting to reproduce these studies with the consideration of an alternative pattern. The pattern contained in Recommendation ITU-R F.699-8, considered under section 0 for the 12 dBi SOS earth station, provides a more realistic alternative, as shown in the comparison provided in Figure 16.

FIGURE 16

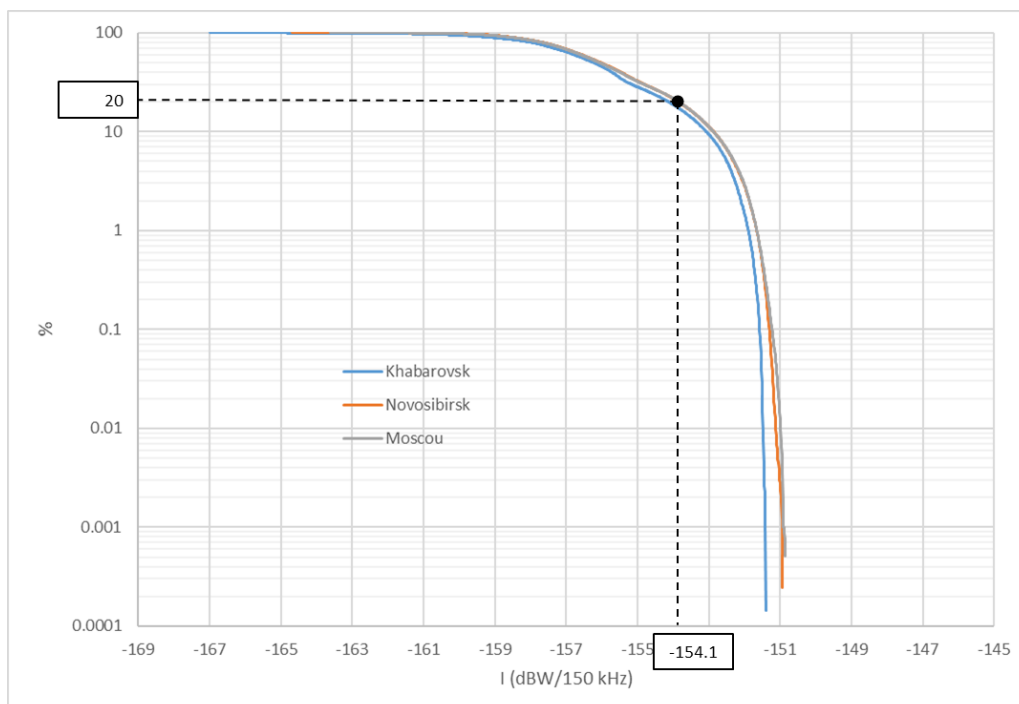
Comparison of the off-axis patterns for the 10 dBi MetSat earth station obtained with RR Appendix 8 and with Recommendation ITU-R F.699-8



With the consideration of the Recommendation ITU-R F.699-8 pattern for the 10 dBi MetSat earth station, dynamic studies with two AMS(R)S satellites maximum always active provide the following results.

FIGURE 17

Dynamic study with two AMS(R)S satellites maximum always active within the 20°-70° operational elevation range, with Recommendation ITU-R F.699-8 pattern for the MetSat earth station Assessment of the maximum aggregate power level per 150 kHz at MetSat receiver input for the spurious emissions above 137 MHz resulting from AMS(R)S emissions in 117.975-136 MHz



With the consideration of this more realistic antenna pattern, the maximum emission power level at MetSat receiver input exceeded not more than 20% of time is now -154.1 dB(W/150 kHz).

This value is to be lowered by 3 dB in order to account for two voice carriers being possibly transmitted simultaneously in the 25 kHz channels under consideration, as indicated in section 0, resulting in the level of -151.1 dB(W/150 kHz), to be compared with the long term criteria -151 dB(W/150 kHz).

The margin of 0.1 dB obtained through dynamic studies with the consideration of a realistic pattern for the 10 dBi earth station shows that, based on assumptions considered in studies, protection criteria for MetSat above 137 MHz is met from AMS(R)S satellite emissions in 117.975-136 MHz. It should be noted that such low margin highly depends on number of active satellites and requires proper emission control to ensure compatibility with MetSat.

Alternative approach study

It is also possible to define maximum pfd limit at Earth surface as alternative to spurious emission limit. Considering protection criteria “ -151 dBW per 150 kHz and -137 dBW per 150 kHz” and possible isotropic MetSat antenna maximum interference would be -151 dBW and -137 dBW respectively. Based on ITU-R P.525 it is possible to conclude that pfd limit could be calculated as:

$$S = I_{max} + 20\log_{10}f + 21.4$$

Which leads to maximum pfd values of -146.93 dB (W/(m²·150kHz)) at Earth surface for 20% of the time and -132.93 dB (W/(m²·150kHz)) at Earth surface for 0.0013% of the time. This limit could be used as maximum aggregate pfd value for all AMS(R)S systems combined. For higher MetSat antenna gains this value would be lowered by relevant gain value.

8.4.6 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 dB(W/m²) in a reference bandwidth of 2.95 MHz for the protection of radio astronomy in the frequency 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 frequency 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 Report ITU-R 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.

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

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

- Protection of in-band systems operating under AM(R)S and AM(OR)S, and of adjacent band systems below 117.975 MHz under ARNS would be resolved through conventional frequency planning exercise, involving the relevant aeronautical authorities including ICAO, and assigning frequencies to the satellite system over interested regions in a manner that ensures compatibility between ground and satellite facilities.
- Protection criteria for adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth) and Meteorological satellite service (space-to-Earth) is met with a 1 MHz guard band (136-137 MHz) and RR Appendix 3 limits for AMS(R)S spurious emissions falling above 137 MHz, under the assumptions considered in studies. Different assumptions on AMS(R)S systems may lead to different conclusions.
- Regarding protection of adjacent-band systems operating above 137 MHz in the Space operation service (space-to-Earth) and Space research service (space-to-Earth):
 - When AMS(R)S spurious emissions is considered as uncorrelated interference events distributed over time, protection is also met with a 1 MHz guard band (136-137 MHz) and RR Appendix 3 limits for AMS(R)S spurious emissions falling above 137 MHz, under the assumptions considered in studies relative to the maximum number of co-frequency satellites seen from any point on the Earth.
 - When AMS(R)S spurious emissions is considered as constant interference events possibly existing simultaneously with other sources of interference, protection criteria could not be met, unless there is a limit, yet to be defined, to the level of AMS(R)S spurious emissions.

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

The sharing and compatibility context is already explained in section 8. However, one significant difference with respect to services to be protected above 137 MHz is that they are now in an immediately adjacent band, therefore the AMS(R)S unwanted emissions in the upper last channel (corresponding to the VDL mode 2 common signalling channel centred in 136.975 MHz) are in the out-of-band domain.

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

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

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

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

9.3 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 8.3. Considerations developed in this section for AMS(R)S voice application in 117.975-136 MHz are also relevant for AMS(R)S VDL mode 2 application in 136-137 MHz.

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

9.4.1 General consideration

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

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

Characteristics and protection criteria for MSS systems in the range 137-138 MHz used in this compatibility study are given in section 0.

Table 17 below provides an assessment of the received power at subscriber terminals in the mobile satellite service from unwanted emission levels above 137 MHz from systems operating in the aeronautical mobile satellite (route) service in the frequency band 136-137 MHz, taking into account:

- The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the MSS earth station (instead of 5 dB towards aircraft).
- The 14 kHz necessary bandwidth considered for VDL Mode 2 emission in section 7.2.
- AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2.2) is 60 dB.
- MSS long-term protection criteria from section 0, as it is more stringent than the short-term criteria in the frame of such a static analysis.

TABLE 17

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

Long-term protection of MSS subscriber receiver	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											

RF Power for 25 KHz channel	W	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
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	22.6	22.6	22.6	22.4	21.5	20.1	18.2	15.3	12.4	9.1
Signal Propagation											
Free space path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
Additional. propagation loss	dB	1	1	1	1	1	1	1	1	1	1
Polarization losses	dB	0	0	0	0	0	0	0	0	0	0
Receiver											
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
Minimum attenuation above 137 MHz	dB	60	60	60	60	60	60	60	60	60	60
Rx signal power level in 19.2 kHz	dBW	-186.2	-182.8	-180	-177.9	-177.1	-177.2	-178.2	-180.5	-183	-186.2
MSS long-term protection requirement	dBW	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9	-159.9
Margin	dB	26.3	22.9	20.1	18.0	17.2	17.3	18.3	20.6	23.1	26.3

The 17.2 dB minimum margin obtained is to be lowered by a factor of 3 dB assuming the maximum simultaneous operation of 2 active AMS(R)S space stations using VDL Mode 2, as visible from the MSS earth station (see section 0).

This shows that, based on assumptions considered in studies, protection criteria from MSS above 137 MHz is met from AMS(R)S satellite emissions in 136-137 MHz.

9.4.3 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

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

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

- The worst case assumption of the SOS antenna pointing towards the AMS(R)S satellite.
- The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the SOS earth station (instead of 5 dB towards aircraft).
- The 14 kHz necessary bandwidth considered for VDL Mode 2 emission in section 7.2.
- AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2.2) is 60 dB.

TABLE 18

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

AMS(R)S satellite downlink into SOS earth station receiver	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											
	RF Power for 25 KHz channel	W	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
	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	22.6	22.6	22.6	22.4	21.5	20.1	18.2	15.3	12.4	9.1
	Signal Propagation											
	Free space path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
	Additional. propagation loss	dB	1	1	1	1	1	1	1	1	1	1
	Receiver											
	SOS Rx antenna gain	dBi	12	12	12	12	12	12	12	12	12	12
	Rx signal power level per 1 kHz	dBW	-122.1	-118.8	-115.9	-113.9	-113.1	-113.2	-114.2	-116.4	-119	-122.1
	Minimum attenuation above 137 MHz	dB	60	60	60	60	60	60	60	60	60	60
	Maximum power level per 1 kHz at SOS receiver input	dBW	-182.1	-178.8	-175.9	-173.9	-173.1	-173.2	-174.2	-176.4	-179	-182.1
	SOS protection criteria: max. interference power in 1 kHz	dBW	-164	-164	-164	-164	-164	-164	-164	-164	-164	-164
	Margin	dB	18.1	14.8	11.9	9.9	9.1	9.2	10.2	12.4	15.0	18.1

There are two understandings provided in this report on adjacent-band apportionment of the protection criteria. One understanding assumes uncorrelated interference events distributed over time. Another understanding assumes constant interference and possible simultaneous arrival from different sources. The summaries of the results of the study under each understanding are described hereafter.

The minimum margin obtained through Table 18 is 9.1 dB under the first understanding, when the protection criteria for SOS is assumed to be -164 dBW for more than 0.01% of the time from section 0. This margin is to be lowered by a factor of 3 dB assuming the maximum simultaneous operation of 2 active AMS(R)S space stations using VDL Mode 2, as visible from the SOS earth station (see section 0).

This shows that, based on assumptions considered in studies, protection criteria for SOS above 137 MHz is met from AMS(R)S satellite emissions in 136-137 MHz.

Another understanding of the protection criteria is also considered as follows. The minimum margin obtained through Table 18 is -10.9 dB under this understanding, when the protection criteria for SOS is assumed to be -184 dBW for more than 1% of the time from section 0. This margin is to be lowered by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the SOS earth station.

This shows that, based on assumptions considered in studies, protection criteria for SOS above 137 MHz could not be met from AMS(R)S satellite emissions in 136-137 MHz, unless there is a limit, yet to be defined, to the level of AMS(R)S unwanted emissions.

9.4.4 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 137 MHz

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

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

- The worst case assumption of the SRS antenna pointing towards the AMS(R)S satellite.
- The value of 3.2 dBi for the peak antenna gain of SRS earth stations at 137 MHz, as recommended by the ITU-R expert group responsible for this service.
- The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the SRS earth station (instead of 5 dB towards aircraft)
- The 14 kHz necessary bandwidth considered for VDL Mode 2 emission in section 7.2.
- AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2.2) is 60 dB.

TABLE 19

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

AMS(R)S satellite downlink into SRS earth station receiver	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											
	RF Power for 25 KHz channel	W	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
	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	22.6	22.6	22.6	22.4	21.5	20.1	18.2	15.3	12.4	9.1
	Signal Propagation											
	Free space path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
	Additional. propagation loss	dB	1	1	1	1	1	1	1	1	1	1
	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	-160.9	-157.6	-154.7	-152.7	-151.9	-152	-153	-155.2	-157.8	-160.9
	Minimum attenuation above 137 MHz	dB	60	60	60	60	60	60	60	60	60	60
	Maximum power level per 1 Hz at SRS receiver input	dBW	-220.9	-217.6	-214.7	-212.7	-211.9	-212	-213	-215.2	-217.8	-220.9
	SRS protection criteria: max. interference power in 1 Hz	dBW	-196	-196	-196	-196	-196	-196	-196	-196	-196	-196
	Margin	dB	24.9	21.6	18.7	16.7	15.9	16.0	17.0	19.2	21.8	24.9

There are two understandings provided in this report on adjacent-band apportionment of the protection criteria. One understanding assumes uncorrelated interference events distributed over time. Another understanding assumes constant interference and possible simultaneous arrival from

different sources. The summaries of the results of the study under each understanding are described hereafter.

The minimum margin obtained through Table 19 is 15.9 dB under the first understanding, when the protection criteria for SRS is assumed to be -196 dBW for more than 10^{-5} % of the time for manned missions and for more than 10^{-3} % of time for unmanned missions from section 0. This margin is to be lowered by a factor of 3 dB assuming the maximum simultaneous operation of 2 active AMS(R)S space stations using VDL Mode 2, as visible from the SRS earth station (see section 0).

This shows that, based on assumptions considered in studies, protection criteria for SRS above 137 MHz is met from AMS(R)S satellite emissions in 136-137 MHz.

Another understanding of the protection criteria is also considered as follows. The minimum margin obtained through Table 19 is -4.1 dB under the second understanding, when the protection criteria for SRS is assumed to be -216 dBW for more than 10^{-3} % of the time for manned missions and for more than 10^{-1} % of time for unmanned missions from section 0. This margin is to be lowered by a factor depending on the maximum number of satellites of the AMS(R)S constellation possibly visible from the SRS earth station.

This shows that, based on assumptions considered in studies, protection criteria for SRS above 137 MHz could not be met from AMS(R)S satellite emissions in 136-137 MHz, unless there is a limit, yet to be defined, to the level of AMS(R)S unwanted emissions.

9.4.5 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

Characteristics and protection criteria for meteorological satellite systems in the frequency band 137-138 MHz used in this compatibility study are given in section 0.

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

- The worst case assumption of the MetSat antenna pointing towards the AMS(R)S satellite.
- The value of 10 dBi for the peak antenna gain of MetSat earth stations at 137 MHz. This represents a worst case from the sharing point of view under this static analysis, the alternative being the lower 2 dBi antenna gain.
- The AMS(R)S maximum downlink power of 36 W, with only 1 dB propagation loss on the path towards the MetSat earth station (instead of 5 dB towards aircraft).
- AMS(R)S VDL Mode 2 signal attenuation above 137 MHz (see section 7.2.2) is 60 dB.
- MetSat long-term protection criteria from section 0, as it is more stringent than the short-term criteria in the frame of such a static analysis.
- The worst case assumption is for six simultaneous AMS(R)S carriers (one 14 kHz carriers per 25 kHz channel) within the 150 kHz bandwidth of MetSat receiving earth station.

TABLE 20

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

AMS(R)S satellite downlink into MetSat earth station receiver	Frequency	MHz	137	137	137	137	137	137	137	137	137	137
	AMS(R)S satellite altitude	km	600	600	600	600	600	600	600	600	600	600
	Elevation	(degrees)	0	10	20	30	40	50	60	70	80	90
	Range	km	2831	1932	1392	1075	882.4	760.8	683.2	634.9	608.4	600
	Transmitter											
	RF Power for 25 KHz channel	W	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0	36.0
	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	22.6	22.6	22.6	22.4	21.5	20.1	18.2	15.3	12.4	9.1
	Signal Propagation											
	Free space path loss	dB	144.2	140.9	138.1	135.8	134.1	132.8	131.9	131.2	130.9	130.7
	Additional. propagation loss	dB	1	1	1	1	1	1	1	1	1	1
	Receiver											
	MetSat Rx antenna gain	dBi	10	10	10	10	10	10	10	10	10	10
	Rx signal power level per 150 kHz	dBW	-104.9	-101.6	-98.71	-96.66	-95.84	-95.96	-96.92	-99.19	-101.7	-104.9
	Minimum attenuation above 137 MHz	dB	60	60	60	60	60	60	60	60	60	60
	Maximum power level per 150 kHz at MetSat receiver input	dBW	-164.9	-161.6	-158.7	-156.7	-155.8	-156	-156.9	-159.2	-161.7	-164.9
	MetSat protection criteria: max. interference power in 150 kHz	dBW	-151	-151	-151	-151	-151	-151	-151	-151	-151	-151
	Margin	dB	13.9	10.6	7.7	5.7	4.8	5.0	5.9	8.2	10.7	13.9

The 4.8 dB minimum margin obtained is to be lowered by a factor of 3 dB assuming the maximum simultaneous operation of 2 active AMS(R)S space stations using VDL Mode 2, as visible from the MetSat earth station (see section 6.1). Hence minimum margin taking all factors into account is 1.8 dB.

This shows that, based on assumptions considered in studies, protection criteria for MetSat above 137 MHz is met from AMS(R)S satellite emissions in 136-137 MHz. It should be noted that this result depends on number of active satellites and requires proper emission control to ensure compatibility with MetSat.

From the AMS(R)S characteristics considered for this analysis (satellite altitude, EIRP density level, 60 dB roll-off factor, 1.8 dB minimum remaining margin at 40° elevation when all factors are considered under worst case assumptions), it can be concluded that, based on assumptions considered in studies, the protection criteria for MetSat is met provided that the power-flux density (pfd) for the unwanted emissions above 137 MHz AMS(R)S systems operating in the frequency band 136-137 MHz does not exceed the following level, derived from the 40° elevation column:

$$\begin{aligned} \text{Maximum pfd} &= 21.5 - 10 \cdot \log(4\pi(882400)^2) - 60 + 1.8 \quad \text{dB(W/(m}^2 \cdot 14 \text{ kHz))} \\ &= -166.6 \quad \text{dB(W/(m}^2 \cdot 14 \text{ kHz))} \end{aligned}$$

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

9.5 Summary of adjacent band compatibility with non-ICAO services

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

- Protection of in-band systems operating under AM(R)S and AM(OR)S, and of adjacent band systems below 117.975 MHz under ARNS would be resolved through conventional frequency planning exercise, involving the relevant aeronautical authorities including ICAO, and assigning frequencies to the satellite system over interested regions in a manner that ensures compatibility between ground and satellite facilities.
- Protection criteria for adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth) and Meteorological satellite service (space-to-Earth) is met through a roll-off factor for AMS(R)S unwanted emissions, under the assumptions considered. Studies show that a maximum PFD level of $-166.6 \text{ dB(W/(m}^2 \cdot 14 \text{ kHz))}$ for the unwanted emissions above 137 MHz of AMS(R)S systems operating in the frequency band 136-137 MHz is required to ensure this result.
- Regarding protection criteria of adjacent-band systems operating above 137 MHz in the Space operation service (space-to-Earth) and Space research service (space-to-Earth):
 - When AMS(R)S unwanted emissions is considered as uncorrelated interference events distributed over time, protection is also met with a maximum PFD level of $-166.6 \text{ dB(W/(m}^2 \cdot 14 \text{ kHz))}$ for the unwanted emissions above 137 MHz of AMS(R)S systems operating in the frequency band 136-137 MHz, under the assumptions considered in studies relative to the maximum number of co-frequency satellites seen from any point on the Earth.
 - When AMS(R)S unwanted emissions is considered as constant interference events possibly existing simultaneously with other sources of interference, protection criteria is met with a maximum pfd level of [TBD] $\text{dB(W/(m}^2 \cdot 14 \text{ kHz))}$ for the unwanted emissions above 137 MHz of AMS(R)S systems operating in the frequency band 136-137 MHz.

10 Adjacent band compatibility studies related to the protection of receiving space stations of the aeronautical mobile-satellite (route) service (Earth-to-space) in the frequency band 117.975-137 MHz from unwanted emissions of transmitting space stations operating above 137 MHz

As indicated in Section 3.2, the frequency band 137-138 MHz is allocated on a primary basis to the Mobile satellite service (space-to-Earth), the Space operation service (space-to-Earth), the Space research service (space-to-Earth), and the Meteorological satellite service (space-to-Earth). Pursuant to Resolution **428 (WRC-19)**, it is necessary to ensure that a new AMS(R)S allocation in all or part of the frequency band 117.975-137 MHz will not adversely impact planned usage of systems operating in these adjacent band allocations. This sections therefore provides compatibility studies between receiving AMS(R)S satellites below 137 MHz and transmitting MSS/SOS/SRS/MetSat satellites in the frequency band 137-138 MHz.

10.1 Characteristics of space systems operating above 137 MHz

Compatibility studies between these transmitting MSS/SOS/SRS/MetSat space stations and receiving AMS(R)S space stations are performed on a static basis, by assessing the minimum worst-case C/I

that would be experienced at AMS(R)S satellite receivers by spurious emissions from the above-mentioned services operating above 137 MHz.

Characteristics used for MSS/SOS/SRS/MetSat space stations are those recommended by the corresponding ITU-R expert group, in particular Table 2 of Recommendation ITU-R M.1231 for MSS, Table 2 of Report ITU-R SA.2426 for SOS, and Tables 1 and 4 of Report ITU-R SA.2488 for MetSat.

The maximum level of MSS/SOS/SRS/MetSat spurious emissions are derived from the section of Appendix 3 of the Radio Regulations related to space services, noting that this level applies for the spurious domain, i.e. at a separation of 250 % of the necessary bandwidth from the centre frequency. Hence, the attenuation ($43 + 10 \log(P)$ or 60 dBc, whichever is the less stringent, calculated in a 4 kHz reference bandwidth) below the power supplied to the antenna transmission line is used to calculate maximum permitted spurious domain emission power levels, as indicated in Table 1 of Appendix 3. Assuming that MSS/SOS/SRS/MetSat emissions are at the edge of their allocation, the spurious domain corresponds to frequencies below $137 - 2 \cdot \text{NB}$ (MHz), where NB is the MSS/SOS/SRS/MetSat necessary bandwidth expressed in MHz.

The case of MSS/SOS/SRS/MetSat out-of-band emissions requires further studies, on the basis of precise characteristics for satellite systems architectures and emissions.

10.2 Worst-case assumptions for the adjacent-band compatibility study

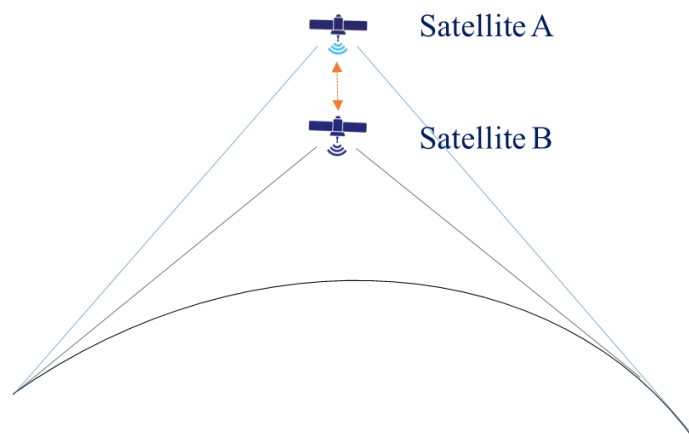
The C/I at the AMS(R)S satellite receiver is evaluated considering the following worst-case assumptions:

- A minimum received wanted power at the AMS(R)S receiver of -100.5 dBm. This corresponds to the minimum received value (70° elevation) considering 5 dB scintillation (see Table 6 in Section 6.4), and is therefore a worst-case received value.
- Maximum MSS/SOS/SRS/MetSat spurious levels as defined per Appendix 3 of the Radio Regulations
- Up to three static scenarios, as described in the following sections.

10.2.1 Scenario 1 : “above / below”

In this scenario, Satellite B is passing at the nadir of Satellite A. In that case, Satellite A is located in the backlobes of Satellite B, and the distance between Satellite A and Satellite B is minimum.

In this scenario, when the AMS(R)S altitude is lower than the interfering satellite altitude, the AMS(R)S backlobes gain is assumed to be 0 dBi .

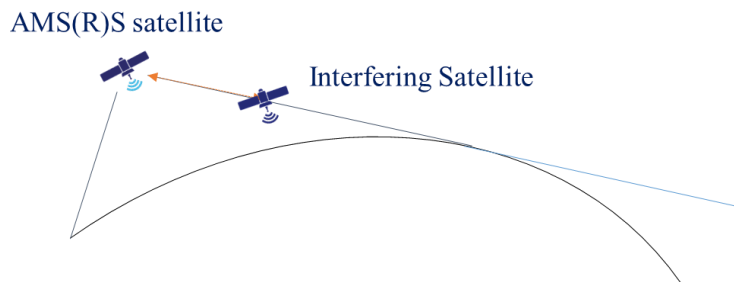


10.2.2 Scenario 2: “at the limit of the coverage of a system operating in the aeronautical mobile satellite (route) service ”

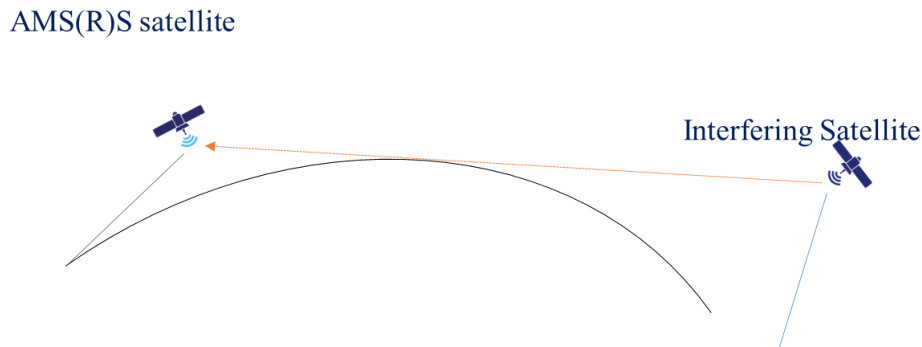
In this scenario, the interfering satellite is assumed to be located at the limit of the AMS(R)S coverage area (i.e. in the direction where the AMS(R)S is seen at 0° elevation as seen from the Earth). This scenario is of particular importance as the AMS(R)S satellite gain towards the horizon is important (8 dBi).

Two cases are considered:

- Case 1: the altitude of the AMS(R)S satellite is greater than the altitude of the interfering satellite. In such a case, the AMS(R)S satellite is located backwards the interfering satellite and is therefore in the backlobes of the interfering satellite antenna.



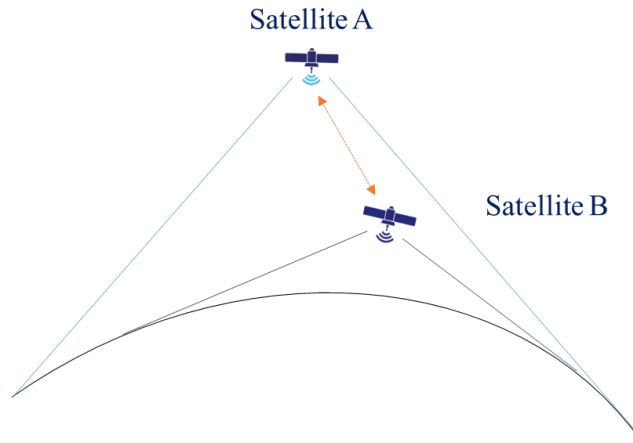
- Case 2: the altitude of the AMS(R)S satellite is lower than the altitude of the interfering satellite. In such a case, the 2 satellites are located opposite from the Earth, and each satellite is located in the sidelobes of the antenna of the other one.



10.2.3 Scenario 3: “in between”

This scenario is considered when the antenna of Satellite A is isoflux. Calculation is made for the particular Satellite A antenna off-nadir angle for which the combination (Free Space Loss – Gain) is minimum.

This particular configuration occurs for example in the case where the altitude of the AMS(R)S satellite is greater than the interfering satellite altitude, for the particular off-nadir angle of 44.4° at the AMS(R)S satellite antenna (40° elevation angle as seen from the Earth). In that case, AMS(R)S antenna gain is 6.9 dBi.



10.3 Assessment of the impact of spurious emissions from systems operating in the mobile satellite service, space operations service, space research service and MetSat satellites on satellite receivers operating in the aeronautical mobile satellite (route) service below 137 MHz

10.3.1 Adjacent band compatibility with satellite systems operating in the mobile satellite service

MSS satellite parameters used in the compatibility study are based on Recommendation ITU-R M.1231 and summarized in Table 21.

TABLE 219

Satellite parameters of systems operating in the mobile satellite service used in the compatibility study

MSS modulation type		DPSK	OQPSK
MSS satellite altitude	km	775	
MSS satellite antenna pattern		Assumed to be omni	
MSS satellite antenna gain	dBi	3.1 (worst-case assumption)	0.8
Transmit output power	dBW	13.1	7.1
Filter/cable line losses	dB	1	1.4
Reference bandwidth – BW	kHz	19.2	44.0
Appendix 3 calculations			
Attenuation requirement (Appendix 3)	dBc	56.1	50.1
MSS maximum spurious level	dBW/4kHz	-43.0	-43.0
	dBW/BW	-36.2	-32.6
	dBW/5kHz	-42.0	-42.0
Spurious attenuation	dB	49.3	39.1

The MSS satellite antenna gain is assumed to be omnidirectional. Hence, and given that MSS satellite altitude is higher than AMS(R)S satellite's one, scenario 1 and scenario 2 (case 2) are considered below.

The worst-case C/I experienced at the AMS(R)S receiver due to MSS spurious emissions is calculated in Table 22.

TABLE 12

Estimation of C/I received at a satellite receiver operating in the aeronautical mobile satellite (route) service due to spurious emissions from systems operating in the mobile satellite service

			Scenario 1	Scenario 2
Free space losses		dB	120.0	150.8
AMS(R)S satellite antenna gain in the direction of the MSS satellite		dBi	0	8
AMS(R)S feeder loss		dB	1	
Minimum C/I	DPSK	dB	30.5	53.3
	OQPSK		33.2	56.0

Calculations show that the minimum worst-case C/I experienced at the AMS(R)S receiver due to MSS spurious emission would be greater than 30 dB, for both MSS modulation types.

Considering the MSS emission bandwidth of 44 kHz (OQPSK modulation), the minimum worst-case C/I would be achieved below the 136.912 MHz spurious boundary (considering a MSS emission at the limit of the 137 MHz MSS allocation).

10.3.2 Adjacent band compatibility with satellite systems operating in the space operations service

SOS satellite parameters used in the compatibility study are based on Table 2 of Report ITU-R SA.2426 and summarized in Table 23.

SOS satellite altitudes are within the range 300 to 1000 km. In the following, calculations are made assuming 300, 500, 750 and 1000 km altitude for the SOS spacecraft.

TABLE 23

Satellite parameters of systems operating in the space operations service used in the compatibility study

SOS satellite altitude	km	300, 500, 750 and 1000 km
SOS satellite antenna pattern		Omni
SOS satellite antenna gain	dBi	3
Transmit output power	dBW	0
Reference bandwidth	kHz	25
Attenuation requirement (Appendix 3)	dBc	43
Appendix 3 calculations		
SOS maximum spurious level	dBW/4kHz	-43.0
	dBW/25kHz	-35.0
	dBW/5kHz	-42.0
Spurious attenuation	dB	35.0

Depending on the SOS satellite altitude, the following interference scenario are considered:

- Scenario 1, 2 (case 1) and 3 in the case of SOS satellite altitude of 300 and 500 km
- Scenario 1 and 2 (case 2) in the case of SOS satellite altitude of 750 and 1000 km.

The worst-case C/I experienced at the AMS(R)S receiver due to SOS spurious emissions is calculated in the Table 24.

TABLE 24

Estimation of C/I received at a satellite receiver operating in the aeronautical mobile satellite (route) service due to spurious emissions from systems operating in the space operations service

	SOS satellite altitude		Scenario 1	Scenario 2	Scenario 3
Free space losses	300 km	dB	124.7	133.8	127.8
	500 km		115.2	123.4	118.2
	750 km		118.7	150.8	
	1000 km		127.2	151.5	
AMS(R)S satellite antenna gain in the direction of the SOS satellite	300 km	dBi	-5.5	8	6.9
	500 km				
	750 km		0	8	
	1000 km				
AMS(R)S feeder loss		dB	1		
Minimum C/I	300 km	dB	39.7	35.3	30.5
	500 km		30.2	24.9	20.8
	750 km		28.2	52.3	
	1000 km		36.7	53.0	

Calculations show that in the cases listed above, the minimum worst-case C/I experienced at the AMS(R)S receiver due to SOS spurious emission is 20.8 dB. This minimum worst-case C/I would be achieved below the 136.95 MHz spurious boundary (considering a SOS emission at the limit of the 137 MHz SOS allocation).

Logically, the C/I value greatly depends on the SOS altitude: the closer the SOS satellite to the 600 km altitude, the lower the C/I at the AMS(R)S receiver. Especially, if the SOS satellite altitude is close to the AMRS(R)S 600 km orbit then the C/I at the AMS(R)S satellite receiver could be lower than the ones shown in Table 24. For such situations, the detailed calculation of C/I would need to be made, knowing precisely the exact orbit parameters of the satellites (inclination, apogee, perigee, mean anomaly, longitude of the right ascending node,...). And in such cases, experienced interference at the AMS(R)S satellite receiver – if any – is expected to be short in time and in probability.

10.3.3 Adjacent band compatibility with satellite systems operating in the space research service

SRS satellite parameters used in the compatibility study are based on information provided by corresponding ITU-R expert group and summarized in Table 25. As indicated in Recommendation ITU-R SA.354, the SRS transmission bandwidth is assumed to be narrowband and the SRS satellite is assumed to be omnidirectional. A SRS satellite antenna gain of 5 dBi is used, which is considered a maximum representative value in this frequency range. A value of SRS spurious emission levels of -43 dBW/4kHz is used in the following calculations. This level is considered as typical satellite maximum spurious emissions for this frequency range.

TABLE 25

Satellite parameters for systems operating in the space research service used in the compatibility study

SRS satellite altitude	km	826 / 846 km
SRS satellite antenna pattern		Omni
SRS satellite antenna gain	dBi	5
SRS maximum spurious level	dBW/5kHz	-42.0

Given that the SRS satellite altitude is higher than AMS(R)S satellite's one, scenario 1 and scenario 2 (case 2) are considered below.

The worst-case C/I experienced at the AMS(R)S receiver due to SRS spurious emissions is calculated in Table 26.

TABLE 26

Estimation of C/I received at a satellite receiver operating in the aeronautical mobile satellite (route) service due to spurious emissions from systems operating in the space research service

		Scenario 1	Scenario 2
Free space losses	dB	122.3 / 123.0	151.0 / 151.1
AMS(R)S satellite antenna gain in the direction of the SRS satellite	dBi	0	8
AMS(R)S feeder loss	dB	1	
Minimum C/I	dB	29.8 / 30.5	50.5 / 50.6

Calculations show that based on the assumptions detailed above, the minimum worst-case C/I experienced at the AMS(R)S receiver due to SRS spurious emission would be in the range of 30 dB.

10.3.4 Adjacent band compatibility with MetSat satellite systems

MetSat satellite parameters used in the compatibility study are based on Table 1 and 4 of Report ITU-R SA.2488 and summarized in Table 27.

TABLE 27

MetSat satellite parameters for use for compatibility study

[Additional explanations on "Function" acronyms is required]

Function		APT		TIP	LRPT
Satellite		A and D	B	D	B
Minimum centre frequency of the emission	MHz	137.5 (A) 137.1 (D)	137.5	137.35	137.1
MetSat satellite altitude	km	812 (A) 854 and 870 (D)	835	854 and 870	835
MetSat satellite gain at nadir	dBi	3.7	4	5.8	4
MetSat satellite gain at horizon	dBi	-0.25	~2	-6	~2

Transmit output power	dBW	4.9	4	-2.5	5
Reference bandwidth	kHz	38	56.8	46	144
Appendix 3 calculations					
Attenuation requirement	dBc	47.9	47	29.9	48
MetSat maximum spurious level	dBW/4kHz	-43	-43	-43	-43
	dBW/BW	-33.2	-31.5	-32.4	-27.4
	dBW/5kHz	-42	-42	-42	-42
Spurious attenuation	dB	38.1	35.5	29.9	32.4
Frequency under which spurious levels apply	MHz	137.424 (A) 137.024 (D)	137.3864	137.258	136.812

Given that MetSat satellites altitudes are higher than AMS(R)S satellite's one, scenario 1 and scenario 2 (case 2) are considered below.

The worst-case C/I experienced at the AMS(R)S receiver due to MetSat spurious emissions is calculated in Table 28.

TABLE 28

Estimation of C/I received at a satellite receiver operating in the aeronautical mobile satellite (route) service due to MetSat spurious emissions

[Additional explanations on "Function" acronyms is required]

	Function	Satellite	Units	Scenario 1	Scenario 2
Free space losses	APT	A	dB	121.7	151.0
		D		123.3 / 123.8	151.1
		B		122.6	151.0
	TIP	D		123.3 / 123.8	151.1
	LPRT	B		122.6	151.0
AMS(R)S satellite antenna gain in the direction of the MetSat satellite	APT	A	dBi	3.7	-0.25
		D		4	2
		B		5.8	-6
	TIP	D		4	2
	LPRT	B		4	2
AMS(R)S feeder loss			dB	1	
Minimum C/I	APT	A	dB	30.5	55.7
		D		32.1 / 32.6	55.9
		B		31.4	55.8
	TIP	D		30.0 / 30.5	61.6 / 61.7
	LPRT	B		31.1	53.6

Calculations show that the minimum worst-case C/I experienced at the AMS(R)S receiver due to MetSat spurious emission would be of the order of 30 dB.

Considering the MetSat LRPT emission bandwidth of 144 kHz this minimum worst-case C/I would be achieved below the 136.812 MHz spurious boundary.

10.4 Conclusion of adjacent band compatibility studies on the protection of receiving space stations operating in the aeronautical mobile satellite (route) service from the unwanted emissions of systems operating in the mobile satellite service, space operations service, space research service and MetSat space stations operating above 137 MHz

Adjacent band compatibility studies detailed in previous sections show that, when considering MSS/SOS/SRS/MetSat spurious emissions, the expected minimum C/I experienced at AMS(R)S satellite receiver would be of the order of 30 Db under worst case assumptions. It can therefore be considered that AMS(R)S satellite reception is adequately protected from these spurious emissions. On the basis of the ranges considered for the necessary bandwidth of MSS/SOS/SRS/MetSat emissions, these minimum C/I values would be reached below about 136.8 MHz.

This paragraph may need to be revisited. For instance, on the basis of the absence of AMS(R)S protection criteria, conclusion should rather be that impact of systems above 137 MHz on AMS(R)S is negligible.

It can therefore be concluded that :

- The protection of AMS(R)S receiving space stations from the spurious emissions of adjacent-band satellite 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) is ensured.
- This applies for the spurious domain of MSS/SOS/SRS/MetSat emissions, hence at a certain frequency separation below 137 MHz, depending on the maximum necessary bandwidth of MSS/SOS/SRS/MetSat emissions.
- Protection of AMS(R)S receiving space stations from the out-of-band of adjacent-band satellite systems operating above 137 MHz requires further studies, on the basis of precise characteristics for satellite systems architectures and emissions

11 Dynamic analysis on protection of receiving space stations operating in the aeronautical mobile satellite (route) service below 137 MHz from the unwanted emissions of systems operating in the mobile satellite service, space operations service, space research service and MetSat operating in the frequency band 137-138 MHz

11.1 Introduction

This chapter reports on a study simulating the interference from satellite networks and satellite constellation networks of the MSS, SOS, SRS, MetSat operating in the frequency band 137-138 MHz into the receiving space stations in the AMS(R)S in the frequency band 117.975-137 MHz.

In accordance with Resolution **428 (WRC-19)**, it is necessary to ensure that planned usage of systems operating above 137 MHz will not be adversely affected.

This chapter reports on the compatibility study to evaluate the potential interference received in space receiver of the AMR(R)S below 137 MHz due to emissions from systems operating in the MSS/SRS/MetSat/SOS services above 137 MHz.

11.2 Basis and assumptions for dynamic compatibility studies

AMS(R)S are intended to be provided in the frequency bands ranging from 117.975 MHz to 137 MHz, in particular:

- 1 Voice and Data Link services (DSB-AM modulation) are used in frequency range 117.975-136 MHz.
- 2 Data Link services over VDL Mode 2 application (D8PSK modulation) are used in frequency range 136-137 MHz.

The interference is computed for the worst case of interference level received in the first 25kHz below 137 MHz affecting only to the AMS(R)S operating over VDL Mode 2 application (D8PSK modulation).

As indicated in section 3.2, the space services allocated in the frequency band 137-138 MHz on a primary basis are (direction space-to-Earth):

- 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).

The satellites systems considered in this study are those providing the above services operating in the frequency band 137-138 MHz and their characteristics have been extracted from the ITU Space Network Systems Online Data Base system.

Note should be taken that this scenario studied is a theoretical worst-case, as it assumes that all interfering systems considered would be in operation, which could not be the case as it would be interference between those systems. The assumption in this study is to assume that all those systems would be able to simultaneously operate, irrespective of the interference which would be created between themselves.

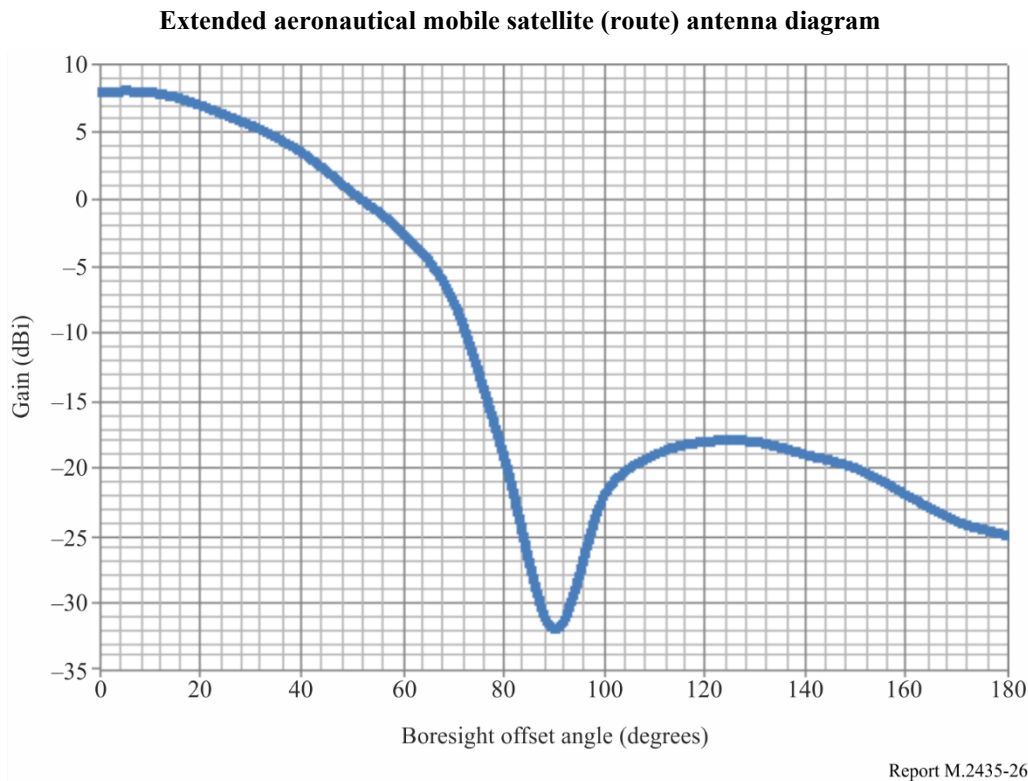
11.3 Typical characteristics of space systems operating in the aeronautical mobile satellite (route) service

The characteristics used for AMS(R)S space system in this dynamic study are those from section 6, and additional parameters assumed for conducting the dynamic study are the following:

- 1 Satellite keplerian orbit:
 - a) 600 km altitude. Semimajor axis = 6978.137 km
 - b) Circular orbit. Eccentricity = 0
 - c) Polar orbit. Inclination = 90 deg
 - d) Right Ascension of Ascending Node, Argument of pericentre and anomaly randomly selected.
- 2 VHF antenna radiation diagram follows the profile provided in Table 2.

The above pattern is further extended as per Report ITU-R M.2435-0, Figure 26. The antenna is considered with the boresight at 66° tilt in the direction of satellite movement.

FIGURE 18



- 3 Space system receiver (as per Table 10):
 - a) Feeder Loss: 1 dB.
 - b) Rx sensitivity target: -107 dBm, i.e. -137 dBW.
 - c) Rx Signal power level: -101.8 dBm (i.e. -131.8 dBW), worst case reference for VDL Mode 2, with 5 dB scintillation losses corresponding to 70° useful elevation angle.
- 4 Expected noise level at receiver input (RTCA document DO-224D “Signal-In-Space Minimum Aviation System Performance Standards (MASPS) For Advanced VHF Digital Data Communications Including Compatibility with Digital Voice Techniques”):
 - a) Assuming an equivalent worst case for long range for VHF Digital radio (DO-224D, Table 3-98), the typical value for total system noise power density is -160.4 (dBm/Hz), assuming worst case for channelling receiver with a 25 kHz bandwidth reception, the total system noise power is -116.4 dBm (-146.4 dBW).

11.4 Satellite characteristics of space systems operating in the frequency band 137-138 MHz

- 1 The list of satellites with their parameters was extracted on 21 September 2022 from the ITU SNS database (Space International Frequency Information Circular Databases Online <https://www.itu.int/online/sns/>). This list extracts the filings from space networks with frequencies from 137 MHz to 138 MHz. The satellites/constellations identified in the frequency range 137-138 MHz are 4429 satellites.
- 2 The radiation diagram employed for the simulations is an isotropic antenna, specified as ND-SPACE, with Gain = 0dB, as declared on ITU filings. Some satellites have specific radiation diagrams declared, nevertheless, due to the similarity to an omnidirectional antenna, this has been maintained through all the networks, and maintaining the declared Gain, being the worst-case scenario.

- 3 All orbital characteristics of these satellite/constellations are extracted from their filings data. The rest of the required orbital elements are randomly assigned on the simulation.
- a) Keplerian orbit.
 - b) Semimajor axis is computed using apogee and perigee provided in Annex 1 in km.
 - c) Eccentricity is computed using apogee and perigee provided in Annex 1 in km.
 - d) Inclination is provided in Annex 1 in degrees.
 - e) Right Ascension of Ascending Node provided in Annex 1 in degrees. If not present in the table for a satellite/constellation, it is randomly assigned on the simulation.
 - f) Argument of perigee is randomly assigned on the simulation.
 - g) Anomaly, randomly assigned for the first satellite of an orbital plane. The rest of satellites in the same orbital plane are equally spaced in anomaly. Each row in the tables of Annex 1 define one orbital plane.

- 4 The out of band spectrum roll-off attenuation assumed is calculated as described on ITU-R SM.1541-6, Annex 5, section 3, for OoB emissions, extrapolating to the range below 1GHz as the worst-case when no other recommendation is specified, according to the formula:

$$Attenuation = 40 \log_{10} \left(\frac{F}{50} + 1 \right) dB_{sd}$$

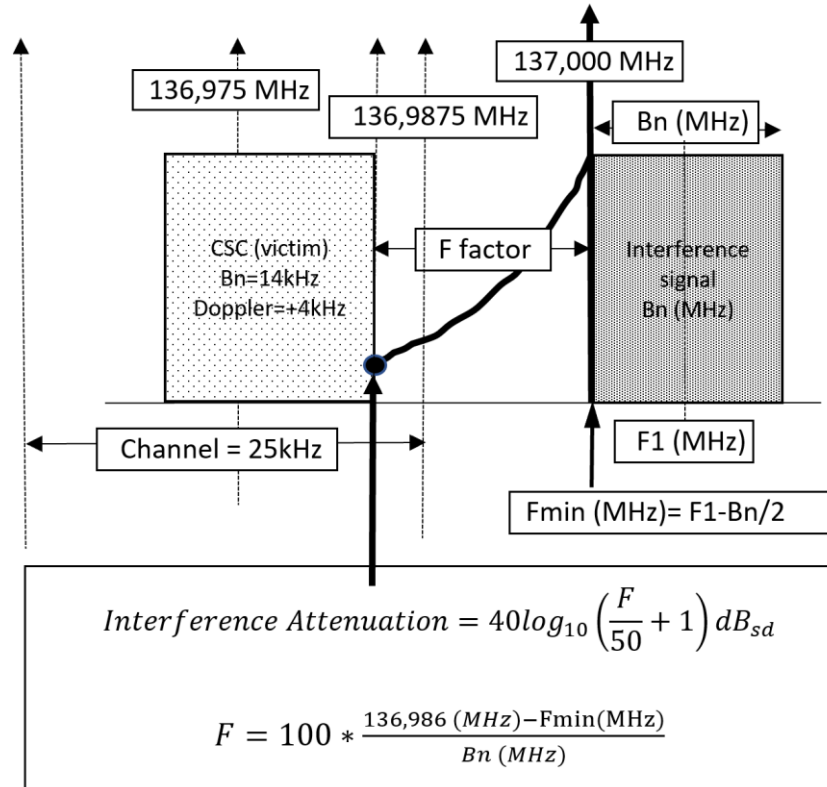
Where F is the frequency offset from the edge of the total assigned band, expressed as a percentage of necessary bandwidth:

$$F = 100 * \frac{136,986(MHz) - Fmin(MHz)}{Bn (MHz)}$$

The F frequency offset it is calculated at the higher border of the last assigned frequency channel, that is at 136,975 MHz, adding the Bn/2, where Bn is the VDLM2 necessary bandwidth as described in section 7.2. Additionally, a worst case of 4 kHz frequency shift for a Doppler effect has been taken into account, the final reference to use the F frequency offset and to calculate the Attenuation factor is 136,986 MHz. The following Figure shows this detail.

FIGURE 19

Attenuation and F offset applicability



If the frequency offset from the edge (F) is higher than 200%, the emission is considered to be within the spurious region, applying an attenuation of 60 dBsd or $43 + \log_{10}(P)$, whichever is less stringent, and where P has been considered as the maximum peak power as per every ITU filing. Reference: Appendix 3, Table I, Radio Regulations 2020.

The bandwidth used for the calculation, has been obtained from the emission designator. In case there is more than one emission, the worst-case scenario has been selected: highest power spectral density, minimum bandwidth with maximum power.

5 The interference power has been computed with the maximum peak power on each of the filings for the current emission designator.

6 All notified satellite networks are taken into account for the analysis. In addition, all satellite networks that have been launched (at least one satellite) are included in the analysis too, regardless their ITU status (API, coordination or notification). The overall resulting number of satellites is 580, of which 156 have already been launched.

7 Of these 580 satellites, 222 satellites include frequency assignment and associated bandwidth of the emissions that would cause out-of-band emissions below 137 MHz. Similarly, 358 satellites would contribute to interference in the spurious domain. It should be noted that all theoretical frequency assignment of the interfering satellites is considered in the study, despite this scenario would be non-realistic (frequency assignment with minimum frequency starting at 137.000 MHz).

8 For constellations with spacecraft with different TX attenuated power, the selection of which spacecraft transmits with which attenuated power is assigned randomly.

- 9 The operational channel selected for the calculations, is the closest in frequency to 137 MHz, where the lowest attenuation is calculated, therefore highest OoB emissions will occur. It is assumed that the satellites are operating only on the mentioned channel, which gives the worst-case scenario.
- 10 On one case it has been considered that the constellation of 150 satellites is uniformly distributed among the 34 channels declared, having 4.4 satellites on each of the channels, distributed randomly. To select a worse case, we have considered that 5 satellites are operating within each band, calculating therefore the attenuation of the OoB signals as well as within the spurious domain. These channels are distributed in the frequency band 137-138 MHz, with 20.8kHz of bandwidth each, operating in the MSS service for IoT purposes. Only 5 satellites are falling within the OoB emissions, with 145 satellites in the spurious domain.
- In the IoT literature, following standard ETSI EN300.220, section 7.2.3, the maximum duty cycle for IoT services is limited to 10% of the time. On this study it has been assumed that these satellites are transmitting 10% of the time in bursts.
- 11 In other case, being a large constellation and as well with IoT purposes and several channels, all these channels are within the spurious domain, therefore they have been grouped for the purpose of these calculations.
- 12 All satellites are assumed to be transmitting 100% of the time, except for those used for IoT which are assumed to be transmitting 10% of the time due to the nature of their service (see item 10 above).

11.5 Study methodology

The methodology for the analysis is here summarized:

- 1 The simulation computes different parameters over one day with steps of 10 seconds.
- 2 Over one day, the received power by all satellites is stored at steps of 10 seconds.
- 3 At each time step, the position of all satellites involved is computed.
- 4 For those satellites which are not operational 100% of the time, at each timestep, the satellite is considered to compute the total power received with the probability to be on based on the generation of a random number with a uniform distribution and checking if the result is over or below the percentage of its operational time.
- 5 Interfering satellites are setup with the orbit defined in assumptions with the orbital parameters provided their filings data. The antenna uses an isotropic radiation diagram with capabilities to radiate in any direction.
- 6 The power received by all satellites visible at each time step is added as interfering power.
- 7 For each power level, the number of steps with received power over the required power level is computed and divided by the total number of simulation time steps to get the percentage of time at which the power received by interfering satellites is over the required level.
- 8 AMS(R)S satellite is setup with the orbit defined in assumptions.
- 9 The scenarios evaluated are the following:
 - a) Scenario 1 considers both notified satellites plus operational (not yet notified) satellites (580 satellites).

- b) Scenario 2 considers only operational satellites (156 satellites), some operational satellites are not yet notified but have been included in the study. When a constellation is not complete in operation, the number of satellites launched have been allocated in their announced orbit in a random position.

11.6 Outcome of the dynamic study

The number of spacecrafts per service and notification status with detail of spacecraft already launched between brackets is shown in the following table:

TABLE 29
Number of spacecraft per service and notification status

	N	C	A	All
SOS	210	150 (2)	0	360 (2)
SRS	1	0	0	1
MET	5 (3)	0	0	5 (3)
MSS	190 (151)	0	0	190 (151)
Other	24	0	0	24
All	430 (154)	150 (2)	0	580 (156)

Note: Number in brackets are the number of spacecrafts currently in operation.

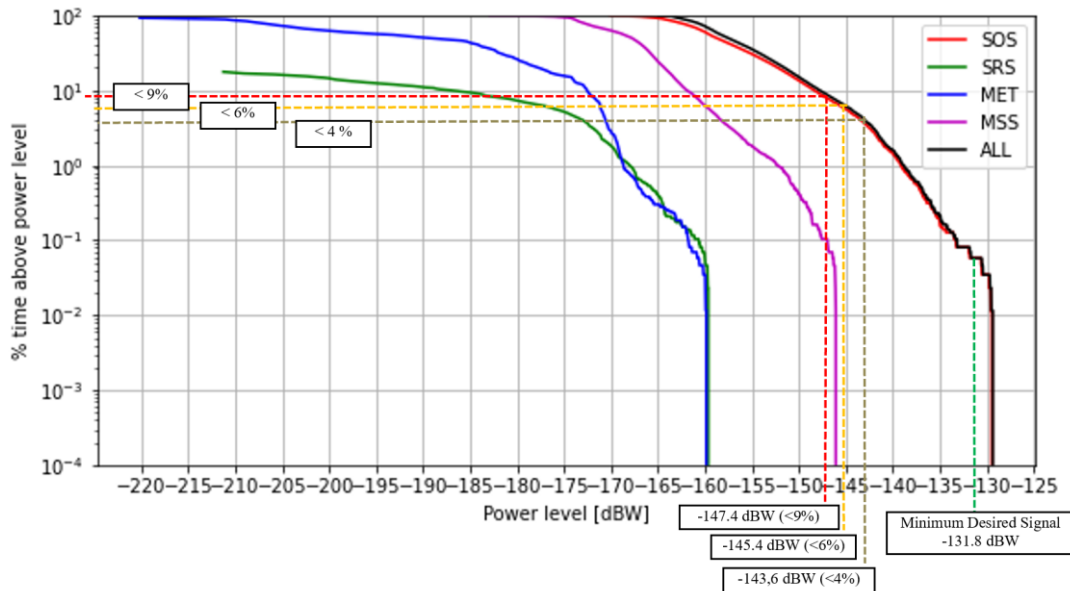
The total number of interfering spacecrafts from all reported spacecraft/constellations is 580 of which 156 are currently in operation.

11.6.1 Scenario 1: Spacecrafts in operational and notified status – power level received

The following Figure 20 shows the probability to receive a power level over a certain level considering all constellation networks in operational of notified status.

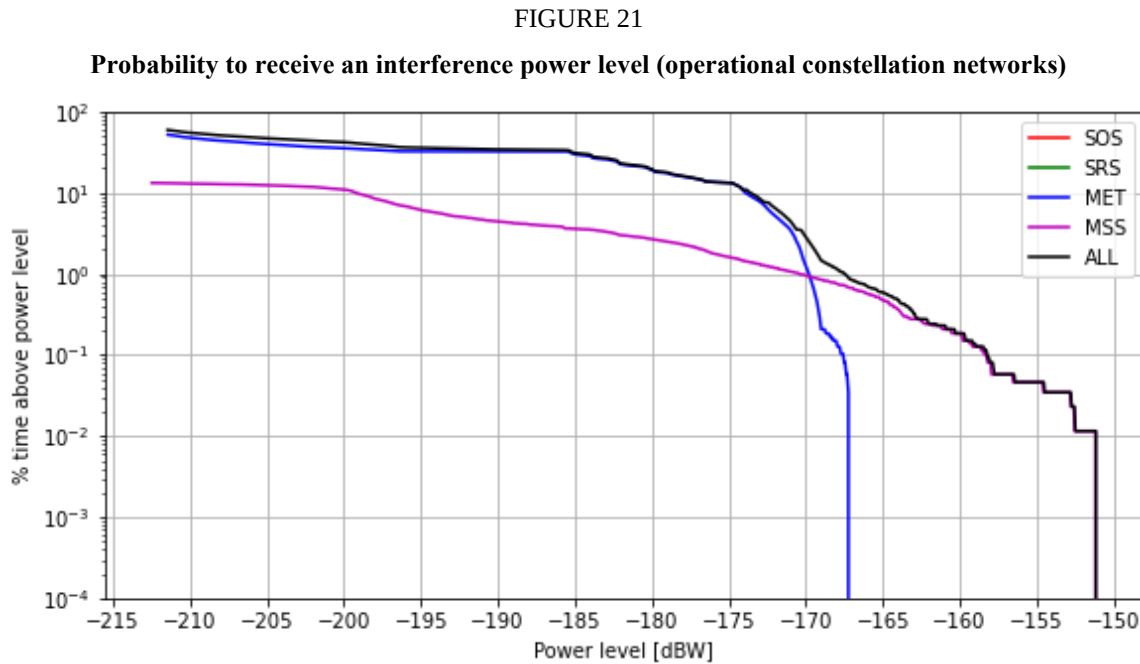
FIGURE 20

Probability to receive an interference power level (operational and notified constellation networks)



11.6.2 Scenario 2: Spacecrafts in operational status – power level received

The following Figure 21 shows the probability to receive a power level over a certain level considering all spacecraft and constellation networks in operational status.



The following table shows the probability to receive a power level above interference threshold for different thresholds.

TABLE 30
Percentage of time with interference level over a threshold

Threshold	Scenario 1: Operational and notified [%] of time over threshold	Scenario 2: Operational [%] of time over threshold
-143.6dBW	< 3%	< 10 ⁻⁴ %
-145.4dBW	< 6%	< 10 ⁻⁴ %
-147.4 dBW	< 9%	< 10 ⁻⁴ %

In order to examine the impact of the above interference probability into a AMS(R)S data link and considering the Document RTCA DO-224D, an uncorrected Bit Error Ratio (BER) of 10⁻³ equivalent to ICAO SARPs corrected BER of 10⁻⁴ for Mode 2 data operations, could operate with a value of Eb/No = 13 dB assuming 0,8 dB compensation.

Table 31 provides the aggregated interference level (I) that will allow achieving an Es/(No+Io) equal to the desired Es/No (to fulfil the BER reference value). Using this interference (I) values, it is possible to obtain in Figures 22 and 23 the interference level thresholds (power and time). This calculation has been made for minimum, maximum and average desired signal, extracted from Table 10, and for Scenario 1 and Scenario 2.

TABLE 31
Interference Threshold for uplink

Parameter	Source Data	PDNR Received Level			Unit
		Minimum	Average	Maximum	
C/I	Computed	14,6	14,4	14,3	dB
C	According to Table 10	-101,8	-100,1	-98,4	dBm
Ts	ITU-R SA.2426-0. Table 3	1000,0	1000,0	1000,0	K
No	$10 \log (kTs)$	-168,6	-168,6	-168,6	dBm
C/No	C-No	66,8	68,5	70,2	dB
BW	Channel Bandwidth	25,0	25,0	25,0	kHz
C/Io	$C/I + 10 \log (BW)$	58,6	58,4	58,3	dB/Hz
C/(No+Io)	$-10 \log \left(10^{-\frac{C}{10}} + 10^{-\frac{C}{10}} \right)$	58,0	58,0	58,0	dB/Hz
Es/(No+Io) - Computed up to obtain Margin 0.8	$\left(\frac{C}{No + Io} \right) - 10 * \log(10500)$	17,8	17,8	17,8	dB
Eb/No (10^{-3} uncorrected BER)	DO-224D. (3.6.1-Note)	13,0	13,0	13,0	dB
Es/Eb	DO-224D. Table 3-97	4,8	4,8	4,8	dB
Theory Es/No for Spec Block Error Rate (dB)	DO-224D. Table 3-98	17,8	17,8	17,8	dB
Margin= Es/(No+Io)-Es/No.	DO-224D. (3.7.4 - Note)	0,8	0,8	0,8	dB
Interference In 25 kHz Channel	Target Value M=0.8 - I (C-C/I)	-117,4	-115,4	-113,6	dBm
Interference In 25 kHz Channel	Target Value M=0.8 - I (C-C/I)	-147,4	-145,4	-143,6	dBW
% I from 137-138MHz Sat > Threshold - Scenario 1	Figure 22	9	6	3	% time
% I from 137-138MHz Sat > Threshold - Scenario 2	Figure 23	< 10⁻⁴	< 10⁻⁴	< 10⁻⁴	% time

The above figures have been calculated for the 100% of time with the AMS(R)S space system in receiving mode but the real operation is that when the AMS(R)S space system is in transmission mode the AMS(R)S space system is not receiving and therefore, the potential interferences are not affecting. Assuming a 50% ratio transmission/reception the above [%] figures could be reduced to the half.

No further margins are considered regarding improved AMS(R)S receiver antenna design which could be further improved to reduce the lateral beam lobes and reduce the potential undesired interferences.

Among other factors contributing to margins are:

- That the satellites transmitting the maximum declared power and not the coordinated power, but some SOS space stations could be operating under Resolution **660 (WRC-19)** with power flux-density at any point on the Earth's surface limited to $-140 \text{ dB(W/(m}^2 \cdot 4 \text{ kHz))}$.
- Even being the interfered satellite in reception status, it should be considered the probability to receive an interference just in the moment when a desired signal is arriving to the Space System receiver. Being these two processes random and independent phenomena, the interference could be reduced even by a considerable factor in terms of % in time of real interference.
- Another margin and an important operational factor is that the communications protocol used by the VDLM2 data services contains message recovery mechanisms that will reduce drastically the effect of any potential interferences.

Should be taken into account all the improvement factors detailed in the previous paragraphs, it could be extrapolated that an improvement factor of 10 is perfectly feasible and therefore it could be concluded that the interference levels obtained would not exceed 1% of the time when $C/I > 14$ dB or an aggregate interference level < -146.6 dBW.

These above figures are based on theoretical simulation statistic results which required further interpretation of their practical impact of each interfering ephemeris. The interfering time slots are really very short term which mean that each interfering episode would have not practical impact and would not risk the quality of the uplink in the space system of AMS(R)S.

These results allow concluding that currently operating satellite networks would not cause any harmful interference to an operating AMS(R)S network (Scenario 2). In the hypothetical case that more than 200 satellites were operating in the frequency band 137-138 MHz with interfering radiation in the frequency band below 137 MHz (Scenario 1), even though the service availability margin would be limited, they would not cause any risk of harmful interference to the AMS(R) service.

11.7 Conclusions of dynamic analysis on protection of aeronautical mobile satellite reception below 137 MHz from mobile satellite service, space operations service, space research service and MetSat satellite unwanted emissions in the frequency band 137-138 MHz.

This section may need to be revisited and possibly completed with the set of assumptions used, including the arguments for AMS(R)S protection.

This study reports on the results obtained via a simulation of interference from satellite networks and satellite constellation networks of the MSS, SOS, SRS, MetSat operating in the frequency band 137-138 MHz. This study is consistent with technical characteristic defined in this Report and adding data extracted from the ITU SNS database (Space International Frequency Information Circular Databases Online). to allow represent overall interference scenarios. The simulations have been undertaken using the published parameters of the interfering satellite networks including their maximum transmitting power.

The Out of Band transmitting power considered follows the pattern defined by ITU-R SM.1541-6 for OoB emissions. When the interfering transmitting power falls in the spurious domain, Appendix 3, Table I, Radio Regulations 2020 was taken into account. The interference power radiated below 137 MHz from all satellites has been calculated as an aggregated interference, considering 580 aggregated interfering sources originated by current and future operating satellites of which 156 aggregated interfering sources generated by the current satellites in operation.

The result of the study allows concluding that the interference created by adjacent band satellite services into space receivers of AMS(R)S would not create any relevant degradation of the AMS(R)S because the percentages of time when interference assumable threshold would be exceeded are very short-term, even without taking into consideration any other improvement (factor like dual or multiple operation of several AMS(R)S space receivers providing redundancies). Consequently, the impact on the AMS(R)S due to the time slots when interference thresholds are exceeded, is negligible. Therefore, the operation of AMS(R)S in the 117.975-137 MHz would not require any new constrains on existing VHF systems operating the in the frequency band 137-138 MHz.

12 Summary

In the framework of the consideration of a possible new allocation to the AMS(R)S within the aeronautical frequency band 117.975-137 MHz, this report defines the relevant technical characteristics of a reference satellite system that would relay VHF voice communications operating

today under the Aeronautical Mobile (Route) Service (AM(R)S), and complement terrestrial communications infrastructures for the coverage of oceanic and remote areas.

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

Main results are as follows:

- Protection of in-band systems operating under AM(R)S and AM(OR)S, and of adjacent band systems below 117.975 MHz under ARNS would be resolved through conventional frequency planning exercise, involving the relevant aeronautical authorities, and assigning frequencies to the satellite system over interested regions in a manner that ensures compatibility between ground and satellite facilities. Depending on the decision of the Conference on the matter, further action may be necessary to address necessary coordination aspects.
- For an AMS(R)S system operating in the frequency band 117.975-136 MHz
 - Protection criteria for adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth) and Meteorological satellite service (space-to-Earth) is met with a 1 MHz guard band (136-137 MHz) and RR Appendix 3 limits for AMS(R)S spurious emissions falling above 137 MHz, under the assumptions considered in studies. Different assumptions on AMS(R)S systems may lead to different conclusions.
 - Regarding protection criteria of adjacent-band systems operating above 137 MHz in the Space operation service (space-to-Earth) and Space research service (space-to-Earth), two possibilities below are considered at this stage:
 - When AMS(R)S spurious emissions is considered as uncorrelated interference events distributed over time, protection is also met with a 1 MHz guard band (136-137 MHz) and RR Appendix 3 limits for AMS(R)S spurious emissions falling above 137 MHz, under the assumptions considered in studies relative to the maximum number of co-frequency satellites seen from any point on the Earth.
 - When AMS(R)S spurious emissions is considered as constant interference events possibly existing simultaneously with other sources of interference, protection criteria could not be met, unless there is a limit, [TBD] dB below the level of Appendix 3, to the level of AMS(R)S spurious emissions.
- For an AMS(R)S system operating in the frequency band 136-137 MHz
 - Protection criteria for adjacent-band systems operating above 137 MHz in the Mobile satellite service (space-to-Earth) and Meteorological satellite service (space-to-Earth) is met through a roll-off factor for AMS(R)S unwanted emissions, under the assumptions considered. Studies show that a maximum PFD level of -166.6 dB(W/(m² · 14 kHz)) for the unwanted emissions above 137 MHz of AMS(R)S systems operating in the frequency band 136-137 MHz is required to ensure this result. Different assumptions on AMS(R)S systems may lead to different conclusions.
 - Regarding protection criteria of adjacent-band systems operating above 137 MHz in the Space operation service (space-to-Earth) and Space research service (space-to-Earth), two possibilities below are considered at this stage:
 - When AMS(R)S unwanted emissions is considered as uncorrelated interference events distributed over time, protection is also met with a

maximum pfd level of $-166.6 \text{ dB(W/(m}^2 \cdot 14 \text{ kHz))}$ for the unwanted emissions above 137 MHz of AMS(R)S systems operating in the band 136-137 MHz, under the assumptions considered in studies relative to the maximum number of co-frequency satellites seen from any point on the Earth.

- When AMS(R)S unwanted emissions is considered as constant interference events possibly existing simultaneously with other sources of interference, protection criteria is met with a maximum pfd level of [TBD] $\text{dB(W/(m}^2 \cdot 14 \text{ kHz))}$ for the unwanted emissions above 137 MHz of AMS(R)S systems operating in the frequency band 136-137 MHz.

Additional work may be required on the confirmation of AMS(R)S operational concepts and related assumptions in compatibility studies. In particular on the following points:

- Assumption that the AMS(R)S system would be operationally controlled to ensure that, for any point on the Earth, no more than 2 satellites are visible and operating on the same channel within 20° - 70° elevation angle.
- Potential aggregate impact of AMS(R)S system operating in the band 117.975-136 MHz and of AMS(R)S system operating in the band 136-137 MHz.

In addition, considerations could be added on an alternative approach, which would define a maximum pfd value from the aggregated unwanted emissions above 137 MHz of all AMS(R)S systems combined. First analysis under this approach provides the following values for the protection of low gain receiving earth stations in the different services, to be lowered by relevant gain value for higher antenna gains:

- maximum pfd value of $-179.93 \text{ dB (W/(m}^2 \cdot \text{kHz))}$ at Earth surface for 1% of time in the case of SOS protection, under the understanding of constant interference.
- maximum pfd value of $-211.93 \text{ dB (W/(m}^2 \cdot \text{Hz))}$ at Earth surface for 10-3 % of the time in the case of SRS protection, under the understanding of constant interference.
- maximum pfd values for out of band [and spurious] emissions of $-146.93 \text{ dB (W/(m}^2 \cdot 150\text{kHz))}$ at Earth surface for 20% of the time and $-132.93 \text{ dB (W/(m}^2 \cdot 150\text{kHz))}$ at Earth surface for 0.0013% of the time in the case of MetSat protection.

{Editor's Note: it as to be noted that under this alternative approach further consideration would be needed in order to take into account the aggregation of all unwanted emission of all service}

- Regarding protection of AMS(R)S space stations receivers operating below 137 MHz from the unwanted emissions of transmitted space stations of satellite systems operating above 137 MHz in the MSS; SOS, SRS and MetSat:
 - A static study conducted on spurious emissions
 - A dynamic study conducted on out-of-band emissions
 - Both studies conclude that the operation of the AMS(R)S would not require any new constraints on services allocated above 137 MHz

[Editor's note: These studies were considered for the first time at the November 2022 meeting of WP5B and deserve further considerations.]

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**Annex 2 to
Document 5B/649-E
29 July 2022
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Annex 2 to Working Party 5B Chairman's Report

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

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

Three methods are considered to address this agenda item:

- Method A: NOC
- Method B: This Method, which provides general common elements required to be complemented with Methods B1 or B2, proposes to add a new allocation to the AMS(R)S

* **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.

in the frequency band 117.975-137 MHz, or part thereof, limited to non-geostationary satellite systems and to internationally standardized aeronautical systems. This Method is not an independent and standalone Method as such and thus should be considered together with Methods B1 or B2.

- Method B1 is containing the elements of Method B, and proposes to add a power flux density (pfd) limit, where appropriate, on AMS(R)S space stations unwanted emissions falling above 137 MHz, in order to ensure protection of adjacent band services above 137 MHz.
- Method B2 is containing the elements of Method B, and proposes that systems operating under an allocation to the AMS(R)S be subject to the application of regulatory and technical measures to ensure compatibility with existing systems operating under an allocation to a different service in co-frequency bands and in the adjacent bands.

2/1.7/2 Background

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 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 and reception by satellite of automatic dependent surveillance-broadcast 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 AMS(R)S within the frequency band 117.975-137 MHz, to relay standard VHF communications operating under the 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 systems operating under an allocation either in-band or adjacent band were identified and sharing and compatibility studies were carried out to determine the operating conditions for systems intended to operate under a new AMS(R)S allocation. This is to ensure the protection of these in-band and adjacent band systems from possible interference resulting from the introduction of a new AMS(R)S system in this frequency band.

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

2/1.7/3.1 Summary of technical and operational studies

In liaison with the International Civil Aviation Organization (ICAO), ITU-R has studied the architecture, parameters, and baseline link budgets of a reference AMS(R)S system for the provision of standardized communications for air traffic management, without modification to aircraft equipment. Voice is considered in the frequency band 117.975-136 MHz, and VHF data link (VDL) mode 2 application in the frequency band 136-137 MHz ITU-R has determined that an AMS(R)S system would have to rely on non-geostationary satellites. In order to support compatibility studies, example of link budgets for satellite-to-aircraft (downlink) and aircraft-to-satellite (uplink) VHF links have been developed, based on propagation considerations discussed with the relevant ITU-R group. Additionally, an example architecture for a constellation providing global coverage is considered in order to support dynamic studies where required.

Maximum Doppler shift and latency times associated with the AMS(R)S system were studied. 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.

Studies with existing systems operating under an in-band/adjacent band allocation to a primary service has been assessed in close liaison with ICAO and the relevant ITU-R Working Parties:

In addition, consideration has been given to the in-band co-existence between AMS(R)S and the aeronautical mobile (off-route) service (AM(OR)S) which is allocated on a primary basis under Radio Regulations (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.1026-5, [SA.1027-6](#) and [SA.1743](#).

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

2/1.7/3.3 Analysis of the results of studies

2/1.7/3.3.1 In-band sharing between the systems operating in the aeronautical mobile-satellite (route) service and systems operating in the aeronautical mobile (route) service

AM(R)S and AMS(R)S would represent two different radiocommunication services within the frequency band 117.975-137 MHz, with the same on-board cockpit avionics system (for aeronautical VHF communications) being used for ground and satellite communications. It is planned that AMS(R)S would relay VHF communications operating under the AM(R)S over oceanic and remote areas, without modification to aircraft equipment.

It was indicated by ICAO that in case that there would be any potential interference between AM(R)S and AMS(R)S, which could stem from the possibly significantly larger service area of AMS(R)S compared to that of AM(R)S, they are currently working on this issue with a view, to the extent practicable, to resolve it 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 between systems operating under 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 ATC VHF communications) would be used for ground and satellite communications.

One view is that, until ICAO has completed its frequency planning exercises, the possible application of RR No. **9.11A** coordination procedure to AMS(R)S is being considered under this agenda item. It may also provide a mechanism for administrations to ensure compatibility between their AM(R)S systems and AMS(R)S systems.

Another view is that, considering that the service area of the AMS(R)S is significantly larger (several or even ten times) than the service area of the AM(R)S, then it may cause problems of compatibility between AMS(R)S and AM(R)S stations of other administrations that were previously out of interference area. There is no procedure in ICAO for assigning frequencies for AMS(R)S of the Administrations, taking into account the compatibility with AM(R)S of other Administrations. From a practical point of view, the establishment of such a procedure is unlikely in the next few years. To ensure the protection of AM(R)S systems from AMS(R)S systems of another Administration coordination procedures for AMS(R)S (for example, RR Nos. **9.11A** or **9.14** or **9.21**) can be applied.

2/1.7/3.3.2 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

ICAO has indicated that the frequency planning and coordination works on-going within ICAO will be performed to ensure compatibility between systems operating in the AMS(R)S and aeronautical radionavigation service (ARNS).

One view is that, currently, there are no ICAO standards related to AMS(R)S within the frequency band 117.975-137 MHz. However, such standards would be developed in the future, and would address the question of adjacent band compatibility between systems operating under allocations to the AMS(R)S above and ARNS below 117.975 MHz, if required, as a complement to ICAO frequency planning exercises. It is expected that such AMS(R)S standards would provide equivalent protection to ARNS in adjacent band as that afforded to ARNS by current AM(R)S standards.

Another view is that ICAO does not carry out any work on planning and coordinating frequencies between AM(R)S in the frequency band 117.975-137 MHz of one Administration and ARNS in the frequency band 108-117.975 MHz of the other Administration. In practice, these issues are resolved by regional agreements between the countries and compliance with ICAO standards for AM(R)S and ARNS equipment. Currently, there are no ICAO standards for transmitting and receiving space stations equipment of AMS(R)S.

According to this view, to ensure compatibility of AMS(R)S in the frequency band 117.975-137 MHz with ARNS in the frequency band 108-117.975 MHz it is required to develop and adopt the appropriate technical and/or regulatory conditions for the AMS(R)S.

For example, to protect the ARNS in the frequency band 108-117.975 MHz from the AMS(R)S space stations operating in the frequency band 117.975-137 MHz it is necessary:

- for transmitting AMS(R)S space stations to accept limits for unwanted emissions in the frequency band 108-117.975 MHz. Such limits shall not be worse than those established in the ICAO standards and Recommended Practices (SARPs) for on-board AM(R)S transmitting stations in the adjacent channels (see section 6.3.4, Annex 10 to the Convention on International Civil Aviation, *Aeronautical Telecommunications*, Volume III. *Communication systems*, ICAO);
- for receiving AMS(R)S space stations to accept the condition: "do not claim protection from interference caused by ARNS stations operating in the frequency band 108-117.975 MHz."

2/1.7/3.3.3 Adjacent band compatibility with systems operating above 137 MHz

A possible new primary AMS(R)S allocation within the frequency band 117.975-137 MHz is planned to be in both directions (Earth-to-space and space-to-Earth). However, transmitting earth stations in the AMS(R)S (Earth-to-space) would correspond to the AM(R)S aircraft station that is already in place. Therefore, compatibility studies should only be considered with respect to:

- the transmitting space stations in the AMS(R)S (space-to-Earth), operating in the frequency band 117.975-137 MHz into the receiving earth stations of adjacent band services;
- the transmitting space stations of adjacent band services into the receiving space stations in the AMS(R)S in the frequency band 117.975-137 MHz.

Characteristics and protection criteria have been received for systems operating above 137 MHz in the mobile satellite service (MSS) (space-to-Earth), the space operations service (SOS) (space-to-Earth), the space research service (SRS) (space-to-Earth), and the MetSat (space-to-Earth).

Compatibility studies were conducted and are referenced in preliminary draft new Report ITU-R M.[SPACE-VHF].

- For transmitting space stations in AMS(R)S operating in the sub band 117.975-136 MHz, unwanted emissions falling above 137 MHz correspond to spurious emissions, and the regulatory limit contained in RR Appendix 3 for spurious emissions of space services ensures that the required 60 dB attenuation, based on complementary static and dynamic studies, will be achieved. This is subject to further confirmation.
- For transmitting space stations in AMS(R)S operating in the sub band 136-137 MHz
 - Protection of receiving stations in the adjacent-band systems operating above 137 MHz in the MSS(space-to-Earth), SOS (space-to-Earth), SRS (space-to-Earth), and MetSat (space-to-Earth) can be ensured by limiting the out-of-band radiation of AMS(R)S in the adjacent band above 137 MHz, to [60] dB lower than its maximum in-band level, for example limiting to a maximum power flux density of [-166.6 dB(W/(m².14 kHz))] in any adjacent band above 137 MHz. This requires finalization of studies for its confirmation.
- For receiving space stations in AMS(R)S operating in the band 117.975-137 MHz:
 - One view is that compatibility studies are still being considered with respect to the transmitting space stations of adjacent band services above 137 MHz. In accordance with Resolution **428 (WRC-19)**, it is necessary to ensure that planned usage of systems operating above 137 MHz will not be adversely affected.
 - Another view is that protection of transmitting stations in the adjacent-band systems operating above 137 MHz in the MSS (space-to-Earth), SOS (space-to-Earth), SRS (space-to-Earth), and MetSat (space-to-Earth) from potential new limits of AMS(R)S can be ensured subject to the receiving space stations of AMS(R)S shall not claim protection from the adjacent-band services operating above 137 MHz.

Protection of the radio astronomy service in the frequency band 150.05-153 MHz has also been addressed. Considering that AMS(R)S emissions are narrow band, and that the frequency separation between the possible new AMS(R)S allocation and the radio astronomy allocation in 150.05-153 MHz would be 13.05 MHz or more:

- One view is that, given this frequency separation, it does not appear necessary to mandate specific protection limit.
- Another view is that, as the RR currently provides conditions for the protection of the radio astronomy service from unwanted emissions of space stations in the MSS allocated in the frequency band 137-138 MHz (see RR No. **5.208A**), therefore, similar conditions can be applied for the new allocation of the AMS(R)S in the band 117.975-137 MHz.

2/1.7/3.3.4 In-band sharing with other services

One view is that the characteristics of AM(OR)S systems are not available and no sharing studies have been undertaken. Nevertheless, the AM(OR)S systems are understood to operate in channels within the national assignments of AM(R)S, thus the compatibility between AM(OR)S and AMS(R)S assignments would be resolved through the existing frequency planning exercise. If a new allocation is made to AMS(R)S in this VHF band, ICAO, regional organizations as well as national regulators will continue to perform the conventional frequency planning exercise, assigning frequencies to the satellite system over interested regions, to ensure compatibility between ground and satellite facilities.

This planning exercise will continue to be reflected as necessary in ICAO SARPs. This approach will protect any existing assignments including those for AM(OR)S.

Another view is that the use of AM(OR)S is carried out within the current primary allocations in the frequency bands 132-138 MHz in a number of countries (see RR Nos. **5.201**, **5.202**, **5.206**), as well as in the frequency band 138-144 in Region 1. At present, the RR already have an example of the joint use of MSS (space-to-Earth) and AM(OR)S in the frequency band 137-138 MHz. MSS (space-to-Earth) compatibility with AM(OR)S in the frequency band 137-138 MHz is achieved by applying the coordination procedures of RR No. **9.11A** for the MSS (see RR No. **5.208**) and limiting the use of non-geostationary satellite systems to the MSS only.

According to this view, given that:

- AM(OR)S systems in the 137-138 MHz frequency band and AM(OR)S systems in the 132-137 MHz frequency band are of the same type and have similar characteristics,
- transmitting earth stations in AMS(R)S (Earth-to-space) will correspond to AM(R)S aircraft stations that are already in use (in fact, the same aircraft stations will be used);
- planned AMS(R)S (space-to-Earth) systems in the frequency band 117.975-137 MHz will be limited to non-geostationary systems and their performance will be similar to those of MSS (space-to-Earth) systems in the band 137-138 MHz for which allocations already exist and the conditions of combination in the RR are defined,

therefore, the alignment of AMS(R)S with AM(OR)S in the frequency band 117.975-137 MHz can be provided under the same conditions as the alignment of MSS (space-to-Earth) and AM(OR)S in the frequency band 137-138 MHz. This means that ensuring compatibility of AMS(R)S systems with AM(OR)S systems in the co-frequency bands in the range 117.975-137 MHz is possible under the following conditions:

- application of the coordination procedures under RR No. **9.11A** (RR No. **9.14**) for AMS(R)S systems in the event that space stations exceed the pfd level ($-140 \text{ dB(W)/(m}^2 \text{ in 4 kHz)}$) the Earth's surface (by analogy as this is done in the band 137-138 MHz - see RR No. **5.208**, and Annex 1 to RR Appendix 5);
- AMS(R)S systems should not require protection from AM(OR)S systems.

2/1.7/3.3.5 Compatibility between systems operating in the aeronautical mobile (route) service from different administrations

One view is that the new AMS(R)S allocation might be used by several systems filed by different administrations. In this case, it is anticipated that compatibility between these systems would be addressed within ICAO through its conventional frequency planning exercise, assigning frequencies to the satellite system over interested regions.

In addition, the possible application of RR No. **9.11A** coordination procedure to AMS(R)S is being considered under this agenda item. It may also provide a mechanism for administrations to ensure compatibility between their respective AMS(R)S systems.

Another view is that, when allocating the frequency band 117.975-137 MHz to AMS(R)S, it is possible that such allocation will be used by several AMS(R)S systems filed by different administrations. In this case, mutual interference between these systems is possible.

Interoperability between AMS(R)S systems of different administrations is possible by introducing the coordination procedure under RR No. **9.11A**, as provided in the RR in many other cases for non-geostationary-satellite MSS systems (e.g. see RR No. **208**).

2/1.7/4 Methods to satisfy the agenda item

2/1.7/4.1 Method A: No change

2/1.7/4.2 Method B: New allocation to the aeronautical mobile-satellite (route) service within the frequency band 117.975-137 MHz

This Method is not an independent and standalone Method as such and thus should be considered together with Methods B1 or B2.

Create a new co-primary allocation for the AMS(R)S in the Earth-to-space and space-to-Earth directions in the frequency band 117.975-137 MHz, or part thereof, under following conditions:

- the use of frequency band 117.975-137 MHz is limited to non-geostationary satellite systems only;
- limiting the use of the new AMS(R)S allocation to internationally standardised aeronautical systems;

2/1.7/4.2.1 Method B1: Method B with the following additions

- ensuring protection of AM(OR)S service in the frequency band 132-137 MHz, noting that the characteristics of AM(OR)S are not available. Nevertheless, AM(OR)S systems are understood to operate on channels within national assignments of AM(R)S, and coexistence between AM(R)S, AMS(R)S and AM(OR)S might therefore be envisioned through frequency planning and coordination;
- ensuring protection of services in adjacent bands and not constraining these services.

In-band coexistence between AM(R)S and AMS(R)S and adjacent-band coexistence between ARNS and AMS(R)S around 117.975 MHz needs to be ensured through frequency planning and coordination work.

The protection of adjacent band services operating above 137 MHz from AMS(R)S space stations unwanted emissions falling above 137 MHz is ensured:

- through the 1 MHz guard band in 136-137 MHz, as RR Appendix 3 provides appropriate limits for spurious emissions for AMS(R)S systems operating in 117.95-136 MHz;
- through a limit of satellite pfd of $-166.6 \text{ dB(W/(m}^2 \cdot 14 \text{ kHz))}$ on the level of unwanted emissions above 137 MHz for AMS(R)S emissions from systems operating in 136-137 MHz.

2/1.7/4.2.2 Method B2: Method B with the following additions

- applying RR No. **9.11A** coordination procedures (including RR No. **9.14**) for AMS(R)S systems, e.g. extending scope of RR No. **5.208** to AMS(R)S in 117.975-137 MHz;
- applying coordination threshold ($-140 \text{ dB(W/(m}^2 \text{ at } 4 \text{ kHz))}$) at the Earth's surface for AMS(R)S space stations during coordination under RR No. **9.14**, by including AMS(R)S in the frequency band 117.975-137 MHz in Annex 1 to Appendix 5 of the RR;
- ensuring protection of systems operating in adjacent bands and not constraining these systems by adopting restrictions on unwanted emissions from AMS(R)S space stations. Such limits should not be worse than those specified in ICAO SARPs for AM(R)S aircraft transmitting stations in adjacent channels (see Section 6.3.4, Annex 10 to the Convention on International Civil Aviation — Aeronautical Telecommunications, Volume III — Communication Systems, ICAO);
- AMS(R)S systems in the frequency band 117.975-137 MHz should not claim protection from interference from AM(R)S and AM(OR)S systems operating in the common

frequency band, as well as from ARNS, MSS (space- Earth), SOS (space-to-Earth), SRS (space-to-Earth) and MetSat (space-to-Earth) operating in adjacent frequency bands;

- applying RR No. **5.208A** and RR No. **5.208B** for the application of the conditions for new AMS(R)S allocations in the frequency band 117.975-137 MHz.

Studies are on-going for the protection of adjacent band services operating above 137 MHz from AMS(R)S emissions. Subject to confirmation, this protection might be ensured through a limit [XXX] on the level of unwanted emissions above 137 MHz for AMS(R)S emissions from systems operating in 117.95-137 MHz.

2/1.7/5 Regulatory and procedural considerations

2/1.7/5.1 For Method A: NOC

NOC

ARTICLES

NOC

APPENDICES

2/1.7/5.2 For Method B: New allocation to the aeronautical mobile-satellite (route) service within the frequency band 117.975-137 MHz

2/1.7/5.2.1 For Method B1

ARTICLE 5

Frequency allocations

Section IV – Table of Frequency Allocations (See No. 2.1)

MOD

75.2-137.175 MHz

Allocation to services			
Region 1	Region 2		Region 3
117.975-~~137~~136	AERONAUTICAL MOBILE (R) <u>AERONAUTICAL MOBILE-SATELLITE (R) MOD 5.209 ADD 5.A17</u> 5.111 5.200 5.201 5.202		
~~117.975~~136-137	AERONAUTICAL MOBILE (R) <u>AERONAUTICAL MOBILE-SATELLITE (R) MOD 5.209 ADD 5.A17</u> <u>ADD 5.B17</u> 5.111 5.200 5.201 5.202		

MOD

5.209 The use of the band 117.975-137 MHz by the aeronautical mobile-satellite (R) service and 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-9723)

ADD

5.A17 The use of the frequency band 117.975-137 MHz by the aeronautical mobile-satellite (R) service is limited to internationally standardized aeronautical systems. (WRC-23)

Reasons: To ensure that the new AMS(R)S allocation is used only by internationally standardised aeronautical systems.

ADD

5.B17 In the frequency band 136-137 MHz, space stations operating in the aeronautical mobile-satellite (R) service should ensure that their maximum level of their emissions above 137 MHz does not exceed a pfd of $-166.6 \text{ dB(W/(m}^2 \cdot 14 \text{ kHz))}$. (WRC-23)

Reasons: To ensure the protection of the incumbent services above 137 MHz.

2/1.7/5.2.2 For Method B2

ARTICLE 5

Frequency allocations

Section IV – Table of Frequency Allocations (See No. 2.1)

MOD

75.2-137.175 MHz

Allocation to services			
Region 1	Region 2	Region 3	
117.975-~~137~~136	AERONAUTICAL MOBILE (R) <u>AERONAUTICAL MOBILE-SATELLITE (R) MOD 5.208 MOD 5.208A</u> <u>MOD 5.209 ADD 5.C17</u> 5.111 5.200 5.201 5.202		
~~117.975~~136-137	AERONAUTICAL MOBILE (R) <u>AERONAUTICAL MOBILE-SATELLITE (R) MOD 5.208 MOD 5.208A</u> <u>MOD 5.209 ADD 5.C17 ADD 5.D17</u> 5.111 5.200 5.201 5.202		

MOD

5.208 The use of the bands 117.975-137 MHz by aeronautical mobile-satellite (R) service and 137-138 MHz by the mobile-satellite service is subject to coordination under No. **9.11A**. (WRC-9723)

MOD

5.208A In making assignments to space stations in the aeronautical mobile-satellite (R) service in the frequency band 117.975-137 MHz and 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. (WRC-1923)

MOD

5.209 The use of the band 117.975-137 MHz by the aeronautical mobile-satellite (R) service and 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-9723)

ADD

5.C17 The use of the frequency band 117.975-137 MHz by the aeronautical mobile-satellite (R) service is limited to internationally standardized aeronautical systems. The unwanted emissions from aeronautical mobile-satellite (R) service space stations operating in the frequency band 117.975-137 MHz should not be worse than the unwanted emissions in adjacent channels specified in ICAO SARPs for aeronautical mobile (R) service airborne transmitting stations operating in the same band. frequencies (see Section 6.3.4, Annex 10 to the Convention on International Civil Aviation — Aeronautical Telecommunications, Volume III — Communications Systems, ICAO). (WRC-23)

Reasons: To ensure that the new AMS(R)S allocation is used only by internationally standardised aeronautical systems.

ADD

5.D17 In the frequency band 117.975-136 MHz, systems operating in the aeronautical mobile-satellite (R) service shall ensure that their maximum level of their emissions above 137 MHz does not exceed [XXX]. Aeronautical mobile-satellite (R) service systems in the frequency band 117.975-137 MHz should, to the extent practicable, not claim protection from interference from aeronautical mobile (R) service and aeronautical mobile (OR) service systems operating in the common frequency band, as well as from aeronautical radionavigation service, mobile-satellite service (space- Earth), space operation service (space-to-Earth), space research service (space-to-Earth) and meteorological-satellite service (space-to-Earth) operating in adjacent frequency bands. (WRC-23)

Reasons: To ensure the protection of the incumbent services above 137 MHz.

2/1.7/5.3 For all Methods: SUP Resolution 428 (WRC-19)

SUP

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