CEPT ECC
Electronic Communications Committee

ECC Report 306

CEPT investigations on possible usage of low power audio PMSE in the band 960-1164 MHz

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EXECUTIVE SUMMARY

Introduction:

For many years, CEPT has worked on identifying suitable long-term solutions for wireless microphones to compensate for the reduced spectrum availability within the “UHF TV broadcast band", as a result of the introduction of IMT systems in the 800 MHz band, following decision at WRC-07, and planned complete reallocation of the 700 MHz band to the mobile service following decisions at WRC-12 and WRC-15.

CEPT discussions on the possible introduction of PMSE within the band 960-1164 MHz were triggered by the decision by Ofcom in the United Kingdom to make the band available in the UK to low power (<17 dBm) audio PMSE in March 2016. Ofcom (UK), was invited ECC #42, Stockholm, June 2016 to present the work undertaken.

Investigations on regulatory and legal issues on the feasibility of introducing low power audio PMSE in the band 960-1164 MHz:

Appendix 1 addresses various regulatory and legal issues with regard to the feasibility of introducing audio PMSE in the frequency band 960-1164 MHz.

Within the International Telecommunication Union (ITU) Radio Regulations (RRs) the frequency band 960-1164 MHz is allocated to the Aeronautical Radionavigation Service (ARNS), Aeronautical Mobile (Route) Service AM(R)S and in part to the Aeronautical Mobile-Satellite (Route) Service (AMS(R)S) (Earth-to-space). In addition, the frequency band is shared with Link 16, a military datalink and communications system and Radiolocation Systems for Short Range Navigation (RSBN), a military short-range navigation system. In addition to the ARNS, the adjacent band 1164-1215 MHz is also used by the radionavigation satellite service (RNSS).

ITU RR No. 4.4[1] provides the regulatory mechanism by which administrations could authorise PMSE within the frequency band 960-1164 MHz. However, should administrations allow access to this frequency band for PMSE then they need to ensure compliance with the provisions of ITU RR No. 4.10[2] (as is the case for Link16 operating in the band).

The ICAO Convention (Chicago Convention) [2] obliges States to undertake or adopt measures to ensure the safety of overflying aircraft. ICAO Annex 10 includes standards and recommended practices which require aircraft and aeronautical service providers on the ground to operate certain ICAO standardised equipment for Communication, Navigation and Surveillance (CNS).

As per the provisions contained in ICAO Annex 19, “Safety Management” each State, as part of its state safety programme, shall ensure that service providers under its authority implement a safety management system. As part of the safety management system a service provider needs to develop a safety case for each of the systems it operates including the necessary hazard identification and risk management processes[3].

Safety cases are required as means to support aircraft operations by structuring and documenting the demonstration of the safety of air traffic management services and systems. The introduction of a new system in the band 960-1164 MHz would change the RF environment thus invoking the requirement to reviewing the safety cases. The safety risk assessment developed by the aeronautical service provider will need to

[1] ITU RR No. 4.4: Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations

[2] ITU RR No. 4.10: Member States recognize that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies

[3] A safety case is a structured argument, supported by evidence, intended to justify that a system is acceptably safe for a specific application in a specific operating environment

demonstrate that an equivalent level of safety or an alternative acceptable means of compliance can be achieved.

Safety cases do not only take account of the technical environment, but also of human factor issues. If a new system such as PMSE were to be introduced in an aeronautical frequency band, the safety case analysis would need to take a number of additional factors into account, such as PMSE users not respecting their license conditions (intentional or unintentional wrong frequency selection, wrong location etc.). Similarly, the safety risk assessment would need to address the potential of PMSE equipment not meeting its specifications.

This Report identifies a number of regulatory issues which may affect the feasibility of audio PMSE sharing in the band. It also notes a number of risks and areas of concern that administrations should be aware of. Introducing a new non-aeronautical system in the 960-1164 MHz band without following an appropriate process, including safety assessment and validation, could impact the efficient use of spectrum designated for aeronautical use, and in the worst-case cause safety issues. The Report also identifies possible effects of potential harmful interference from PMSE on aeronautical systems and aircraft, including some elements addressing potential costs.

The potential for effectively sharing in the band depends on two conditions, firstly providing adequate protection to incumbent systems, and secondly the spectrum providing sufficient quality for PMSE to operate. A second order consideration is the quantity of spectrum that would be available for use by PMSE, as a small amount would not be operationally or economically viable.

Provided that international radio regulatory and aeronautical safety obligations are met, the introduction of low power audio PMSE in the band 960-1164 MHz is a sovereign decision on the designation of spectrum under the full liability of the state. Such a decision would involve agreement between the national spectrum regulator, the national aviation authorities, ANSPs and Defence.

Testing and trials of PMSE operation in the 960-1164 MHz band has been carried out in the United Kingdom since July 2016 by PMSE stakeholders.

Sharing studies:

Appendix 2 addresses numerous technical studies relative to the possible use of low power audio PMSE (excluding airborne use) in the frequency band 960-1164 MHz that have been carried out using different approaches and are available in the annexes 1 to 12. This has resulted in diverging conclusions on the possible use of low power audio PMSE in the 960-1164 MHz band taking into account sharing with the aeronautical and governmental services in this band and the RNSS in the adjacent band.

Due to the complexity of the systems under consideration and the use cases, no consensus has been reached on the following aspects:

- Input parameters;
- Coexistence scenarios, e.g. single vs. multiple systems and sources of interference;
- Propagation models and application of real effective antenna heights Above ground or Above Mean Sea Level;
- Real receiver sensitivity of operational receiver;
- Applicable antenna elevation contour pattern ;
- Building attenuation and the impact of the human body;
- Safety margin for civil aviation equipment.

In addition, consensus was not reached on the extent of the applicability of presented results from measurements and trials.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ACAS	Airborne Collision Avoidance System
ACIR	Adjacent Channel Interference Ratio
ACLR	Adjacent Channel Leakage Ratio
ACS	Adjacent Channel Selectivity
ADS-B	Automatic Dependent Surveillance-Broadcast (ADS-B)
AGL	Above Ground Level
AIM	Aeronautical Information Management
AM(R)S	Aeronautical Mobile (Route) Service
AMS(R)S	Aeronautical Mobile-Satellite (Route) Service
AMSL	Above Mean Sea Level
ANS	Air Navigation Services
ANSP	Air navigation Service provider
APNT	Alternative Position Navigation and Timing
ARNS	Aeronautical Radionavigation Service
ARP	Airport Reference Point
ASOP	Acquire Stable Operating Point
ATAG	Air Transport Action Group
ATC	Air Traffic Control
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATSEP	Air traffic safety electronics personnel
BEL	Building Entry Loss
BRE	Beacon Reply Efficiency
BW	Bandwidth
C/I	Carrier to Interference
CAA	Civil Aviation Authority
CEPT	European Conference of Postal and Telecommunications Administrations
CIS	Commonwealth of Independent States
CMA	Continuous Monitoring Approach
CNPC	Control and Non-Payload Communications
CNS	Communication, Navigation and Surveillance
CRCO	Central Route Charges Office
CS	ITU Constitution

Abbreviation	Explanation
dBc	decibels below carrier
DME	Distance Measuring Equipment
DOM	Depth of Modulation
DTT	Digital Terrestrial Television
DUT	Device Under Test
e.i.r.p.	Equivalent Isotropically Radiated Power
EASA	European Aviation Safety Agency
EC	European Commission
ECA	European Common Allocation table
ECC	Electronic Communications Committee
EFIS	ECO Frequency Information System
EME	ElectroMagnetic Environment
EMI	ElectroMagnetic Interference
ESARR	European SAfety Regulatory Requirement
ESE	Extraneous Signal Environment
EU	European Union
EUR	Euros (€)
EUROCAE	EURopean Organisation for Civil Aviation Equipment
EUROCONTROL	European Organisation for the Safety of Air Navigation
EUT	Equipment Under Test
f	frequency
FABEC	Functional Airspace Block Europe Central
FABs	Functional Airspace Blocks
FCA	Frequency Clearance Agreement
FIS-B	Flight Information Service - Broadcast
FL	Flight Level
FSL	Free Space Loss
GALILEO	European Global Satellite Navigation System
GANP	Global Air Navigation Plan
GBP	Pound sterling (£)
GHz	GigaHertz – 1 billion cycles per second
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema or Global Navigation Satellite System
GND	Ground
GNSS	Global Navigation Satellite System
GPS	Global Positioning System

Abbreviation	Explanation
HF	High Frequency
HLA	High Level Agreement
I/N	Interference to Noise
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IEM	In Ear Monitor
IFF	Identification Friend or Foe
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	inertial navigation system
IOSA	IATA Operational Safety Audit
ISAGO	IATA Safety Audit for Ground Operations
ITU	International Telecommunication Union
JTIDS	Joint Tactical Information Distribution System
kHz	kilohertz
L-DACS	L-band Digital Aeronautical Communication System
MAB	Military ATM Board
MCL	Minimum Coupling Loss
MDS	Minimum Detectable Signal
MHz	megahertz – 1 million cycles per second
MIDS	Multifunctional Information Distribution System
MLAT	Multilateration system
MM	Maritime Mobile
MoC	Means of Compliance
MOD	Ministry of Defence
MOPS	Minimum Operational Performance Standards
MoU	Memorandum of Understanding
MSL	Mean Sea Level
MTL	Minimum Triggering Level
MUAC	Maastricht Upper Area Control Centre
NATO	North Atlantic Treaty Organization
NJFA	NATO Joint Civil/Military Frequency Agreement
NM	Nautical mile
NSAs	National Supervisory Authorities
OOB	Out-Of-Band

Abbreviation	Explanation
OOBE	Out-Of-Band Emission
PAM	Pulse Amplitude Modulation
PANS	Procedures for Air Navigation Services
PAPR	Peak-to-Average Power Ratio
PBN	Performance Based Navigation
PC	Public consultation
PMSE	Programme Making and Special Events
PNT	Positioning, Navigation and Timing
PSR	Primary Surveillance Radar
QMS	Quality management system
R&D	Research and Development
RF	Radio Frequency
RFI	Radio Frequency Interference
RLOS	Radio Line Of Sight
RNAV	Requirements for area navigation
RNP	Required navigation performance
RNSS	Radionavigation satellite service
RNSS	Radio Navigation Satellite Service
RPAS	Remotely Piloted Aircraft System
RPG	Reference Pulse Groups
RR	Radio Regulations
RSBN	Radiolocation Systems for Short Range Navigation
RTCA	Radio Technical Commission for Aeronautics
RX	Receiver
SAFIRE	Spectrum and Frequency Information Resource
SARPs	Standards and Recommended Practices
SES	Single European Sky
SESAR	European Sky ATM Research
SINAD	Signal to Noise And Distortion
SJU	SESAR Joint Undertaking
SMS	Safety Management System
SSC	Single Sky Committee
SSR	Secondary Surveillance Radar
T&D	Test and Development
TACAN	Tactical Air Navigation

Abbreviation	Explanation
TCAS	Traffic Collision Avoidance System
TDD	Time Division Duplex
TIS	Traffic Information Service
TSDF	Time Slot Duty Factor
TSO	Technical Standard Order
TTA	Time To Acquire
TV	Television
TV	Television
Tx	Transmitter
UAS	Unmanned Aircraft System
UAT	Universal Access Transceiver
UHF	Ultra High Frequency
UHF	Ultra High Frequency
UK	United Kingdom
UN	United Nations
USD	United States Dollar (USD)
USOAP	Universal Safety Oversight Audit Programme
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
W	Watt
WAM	Wide Area Multilateration
WG FM	Working Group Frequency Management
WG SE	Working Group Spectrum Engineering
WRC	World Radiocommunication Conference

APPENDIX 1: INVESTIGATIONS ON REGULATORY AND LEGAL ISSUES ON THE FEASIBILITY OF INTRODUCING LOW POWER AUDIO PMSE IN THE BAND 960-1164 MHZ

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0 INTRODUCTION

Background

Within CEPT, spectrum for audio PMSE has been identified and included in ERC Recommendation 25-10 [3]. Spectrum availability for audio PMSE in the band 470-790 MHz is reducing as a consequence of the WRC-12 and WRC-15 decisions to allocate the 700 MHz band (694-790 MHz) for terrestrial systems capable of providing wireless broadband electronic communications services.

Testing and trials of PMSE operation in the 960-1164 MHz band has been carried out in the UK since July 2016 by PMSE stakeholders in a variety of scenarios. Trials have predominately been indoors within studios, with a limited number of outdoor deployments. In addition, PMSE stakeholders have also carried out spectrum monitoring (from the perspective of interference into PMSE).

Incumbent use

The 960 MHz band is used by a number of aeronautical safety and regularity of flight systems, for both civil and military purposes, to provide Communications, Navigation and Surveillance (CNS) which require an appropriate coordination between all of them.

The main use of the band is for Distance Measuring Equipment (DME). This is an interrogator (airborne) / transponder (ground based) system which provides an aircraft with its slant range from the ground transponder. The aircraft interrogates the ground transponder on a frequency and the transponder replies on a separate frequency separated by 63 MHz. The military system TACAN is similar in operation to DME but with additional modulation which allows an aircraft to determine its bearing from the transponder as well as its slant range.

In addition to DME there are a number of systems which operate on 1030 MHz and 1090 MHz. Principally this is Secondary Surveillance Radar (SSR) which is also an interrogator/transponder system, however, in this case the interrogator is ground based and transmits on 1030 MHz using a rotating, high gain antenna, and the aircraft responds on 1090 MHz. The radar is then able to determine the range and bearing of the aircraft. Aircraft replies can also include additional data such as aircraft identity, altitude and speed.

In addition to SSR, a number of other systems also utilise 1030 MHz and 1090 MHz such as multilateration systems and Airborne Collision Avoidance and Traffic Collision Avoidance Systems (ACAS and TCAS). Automatic Dependent Surveillance-Broadcast (ADS-B) provides aircraft identity, aircraft derived position plus other data (this is also receivable in space). The military also use 1030 MHz and 1090 MHz for Identification Friend or Foe (IFF).

The band 960-1215 MHz is allocated to the Aeronautical Radionavigation Service (ARNS), WRC-07 allocated the 960-1164 MHz band to the aeronautical mobile (route) service (AM(R)S) subject to footnote 5.327A ("The use of the band 960-1164 MHz by the aeronautical mobile (R) service is limited to systems that operate in accordance with recognized international aeronautical standards. Such use shall be in accordance with Resolution 417 (WRC-07)"). WRC-15 revised Resolution 417 and in the current edition of the Radio Regulations, footnote 5.327A refers to the revised Resolution 417. The band has been identified for use by L-DACS (L-band Digital Aeronautical Communication System). While not currently operational, standardisation work is underway in ICAO and the system is expected to be introduced in the mid-2020s.

WRC-15 allocated part of the 960-1164 MHz band to the Aeronautical Mobile-Satellite (Route) service (AMS(R)S) (Earth-to-space) in all three ITU Regions.

The adjacent band 1164-1215 MHz is used by the Radionavigation Satellite Service (RNSS) in addition to DME and TACAN. Galileo band E5a (i.e. centre frequency at 1176.45 MHz and receiver reference bandwidth of 20.46 MHz) and GPS band L5 (i.e. 1176.45 MHz with a bandwidth of 12.5 MHz) are immediately adjacent (1164-1189 MHz).

There are other aeronautical systems operating in 960 MHz band, and a full list of incumbent and future RD systems is provided in section 2.

Regulatory aspects

The 960 MHz band is subject to regulations under a number of regulatory bodies. Some of these relate directly to the spectrum band itself, i.e. the ITU Radio Regulations, and others relate to aeronautical use of the band, i.e., ICAO's responsibility relating to civil aviation Standards and Recommended Practices (SARPs) and policies.

In accordance with current usage of the 960 MHz band, other organisations are involved in the regulatory process. It is important to take into account these regulations if considering introducing audio PMSE into the 960 MHz band.

1 REGULATORY AND OPERATIONAL RESPONSIBILITY OF RELEVANT INSTITUTIONS

1.1 INTERNATIONAL TELECOMMUNICATION UNION (ITU)

1.1.1 Constitution and Convention

The International Telegraph (later Telecommunication) Convention, today the Constitution and Convention of ITU, is the basic treaty that establishes the legal basis for the Union and defines its purpose and structure.

A thoroughly revised Constitution and Convention of the International Telecommunication Union was adopted at the 1992 Additional Plenipotentiary Conference held in Geneva. Subsequent plenipotentiary conferences have adopted only amending instruments to the 1992 documents. The Constitution and Convention currently in force are the Constitution and Convention of the International Telecommunication Union (Geneva, 1992) as amended by subsequent plenipotentiary conferences [1].

The ITU Constitution (CS) states:

- CS Article 40: Priority of Telecommunications Concerning Safety of Life:
  - 191 International telecommunication services must give absolute priority to all telecommunications concerning safety of life at sea, on land, in the air or in outer space, as well as to epidemiological telecommunications of exceptional urgency of the World Health Organization.
- CS No. 1003 (also RR No. 1.169):
  - 1003 Harmful Interference: Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs or repeatedly interrupts a radiocommunication service operating in accordance with the Radio Regulations.

1.1.2 ITU Radio Regulations

The ITU Radio Regulations (RR) also state:

- ITU RR No. 4.4: Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations;
- ITU RR No. 4.10: Member States recognize that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies;
- ITU RR Article 43: "Special rules relating to the use of frequencies"
  - 43.1 § 1 Frequencies in any band allocated to the aeronautical mobile (R) service and the aeronautical mobile-satellite (R) service are reserved for communications relating to safety and regularity of flight between any aircraft and those aeronautical stations and aeronautical earth stations primarily concerned with flight along national or international civil air routes.

ITU RR Article 5 (see Table 1) states that the band 960-1164 MHz is allocated to the Aeronautical Radionavigation Service (ARNS), Aeronautical Mobile en-route service AM(R)S and in part to the Aeronautical mobile-satellite en-route service (AMS(R)S) (Earth-to-space) in all three ITU Regions.

Moreover, the adjacent band 1164-1215 MHz is allocated to the radionavigation-satellite service (RNSS) space-to-Earth) and used by GNSS systems and to the Aeronautical Radionavigation Service (ARNS).

Table 1: RR allocation in the band 960-1164 MHz

Frequency band	RR Allocation to services
960-1164 MHz	AERONAUTICAL MOBILE (R) 5.327A AERONAUTICAL RADIONAVIGATION 5.328 5.328AA
5.327A: The use of the frequency band 960-1164 MHz by the aeronautical mobile (R) service is limited to systems that operate in accordance with recognized international aeronautical standards. Such use shall be in accordance with Resolution 417 (Rev.WRC-15) (WRC-15). 5.328: The use of the band 960-1 215 MHz by the aeronautical radionavigation service is reserved on a worldwide basis for the operation and development of airborne electronic aids to air navigation and any directly associated ground-based facilities (WRC-2000). 5.328AA: The frequency band 1 087.7-1 092.3 MHz is also allocated to the aeronautical mobile-satellite (R) service (Earth-to-space) on a primary basis, limited to the space station reception of Automatic Dependent Surveillance-Broadcast (ADS-B) emissions from aircraft transmitters that operate in accordance with recognized international aeronautical standards. Stations operating in the aeronautical mobile-satellite (R) service shall not claim protection from stations operating in the aeronautical radionavigation service. Resolution 425 (WRC-15) shall apply (WRC-15).	

WRC-07[4] has allocated the band 960-1164 MHz to the aeronautical mobile (R) service (AM(R)S) in order to make available this frequency band for new AM(R)S systems, and in doing so enabled further technical developments, investments and deployments by the aeronautical sector. This WRC-07 AM(R)S allocation in the band 960-1164 MHz is limited to systems operating in accordance with international aeronautical standards.

This AM(R)S allocation is to support the introduction of applications and concepts in air traffic management supporting safety critical aeronautical communication.

1.2 INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO)

ICAO is a specialised agency of the United Nations, established by States in 1944 to manage the administration and governance of the Convention on International Civil Aviation [1], also known as the Chicago Convention.

1.2.1 ICAO Standards and Recommended Practices (SARPs)

ICAO works with the Convention's 193 Member States and industry groups to reach consensus on Standards and Recommended Practices (SARPs) and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector.

The SARPs contained in the Annexes to the Convention on International Civil Aviation, constitute the rule of law for international civil aviation. These SARPs and policies, as used by the ICAO Member States, ensure that their national civil aviation operations and regulations conform to global norms, which in turn permits more than 120,000 flights every day in aviation's global network to operate safely and reliably in every region of the world.

1.2.2 SARPs for Radiocommunication and Radionavigation systems

The SARPs for radiocommunication and radionavigation systems (in aeronautical terms: Communication, Navigation and Surveillance (CNS) systems), as contained in Annex 10 "Aeronautical Telecommunications" [74], are developed in accordance with Article 37 of the ICAO Convention [1] for the purpose of ensuring the safety and regularity of air navigation. In addition to the Radio Regulations, the SARPs and related documents

[4] RESOLUTION 417 (WRC-15): Use of the band 960-1164 MHz by the aeronautical mobile (R) service https://www.itu.int/net/ITU-R/conferences/docs/ties/wrc-res-417-en.pdf

specify interface and performance standards for internationally agreed aeronautical systems to ensure that they meet the specific operational requirements of those aeronautical systems. Several systems used for aeronautical radionavigation and radiocommunication are operated in the band 960-1215 MHz, see section 2 for further details.

1.2.3 SARPs for Safety Management

The SARPs contained in Annex 19 "Safety Management" [73], outline the safety management responsibilities of States, aeronautical service providers and aircraft operators, ensuring preventative action to avoid any issue which would compromise the safety of aeronautical operations. Additional provisions on safety management are provided in ICAO Doc 9859 [100]. Safety Cases are a means of structuring and documenting the demonstration of the safety of air traffic management services and systems as well as aircraft operations. Examples of a requirement for a Safety Case assessment include: Whenever a new system or service is taken into use by an aeronautical operator, e.g. radiocommunication, radionavigation aids or surveillance systems; whenever there may be a significant change to the quality of the service provided by those systems; whenever an aircraft operator starts operating on a new air route or whenever there may be a significant change to operational parameters associated with that air route, such as reduced reliability of radionavigation aids along the air route.

1.2.4 "No country left behind" initiative

In addition to its core work, ICAO also coordinates assistance and capacity building for States in support of numerous aviation development objectives; produces global plans to coordinate multilateral strategic progress for safety and air navigation; monitors and reports on numerous air transport sector performance metrics; and audits States' civil aviation oversight capabilities in the areas of safety and security.

1.3 EUROPEAN CONFERENCE OF POSTAL AND TELECOMMUNICATIONS ADMINISTRATIONS (CEPT)

As refers to ERC Report 25, the ECA table [4], the allocation for 960-1164 MHz at CEPT level refers to ITU with additional footnote regarding the harmonisation by NATO in this band.

Table 2: ECA table allocations and applications in the band 960-1164 MHz

960-1164 MHz			
RR (including ITU Region 1) Allocation and RR footnotes applicable to CEPT	European Common Allocation and ECA Footnotes	Applications	Notes
AERONAUTICAL MOBILE (R) 5.327A AERONAUTICAL RADIONAVIGATION 5.328 5.328AA	AERONAUTICAL MOBILE (R) 5.327A AERONAUTICAL RADIONAVIGATION 5.328 5.328AA ECA36	Aeronautical military systems Aeronautical navigation	Military use includes JTIDS/MIDS Including DME, SSR and TACAN

5.327A: The use of the frequency band 960-1164 MHz by the aeronautical mobile (R) service is limited to systems that operate in accordance with recognised international aeronautical standards. Such use shall be in accordance with Resolution 417 (Rev.WRC-15). (WRC-15).

5.328: The use of the band 960-1 215 MHz by the aeronautical radionavigation service is reserved on a worldwide basis for the operation and development of airborne electronic aids to air navigation and any directly associated ground-based facilities. (WRC-2000).

5.328AA: The frequency band 1 087.7-1 092.3 MHz is also allocated to the aeronautical mobile-satellite (R) service (Earth-to-space) on a primary basis, limited to the space station reception of Automatic Dependent Surveillance-Broadcast (ADS-B) emissions from aircraft transmitters that operate in accordance with recognised international aeronautical standards. Stations operating in the aeronautical mobile-satellite (R) service shall not claim protection from stations operating in the aeronautical radionavigation service. Resolution 425 (WRC-15) shall apply. (WRC-15).

ECA36: Frequency band, which has been harmonised by NATO and NATO member nations for military use as defined in the NATO Joint Civil/Military Frequency Agreement (NJFA) 2014. Note: A public version of the NJFA 2014 has been provided by NATO and presented to ECC in February 2017.

1.4 NATIONAL REGULATORY STATUS IN CEPT

In CEPT countries, the band 960-1164 MHz is allocated to the aeronautical mobile en-route, aeronautical radionavigation services, and in part to the Aeronautical Mobile satellite en-route service (Earth-to-space).

One administration has made the decision to make parts of this band available for audio PMSE[5]. According to EFIS[6], one administration has made part(s) of this band available for fixed services.

In many CEPT administrations, this frequency band is shared between Civil Aviation and the Defence systems based on national joint agreements and on mutually agreed sharing procedures.

1.5 OTHER ORGANISATIONS

1.5.1 European Union (EU)

1.5.1.1 Single European Sky (SES)

Within the EU, Single European Sky (SES)[7] legislation (e.g. Commission Implementing Regulation 2017/373 [20]) is in force and may also have more widespread applicability. This regulatory regime requires that hazard identification as well as risk assessment and mitigation are systematically conducted for any changes to those parts of the Air Traffic Management (ATM) functional system and supporting arrangements within their managerial control by air traffic service providers (ANSPs) before bringing new ATM facilities into use or when changes to existing facilities are foreseen; in the present context such changes to be investigated may include changes to the RF environment.

Since 2004, the European Union (EU) has gained competences in ATM and the decision-making process has moved away from an intergovernmental practice to the EU framework. The EU's main objective is to reform ATM in Europe in order to cope with sustained air traffic growth and operations under the safest, most cost- and flight-efficient and environmentally friendly conditions. This implies de-fragmenting the European airspace, reducing delays, increasing safety standards and flight efficiency to reduce the aviation environmental footprint, and reducing costs related to service provision. Achievements have already been made at operational, technological and institutional levels; efforts are ongoing to maximise the benefits of activities initiated under the SES framework.

The SES legislative framework consists of four Basic Regulations (N° 549/2004 [8], 550/2004 [9], 551/2004 [10] and 552/2004 [11]) covering the provision of air navigation services (ANS), the organisation and use of airspace and the interoperability of the European Air Traffic Management Network (EATMN). The four Regulations adopted in 2004 (the SES I Package) were revised and extended in 2009 with Regulation (EC) n° 1070/2009 [12] aimed at increasing the overall performance of the air traffic management system in Europe (the SES II Package). On this basis, the Commission adopted and implemented extensive and comprehensive implementing legislation; this framework also includes more than 20 Implementing Rules and Community Specifications ("technical standards") adopted by the European Commission in view of ensuring the interoperability of technologies and systems.

Major developments have been possible due to the extensive involvement of stakeholders from the ATM community: industry partners, air navigation service providers (ANSPs), national supervisory authorities

[5] In the one example of PMSE sharing in the 960 MHz band, guard bands of ±15 MHz have been introduced to protect 1030/1090 MHz and a 10 MHz guard band at 1154 MHz is applied to protect RNSS above 1164 MHz. To protect ground station receivers, additional frequency restrictions based on geographic exclusion zones are also implemented e.g. ±25 MHz guard band at 1090 MHz within 500 m of an SSR ground receiver.

[6] www.efis.dk (see applications of Georgia for military use)

[7] https://ec.europa.eu/transport/modes/air/ses_en

(NSAs[8]), social dialogue with staff unions, airport authorities, the military and the certification authorities, and enhanced cooperation with EUROCONTROL.

The SES framework has been supplemented by an integrated approach towards safety by the extension of the competencies of the EASA in the field of aerodromes, air traffic management and air navigation services, through the establishment of a joint undertaking (JU) on R&D), the SESAR JU (SESAR standing for the Single European Sky ATM Research) and of a SESAR Deployment Manager. A Network Manager for the European ATM network has been created, while an independent Performance Review Body (PRB) supports the Commission in the development and management of the SES performance scheme in which Functional Airspace Blocks (FABs) have a key role to play.

The overall SES objectives will be achieved through a holistic approach that encompasses five interrelated pillars: the performance-based regulatory framework, the safety pillar, the technological contribution, the human factor and the optimisation of airport infrastructure.

The SES does not stop at the border of the European Union. Its extension to third 'neighbouring' countries primarily relies on the EU's policy in the field of international relations. This policy, which gives priority to the association and/or integration of third countries into the EU legal framework, also considers the added value of regional cooperation activities carried out at the level of international organisations, such as the ICAO and EUROCONTROL. EU representatives are active in these organisations to ensure overall consistency between its action in the external field and action undertaken under the aegis of such organisations. Cooperative operational arrangements with ANSPs from key partners of the EU are also being promoted by the Commission as a significant task of the Network Manager in order to better manage intercontinental traffic to/from the EU and improve the performance of the European ATM network.

The Single European Sky (SES) is an ambitious initiative launched by the European Commission in 2004 to reform the architecture of European ATM. It proposes a legislative approach to meet future capacity and safety needs at a European rather than local level.

The key objectives of the SES are:
- to restructure European airspace as a function of air traffic flows;
- to create additional capacity;
- to increase the overall efficiency of the air traffic management system.

In order to fulfil these objectives, the European Commission set the following high-level goals:
- enable a three-fold increase in capacity which will also reduce delays both on the ground and in the air;
- improve safety by a factor of 10;
- enable a 10% reduction in the effects flights have on the environment;
- provide ATM services to the airspace users at a cost of at least 50% less.

EU Co-operation with EUROCONTROL[9]

The European Commission is working closely together with the European Organisation for the Safety of Air Navigation (EUROCONTROL) to achieve the objectives of the Single European Sky Initiative.

Over the last decade, several elements of the EUROCONTROL regime, such as the charging and performance review and the common air traffic flow management system, have been successfully enhanced under EU law. As a result, EUROCONTROL performs tasks now under the SES legislation. Starting from 2010, the organisation has been charged with four major tasks/roles:

1 technical support to the European Commission and EASA for assisting them in their regulatory actions;

[8] National Supervisory Authorities (NSAs) ensure the supervision of the regulatory framework in all Member States. They are responsible, in particular, for certifying and overseeing air navigation service providers as well as for the preparation of national performance plans of the Member States concerned

[9] https://ec.europa.eu/transport/modes/air/single_european_sky/co-operation_eurocontrol_hr

2 the Performance Review Body to assist the Commission in the development and implementation of the performance scheme (designation by the Commission until 2016);

3 the Network Manager for the ATM Network functions;

4 furthermore, EUROCONTROL plays an important role in the SESAR Joint Undertaking's activities as a founding member together with the EU (since 2007).

In December 2012, a High Level Agreement (HLA) was signed which recognises the contribution that each organisation can make to European ATM. The respective roles of the EU as single pan-European regulator and that of EUROCONTROL in technical support of the achievement of the objectives of the SES policy were reaffirmed in this agreement.

The European Union will become a member of EUROCONTROL. Currently the Union’s membership is being implemented on a provisional basis to enable the Union's participation in EUROCONTROL governing bodies. Full membership will be realised when all EUROCONTROL member states have ratified the protocol on the accession of the European Union to the EUROCONTROL convention.

1.5.1.2 European Aviation Safety Agency (EASA)

The European Aviation Safety Agency (EASA) is established under the European Regulation (EC) No. 216/2008 [13] on common rules in the field of civil aviation and establishing a European Aviation Safety Agency in order to:

- ensure the highest common level of safety protection for EU citizens;
- ensure the highest common level of environmental protection;
- establish a single regulatory and certification process among Member States;
- facilitate the internal aviation single market and create a level playing field;
- work with other international aviation organisations and regulators.

EASA undertakes the following activities:

- draft implementing rules in all fields pertinent to the EASA mission;
- certify and approve products and organisations, in fields where EASA has exclusive competence (e.g. airworthiness);
- provide oversight and support to Member States in fields where EASA has shared competence (e.g. Air Operations and Air Traffic Management);
- promote the use of European and worldwide standards;
- cooperate with international actors in order to achieve the highest safety level for EU citizens globally (e.g. EU safety list and Third Country operators authorisations);

The EU and EASA rules ensure that the flight is safe for passengers and crew, and free from risk of damage to persons and property on the ground. Building on the ICAO regulatory framework, the processes of airworthiness approval, equipment type certification and safety management are described in detail in these rules. As a part of this regulatory process, the radio installations must conform to agreed performance standards, must operate in correct frequency bands, must be licensed by appropriate authorities, and be operated by licensed personnel.

To illustrate the above: The radio in an aircraft requires the assurance of correct functioning after its installation, which includes its performance as a working communications or radionavigation system, as well as its compatibility with other on-board radio and electronic systems. Prior to its installation, the installation must have received approval issued by EASA.

The EASA rules ensure that the flight is safe for passengers and crew, and free from risk of damage to persons and property on the ground. As a part of this regulatory process, the radio installations must conform to agreed performance standards, must operate in correct frequency bands, must be licensed by appropriate authorities, and be operated by licensed personnel.

1.5.1.3 Single European Sky ATM Research (SESAR)

The SESAR Joint Undertaking (SJU) was established under Council Regulation (EC) 219/2007 [14] of 27 February 2007 as modified by Council Regulation (EC) 1361/2008 [15] (SJU Regulation) and last amended by the Council Regulation (EU) 721/2014 [16].

As the technological pillar of Europe’s ambitious Single European Sky (SES) initiative, SESAR is the mechanism which coordinates and concentrates all EU research and development (R&D) activities in ATM, pooling together a wealth of experts to develop the new generation of ATM. Today, SESAR unites around 3.000 experts in Europe and beyond.

In 2007, the SESAR Joint Undertaking was set up in order to manage this large scale and truly international public-private partnership.

Air traffic management (ATM) is an essential part of European air transport and aviation, connecting cities and people citizens as well as boosting jobs and growth. While unseen and unnoticed by passengers, ATM plays several specific and important roles:

- acts as a guardian of safety;
- connects European cities and Europe with the rest of the world;
- addresses climate change by enabling green and efficient routes;
- maximises current infrastructure while delivering advanced information services;
- acts as a catalyst for Europe’s competitiveness and innovative capacity.

The objective of SESAR is to modernise European ATM by defining, developing and delivering new or improved technologies and procedures (SESAR Solutions).

On 10 March 2004 the European Parliament and the Council adopted Regulation (EC) No 549/2004 [8] laying down the framework for the creation of the Single European Sky (the framework Regulation):

a) Regulation (EC) No 550/2004 [9] on the provision of air navigation services in the single European sky (the service provision Regulation) (2);

b) Regulation (EC) No 551/2004 [10] on the organisation and use of the airspace in the single European sky (the airspace Regulation);

c) Regulation (EC) No 552/2004 [11] on the interoperability of the European Air Traffic Management network (the interoperability Regulation).

The project to modernise air traffic management in Europe, (the SESAR project), is the technological element of the single European sky. by 2020, it aims to give the Community a high-performance air traffic control infrastructure which will enable the safe and environmentally friendly development of air transport, benefiting fully from the technological advances of programmes.

Following the European Community's accession to EUROCONTROL, the Commission and EUROCONTROL have signed a cooperation framework agreement for the implementation of the single European sky and for research and development activities in the field of air traffic control.

The SESAR project includes evaluation of LDACS under SESAR 2020 project (P14.02.01 - FCI Terrestrial Data Link) which is a solution of the PJ14 EECNS [75]. PJ14 EECNS project providing advanced, integrated and rationalised aviation infrastructure for Communication, Navigation and Surveillance (CNS), and providing the underlying technical capabilities to meet the operational improvements described in the European ATM Master plan.

As the technological pillar of the Single European Sky, SESAR (Single European Sky ATM Research) is one of the key contributors with goals through the delivery and deployment of SESAR Solutions with demonstrated and measurable performance benefits. The SESAR performance ambition for 2035 is as follows:

- efficiency and predictability: up to 6% reduction in flight times and up to 30% reduction in departure delays;
- environment: up to 10% reduction in fuel burn and CO^2 emissions;

- capacity: a system capable of handling up to 100% more traffic, and up to 10% additional flights landing at congested airports;
- cost-efficiency: up to 40% reduction in air navigation services costs per flight;
- safety: improved by a factor of 3-4 times coping with the expected traffic increase.

1.5.1.4 Spectrum needs for other specific Union policies

Decision No 243/2012/EU [17] of The European Parliament and of the Council of 14 March 2012 established a multiannual radio spectrum policy programme which includes:

Article 8: Spectrum needs for other specific Union policies:

1. Member States and the Commission shall ensure spectrum availability and protect the radio frequencies necessary for monitoring the Earth's atmosphere and surface, allowing the development and exploitation of space applications and improving transport systems, in particular for the global civil navigation satellite system established under the Galileo programme, for the European Earth monitoring programme (GMES), and for intelligent transport safety and transport management systems.

Galileo is an RNSS system that operates in a range of bands including 1164-1189 MHz.

1.5.2 EUROCONTROL

EUROCONTROL is an intergovernmental organisation with 41 Members and 2 Comprehensive Agreement States. EUROCONTROL is committed to building, together with its partners, a Single European Sky that will deliver the air traffic management (ATM) performance required for the twenty-first century and beyond.

EUROCONTROL has multiple expertise; covering both operational and technical elements; advising on both civil and military aspects of ATM; having experience at bringing States with different needs together for a common goal.

EUROCONTROL helps its Member States to run safe, efficient and environmentally-friendly air traffic operations throughout the European region. In working together with its partners to deliver a Single European Sky that will help overcome the safety, capacity and performance challenges facing European aviation in the 21st century.

EUROCONTROL supports the European Commission, EASA and National Supervisory Authorities in their regulatory activities.

EUROCONTROL is actively involved in research, development and validation and make a substantial contribution to the SESAR Joint Undertaking aiming to deliver tangible results which will improve the ATM system's performance in the medium term and in the long term.

EUROCONTROL has a unique platform for civil-military aviation coordination in Europe.

The Single European Sky (SES) framework Regulation establishes a harmonised regulatory framework in conjunction with the airspace, service provision and interoperability Regulations and calls for the adoption of implementing rules by the European Commission.

EUROCONTROL develops specifications which can act as Means of Compliance (MoC) to SES regulations. EUROCONTROL also develops guidance material and provides implementation support activities to its stakeholders.

Under the SES framework, the European Commission may develop the implementing rules themselves, but may also issue a mandate to an organisation which is then tasked with implementing rule drafting. EUROCONTROL is one such organisation and has developed numerous draft regulations which were submitted by the EC to the Single Sky Committee (SSC) for its formal opinion.

EUROCONTROL operates a number of stakeholder consultation meetings involving Air Navigation Service Providers (ANSP), regulators, aircraft operator and airport representatives. These forums help shape policy advice for the EU, EASA and ICAO, and are instrumental in setting research priorities and agreeing domain-specific strategies, such as the planned evolution of navigation services to support Air Traffic Management (ATM) improvements. Decisions at forums such as the Navigation Steering Group and its parent CNS Infrastructure team help determine the European ATM Master Plan, consistent with the ICAO Global Air Navigation Plan (GANP) [83].

1.5.2.1 Network Manager Directorate

In its role as the SES Network Manager, it coordinates network management functions relating both to network planning (airspace design) and operations (Air Traffic Flow and Capacity Management (ATFCM), Aeronautical Information Management (AIM)) and also to the coordinated pan-European deployment of operational and technical improvements, including those related to SESAR. It provides support to airport activities; it coordinates safety actions and the management of spectrum, frequencies and scare resources. It also delivers support services to air navigation service providers and FABs (when required) as well as ATM training; finally it monitors the network management contribution to the performance targets of the SES.

The Network Manager has extended the role of the former Central Flow Management Unit and now proactively manages the entire ATM Network (with nearly ten million flights every year), in close liaison with the air navigation service providers, airspace users, the military and airports.

The network functions have been created by the Single European Sky II legislation with the strong support of stakeholders. They are aiming to:

- develop and create Route Network Design;
- organise the management and operations of the functions, including ATFM;
- provide a central function for Frequency Allocation;
- coordinate the improvement of SSR Code Allocation.

The Network Functions Implementing Rule (Commission Regulation (EU) No 677/2011 [18]) lists at Article 4 the tasks to be performed by the Network Manager in relation to the functions listed above. The Network Manager also supports the work of the European Aviation Crisis Coordination Cell, responsible for mitigating events having a negative impact on aviation at network level and to coordinate appropriate responses between Member States; it also contributes to the deployment of SESAR.

The Network Manager, play a vitally important role for the competitiveness of Europe's aviation industry, is a key actor for the operational network performance in the areas of capacity and flight efficiency.

The European Commission’s Single European Sky (SES II) foresaw the creation of a Network Manager as a centralised function. The Network Manager is the operational arm of the SES and manages air traffic management network functions (airspace design, flow management) as well as scarce resources (transponder code allocations, radio frequencies), as defined in Commission Regulation (EU) N° 677/2011.

The European Commission nominated EUROCONTROL as the Network Manager in 2011 (see Commission Decision on 7 July 2011C(2011) 4130 final [19]), with a mandate that runs until the end of the Performance Scheme’s second Reference Period - that is, until 31 December 2019. EUROCONTROL has been undertaking major organisational changes to ensure its re-designation as Network Manager for the period beyond 31 December 2019.

The Network Manager addresses performance issues strategically, operationally and technically. Its overarching mission is to contribute to the delivery of air traffic management’s (ATM) performance in the pan-European network in the areas of safety, capacity, environment/flight efficiency and cost-effectiveness.

With the comprehensive picture of the European ATM network and unique in-depth expertise, the Network Manager’s priority is to forge operational partnerships and to foster cooperative decision-making, both of which are needed to achieve the performance targets in a transparent and impartial way.

The European ATM network includes all the European Union's 28 and EUROCONTROL's 41 Member States, as well as others which have bilateral agreements with the Network Manager.

Besides the binding legal acts governing the network management functions and tasks of all actors involved, the Network Manager needs to develop the tools to execute those functions and tasks and accomplish the Strategic Objectives as defined in the Network Strategy Plan. Among the contributors are the Network Strategic Projects. They are the main operational and technical evolutions led by the Network Manager. They include network-wide deployment of those technological developments and operational procedures in the course of a Reporting Period.

1.5.3 NATO

The primary role of NATO military forces is to promote peace and to guarantee the territorial integrity, political independence and security of member states. In support of this, NATO use of the radio frequency (RF) spectrum has to be in accordance with ITU Radio Regulations (RR) and also in accordance with NATO military spectrum and frequency doctrine, policies and procedures. Both of these types of governing documents are applicable in times of peace, crisis and war.

The Civil/Military Spectrum Capability Panel (CaP3) is the sole competent source of advice and decisions on the management of the RF spectrum within the Alliance. It works with the NATO Military Committee (MC), the C3 Board (C3B) and the NATO Command Structure (NCS) to satisfy NATO RF spectrum requirements. The CaP3 is composed of representatives from the military and civil spectrum management authorities of NATO member and partner nations, and the Strategic Commands (SCs).

Within NATO the national administrations have agreed to the military use of certain designated frequency bands throughout NATO Europe. This agreement is recorded in the NATO Joint Civil/Military Frequency Agreement (NJFA). The NJFA entries are also reflected in the ECA (ERC Report 25 [4]). In the frequency band 960-1164 MHz, military use includes DME, TACAN, SSR, IFF and also JTIDS/MIDS.

NATO member nations delegated the control of certain frequencies and frequency bands in HF, VHF and UHF ranges to the CaP3, which is supported by the NATO Headquarter C3 Staff / Spectrum and C3 Infrastructure Branch (NHQC3S/SC3IB). The NHQC3S/SC3IB is the supporting staff for the CaP3, and is also the day-to-day staff charged with carrying out the necessary operational work in support of the exercises and operations. In particular, the Staff is dynamically assigning TACAN channels for air/air and deployable land stations. The NATO Maritime Command (MARCOM) is dynamically assigning channels to TACAN maritime stations [26].

1.5.4 International Air Transport Association (IATA)

Founded in 1945, the International Air Transport Association (IATA) is the trade association for the world's airlines, representing some 284 airlines or 84% of total air traffic. IATA supports many areas of aviation activity and helps formulate industry policy on critical aviation issues and is the prime vehicle for inter-airline cooperation in promoting safe, reliable, secure and economical air services - for the benefit of the world's consumers. The modern IATA is the successor to the International Air Traffic Association founded in The Hague in 1919 - the year of the world's first international scheduled services.

Safety and reliability are fundamental to airline operations. The IATA Operational Safety Audit (IOSA) program is an internationally recognised and accepted evaluation system designed to assess the operational management and control systems of an airline. It is the flagship component of a comprehensive strategy that includes audits, cargo, flight operations, infrastructure, training and data collection. IOSA is the global standard for airline safety management that is well recognised by State aviation authorities and government agencies and the IOSA audit creates a standard that is comparable on a world-wide basis. All IATA members are IOSA registered and must remain registered to maintain their IATA membership. Additionally, as of October 2017, 143 (34%) of the 424 airlines on the IOSA Registry are non-IATA member airlines.

The IATA Safety Audit for Ground Operations (ISAGO) is an aviation industry ground service provider registration scheme. It is aimed primarily at establishing safe ground operations and raising cost benefits by, respectively, reducing the risk of aircraft damage and personal injuries and eliminating redundant audits.

2 CURRENT AND FUTURE SYSTEMS AND TECHNOLOGIES IN THE FREQUENCY BAND 960-1164 MHZ WITHIN CEPT

The frequency band 960-1164 MHz is a globally harmonised radionavigation and communications band which is used intensively, and extensively, to support a number of aviation systems, for both civil and military purposes. It is important to note that these aeronautical systems operate up to 1215 MHz. Moreover, the adjacent band 1164-1215 MHz is allocated to the radionavigation-satellite service (RNSS) (space-to-Earth).

The following tables provide preliminary information on systems designed for use in the band 960-1164 MHz.

It should be noted that some of the uses quoted may extend beyond the band and the lists of systems may not be complete.

2.1 CIVIL RADIONAVIGATION AND COMMUNICATION SYSTEMS

Table 3: Civil aeronautical systems currently in use in the band 960-1164 MHz

System	Frequency (MHz)	Notes/Description
Distance Measuring Equipment (DME/TACAN)	962-1164 (Note 1)	Aircraft (interrogator) determines slant range to a ground beacon (transponder) at a known location based on round trip timing of pulses. Aircraft transmits and ground beacon replies on an assigned pair of frequencies separated by 63 MHz both using omnidirectional antennas – for some operational requirements the ground antenna may be directional. Multi-channel interrogators use simultaneous ranging to multiple transponders for the aircraft to determine its location via a multilateration process. DME/TACAN channelisation is across the 960-1215 MHz band
Secondary Surveillance Radar	1030 (Ground Tx, limited Air Tx, Air Rx) 1090 (Air Tx, Ground Rx, limited Air Rx)	Ground (interrogator) at a known location determines azimuth and slant range of aircraft transponder based on round trip timing of pulses. Ground transmissions on 1030 MHz, using a rotating, high gain antenna; all aircraft reply omnidirectionally on 1090 MHz. Different SSR Modes (A, A/C and S) have different additional capabilities with different signal structures including a data channel. Mode A codes aircraft identity, A/C codes identity and aircraft derived altitude, Mode S as for A/C with ability to selectively call specific aircraft / request other aircraft data. There is also limited use of airborne interrogators transmitting on 1030 MHz and receiving on 1090 MHz
Far Field Monitors (FFM)	1090 (Ground Tx) 1030 (Ground Rx)	SSR interrogators have up to two ground based monitors at fixed locations several nautical miles from the interrogator to provide constant confirmation of correct operation and monitoring of health and performance of interrogators
Universal Access Transceiver (UAT) (ADS-B and multiple broadcast services)	978	Universal Access Transceiver (UAT), an ICAO standardised system and a wideband broadcast data link operating on 978 MHz. UAT supports multiple broadcast services, including flight information services (FIS-B) and traffic information services (TIS-B), in addition to automatic dependent surveillance - broadcast (ADS-B). Currently it is used in a number of states outside of Europe, including China, Republic of Korea, South Africa and United States. Some limited trials are taking place in Europe. UAT is being examined as one enabler technology to support Remotely Piloted Aircraft System (RPAS) and General Aviation (smaller aircraft) use

System	Frequency (MHz)	Notes/Description
Automatic Dependent Surveillance-Broadcast (ADS-B)	1090 (Air Tx, Air, Ground and space Rx)	Air-to-air, air-to-ground, air-to-space datalink. Provides aircraft identity, aircraft derived (hence “dependent”) position plus other data. An extension of the SSR Mode S data set (also permitted to be received in space following an allocation by WRC-15). Aircraft fit could be part of SSR transponder or a separate transmitter/receiver
Airborne Collision Avoidance System / Traffic Collision Avoidance System (ACAS/TCAS):	1030 MHz and 1090 MHz (Air Tx and Rx)	Aircraft system on both 1030 MHz and 1090 MHz operating independently of ground-based equipment and air traffic control in warning pilots of the presence of other aircraft that may present a threat of collision. If the risk of collision is imminent, a manoeuvre is initiated that will reduce the risk of collision
Multilateration systems (MLAT)	1030 (Ground Tx, Air Rx) 1090 (Ground and Air Tx, Ground Rx)	Largely passive network of ground receivers (of order of 40 to 50 for a large airport) to enable independent determination of aircraft (and suitably equipped ground vehicle) position on or near an airport using difference in time of arrival techniques based upon SSR Mode S transmissions. Multilateration systems (MLAT systems) also have several ground based 1030 MHz emitters to elicit additional replies from aircraft transponders where necessary and 1090 MHz emitters to provide constant confirmation of correct system operation
Wide area multilateration (WAM)	1030 (Ground Tx, Air Rx) 1090 (Ground and Air Tx, Ground Rx)	Similar to MLAT but over a wider geographic area and typically having a greater reliance on active interrogation at 1030 MHz to augment SSR- and Mode S based Radar detection of aircraft
RSBN (Radio system of short range navigation)	960-1164	A civil/military Aeronautical Navigation system that operates under ITU RR No. 5.312 which is a non-ICAO aeronautical system. RSBN provides information for approach / landing and en-route navigation similar to ILS, VOR, DME and TACAN
Note 1: Airborne transmissions limited to 1025-1150 MHz		

Table 4: Civil aeronautical systems foreseen in the band 960-1164 MHz

System	Frequency (MHz)	Notes/Description
L-Band Digital Aeronautical Communication System (LDACS)	960-1164	LDACS received an allocation between 960 MHz and 1164 MHz at the WRC 2007 (Resolution 417, revised in 2015) and is presently under standardization by ICAO. LDACS is envisaged to use a cellular point-to-multipoint concept, which means that the airspace is segmented into cells. In each cell, all aircraft are connected to a centralised ground station which controls the entire air/ground communication within the cell. It is designed as a frequency-division duplex system, preferably deployed using an inlay approach, interleaving with DME. LDACS is expected to be introduced in the mid-2020s
Mode S Phase overlay	1090	Additional Phase Overlay modulation to the 1090 MHz Mode S telegram to enhance the data throughput from 1

System	Frequency (MHz)	Notes/Description
		Mb/s to ~ 4 Mb/s. Currently under standardisation within ICAO 1090 MHz transmission and reception
Remotely Piloted Aircraft System / Unmanned Aircraft System (UAS)	960-1164	(RPAS/UAS) command and control, known also as Control and Non-Payload Communication (CNPC) which refers to Command and Control or Command, Control and ATC Communications (C2 link). These systems are under development and could be introduced if seen as a viable solution (EUROCAE WG-105)
Improved DME for Alternative Position Navigation and Timing (APNT)	960-1164	Alternative Position Navigation and Timing (APNT), using DME, is planned for use during outage of GNSS. DME performance improvements are projected to occur in the near term with minimal ground-system changes and unchanged avionics.
Integrated CNS System	960-1164	The 13th Air Navigation Conference (2018) recommended that ICAO launch a study to evolve the required CNS and frequency spectrum access strategy and systems roadmap in the short, medium and long term, to ensure that CNS systems remain efficient users of the spectrum resource. The frequency band 960-1164 MHz has been identified as a home for future integrated aeronautical CNS Systems

2.2 MILITARY RADIONAVIGATION AND COMMUNICATION

Table 5: Military aeronautical systems currently in use in the band 960-1164 MHz

System	Frequency (MHz)	Notes/Description
Tactical Air Navigation (TACAN)	962-1164 MHz (Note 1)	Similar to DME in that it allows determination of slant range from aircraft to a known location but with the addition of further modulation(s) that allow aircraft to determine their bearing from the ground beacon. TACAN is also used by Civil Aviation as DME. TACAN also has an air-to-air mode, where aircraft transmit on the beacon frequencies
Interrogation Friend or Foe (IFF)	1030 MHz and 1090 MHz	Mode 4 and its successor IFF Mode 5 operating on the SSR frequencies 1030 MHz and 1090 MHz since about 1980. Employs different modes (signal structures) with different capabilities
Joint Tactical Information Distribution System/Multifunctional Information Distribution System (JTIDS/MIDS) – also known as Link 16	51 channels across the range 969 to 1207 (Note 2)	Link 16 is a multi-platform (air, ground, sea) military datalink and communications system providing secure, flexible and highly survivable communications links which are resistant to jamming. The system employs TDMA and frequency hopping, spread spectrum over 51 distinct channels. Equipment is required to use standardised additional capabilities to mitigate risks of interference to aviation systems (note 3).
RSBN (Radio system of short range navigation)	960-1000.5	A civil/military Aeronautical Navigation system operates under ITU RR No. 5.312 which is a non-ICAO aeronautical system. RSBN provides

System	Frequency (MHz)	Notes/Description
		information for approach / landing and en-Route navigation similar to ILS, VOR, DME and TACAN

Note 1: Airborne transmissions are limited to 1025-1150 MHz except for TACAN used in air-to-air mode for which channels in the whole band could be used (the transponder and the interrogator are both on-board)[10].
Note 2: A frequency remapping of the 51 channels for JTIDS/MIDS is currently being implemented in some terminals. This would lead to a reduction in the number of frequencies used by those JTIDS/MIDS terminals, and a corresponding increase in the usage of the remaining frequencies.
Note 3: The standard performance criteria for MIDS terminal equipment to be used by all military are defined in STANAG 4175 [42]. In particular the purpose of its Annex A is to define the technical characteristics required to:
a) Achieve interoperability among MIDS terminals;
b) Ensure that the electromagnetic emissions from MIDS will not unduly interfere with other users of the frequency bands employed by MIDS.

2.3 EVOLUTION OF SPECTRUM USAGE WITHIN THE 960-1164 MHZ BAND BY AERONAUTICAL SYSTEMS

On a global basis, the frequency band 960-1215 MHz is used for Distance Measurement Equipment (DME) systems. In most airspaces, it is required to navigate using multiple DME ground stations for position determination (DME-DME navigation). DME also provides an essential element of the Instrument Landing System (ILS) precision approach (CAT I, CAT II and CAT III) enabling reduced visibility and automatic landing of aircraft. Use of DME will continue and increase well beyond 2030.

ICAO has defined the Performance Based Navigation (PBN) concept which specifies aircraft area navigation system performance requirements, defined in terms of accuracy, integrity, continuity and functionality, needed within a particular airspace. DME-DME can meet the performance requirements for area navigation (RNAV 1, 2 and 5) and the required navigation performance (Basic RNP 1)[11] as specified in ICAO Doc 4444 [68].

In addition to DME, GNSS navigation sensors are also used as a navigation aid for PBN operation.

Use of GNSS for PBN and precision approach is increasing; however, due to its vulnerability to interference it is not considered reliable enough as a sole means of area navigation or for use with ILS precision approach systems for CAT II and CAT III. During the 12th Air Navigation Conference (2012), ICAO Contracting States agreed to develop an alternative means of navigation in the event of a loss of or disruption to GNSS signals (APNT). APNT solutions will use modified versions of the existing DME (APNT DME) and hybrid approaches including LDACS. Accordingly, DME navigation capability continues to be a fundamental long-term requirement.

Two sub-bands centred around the frequencies 1030 MHz and 1090 MHz are used for Secondary Surveillance Radar (SSR) as well as by a number of other aviation systems, including MLAT, WAM, ACAS, ADS-B and ADS-B reception by satellite. The use of these frequencies for these systems is expected to increase well beyond 2030. Added capabilities are being developed for some of these systems, such as ADS-B IN and ACAS-X including the ACAS-Xu designed as detect and avoid systems for Unmanned Aircraft System (UAS).

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[10] TACAN operates in the UHF (1000 MHz) band with 126 two-way channels in the operational mode (X or Y) for 252 total:

- Air-to-ground DME frequencies are in the 1025-1150 MHz range;
- Ground-to-air frequencies are in the 962-1213 MHz range.

[11] RNAV and RNP systems are fundamentally similar. The key difference between them is the requirement for on-board performance monitoring and alerting. A navigation specification that includes a requirement for on-board navigation performance monitoring and alerting is referred to as an RNP specification. One not having such requirements is referred to as an RNAV specification. An area navigation system capable of achieving the performance requirement of an RNP specification is referred to as an RNP system.

3 LEGAL AND REGULATORY FRAMEWORK APPLICABLE TO THE BAND 960-1164 MHZ

3.1 GLOBAL LEVEL

3.1.1 ITU

Referring to the ITU RR, there is no appropriate allocation supporting PMSE in the band 960-1164 MHz which is globally allocated to the Aeronautical Radionavigation Service (ARNS), Aeronautical Mobile Route Service AM(R)S and in part to the Aeronautical Mobile-Satellite Route Service (AMS(R)S Earth-to-Space).

However, the ITU-R Regulations do not prevent any administration introducing PMSE applications in the band 960-1164 MHz, providing that such uses shall not cause any harmful interference to the aeronautical systems, within or outside the national borders, or claim protection from harmful interference.

The following ITU RR Article should be considered:

- ITU RR No. 4.4: "Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations."

Then, at this stage, PMSE could only operate under ITU RR No. Article 4.4 as referred to above that means, in particular, that no protection can be ensured for the usage of PMSE in the band 960-1164 MHz.

- ITU RR No. 1.169: "harmful interference: Interference which endangers the functioning of a radionavigation service or of other safety services or seriously degrades, obstructs, or repeatedly interrupts a radiocommunication service operating in accordance with Radio Regulations (CS)";
- ITU RR No. 4.10: "Member States recognise that the safety aspects of radionavigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies".

3.1.2 ICAO

The various articles of the ICAO Convention (Chicago Convention) [1] oblige States to undertake or adopt measures to ensure the safety of overflying aircraft. These measures include standards and recommended practices which require aircraft and aeronautical service providers on the ground to operate certain ICAO standardised equipment for Communication, Navigation and Surveillance.

The 960-1164 MHz frequency band is in extensive use on a worldwide basis for aeronautical safety of life systems. In line with the consistent annual growth of air traffic of 5% on a global basis, the use of those systems keeps growing and flexibility in changing frequency assignments is a key element in managing the band.

At WRC-07, WRC-12 and WRC-15, ICAO and the aviation community looked for additional spectrum allocations to support new aviation safety systems. After study, the approach chosen was to implement those systems under new allocations to aeronautical services in bands already allocated and in use by other existing aeronautical services. This approach was only possible because aviation controls the environment in these bands, through the mandatory use of international aeronautical standards (SARPs[12]) and regionally coordinated air navigation agreements.

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12 ITU RR Article 37 calls for the adoption of international Standards and Recommended Practices (SARPs) dealing with, inter alia, communications and navigation aids. SARPs normally address all interface parameters, including radio frequency (RF), performance, coding etc. to ensure worldwide interoperability. These provisions form the major part of the international framework for aviation safety in regard to the radio systems carried by aircraft. It should be noted that ICAO SARPs are only adopted for systems which are standardized on a worldwide basis, and hence do not include such self-contained systems as radio altimeters and airborne weather radar, carried as a mandatory requirement by many aircraft, and which also meet the certificate of airworthiness requirements.

Due to its safety of life nature, aviation cannot afford to be reactive. Hence the ICAO regulatory framework provides provisions not only on equipment standardisation and certification, but also on safety management and aeronautical safety oversight, thus ensuring preventative action to minimise operational risks to an acceptable level, consistent with safe aircraft operation. When the regulatory regime is judged to be insufficient, then aviation has to take appropriate action to maintain safety. That action will be in the form of modifying or in the worst case (e.g. volcanic ash from Eyjafjallajökull, Iceland) cease operations with a resultant economic and political impact.

There is an example of a non-civilian aeronautical system (JTIDS/MIDS) operating in an aeronautical frequency band. This was accomplished through implementation of terminal-resident EMC features that shut the emitter down if it attempts to operate outside the parameters assumed in the safety case. It should be noted the form and function of those EMC features required aviation certification. The current arrangements are the ongoing results of over 40 years of experience.

Aircraft operations need to be supported by appropriate safety cases as a means of structuring and documenting the demonstration of the safety of air traffic management services and systems. In addition to the ICAO regulatory framework, see for example Commission Implementing Regulation (EU) 2017/373 [20]. Risk classification schemes have been developed at a global level, e.g. ICAO Doc 9859 [100] – Safety Management Manual, and at European level, e.g. EUROCONTROL ESARR 4 - Risk Assessment and Mitigation in ATM [82]. In addition, national authorities have also developed guidance on hazard identification, risk assessment and the production of safety cases, for example CAP 760 [76] in the UK.

In accordance with Annex 8 to the ICAO Convention, aeronautical equipment is required to undergo stringent certification (e.g. ETSO, issued by EASA) and in accordance with Annex 19, its operation is required to undergo safety-cases to ensure safe operation of aircraft. If any new system sharing an aeronautical safety of life frequency band is introduced, the existing aeronautical safety cases shall be reviewed.

The current safety cases are conducted on the basis that any aeronautical equipment and its operation in the band must be standardised, certified and licensed[13] for operation in each specific aircraft type (e.g. assurance against causing a safety issue to the aircraft due to equipment malfunction), and comply with appropriate standards and the items listed above, or shut off. If a new system does not comply with these standards is introduced, a new framework for the safety cases needs to be developed.

Human factors principles need to be observed in the design and certification of radio navigation aids and surveillance systems (Ref: ICAO Annex 10 Vol I, Navigation Systems [44] and Vol IV, Surveillance Systems [45]). From the aviation sector perspective, the same considerations should apply to any other systems, which may affect the operations of the radionavigation aids and surveillance systems.

Many airport ILS/DME installations have been certified at the highest level of precision approach procedures (CAT IIIc) and are authorised to be used for autoland operations. Any loss of DME operation in normal or low visibility conditions results in the need for alternative ranging information that require ATC intervention and associated impacts to the operation of that airport, for example flow control being applied with much lower throughput than during normal operations. Any loss of a component part of the ILS requires a demonstration period to be completed, providing fault rectification or resolution to the issue that caused the loss. Depending on the severity of the loss varying periods will be required to prove the stability and operational capability of the facility, for example this could be between 24 and 300 hours or as specified by the ANSP for that aid.

In several ITU Regions, Universal Access Transceiver (UAT), provides frequency diversity for ADS-B applications and has proven highly effective in enhancing aviation safety. UAT, which operates on 978 MHz, also provides real-time weather and traffic information.

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13 ICAO Annex 11 "Air Traffic Services"; ICAO Annex 19 " Safety Management"; ICAO DOC 9718 [29] "Non safety of life services, willing to share a safety of life band have to comply with the aviation safety requirements applicable in that band including certification of radio equipment, software and radio operators, as well as assumption of liability".; Commission regulation (EC) 1321/2014: "on the continuing airworthiness of aircraft and aeronautical products, parts and appliances, and on the approval of organisations and personnel involved in these tasks"

The frequency 978 MHz is globally used and UAT is an ICAO standardised system, which provides /will provide aviation a longer term solution of frequency diversity for ADS-B applications while being fully capable of handling the expected growth.

3.1.2.1 Application of International Law for aeronautical safety oversight

In accordance with the Chicago Convention [1], national safety oversight obligations require States to undertake measures to ensure that every aircraft flying over or manoeuvring within its territory complies with the specific operating regulations relating to the flight and manoeuvre of aircraft therein.

ICAO's Universal Safety Oversight Audit Programme (USOAP) was initially launched in January 1999, in response to widespread concerns about the adequacy of aviation safety oversight around the world. Initially, USOAP activities consisted in regular and mandatory audits of ICAO Member States' safety oversight systems. In 2010, a new approach, Continuous Monitoring Approach (CMA), based on the concept of continuous monitoring and incorporating the analysis of safety risk factors was introduced. USOAP CMA is performed by ICAO based on several principles, and includes the following.

a) Universality: All Member States shall be subject to continuous monitoring activities by ICAO, in accordance with the principles, methodologies, processes and procedures established for conducting such activities, and on the basis of the Memorandum of Understanding (MoU) signed by ICAO and each Member State;

b) All-inclusiveness: The scope of USOAP CMA includes the ICAO SARPs contained in all safety-related Annexes to the Convention, Procedures for Air Navigation Services (PANS), guidance material and related procedures and practices.

Based on this MOU as described above, to provide the necessary air navigation services and aerodromes, States are obliged to adopt and apply appropriate aeronautical standard systems and communications procedures and other operational practices and rules. Compliance with the State’s regulatory requirements is obligatory. Exemptions or exceptions of these requirements should not be granted by the State if such measures would not be supported by appropriate, robust and documented safety risk assessments or aeronautical studies and imposition of limitations, conditions or mitigation measures as appropriate (Ref: ICAO Doc 9734 "Safety Oversight Manual").

Any exception or exemption should only be granted on the basis of a robust rationale. Therefore, the issuance of exceptions or exemptions that is not supported by safety risk assessments or aeronautical studies and by thorough reviews by the competent authority is not acceptable. A safety risk assessment or aeronautical study should be developed by the service provider to demonstrate whether an equivalent level of safety or an alternative acceptable means of compliance can be achieved (Ref: ICAO Doc 9734 "Safety Oversight Manual").

Aeronautical systems operate in accordance with the International Law principles stated above. There is an example of a non-civilian aeronautical system (JTIDS/MIDS) operating in an aeronautical frequency band. This was accomplished in a manner ensuring compliance with the requirements described above, thus ensuring that international obligations were met.

In light of the above, ICAO is of the opinion that introduction of any new system in the 960-1164 MHz band would not be safe unless it can be ensured that:

- the new system is completely compatible with existing and planned aviation systems based the new system is completely compatible with existing and planned aviation systems based on testing and analysis that has been agreed by aviation regulators;
- the parameters for the new system will be captured in an internationally recognised standards document;
- the new system will be certified (including software and hardware) by the competent national regulatory authorities; will be maintained to meet throughout its service life the operational parameters assumed in

the aviation testing/studies; will perform self-monitoring to ensure that it shuts down if it moves outside those agreed parameters; and the self-monitoring/shutdown function itself will also be certified[14];

- the new system will include time-stamped logging of essential transmitter parameters, such as frequency use and power levels for post incident/accident investigation purposes;
- the new system will not impact:

  a) the ability of aviation to manage existing and planned aviation systems;

  b) the ability of aviation authorities to modify operating frequency assignments, powers and signal contents of the aviation systems without introducing additional coordination mechanisms.
- the operator of the new system must accept all legal liability in case of interference to aviation systems (e.g. due to false channel selection, excessive power, human error, device failure), and recognise that aviation systems operators have no liability in case of interference to the new system; and
- personnel responsible for the operation of non-aviation systems in the 960-1164 MHz band shall be required to achieve similar levels of certification to those stipulated in the Radio Regulations for operators of aviation systems (radio operator's certificate).

3.2 REGIONAL AND NATIONAL LEVEL

3.2.1 European law

Within the EU, Single European Skies (SES) legislation, i.e. Commission Implementing Regulations (EU) 2017/373 [20] is in force[15]. This regulatory regime requires that hazard identification as well as risk assessment and mitigation are systematically conducted for any changes to those parts of the ATM functional system and supporting arrangements within their managerial control by air traffic service providers (ANSPs) before bringing new Air Traffic Management facilities into use or when changes to existing facilities are foreseen.

For the considerations of EUROCONTROL, refer to Annex 2.

3.2.2 CEPT

Within CEPT in addition to the work at WG FM, WG SE carried out compatibility studies between low power audio PMSE and incumbent aeronautical systems in the 960-1164 MHz band including compatibility studies with services in adjacent bands.

The results of the technical compatibility studies are provided in Appendix 2 of this Report, and did not address requirements for cross-border coordination between concerned administrations.

3.2.3 National regulation

Provided that international radio regulatory, aeronautical safety obligations are met, the introduction of low power audio PMSE in the band 960-1164 MHz is a sovereign decision on the designation of this public resource.

Therefore, the introduction of PMSE into the band is a national decision, under the full liability of the State, which would involve cooperation between the spectrum regulator, the aviation authorities and Defence. The introduction of audio PMSE in the band 960-1164 MHz could imply review/updating of the national sharing framework between current users. This may be unacceptable to these users if these updates have impacts on their operational environment and requirements.

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14 In the USA, the frequency band 1435-1525 MHz has been made available for audio PMSE based on specific conditions as outlined in . The licensing conditions specify that coordination with AFTRCC prior to operation is required and that automated shutdown is desirable. As yet the detailed conditions have not been agreed.

15 Commission implementing regulations 1034/2011 [6] and 1035/2011[5] have been repealed by Commission implementing regulation (EU) 2016/1377 [7], which applies from 1st January 2019.

The amount of spectrum potentially available for audio PMSE applications in the 960-1164 MHz band may differ from country to country depending on incumbent usage as well as national decisions and agreements, including those of other countries.

In general, authorisation for audio PMSE differs across administrations, i.e. licence exempt, general authorisation or individual licence.

For the introduction of audio PMSE in this band 960-1164 MHz, an individual licensing regime is likely to be required in order to have control of the PMSE usage in this band.

Detection of interference to the aircraft navigation systems by its pilot can be very difficult if not impossible. During a flight, the first priority for the pilot is the safety of the flight. Hence, typically a report of interrupted or reduced reception or performance of the air navigation system will not be filed by the pilot until after the flight, i.e., hours after the incident. In case of interference resulting in an incident or accident (aircraft new route, plane crash …) leading to economic, ecological, environmental, legal or human impacts, responsibilities have to be clarified and established, corrective actions need to be taken and liability issues have to be addressed in accordance with international law.

A PMSE user causing interference (due to the use of wrong channel selection, too high power emission, human error, device problem, etc.) should be identifiable in order to assume the legal and economic consequences of any impact (delays, incidents, re-routing, route-closures, and accidents) to the Air traffic flow.

On the other hand, Administrations would assume the responsibility of safety, legal and economic consequences if it appears that a PMSE user is in full respect of the issued authorisation/regulation and interference still occurs. Considering that the administration in charge of enforcement might be also responsible for harmful interference and also its impact and consequences, appropriate methodology needs to be identified to ensure that all cases are appropriately resolved.

4 ECONOMIC ASPECTS

4.1 ECONOMIC ASPECTS OF AIR TRANSPORT

The economic value of aviation described below relates to the total value of all activities directly and indirectly related to the air transport industry. The estimates include catalytic effects of tourism, i.e. employment and income generated in the economy through air travel tourism, and induced economic benefits, i.e. through people employed in the aviation industry or tourists spending their money on other goods and services. There is no assessment of the economic value of the use of spectrum.

Air traffic is growing. Historically, it is doubling activity every 15 years. A key requirement to sustain growth is the capability to reduce the separation between aircraft while maintaining or increasing the current levels of safety. This is only possible if sufficient performance of the radionavigation and surveillance systems operating in the band 960-1164 MHz (DME-DME and surveillance separation when available) and the adjacent band 1164-1215 MHz (DME-DME and GNSS/GPS - although GNSS in this frequency range is not yet standardised for use) can be ensured.

The level of safety, as enforced by the Air Traffic Services allows for a strong public confidence, which in turn fosters overall economic development. The high level of safety and reliability of operations has enabled massive financial investments in aircraft fleets, ground equipment, and facilities by businesses and commercial operators in order to provide their services. Making a dedicated spectrum of radio frequencies available for safe operations is an integral part of establishing the required level of safety. Due to the many years of reliable and interference free operations enabled by the strictly controlled environment in the 960-1164 MHz band, a worldwide economic and social benefits model has been built.

The data of this section comes from "Aviation: Benefits Beyond Borders" [77] and "Study on the Modelling of Airport Economic Value" [78].

4.1.1 Employment

In 2014, the air transport industry supports 62.7 million jobs globally:

- It directly creates 9.9 million jobs worldwide (60% for airports, 27% for airliners, 11% for aerospace sector, 2% for air navigation service providers (ANSPs), etc.);
- 11.2 million indirect jobs are created via purchases of goods and services from companies in the air transport supply chain;
- 5.2 million jobs are induced through spending by industry employees;
- Almost 36.3 million direct and indirect jobs are created through air transport’s catalytic impact on tourism.

Moreover, it is estimated that aviation supported 67.7 million supply-chain jobs in 2016 and underpinned 3.0 trillion USD in value-added output globally.

4.1.2 Economic aspects

- Aviation provides the only worldwide rapid transportation system which makes it essential for global business and tourism (approximately 3.57 billion passengers transported in 2015);
- Aviation’s total global economic impact (including direct, indirect, induced and the catalytic effects of tourism) is estimated at 2.7 trillion USD, equivalent to 3.5% of world gross domestic product (GDP);
- Aviation carried 51.2 million tonnes of freight in 2015 and 35% of interregional exports of goods by value; daily value of goods sent by air is now 17.5 billion USD;
- Research conducted in the US suggests that for every 100 million USD invested in aerospace yields an extra 70 million USD in GDP year after year.

4.1.3 SESAR (Single European Sky ATM Research) objectives

The band 960-1164 MHz directly supports the development of SESAR objectives.

The objective of European Commission is to reduce the extra costs of close to 5 billion Euro each year to airlines and their customers caused by historical inefficiencies due to Europe's fragmented airspace and to develop means to allow airlines to fly their preferred (and more direct) routes (http://europa.eu/rapid/press-release_IP-13-664_en.htm).

This spectrum resource is considered as strategic for the Single European Sky to increase air traffic capacity.

LDACS is being developed within the framework of the SESAR 2020. Two well-known European aviation equipment manufacturers, namely Frequentis AG and Leonardo, are currently producing LDACS prototypes.

SESAR will be supported by terrestrial data links. The only frequency band available for those operations is the band 960-1164 MHz, initially via LDACS and later on by the integrated CNS systems. The 4D trajectory will be supported by the 960-1164 MHz band to help reach the SESAR performance targets (see section 1.5.1.3).

4.1.4 European airline delay cost[16]

The delay costs outlined in this section are from a report designed as a reference document to assess European delay costs incurred by airlines. The report notes that the costs modelled draw on expert judgement and assumptions, based on published statistics and robust data wherever possible. The report also notes that, as with any such research, some caution is indicated in the use of the findings. The delay costs are independent of the cause of the delay.

The cost of delay is calculated separately for strategic delays (those accounted for in advance) and tactical delays (those incurred on the day of operations and not accounted for in advance). The type of strategic cost focused on is adding buffer to the airline schedule.

Interference in the 960-1164 MHz band may generate additional delays (e.g. during landing approach and departure, en-route, etc.) which could be considered as tactical delays.

Tactical delay costs are given for 5, 15 and 30 minutes. These are scaled up to the network level because on the day of operations, original delays caused by one aircraft (‘primary’ delays) cause ‘knock-on’ effects in the rest of the network (known as ‘secondary’ or ‘reactionary’ delays). For example, in 2009, in Europe, for each minute of primary delay, on average, another 0.8 minutes of reactionary delay were generated in the network.

The data presented here, are dominated primarily by passenger costs, and then fuel burn differences. Maintenance, crew and reactionary costs are also taking into account.

[16] https://www.eurocontrol.int/publication/european-airline-delay-cost-reference-values

Table 6: Delay airline cost (EUR) EN-ROUTE and full tactical cost for 12 core aircraft (2011 values)

Delay (mins)	5	15	30
Boeing 737-300	270	1130	3400
Boeing 737-400	280	1200	3670
Boeing 737-500	250	1030	3090
Boeing 737-800	300	1290	3990
Boeing 757-200	360	1570	4840
Boeing 767-300	700	2710	7600
Boeing 747-400	1160	4340	11810
Airbus 319	270	1110	3390
Airbus 320	280	1200	3720
Airbus 321	320	1400	4380
ATR42-300	80	360	1160
ATR72	110	480	1530

It should be noted that the table above doesn't take into account several points:

- the cost of an eventual diversion due to the interference (which is between 5870 and 64 600 EUR);
- the cost of an eventual cancellation;
- the passenger value of time (which is 47 to 60 EUR per hour and per passenger);
- the extra charge from the airport;
- the cost of the Air Navigation Services;
- the cost of harmful interference researches that leads to the delay (usually a flight inspection is required);
- the amount of emissions released by fuel burn and the cost of pollutants;
- the noise impact due to the delay;
- the network effect of the delay.

4.2 PMSE INTRODUCTION ECONOMIC IMPACT

4.2.1 Civil aviation side

PMSE introduction in the 960-1164 MHz band, if not properly managed by administrations, or if the aviation sector does not have confidence in using this band, may slow down, constrain or freeze the global evolution of aeronautical systems. The potential impact on meeting the SESAR performance ambition for 2035 in terms of efficiency and predictability, environment, capacity, cost-efficiency, safety may need to be considered.

One concern is that potential interference may result in an increase of the separation distance between aircraft to ensure safety and lead to an extra cost for airports and airliners.

Another concern is that, if at a later stage, a need is identified to modify the aeronautical equipment in order to better cope with a scenario with interference caused by not-properly-managed PMSE, this would be associated with a very high cost. The average recurring cost of an airborne air transport DME is roughly 50000 USD (aircraft are equipped with two DMEs). As an order of magnitude, any modification, new qualification and certification of a DME on an aircraft (validation, laboratory and flight tests) would lead to a non-recurring cost between 400000 EUR and 500000 EUR for a given aircraft program. However, an alternative to reengineering of airborne DME equipment would be to withdraw authorisation for audio PMSE to use the band 960-1164 MHz and remove existing and future equipment from the market.

When a DME facility is removed from service (potentially as a result of aggregate interference) due to aircraft reports of unavailability, there will be a negative impact on airport capacity and the published approach procedures cannot be maintained.

To restore the DME back to service as a published navigation aid, this would normally require a flight inspection verification of the system parameters during an airborne analysis. The cost of operating a flight inspection aircraft to restore a navigation aid back to operational service can range from 3000 to 7000 EUR per hour, depending on the aircraft type and the location it must fly from to perform the inspection.

4.2.2 Military side

The Link 16 is operated on non-interference-basis to aeronautical radionavigation systems. In every country a national frequency clearance agreement between Defence and Civil Aviation Authorities (CAA) specifies the sharing conditions and constraints for the use of Link 16 in the national airspace. In many Nations, Defence is required to perform comprehensive laboratory compatibility tests to assess the impact of Link 16 on aeronautical radionavigation systems in the band taking into account the whole electromagnetic environment (EME).

Each CAA may require its Defence counterpart to perform a new test campaign with new EME scenarios due to the introduction of PMSE in this band (albeit this was not the case in UK). These laboratory tests are resource intensive in terms of time and money, and even the scenarios and parameters to produce the PMSE-induced EME may be difficult to define accurately for proving the non-interference to civil aeronautical radionavigation systems.

Furthermore, NATO and EUROCONTROL military ATM Board considerations on the prerequisites for the introduction of PMSE in the band 960-1164 MHz are provided in Annex 1 and in Annex 3 respectively.

4.3 SAFETY CASE AMENDMENTS

It is worth studying the cost implications of reviewing all safety cases, before changing the regulatory framework.

The mitigation of certain hazards due to PMSE introduction may need additional measures in order to reduce the associated risks to appropriate levels, perhaps involving additional functionality, processes, training of personnel etc.

Practically this means that analyses need to be carried out during the development of the new / changed system before the implementation of any change.

Risk classification schemes have been developed at a European level, e.g. EUROCONTROL ESARR 4 - Risk Assessment and Mitigation in ATM, which provides minimum requirements when introducing and/or planning changes to the CNS/ATM System.

Where the changes to facilities are deemed to have certain levels of potentially severe outcome then the competent authorities are required to review the safety arguments provided by the ANSPs associated with the new functional systems or proposed changes to existing functional systems. This collation of the safety arguments etc. can be known as a “safety case”.

It appears to be appropriate that consideration of the sharing of frequency bands within which ATM equipment operates should also be subject to a similar process of systematic hazard identification, risk assessment and mitigation consideration. Means of risk reduction may require technical mitigations to be included in the standards before the introduction of PMSE in the 960-1164 MHz band.

In spectrum management, costs incurred by incumbent users as a consequence of any change should be considered against the potential benefits. If the benefits outweigh the costs then the spectrum management authority may conclude that the change is worth making. The approach taken in the UK was based on requiring no change of equipment or operation by the incumbent users (both civil and military). The Safety Assurance

Case (different from a Safety Case) accepted by UK may be used by the Air Traffic Service Providers to review or to update part of their safety cases.

4.4 SPECTRUM MANAGEMENT

Administrations may have to consider the cost of planning, supervision and enforcement of technical and regulatory constraints that would be necessary to allow PMSE use in the band.

4.5 ECONOMIC VALUE OF PMSE (EXAMPLE IN UK)

It has to be noted, that this economic value has no direct link with the particular band 960-1164 MHz but is in relation with the current frequency bands that PMSE are using.

Audio PMSE is present in almost every media, cultural, sporting and entrainment activity it is dynamic and evolving. Producers continually seek new experiences for audiences exploiting the rapidly changing landscape including virtual reality, HD TV, 3D, and the web with consequential changes in demand for spectrum. Productions, particularly large-scale events, require significant investment and planning and have the potential to realise substantial returns on that investment. Consequently, a high degree of professionalism is applied in order to protect that investment.

As explained in ECC Report 204 [21], it is difficult to clearly identify the specific financial and social value of PMSE as it is an enabling technology which allows for the production or event to take place. However, in the UK there have been studies and the entertainment and event sector do provide economic reports on a regular basis.

The Wyndham Report (now out of print) from the London School of Economics (LSE) in 1998 showed that an average of 4.4 GBP was spent in the wider West End economy by theatregoers for every 1 GBP they spent at the Box Office on tickets. There is no reason to suppose the overall ratios have changed.

The Society of London Theatre’s 2016 Box Office figures provide economic figures for London’s theatre industry:

- attendances -14.3 million people;
- gross box office revenue - 645 million GBP;
- VAT paid - 107.5 million GBP.

Applying the multiplier from the Wyndham Report, this equates to an additional 2.838 million GBP for the economy.

UK Music is an industry-funded body established in October 2008 to represent the collective interests of the recorded, published and live arms of the British music industry. In its 2017 report on the contribution of live music to the UK economy [79], it notes the following economic results for music tourism in 2016:

- 12.5 million music tourists;
- 656 million GBP in box office spend on tickets;
- 4 billion GBP in direct and indirect spend generated by music tourism.

The economic benefits presented here are just for two examples of activities supported by PMSE in the UK only.

Additionally, the UK Government’s Department of Digital Culture Media and Sport has reported (in November 2017) that in 2016, the creative industries’ combined input to the UK economy was 92 billion GBP. This was an increase on the 2015 figure of 85 billion GBP – meaning that, in 2016, the creative sector grew by twice the rate of the UK economy. At the front end of content production, PMSE has played a pivotal role in that growth.

4.6 ECONOMIC VALUE OF GNSS

The adjacent band 1164-1215 MHz is also used by the GNSS. Consumers and citizens benefit in an extremely wide way from GNSS such as Galileo. The benefits include those which are quantifiable and also others which are non-quantifiable. Note that most of the value is at the user side and the majority of this usage involves the freely available service. Most of the value is at the user end and not visible to the GNSS community.

The Global Navigation Satellite Service (GNSS) Market Report No. 5 [80] identified that:

- 5.7 billion GNSS devices in use globally in 2017, forecast to increase to almost 8 billion by 2020;
- within Europe there were on average 1.3 devices / capita in 2015, expected to grow to 2.4 by 2025;
- overall European GNSS systems are expected to generate a total discounted benefit of around 60 billion EUR by 2027.

A study by Oxera Consulting Ltd for Google [81] on the impact of geo-services identified that the geo-services sector generates 150-270 billion USD of revenue globally, with a GVA (gross value added) of around 113 billion USD.

5 ISSUES RELATED TO A POTENTIAL INTRODUCTION OF PMSE IN THE BAND 960-1164 MHZ

5.1 IMPACT ON EXISTING AND FUTURE AERONAUTICAL SYSTEMS RELATED TO INTRODUCTION OF PMSE IN THE FREQUENCY BAND 960-1164 MHZ

5.1.1 Concerns regarding constraints on current and future aeronautical systems operating in the band

The frequency band 960-1164 MHz is used by aeronautical applications under the ARNS, AM(R)S and AMS(R)S allocations worldwide. This internationally recognised status allows worldwide-harmonised aeronautical systems to be standardised by ICAO (International Civil Aviation Organisation), as necessary in order to support air traffic services on a worldwide basis.

Currently many States are working on improving and optimizing their networks of DME stations to better support PBN applications. While GNSS generally provides better positioning accuracy than DME, its signals are vulnerable to failure, disruption and interference by natural causes or motivated action, e.g. jamming.

Although PMSE would be introduced on a non-protected, non-interfering basis, similar to the current situation in the UHF band, where PMSE is using white-space TV spectrum, the civil aviation community remains concerned that the introduction of PMSE may compromise the possibility to modify/adjust/optimise the use of the globally harmonised aeronautical spectrum within Europe for global aircraft operation, as well as the implementation of future aeronautical systems.

The idea of PMSE sharing the 960-1164 MHz band is to provide a long-term solution to accommodate local and temporary PMSE bandwidth demands. If administrations choose to make this band available for PMSE, they may later, within their spectrum management responsibilities, need to limit or withdraw the access to PMSE within the band in order to avoid potential constraints to new aeronautical systems being introduced in the band.

The development of the Unmanned Aircraft Systems (UAS) (also known as Remotely Piloted Aircraft Systems) is proceeding at a fast rate. Hence the need for spectrum for UAS Control and Non-Payload Communication (CNPC) and for aeronautical "detect and avoid"[17] systems is foreseen to increase already in the short term. CEPT studies have begun to examine a subset of these issues with studies in other bands. The aviation community are considering whether the smaller UAS in particular will make use of UAT (operating at 978 MHz) for their secondary surveillance requirements. In the middle term, SESAR deployment supported by LDACS may constrain PMSE deployment in the band. And in the long term, integrated CNS systems are foreseen to be deployed in the whole band 960-1164 MHz in order to provide Communication, Navigation and Surveillance functions for future civil aviation applications providing for more efficient use of the airspace.

Current global studies of APNT are looking into modifying the existing DME (APNT DME) or using hybrid approaches. LDACS is another system which may be used for APNT. If additional non-aviation users need to be accommodated in the same band, one concern is that this may require time for research, and consequently may cause delay and complicate any such system evolution. While aviation does not expect to be given new spectrum, current research efforts assume that the current spectrum allocations can be retained without additional sharing so that the infrastructure can be evolved within already allocated bands to serve the expanding bandwidth needs or air navigation services.

Due to the large radio horizon, European countries which choose to make the band 960-1164 MHz available for PMSE need to ensure the protection of any aeronautical systems deployed in this band (DME, UAT and CNPC for UAS, LDACS and integrated CNS) in neighbouring countries.

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[17] ICAO Annex 2 defines detect and avoid as "The capability to see, sense or detect conflicting traffic or other hazards and take the appropriate action."

5.1.2 Safety considerations

5.1.2.1 Safety Case

Safety cases are required as means to support aircraft operations by structuring and documenting the demonstration of the safety of air traffic management services and systems. ICAO Annex 11[18] and ICAO Doc 9735[19] instruct that any significant safety-related change to the ATS system, shall only be effected after a safety assessment has taken place and demonstrated that an acceptable level of safety will be met, and after all affected users have been consulted. The introduction of a new system in the band 960-1164 MHz would change the RF environment thus invoking the requirement to review the safety cases.

In addition to a generic safety assessment of the PMSE itself under the authorisation of relevant State authorities or agencies[20], ANSPs have the responsibility to re-assess their current safety risk assessments and/or develop new ones, taking account of the possible effects that PMSE may have to the air-navigation and surveillance systems operating in the band.

The safety risk assessment developed by the aeronautical service provider will need to demonstrate that an equivalent level of safety or an alternative acceptable means of compliance can be achieved. This may involve inputs and participation by civil aviation authorities, spectrum regulator, the aviation safety regulator and other interested parties (e.g. military authorities, air navigation service providers, airports, airlines, etc.). Aircraft operators and concerned aeronautical service providers may be required to review their safety cases for existing airport, take-off, landing and en-route operations due to the potential impact on aeronautical navigation and surveillance systems and procedures.

Safety cases do not only take account of the technical environment, but also of human factor issues. Current safety cases rely on the assurance that users are properly trained and qualified (e.g. Air Traffic Safety Electronics Personnel). If a new system such as PMSE were to be introduced in an aeronautical frequency band, the safety case analysis would need to take a number of additional factors into account, such as PMSE users not respecting their license conditions (intentional or unintentional wrong frequency selection, wrong location etc.). Similarly, the safety risk assessment would need to address the potential of PMSE equipment not meeting its specifications. In coordination with the CAA/NSA, the initial risk assessment could be developed by the spectrum management authority and be provided for reference by ANSPs in their review and possible revision of their safety cases.

If PMSE use is allowed in the 960-1164 MHz band before an appropriate safety risk assessment has taken place, this may result in potential restrictions being necessary to normal airspace access until the new required safety risk assessment has been developed, taking full account of the potential change to the RF environment. If the safety risk assessment identifies PMSE to have a potential impact on aeronautical navigation or surveillance systems then mitigation measures would have to be identified and put in place. Before authorising non-aeronautical systems in the aeronautical L-band, administrations should consider putting in place a licensing procedure ensuring that new equipment, processes, operational procedures, SMS, safety cases and mitigation techniques respect the national regulatory framework. It is the duty of the National Supervisory Authority to coordinate CAA and ANSPs actions.

5.1.2.2 The aeronautical safety assessment in the UK

In accordance with the ICAO (Ref: ICAO Annex 19; ICAO Doc 9734) and EASA regulatory frameworks, a Safety Case has to be developed by the affected Air Traffic Service Providers and approved by the NSAs.

In December 2018, the UK Spectrum Regulatory Authority (UK Ofcom) and the UK Civil Aviation Authority (UK CAA) released a joint communication indicating UK Ofcom's decision to operate PMSE within the 960-1164

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[18] ICAO Annex 11 "Air Traffic Services"

[19] ICAO Doc 9735 "Universal Safety Oversight Audit Programme Continuous Monitoring Manual"

[20] In ICAO Annex 19, the term "relevant authorities or agencies" is defined "in a generic sense to include all authorities with an aviation safety oversight responsibility, which may be established by the State as separate entities. This includes: Civil Aviation Authorities, Airport Authorities, Air Traffic Service Authorities, Accident Investigation Authority and Meteorological Authority".

MHz band. This decision was made possible due to the acceptance of UK CAA of a Safety Assurance Case (SAC) developed by UK Ofcom [87]. The SAC document is intended to facilitate the development of Safety Cases by the affected Air Traffic Service Providers.

It should be noted that the decision by the UK CAA to agree the SAC was made based on the assumptions on the PMSE usage and licensing process relevant for the situation in the UK.

5.1.2.3 Flight safety and safety of life

This section assesses the impact on the safety in case of interference. As procedures are only published for current systems, this section only studies the impact of interference on a DME and on 1030 MHz and 1090 MHz frequencies.

Figure 1 assesses the safety impact of interference into a DME airborne receiver. With DME-DME positions, an aircraft can perform a navigation accuracy of 1 NM (RNAV 1). In other words, the aircraft is able to determine its position with an accuracy of 1 NM. GNSS and DME/DME/IRU (inertial reference unit) also meet the criteria for RNAV 1.

Position updating for RNAV 1 DME applications requires a minimum of two DMEs. When interference occurs on one of those DMEs, the accuracy of the DME/DME positioning may be degraded or lost and the aircraft will have to rely solely, or partly, on other navigation systems. If the aircraft is equipped with a GNSS receiver this should not present a significant problem, however approval for RNAV 1 does not require GNSS, therefore many aircraft do not have a GNSS receiver and in the scenario described would lose their ability to navigate to RNAV 1 requirements. If the capability of the remaining navigation systems does not support RNAV 1, then the separation and therefore safety of aircraft on the original route cannot be maintained.

As can be seen on the figure, if there is loss of 1 Nautical Mile (NM) accuracy of the RNAV 1 route due to interference, aircraft positions cannot be accurately known and the aircraft may be in dangerous proximity with other aircraft on other routes. In this case, in order to maintain the required level of safety of aircraft operations, de-conflicting actions need to be taken by air traffic control.

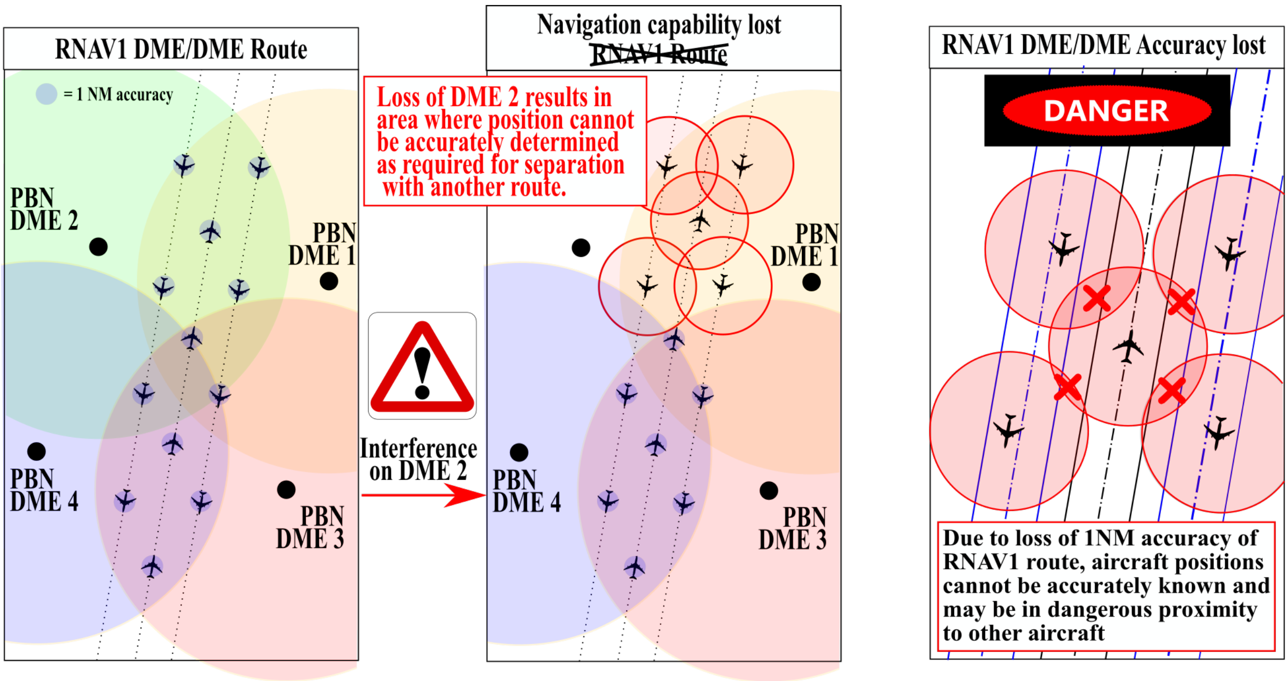

Figure 1: Safety impact on DME in case of interference in 960-1164 MHz band

Figure 2 assesses the safety impact interferences into the two frequencies 1030 MHz and 1090 MHz of an airborne receiver.

During the final approach phase before landing, the air traffic controller uses secondary surveillance radar and/or ADS-B and/or Multilateration to apply separation between aircraft, thus ensuring a minimum separation of, typically, 3 NM. In case of interference on 1030 MHz or 1090 MHz the air traffic controller will not be able to ensure the separation and will have to de-conflict the aircraft accordingly. It has to be noted that the level of safety decreases during this transitional phase. Until sufficient separation is reached between the aircraft a non-safe flight environment is being experienced.

It also has to be noted that an interference on the two frequencies 1030 MHz and 1090 MHz has a direct impact on the air traffic controller screen, e.g. by not giving a full and accurate display of the air traffic. This may lead to very hazardous situations.

In case of interference during a TCAS/ACAS event, there is a direct risk of mid-air collision.

One of the mitigation measures to prevent interference at 1030 MHz and 1090 MHz is to implement appropriate guard bands, which should be agreed on a Europe-wide basis. PMSE equipment should be designed to be unable to operate within these frequency guard bands.

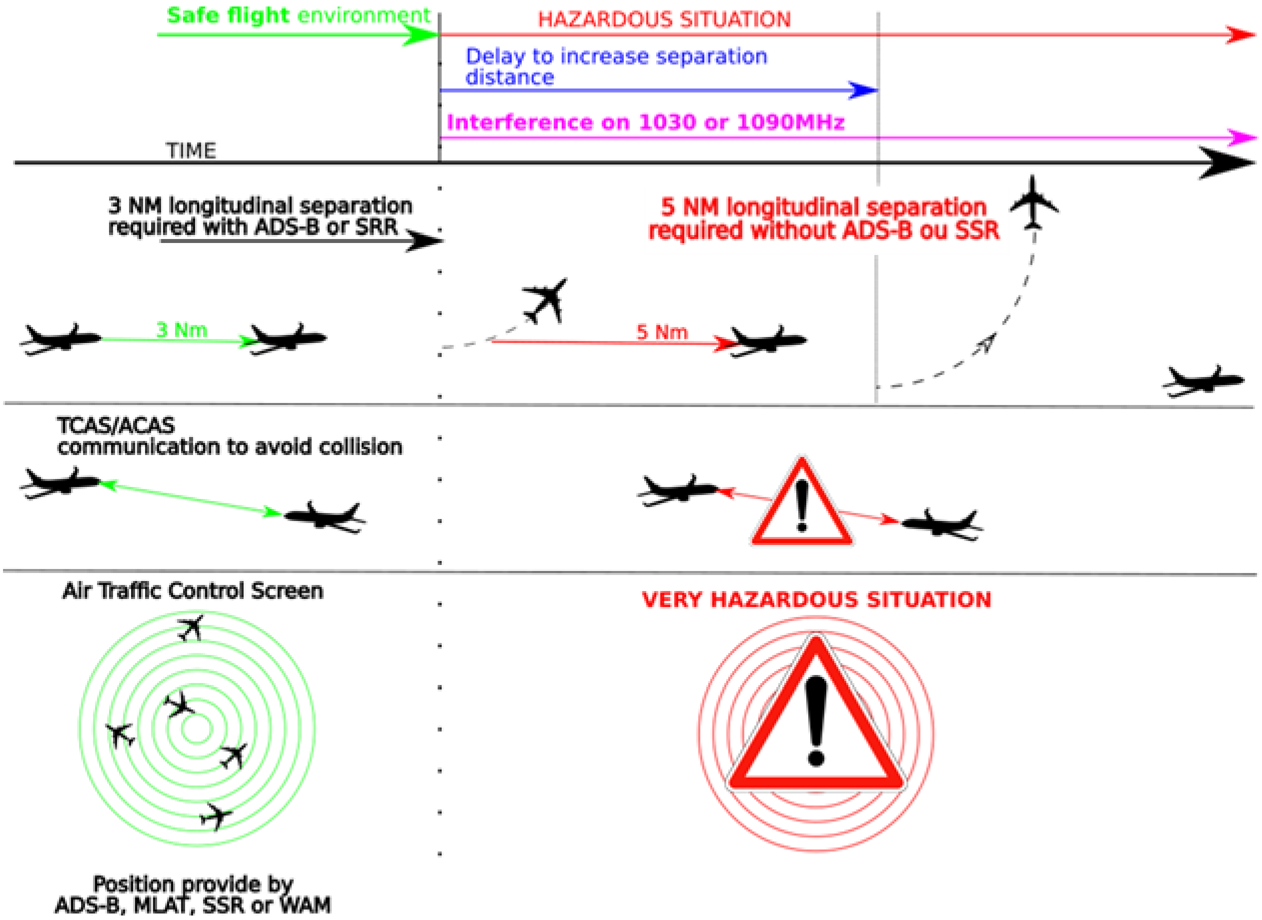

Figure 2: Safety impact in case of interference to the frequencies 1030 MHz and 1090 MHz

5.1.3 Interference considerations

It should be also noted that identification, sourcing and the research of any harmful interference in the band 960-1215 MHz is a very complex and expensive undertaking as it involves critical safety services that are in continuous use. Having an established or published navigational aid removed from service due to harmful interference would be an unacceptable situation.

If a case of harmful interference in the band 960-1164 MHz leads to the removal of a safety service from operational use, an airborne flight inspection analysis would be required and usually take more than 12 hours to be implemented. As possible harmful interference caused by PMSE will be of short duration (less than 12 hours) and potentially intermittent, it will be difficult to identify the main interfering source and to remove the interference in an expeditious manner. Aviation stakeholders believe that time-stamped logging of PMSE usage may be required for post incident and accident investigation purposes.

Availability of accurate PMSE license and usage information could be used to correlate interference reports within a specific geographical location and useful in identifying the interfering source. However, interference from potential unlicensed use of PMSE would be very difficult to locate and remove.

5.1.3.1 A specific case, DME as a component of the Instrument Landing System (ILS)

The safe operation of aeronautical navigation systems, in particular ILS CAT I/II/III requires availability and integrity which is comparable to few if any other radio services, or of the order of magnitude of $1 - 1*10^{-6}$ or better (the specified required integrity for CAT II/III is $1 - 1*10^{-9}$). Such high availability and integrity can only be achieved by ensuring there is no interference to the various components of the ILS from other systems. In this context, extreme propagation anomalies need to be taken into account, as well as intentional or inadvertent co-sharing of a DME frequency by the PMSE user.

Some testing of potential interference scenarios has taken place in the UK to-date [22]. This testing showed that increasing the PMSE signal to greater than -97 dBm caused one interrogator under test to suffer from false range readings, and that PMSE signals greater than -90 dBm caused it to fail to meet the -78 dBm Acquire Stable Operating Point criterion which was derived from the minimum DME signal level specified in ICAO Annex 10 for this test setup. Erroneous indication from any navigation system can be considered even more dangerous than the navigation system becoming inoperable due to interference. As there was a limited number of test scenarios, it may be possible that DME receivers may exhibit this behaviour at even lower signal levels.

Another issue of note is that even a short duration interference to DME, when used as a component of the ILS CAT I/II/III may not only have an impact on the safety of flight, due to aircraft not being able to initiate the CAT I/II/III approach and landing procedure during the interference event, this may also have a longer term effect on the efficiency of airport operations. Strict Air Traffic Control intervention would be required for the provision of alternative ranging information for each flight, this implies flow control with much reduced capacity. A demonstration period would need to be completed before normal operations could be restored, proving fault rectification or resolution to the issue that caused the loss. Depending on the severity of the loss, varying periods will be required to prove the stability and operational capability of the facility, for example this could be between 24 and 300 hours or as specified by the ANSP for that aid. In the meantime, the airport operations will be required to take place at a much lower capacity, thus causing significant financial burden.

5.2 DIFFERENT APPROACHES TO SAFETY AND QUALITY MANAGEMENT BETWEEN THE AERONAUTICAL AND PMSE CULTURES

All personnel currently involved in the operation of aeronautical and military systems in the band 960-1164 MHz are required to understand the principles of both quality management system (QMS) and SMS. While the PMSE industry may already plan events and operate equipment under a methodology similar to QMS, as indicated in ICAO Doc 9718 [101] in order to continue safe aircraft operations and based on the aeronautical regulatory framework, any user operating within this frequency band would also need to apply SMS to their operation in order to ensure no adverse effect to the safety of aircraft operations.

Table 7: Principles of SMS and QMS [27]

QMS	SMS
Quality	Safety
Quality assurance	Safety assurance
Quality control	Hazard identification and risk control
Quality culture	Safety culture
Compliance with requirements	Acceptable level of safety performance
Prescriptive	Performance-based
Standards and specifications	Organisational and human factors
Reactive > Proactive	Proactive > Predictive

In addition to professionally managed large-scale radio and/or television production events, PMSE is also commonly used for smaller scale public or private events, at any location, e.g. Sporting, Music, Theatrical, Religious, Political, Hobby and Corporate Retailing. CEPT Report 32 [24] differentiates PMSE users between critical use ("professional"), and less critical use. Less critical use is defined as "typically community users covering local events. Their use is generally not coordinated with other users. These users are often called 'consumers'. They expect easy access to a small amount of spectrum with no cost and typically use a limited amount of equipment."

Under the existing operational environment, events and productions means that, particularly for large scale, economically and culturally significant productions, sound design is entrusted to highly experienced and highly skilled individuals and organisations that can demonstrate the required proficiency to deliver interference-free live audio in a complex RF environment.

The proficiency of individuals and organisations operating in the PMSE sector is typically gained through prolonged experience within the sector and who are widely recognised, by consensus, as having the essential skills and knowledge to plan and manage the spectrum to deliver the necessary level of production free of interference. In many sectors the definition of an expert is well established by consensus and therefore it is not necessary for individuals to have a professional or academic qualification for them to be accepted as an expert, and this is the case across the PMSE sector.

ICAO Doc 9718 [101] states: “Non-safety-of-life services, willing to share a safety-of-life band, have to comply with the aviation safety requirements applicable in that band including certification of radio equipment, software and radio operators, as well as assumption of liability”. It is highlighted that ICAO Doc 9718 identifies its status as "This handbook contains the ICAO spectrum strategy and policy statements relevant to the aviation requirements for radio frequency spectrum, as approved and amended by the ICAO Council".

ICAO Doc 9868 [102] and ICAO Doc 10057 [103] and European Regulation (EU) 2017/373 [20] contain the required provisions for training and assessment of air traffic safety electronics personnel, building on the provisions and requirements contained in Articles 18 and 37 of the Radio Regulations. ICAO Doc 9868 specifies that “any practical training should be performed under the supervision of an instructor qualified and competent in the technical domain for which the certificate of competency shall be issued. In instances where practical training is provided through on-the-job training, the instructor shall be qualified and competent in the technical domain, and the training shall be conducted under the safety management system of the air navigation service provider”.

In order to maintain the safe RF operating environment of the safety critical aeronautical radionavigation and surveillance systems operating in the frequency band 960-1215 MHz, ICAO has indicated that the personnel responsible for the operation of the non-aviation systems in the 960-1164 MHz band would need to be required to achieve similar levels of certification, as has been done with military operators which shall have ATSEP licenses when sharing this band. To date, no recognised training of PMSE users in the 960-1164 MHz have been established. Therefore, some national aviation authorities may need a reliable internationally PMSE recognised body to count on which can ensure aviation spectrum usage is secured before making this band available for PMSE and also during PMSE operations in the band. This is especially true due to the current vastly different operational cultures in aviation on the one hand and in the PMSE industry on the other hand.

The existing authorisation practice of administrations for audio PMSE has a strong influence on the operational behaviour of PMSE users. In countries with an individual licensing policy, PMSE users apply for access to spectrum and are usually assigned a specific frequency for a given period of time and at a given location; whereas in countries with general authorisation, users have to find available spectrum themselves, which may be done by scanning for interference free spectrum.

It is recognised in this Report that an individual licensing regime is appropriate for a possible introduction of audio PMSE in the band 960-1164 MHz (see section 3.2.3). If individual licensing represents a different licensing regime from that used for other audio PMSE operations (e.g. in the UHF band), then additional measures to assist compliance with the individual licensing regime may be appropriate, for example additional training.

Special note should be taken of the large differences between the operational environment of white spaces between television channels in the 470 and 700 MHz bands on the one hand and the aeronautical environment in the 960-1215 MHz on the other hand. In the television broadcast band, if a channel is free of interference from a nearby television broadcast, then it is normally clear for low-power PMSE use. On the other hand, the aeronautical radionavigation systems in the 960-1215 MHz band operate with a 63 MHz offset between transmit and receive, hence the PMSE user cannot assume that a frequency is clear if he does not detect a signal on the frequency. In the case of PMSE operating on the interrogator (aircraft) receive frequency, the PMSE user may be shielded from the transponder transmit frequency. However, in the case of PMSE operating on the transponder (ground) receive frequency, a PMSE user will likely suffer interference from airborne interrogator transmissions, see Figure 3, making the channel unusable for PMSE.

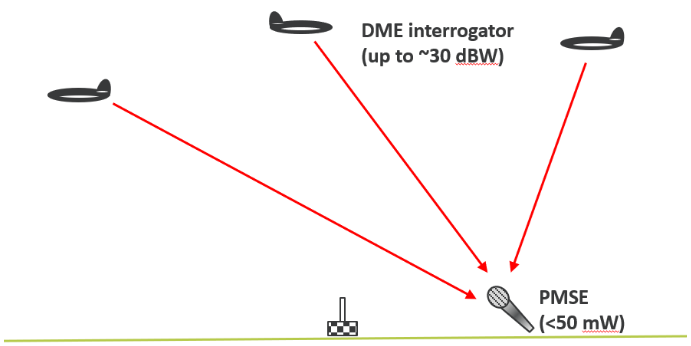

Figure 3: Geometries for airborne interference into PMSE receivers

Due to the various issues highlighted above, experience and knowledge gained from operation in traditional PMSE bands may only be partially applicable to the 960-1164 MHz band.

5.3 IMPACT OF CURRENT AND FUTURE AERONAUTICAL SYSTEMS ON PMSE IN THE FREQUENCY BAND 960-1164 MHZ

5.3.1 Impact of Link 16 on PMSE

The frequency band 960-1164 MHz is shared with military application Link 16 (JTIDS) which are used for aircraft interception that might pose a terrorist threat under 'Renegade' procedure.

The operational use of Link 16 differs significantly from one country to another one due to the strategy on their national security specific for each administration. Careful provisions are set within various countries as part of joint civil aviation/military agreement in order to ensure that Link 16 can be used in accordance with their operational requirements and without causing any threat to civil aviation systems. Some countries allow Link 16 to be used anytime and anywhere in their territory.

Considering that JTIDS/MIDS operates in fast frequency hopping mode all over the frequency band 960-1164 MHz (except guard bands around 1030 MHz and 1090 MHz), it appears that interference free operation of audio PMSE cannot be ensured in the presence of JTIDS/MIDS. Administrations should therefore carefully consider the reliability of the band 960-1164 MHz for supporting the desired quality of service for audio PMSE users.

Furthermore, in countries sharing the band 960-1164 MHz with military systems and intending to introduce audio PMSE in this band, the national agreement between the CAA and military authority should be reviewed due to the new RF environment.

5.3.2 Long-term availability of the 960-1164 MHz frequency band for PMSE

As indicated in the ICAO Global Air Navigation Plan [83], the frequency band 960-1164 MHz is already highly populated with safety critical aeronautical systems and is intended as the home for the implementation of evolving aeronautical systems.

On a global basis, the frequency band 960-1215 MHz is used for Distance Measurement Equipment (DME) systems; this use will continue well beyond 2030.

The variety of Civil/Military radionavigation and communication systems in use today in addition to DME, as well as future civil aeronautical systems in the band 960-1164 MHz, is described in section 2.

The introduction of new aeronautical systems typically takes many years to realise. These long lead times and slow evolution of aeronautical systems may be beneficial to the management of spectrum sharing by regulators and allow plenty of time to respond to any changes in the band. However, care needs to be taken not to constrain the evolution of the aeronautical systems in the band. The introduction of some aeronautical systems is already underway.

ICAO is currently developing international Standards and Recommended Practices (SARPs) for Unmanned Airborne Systems (UAS), indicating this band as one of the bands used for control and non-payload communications (CNPC), while taking into account existing civil aviation applications (DME, SSR...) and governmental applications. ICAO is also considering future CNS systems for operation in this band.

The frequency band 960-1164 MHz is the identified band by ICAO for LDACS, which is furthermore considered as part of the European Union Single European Sky programme. LDACS flight tests began in Germany in Q1 2019 [87].

The evolution of aeronautical systems in the band 960-1164 MHz should be carefully considered in order to assess whether the band 960-1164 MHz can offer a sufficient amount of spectrum as well as long-term stability to the PMSE sector.

5.4 IMPACT ON SERVICES IN ADJACENT BANDS

The adjacent band 1164-1215 MHz is also allocated to the RNSS and used by GNSS. GNSS systems have become essential for a very wide range of services, user groups and communities with many business and operations relying on its ubiquitous and continuous availability. For example, Galileo has operational signals in the 1164-1215 MHz band to provide dual frequency GNSS services to significantly improve performance and robustness, as will GPS and GLONASS in the future. Appropriate protection such as a guard band should therefore be in place to protect these services, which could include safety of life applications.

ANNEX 1: NATO CONSIDERATIONS ON THE PREREQUISITES FOR THE INTRODUCTION OF PMSE IN THE BAND 960-1164 MHZ

The inclusion of new non-safety of life systems in an ARNS and AM(R)S frequency band necessitates robust EMC and regulatory studies, and strict compliance to avoid interference to the incumbent aeronautical and critical military systems. Safety of life aeronautical systems operating in that band must go through a certification process for both the equipment and the operators using the equipment. The band is shared with the military (governmental systems), which are subject to similar civil aviation safety constraints (i.e. Link 16). A system, such as PMSE, would also be expected to have similar requirements placed upon it potentially implying a significant expense of resources to prove compatibility. Additionally, the proliferation of commercial non-safety of life equipment operating in the band can lead to an uncontrolled usage subject to operator error or illegal or unlicensed operation of PMSE equipment in disregard of various national requirements if equipment was procured in another country with different PMSE limitations. This would not be compatible with the safety requirements of existing and future aeronautical systems[21]. It is important to note that interference in this band can have catastrophic and irreversible consequences.

Of utmost interest to NATO is the fact that the introduction of PMSE equipment into the band 960-1164 MHz could impact the current and future operation of NATO systems that operate in the band, including TACAN, DME, Link 16, IFF/SSR, and UAS/RPAS CNPC system links that may be required for military UAs. Especially at risk is Link 16 which is operated under Article ITU RR No. 4.4 in the band. It should be ensured that the presence of PMSE operations will not affect the level of Link 16 compatibility with the primary aeronautical systems and the necessary Link 16 Frequency Clearance Agreement (FCA) criteria that should be met (i.e. no added Link 16 restrictions either for peacetime or large coordinated operations when necessary)[22]. While interference from PMSE equipment to military ground based equipment could be controlled by applying a necessary separation distance (if those locations are known and can be shared), overcoming the impact to an aircraft receiver which can fly essentially at any point in air space is much more difficult to achieve if not impossible. Thus, for example, PMSE equipment could impact airborne military TACAN operations due to the unknown locations and channel assignments for the associated and paired surface mobile TACAN beacons (e.g. shipboard, and ground transportable beacons). This same impact could result during air to air TACAN operations. In other words, the airborne TACAN channel and aircraft location may not be known making it difficult to de-conflict those operations through frequency and distance management.

The incorporation of a continuously transmitting signal such as PMSE in this band raises compatibility concerns as receiver requirements for ICAO and governmental incumbent systems have not been specified to handle non-pulsed type modulated emissions. The additional ICAO requirements needed to support a continuously emitting transmitter would require specifications for robust receiver frequency selectivity and immunity from spurious responses. It is for this reason that all the incumbent system types operating in the band 960-1164 MHz must be tested.

To authorise a system such as the PMSE, it is envisioned that a conservative robust test bench program between the PMSE equipment (both as a source and a victim) and a panel of the primary or incumbent aeronautical equipment, representative of the different technologies and implementations, would be required. This test program should be performed in a simulated maximum RF environment including signals of all systems received under operationally realistic conditions experienced by the aeronautical equipment in the applicable CEPT nations, using the most stringent of compatibility criteria. The tests should consider the PMSE transmitter as a source of interference as well as interference to the PMSE receiver as a victim of the existing RF environment.

The PMSE should also be certified to ensure that any equipment waveform characteristics are compatible and designed such that even in cases where the PMSE radio malfunctions, no interference is caused. To meet the latter requirement, monitor circuitry should be considered for integration into the PMSE device which prevents it from operating on unauthorised channels or deviating from transmission characteristics from those that have

[21] Interference statistics have been addressed within the CEPT where over a staggering 1700 cases of interference have been reported to aeronautical services within the CEPT nations; "CEPT ECC Working Group FM Report with subject "Summary of the Annual Interference Statistics Questionnaire for Reported Cases in 2016" dated 19 May 2017

[22] Such restriction or controls would range from total loss of existing or potential Link 16 authorisation to operate to affecting peacetime training by further limiting the levels of operation in a geographic area, disallowing required functionality, restricting location of operations and adding separation distances to other in-band users

been determined necessary for compatibility. Also to be considered is that the operation of PMSE equipment outside the licensed position/country should be inhibited in unauthorised locations. Equipment acceptance testing should be performed to verify that the device is operating in accordance to required compatibility standards. Additionally, the operational use of the equipment must be verified to meet the special frequency management requirements for a system not operating under the proper service allocation in the band (i.e. non-primary user in the frequency band). For example, the military Link 16 radio terminals are required to incorporate EMC Features monitor circuitry and undergo these requirements as a condition for operating as a non-interference system in the band 960-1215 MHz.

The evaluation process should also consider interference to airborne equipment operation not only in that nation’s airspace but also to airborne and ground equipment within a potentially large distance radio line of sight (RLOS) in another country. Criteria for cross-border coordination should be established for those cases, when the aggregate signal of PMSE devices operated in one country can interfere with airborne or ground equipment in another country. Cross-border coordination for systems and equipment operating on NIB are presently non-existent in CEPT and need to be established. This would also set the conditions for its operation under frequency management rules.

ANNEX 2: EUROCONTROL SAFETY CONSIDERATIONS

From the early days of aviation, the aviation industry develops, maintains and operates safety of life and safety and regularity of flight systems operating in adequately protected spectrum.

The ITU Constitution (CS) and the ITU-R Radio Regulations (RR) have captured the absolute importance to protect safety-of-life spectrum.

By design aviation systems do not expect in-band interference from non-safety systems operating in the same band; it goes the same for processes and operational procedures developed around these environments. Safety cases and mitigation techniques are also developed based on the same assumption.

The ICAO Doc 9718 [101] states: “Non-safety-of-life services, willing to share a safety-of-life band, have to comply with the aviation safety requirements applicable in that band including certification of radio equipment, software and radio operators, as well as assumption of liability”.

Safety related issues of the aeronautical sector are supervised by a designated National Supervisory Authority (NSA). If a radio regulator plans to license a non-safety-of-life user in a frequency band used for safety-of-life purposes, the regulator needs to coordinate with the designated NSA in a manner that provides sufficient evidence that:

1 All aspects of sharing an aviation safety-of-life band are taken into consideration to preserve the safety of the aviation operational environment;

2 Effective actions are taken to prevent any proliferation of equipment having the capability to transmit in the safety-of-life band in question;

3 Efficient market surveillance is performed to ensure that manufacturing and importing of such equipment are fully under control;

4 Efficient monitoring of the band is performed to prevent any illegal use and potential interferences with safety-of-life systems;

5 Licenced non-safety systems are manufactured in conformance with the internationally agreed standards;

6 Traceability of non-safety systems manufactured equipment;

7 Users of the non-safety systems are qualified to operate in ARNS, AM(R)S and AMS(R)S bands and hold a valid certificate; and:

8 Their operational handbooks are valid and maintained properly;

9 Their safety management system (SMS) is accepted and validated by the NSA;

10 They are insured for their liability;

11 An effective and continuous monitoring of the RF environment is put in place;

12 Measures are taken and resources are made available for a diligent intervention;

13 Non-safety systems users can seek a licence only when they can provide evidence that their equipment, processes, operational procedures, SMS, safety cases and mitigations technics are approved by the National Supervisory Authority NSA;

14 It is the responsibility of the NSA to coordinate with the CAA and ANSPs;

15 The performance of non-safety systems’ users regarding the scrupulous respect of rules and terms of their licence shall be recorded by the radio regulator and made available to the NSA;

Non-safety systems users sharing a safety-of-life band cannot be under the responsibility and authority of the CAA; they have to operate under the full responsibility of the Radio Regulator having delivered the licence. As a CAA is liable for licences delivered to Air Navigation Service Providers (ANSPs), Airports, etc., the same processes and procedures shall apply to the Radio Regulators to maintain the required safety-of-life protection. As ANSPs and Airports are liable for their operations, the same processes and procedures shall apply to non-safety systems users sharing a safety-of-life band.

ANNEX 3: EUROCONTROL MILITARY ATM BOARD[23] (MAB) ON LOW POWER AUDIO PROGRAMME MAKING AND SPECIAL EVENTS (PMSE) SHARING IN THE AVIATION BAND 960-1164 MHZ

The MAB acknowledge the consultation and studies related to the 960-1164 MHz aviation band[24] for the possible use of low power audio Programme Making and Special Events (PMSE) equipment.

The band in question is used to support fundamental safety-of-life services for both civil and military aviation. These are based on the operation of systems such as DME, TACAN, SSR, ACAS, Mode S, IFF and some bands of GPS and GALILEO. JTIDS/MIDS uses a set of frequencies in this band.

The MAB acknowledge the risks associated with the Ofcom (UK) decision. Such risks result from sharing this L-band spectrum used for safety-related services with commercial and market-driven non-aviation services which would require strict governance to safeguard the aviation use of the band.

The MAB highlight the importance of relevant regulatory and technical studies to be conducted on the feasibility of such spectrum sharing to completely mitigate the risks of interference with a negative impact on aviation safety. In this respect the MAB fully support the approach described in the ICAO letter E3 5.15, dated 19/04/2017, to the CEPT ECC WG FM Chairman in particular to the 7 caveats identified as pre-conditions to be met to be able to accept any sharing of the band:

1. the new system is completely compatible with existing and planned aviation systems based on testing and analysis that has been agreed by aviation regulators;
2. the parameters for the new system will be captured in an internationally recognised standards document;
3. the new system will be certified (including software and hardware) by the competent national regulatory authorities; will be maintained to meet throughout its service life the operational parameters assumed in the aviation testing/studies; will perform self-monitoring to ensure that it shuts down if it moves outside those agreed parameters; and the self-monitoring/shutdown function itself will also be certified;
4. the new system will include time-stamped logging of essential transmitter parameters, such as frequency use and power levels for post incident/accident investigation purposes;
5. the new system will not impact the ability of aviation to manage existing and planned aviation systems and the ability of aviation authorities to modify operating frequency assignments, powers and signal contents of the aviation systems without introducing additional coordination mechanisms;
6. the operator of the new system must accept all legal liability in case of interference to aviation systems (e.g., due to false channel selection, excessive power, human error, device failure), and recognise that aviation systems operators have no liability in case of interference to the new system;
7. personnel responsible for the operation of non-aviation systems in the 960-1164 MHz band shall be required to achieve similar levels of certification to those stipulated in the Radio Regulations for operators of aviation systems (radio operator's certificate).

In addition to the ICAO caveats, the MAB could only support the introduction of any new system in the 960-1164 MHz band if it can also be ensured that:

- the related liability aspects be identified and clarified in advance; - In case of (harmful) interference, (for instance due to wrong PMSE channel selection, too high power emission, human error, device problems,…) resulting in any incident and/or accident (infringement of safety), responsibilities have to be established and corrective actions need to be taken in a timely manner;

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23 The Military ATM Board is part of the EUROCONTROL consultation arrangements and advises the DG and the PC. Its major role is to act as pan-European military focal point for ATM matters. One of its resulting major tasks is to develop harmonised pan-European military position in regard to civil-military ATM coordination. MAB membership is open to all ECTL member States, NATO, EDA and S-JU have observer status.

24 Considered by the International Telecommunications Union (ITU) as a band for Aeronautical Radio Navigation Service (ARNS), Aeronautical Mobile (Route) Service (AM(R)S and, around 1090 MHz for Aeronautical Mobile Satellite (Route) Service (AMS(R)S).

- no additional technical and operational constraints, resulting from a possible sharing of this band with low power audio PMSE, be imposed to aeronautical applications in 960-1164 MHz band including the military systems.

In respect to the technical studies to be conducted, respecting the fact that NATO could not come to a unanimously agreed position on this issue as obligated to take a formal NATO position and to nevertheless respond to the request of WG FM to represent the military interest, NATO submitted the CaP3 military session paper ‘PMSE Equipment EMC Evaluation Requirements’ Document SE7(17)083 dated 18 September 2017 to WG FM, WG SE and SE7 of CEPT. This document sets the technical parameters to be taken in account for the studies to protect the military interest and use in the respective band. This document and its content are fully supported. The MAB in particular want to stress the rigorous and robust test and evaluation process that needs to be established including hardware testbeds in order to fully assess the electromagnetic compatibility situation.

ANNEX 4: UK DECISION TO ALLOW PMSE TO SHARE THE 960-1164 MHZ BAND SUMMARY

Working with the Civil Aviation Authority (CAA) and Ministry of Defence (MOD), and operating within its statutory duties, rights and obligations as set out in all relevant national and international regulations, Ofcom decided to allow low power audio PMSE (wireless microphones and in ear monitors with a radiated power of less than 50 mW) to operate in the 960-1164 MHz band, sharing the spectrum with civil and military aeronautical navigation and communication systems. In December 2018 the CAA agreed the safety assurance case which assesses the risk of PMSE sharing in the band.

Spectrum availability for PMSE is derived through the Spectrum Management Rules (SMRs). The SMRs identify usable spectrum for PMSE on a geographically interleaved basis with DME/TACAN assignments. The SMRs do not allow access to spectrum within ±15 MHz of 1030 MHz and 1090 MHz (to mitigate the risk of harmful interference to all aeronautical systems that operate at 1030 MHz and 1090 MHz), or to spectrum below 961 MHz and above 1154 MHz to protect services in adjacent bands. Access to the band is on a licensed basis which authorises the frequency, location and duration of the PMSE assignment.

This annex summarises the rationale for looking at additional spectrum for PMSE and the analysis and steps taken to assess compatibility and ensure spectrum sharing in the 960 MHz band can be effectively and safely implemented.

A4.1 BACKGROUND

Following the decision at the World Radiocommunication Conference in 2012 to agree a co-primary allocation for mobile and broadcasting in the 700 MHz band (694-790 MHz) in ITU Region 1, Ofcom carried out an impact assessment of loss of access of this band on Programme Making and Special Events. This analysis concluded that the majority of PMSE users and events would be able to satisfy their spectrum requirements from the remaining spectrum between 470 to 694 MHz. The analysis showed that 93% of events required 24 or fewer assignments which could be accommodated in 20 to 24 MHz of spectrum. This level of demand can comfortably be met in the spectrum between 470 to 703 MHz[25] that PMSE will continue to have access to after the release of the 700 MHz band.

The remaining 7% of events make up the peak demand that would start to be affected by the change of use of the 700 MHz band. However, for only a small subset of these events, with a high count of simultaneous (or near-simultaneous) co-located assignments, the remaining spectrum between 470 to 703 MHz may not be adequate.

To mitigate the loss of access to the 700 MHz band, Ofcom assessed new spectrum sharing opportunities. In looking to identify candidate spectrum Ofcom applied the criteria as set out in Table 8.

Table 8: Criteria to identify candidate spectrum sharing opportunities for low power audio PMSE

Criterion	Rationale
Not already allocated to Mobile	Risk of interference. Audio PMSE applications require high quality of service which can only be provided by spectrum with a low risk of harmful interference. On this basis sharing with mobile services is not considered viable
Not already identified as a candidate mobile band and unlikely to be so in the medium to long term	Any spectrum identified as a candidate mobile band is at risk of reallocation at some future time. While this reallocation may be some time in the future it is not possible to provide any certainty around security of access

[25] In November 2017 Ofcom (UK) published its decision to allow PMSE users to access the 700 MHz guard band, 694 to 703 MHz. This additional 9 MHz was not included in the original impact assessment. This band was not included in the PMSE impact assessment.

Criterion	Rationale
The incumbent use of the candidate band is harmonised at least Europe wide	This would provide the opportunity for other countries to adopt the sharing solution leading to economies of scale in equipment production and distribution
Provides a substantial block of contiguous spectrum	A fragmented spectrum supply would not be viable for PMSE users. Equipment owners and hirers would need to hold multiple items to access small, discrete parcels of spectrum which is not considered economically viable
Introduction of PMSE to be neutral to any incumbent	Access to the band by PMSE should not constrain or require any remedial action by the current users of the band such as a change of working practice or equipment
Below 2 GHz	The current industry consensus is that higher frequencies are inappropriate for PMSE applications due to their propagation characteristics

All bands between 790 MHz and 2 GHz were assessed against the criteria in Table 8. This identified the 960-1164 MHz band as the most viable option for low power audio PMSE as it meets all the above criteria. In particular, given the slow rate of any changes to incumbent use in the band, access for PMSE can be considered to be a viable long-term opportunity.

A4.2 COMPATIBILITY

Compatibility between PMSE and aeronautical services in the 960-1164 MHz band is ensured through the application of the Spectrum Management Rules (SMRs) which define the framework for how spectrum for PMSE is derived. The SMRs identify what spectrum can be used by PMSE and provide an indication of the 'quality' of that spectrum (by assessing the level of potential interference into PMSE from aeronautical services).

Aeronautical services that operate at 1030 MHz and 1090 MHz (e.g. SSR, ACAS, ADS-B etc.) are protected by ±15 MHz guard bands. GNSS operating above 1164 MHz is protected by a 10 MHz guard band from 1154 to 1164 MHz. Services below 960 MHz are protected by a 1 MHz guard band. This means that the spectrum is split into three sub-bands in which PMSE can operate:

- 961-1015 MHz;
- 1045-1075 MHz;
- 1105-1154 MHz (10 MHz guard band at 1154 MHz).

Within the sub-bands noted above the primary sharing arrangement is PMSE geographically interleaving with DME (and TACAN) assignments. The UK Interface Requirement 2038 (for PMSE) clearly identifies the bands that can be used by PMSE and technical limitations such as maximum power and bandwidth.

A4.3 APPROACH TO ASSESSING COMPATIBILITY

Working closely with the CAA and the MOD, Ofcom carried out a detailed compatibility study between aeronautical systems that operate in the 960-1164 MHz band and low power audio PMSE equipment.

To assess compatibility a series of practical coexistence tests were carried out. These tests were agreed with the CAA, MOD and Ofcom and used the same approach and civil and military aeronautical equipment as those practical tests used to derive the UK's Link 16 Frequency Clearance Agreement (FCA) between the CAA and MOD. It was agreed that using the same approach for determining compatibility between Link 16 and aeronautical systems would be suitable for deriving the compatibility between those systems and low power audio PMSE.

The tests included the full Link 16 signal environment as defined in the FCA. This was to ensure that the introduction of PMSE into the band would be neutral to both civil and military use and not cause a need to review or revise the FCA to take account of PMSE.

Testing was carried out by JCSys[26]. Interference thresholds were determined through measurement for a range of aeronautical ground and airborne DME and SSR equipment, for both analogue and digital microphone equipment. The tests also assessed the 'quality' of the spectrum to support PMSE services. The full reports can be found on Ofcom's (UK) web site [85]. The results of the compatibility tests were used to assess spectrum availability for PMSE. The propagation modelling parameters were agreed with the CAA.

Ofcom (UK) consulted on its analysis and assessment of spectrum availability, and in March 2016 published its statement setting out its decision to allow low power audio PMSE to operate in the 960-1164 MHz band [86].

A4.4 SPECTRUM AVAILABILITY

Spectrum availability for PMSE is location dependent as frequency assignments for aeronautical services (DME and TACAN) are based on frequency planning criteria using a 1 MHz channel raster (DME channels are identified by number and 'X' or 'Y'). By incorporating this assignment data in the SMRs it is possible to identify usable spectrum for PMSE, geographically interleaving with DME. Figure 4 summarises the approach.

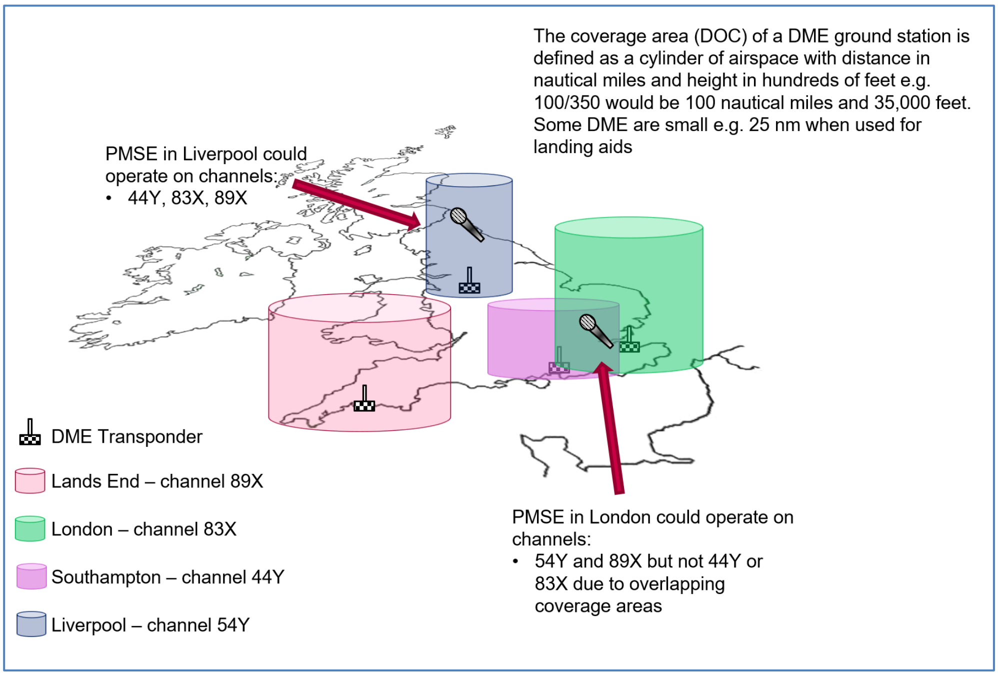

Figure 4: Example of location dependent spectrum availability for PMSE

Information on DME frequency assignments, including location of ground equipment and operational coverage areas, is taken from EUROCONTROL'S Spectrum and Frequency Information Resource (SAFIRE)[27]. The SMRs and licensing platform apply these data to the location of the proposed PMSE assignment to calculate available spectrum. The guard bands at 1030 MHz and 1090 MHz, below 961 MHz and above 1054 MHz are hard coded into the licensing platform so are shown as not available.

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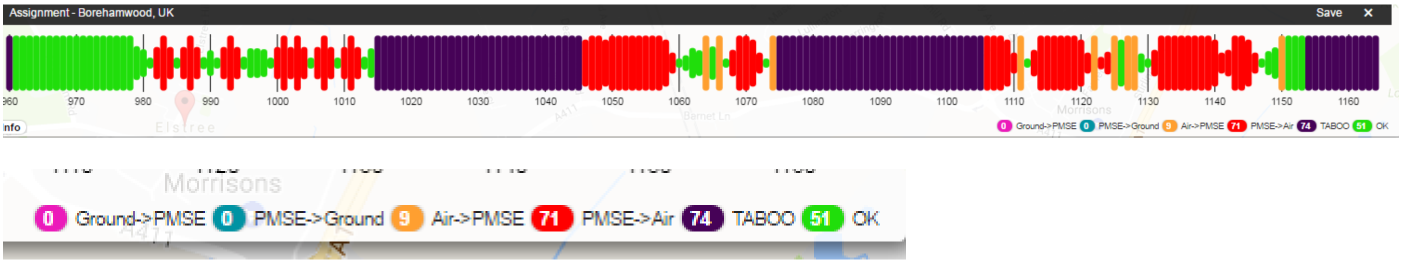
[26] JCsys is the key advisor to the UK MOD providing subject matter expertise support for the Frequency Clearance Agreement compliance and testing

27 SAFIRE provides a platform to manage the coordination and publication of the aviation frequency assignments in the ICAO European region. SAFIRE is built on a database which contains information about every aeronautical frequency assignment in the communication, navigation and surveillance aviation bands.

Figure 5 provides some examples of spectrum availability for BBC studios at Elstree, North London and Pacific Quay, Glasgow. As can be seen in the figure, the guard bands are clearly shown as unavailable ("taboo") and spectrum availability is different between the two locations, i.e. 60 MHz in Elstree and 110 MHz in Pacific Quay. This is because there are more DMEs to be considered in the south east of the UK than in Scotland.

Elstree – 60 MHz available of which 9 MHz at risk of interference into PMSE from airborne DME



Pacific Quay Scotland – 110 MHz available of which 17 MHz at risk of interference into PMSE from airborne DME

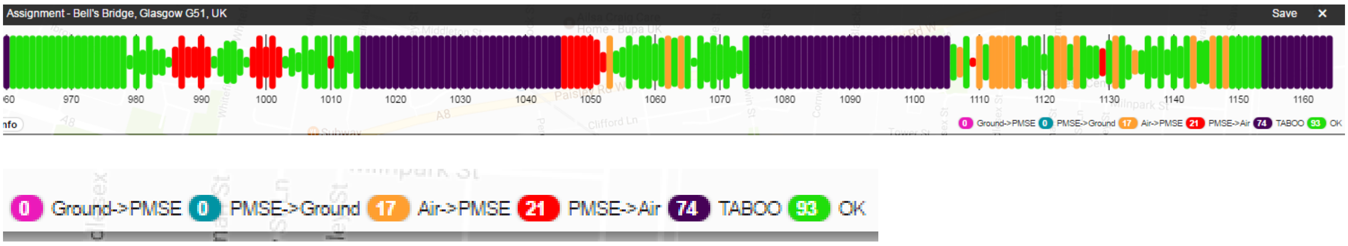


Figure 5: Examples of spectrum availability for low power audio PMSE

A4.5 TESTS AND TRIALS OF PMSE EQUIPMENT

Since 2016, PMSE users have carried out tests and trials within the 960-1164 MHz band (authorised via a trial and innovation licence) to determine whether it provides sufficient quality for productions. These have included long-term monitoring of the band (both indoors and outdoors) and use of wireless microphones within and outside studios, including in live productions at the Sky studios near Heathrow Airport. Further details can be found in ANNEX 5 of appendix 1.

Ofcom (UK) identified that due to the nature of the Link 16 signal, technical coordination is not possible and does constitute a risk of interference to PMSE. The MOD provided information on the typical use for Link 16 in the UK, i.e. above 10000 feet in remote areas. The FCA restricts use of Link 16 near aircraft and ground navigation facilities, and there is protected airspace around airports and major flight lanes. Based on the information provided by the MOD, Ofcom (UK) concluded that the risk of interference from Link 16 is low.

The results of these trials show that spectrum availability and 'quality' aligns with UK Ofcom's the output from the SMRs. Also, the trials and long-term monitoring (including outdoors) has shown no instances of spectrum use, such as Link 16, that would cause harmful interference to PMSE.

UK PMSE users have gained confidence in the band and have stated that it provides a suitable spectrum sharing option to support the high-quality requirements of programme and event production.

A4.6 SAFETY ASSURANCE

As part of the implementation of PMSE sharing in the 960 MHz band Ofcom (UK) has developed a safety assurance case (SAC). The SAC is based on the classification/tolerability matrix from CAP 760, published by the CAA[28].

The SAC assesses the risk on the safe operation/navigation of aircraft from the expected operation of PMSE equipment, such as wireless microphones and in-ear-monitors operating with a radiated power of less than 50 mW. This SAC demonstrates that, based on a real understanding of PMSE stakeholder performance, the system will be safe. The 960 MHz band is currently already shared with Link 16 (JTIDS). The assessment for PMSE has been developed to be consistent with some of the transferrable assumptions and data presented in the Link 16 baseline safety case.

The SAC considers what consequences would arise if elements of the system were to fail, the 'failure case', and identifies any mitigations needed to ensure the system remains safe. There are three principal areas of risk which are dealt with within the SAC:

- Interference with systems on 1030 MHz and 1090 MHz;
- Interference with GNSS systems above 1164 MHz;
- Interference with DME systems.

The SAC has been reviewed by the CAA and it is satisfied that any proposed change to the radio spectrum environment from the introduction of PMSE into the band can be implemented and maintained without interference to aeronautical services.

A4.7 FEASIBILITY OF PMSE OPERATING IN THE 960-1164 MHZ BAND

Working with the CAA and MOD, Ofcom (UK) has carried out theoretical studies and practical compatibility measurements to develop appropriate sharing criteria between PMSE and aeronautical systems in the 960 MHz band. These criteria have been incorporated into the Spectrum Management Rules through which usable spectrum for PMSE is identified and authorised (via a coordinated PMSE licence which is frequency, location and date/time specific), and aeronautical services protected from harmful interference.

Spectrum sharing in bands used by aeronautical systems must respect the high safety standards of the aviation industry. Ofcom (UK) has developed the following documents to support the spectrum sharing arrangements:

- Test reports for the coexistence studies of PMSE with aeronautical services;
- Spectrum Management Rules for the licensing of PMSE users in the 960-1164 MHz band;
- A safety assurance case setting out how PMSE can share access to this spectrum safely.

The UK CAA has reviewed the documentation and is satisfied that any proposed change to the radio spectrum environment can be implemented and maintained without interference to aeronautical services. Ofcom (UK) will continue to work closely with the CAA to provide assurance that the licensing process, spectrum management rules and safety case remain valid, and that the operating practices of PMSE users conform to the rules and assumptions made.

The possibility of any new aeronautical system being introduced in the band is addressed in both the processes and procedures for maintaining the spectrum management rules (SMRs), and in the safety assurance case itself.

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[28] Guidance on the Conduct of Hazard Identification, Risk Assessment and the Production of Safety Cases

ANNEX 5: REPORT ON PRACTICAL PMSE TESTING IN THE UK: JUNE 2016 – MARCH 2019

Following the publication of a statement from Ofcom (UK) on 10 March 2016 [23], Shure engaged with Ofcom (UK) to initiate practical testing of wireless microphone systems in the 960 MHz band. The BBC and Sky participated in the trials to assess whether the 960 MHz band could support the high-quality requirements of PMSE.

For the length of these trials, some 21 months, no interference has been received to the PMSE systems and there have been no reported cases of interference to aeronautical systems. Spectrum availability and quality are in line with Ofcom's spectrum lookup tool.

Ofcom has authorised the use of PMSE equipment in the 960-1164 MHz band since July 2016 via its Innovation and Trial licence; from January 2019 commercial use can be authorised under Ofcom's standard, coordinated PMSE licence. Trials have taken place by the BBC at Borehamwood, Glasgow, Birmingham, Broadcasting House (London) and by Sky at their studio complex at Osterley, West London plus the Cambridge theatre in central London. In addition, long-term monitoring and some PMSE use has taken place at Edgcott near Oxford. To date, no interference to or from PMSE has been noted, which generally endorses the Ofcom view that for the UK under current conditions this band is viable spectrum for secondary use by PMSE.

The Ofcom spectrum tool has been validated and has proven to identify clear spectrum for PMSE. Licensing continues under both the Innovation and Trial regime and standard coordinated authorisation; licences have been issued or renewed as appropriate.

Trials have predominately been indoors within studios, with a limited number of outdoor deployments. This has been a consequence of practical issues rather than any interference concerns with the DME spectrum. Some additional outdoor trials have been made since the initial report on PMSE trials was issued in January 2017. External operation and monitoring using 10 PMSE channels has been carried out at Edgcott for extended periods to assess the risk of intermittent, short-term interference.

During November 2017 an additional 16 channels of Shure and 2 channels of Wisycom equipment have been in use. All equipment has been inspected in the laboratory and found to meet the technical requirements of ETSI EN 300-422-1 [52].

From the initial trials, sufficient confidence was gained in the viability of the spectrum that from early in 2018 Sky extended the trials to use in live productions at the its studios near Heathrow Airport, which is considered one of the heaviest aircraft use areas in the UK, with live programs lasting up to six hours without any interruptions or interference; these trial is ongoing.

A5.1 SPECTRUM TOOL

Ofcom (UK) generates a "map" of available spectrum at a given location by considering both interference to aeronautical services and to PMSE use over the 960-1164 MHz band. The calculation needs to consider all aeronautical services which may be affected. Channels were then labelled:

- OK;
- Taboo; or
- Showed the potential interference to PMSE.

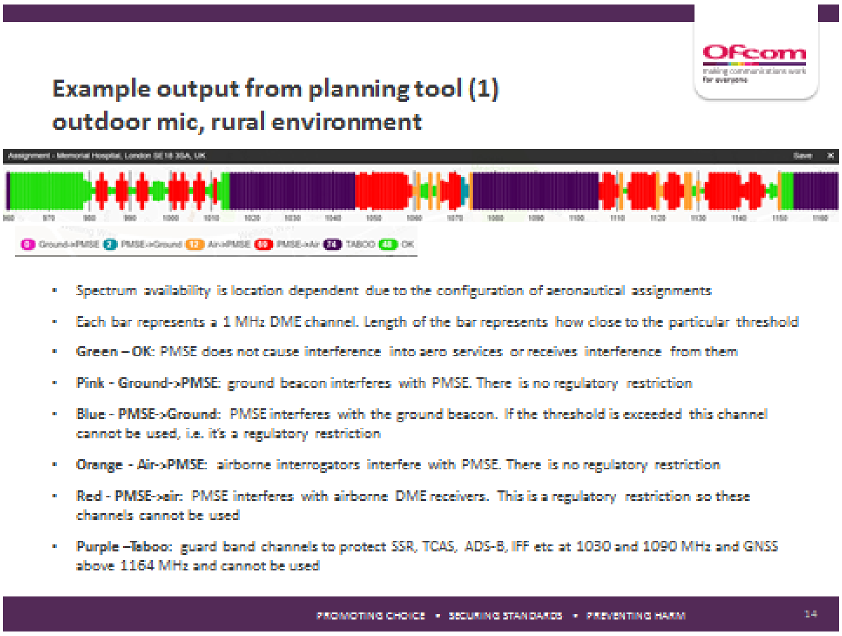

Figure 6: Example output from planning tool (outdoor microphone, rural environment)

A5.2 USE OF THE BAND

The industry regards the 960-1164 MHz spectrum as “top up” for large shows where the remaining 670-694 MHz spectrum is insufficient. Cost and availability of equipment in the 960 MHz compared with that in the 470 MHz band where there is a significant range of cheaper equipment available will have a filtering effect on use.

A5.3 NOISE FLOOR & PROPAGATION

The BBC has carried out extensive monitoring of the 960 MHz and compared this with what is experienced in the 470 MHz band and found the noise floor to be similar. In addition, testing has shown that both bands provide similar link budgets, which is a great advantage when reequipping a site.

APPENDIX 2: SHARING STUDIES

TABLE OF CONTENTS – for appendix 2

1 INTRODUCTION

Numerous technical studies relative to the possible use of low power audio PMSE (excluding airborne use) in the frequency band 960-1164 MHz have been carried out using different approaches and are available in the annexes 1 to 12. This has resulted in diverging conclusions on the possible use of low power audio PMSE in the 960-1164 MHz band taking into account sharing with the aeronautical and governmental services in this band and the RNSS in the adjacent band. Due to the complexity of the systems under consideration and the use cases, no consensus has been reached on the following aspects:

- Input parameters;
- Coexistence scenarios, e.g. single vs. multiple systems and sources of interference;
- Propagation models and application of real effective antenna heights Above ground or Above Mean Sea Level;
- Real receiver sensitivity of operational receiver;
- Applicable antenna elevation contour pattern;
- Building attenuation and the impact of the human body;
- Safety margin for civil aviation equipment;
- In addition, consensus was not reached on the extent of the applicability of presented results from measurements and trials.

2 DEFINITIONS

Below are the definitions (in ICAO Annex 10 Volume I [44]) for ILS integrity and continuity of service. When used as a component of ILS, this applies to DME as well.

Term	Definition
Integrity	That quality which relates to the trust which can be placed in the correctness of the information supplied by the facility. The level of integrity of the localizer or the glide path is expressed in terms of the probability of not radiating false guidance signals.
CITTS	CITTS defines Continuously In Time Transmitted Signal which can have any type of modulation
Continuity of service	The metric which relates to the rarity of radiated signal interruptions. The level of continuity of service of the localizer or the glide path is expressed in terms of the probability of not losing the radiated guidance signals
Continuous Wave	Continuous Wave emission are signals without any modulation as defined in ITU-R SM.329. The source for Continuous Wave signals or spurious radiation as defined by ICAO is local oscillator leakage from one aeronautical transceiver to another.
Distance measuring equipment (DME)	a transponder-based radio navigation technology that measures slant range distance by timing the propagation delay of VHF or UHF radio signals[29]. Distance measuring equipment (DME) is one of the most valuable pieces of avionics in the aircraft, especially for the Instrument Flight Rules (IFR) pilot. The main purpose of the DME is to display an aircraft's distance to a ground station. DME reduces pilot workload by continuously showing the distance to the station, time-to-station, and groundspeed
Link budget	Link budget is the accounting of all of the gains and losses from the transmitter, through the medium (free space, cable, waveguide, fibre, etc.) to the receiver in a radio system. It accounts for the attenuation of the transmitted signal due to propagation, as well as the antenna gains and any cable or feedline losses and miscellaneous losses. Randomly varying channel gains such as fading are taken into account by adding some margin depending on the anticipated severity of its effects. The amount of margin required can be reduced by the use of mitigating techniques such as antenna diversity or frequency hopping. A simple link budget equation is shown below: Received Power (dBm) = Transmitted Power (dBm) + Gains (dB) − Losses (dB)
RF Audio Interference Level	The level in dB (V/m) of an unmodulated RF carrier that, when modulated by an 80% 1 kHz sine wave AM, produces the same level from a weighted square-law detector output as does the modulated RF signal under test when measured with the same weighted square-law detector
VOR/DME	VOR/DME refers to combined radio navigation station for aircraft, which consists of two radio beacons, placed together, a VHF omnidirectional range (VOR) and distance measuring equipment (DME). VOR produces an angle between the station and the receiver in the aircraft, while DME does the same for range

[29] https://leagueofextraordinarytechnicians.wikispaces.com/DIstance+Measuring+Equipment++-+Operation

ANNEX 1: BACKGROUND

A1.1 HISTORY OF SYSTEMS DEPLOYMENT IN THE BAND 960-1215 MHZ

Initially, ITU allocated the band 960-1215 MHz exclusively to the Aeronautical Radio Navigation Systems (ARNS). Later the frequency band 1164-1215 MHz was allocated additionally to RNSS (WRC-2000) and the frequency band 960-1164 MHz to AM(R)S (WRC-2007). Several states throughout the world have considered the frequency band also for use with governmental systems in accordance with the ITU RR No. 4.4., only after extensive theoretical and practical frequency compatibility studies identifying the conditions and restrictions under which sharing is possible. Those studies are revised, whenever the new systems are defined by ICAO for operation or when the Extraneous Signal Environment (ESE) increases due to an increase in air traffic significantly beyond the previously defined scenario.

There is no Radio Frequency Interference (RFI) parameter for the protection of an ARNS system from other ARNS (or non-ARNS) systems. The international aeronautical standards and related provisions do not define therefore any mandatory performance for DME, SSR, and the next generation systems, is ensured by applying specialized discriminators and frequency offset only.

While at the beginning equipment designs and performance were similar in design, if not identical, development of new technology diversified the options for designer to achieve the required performance and achieve much higher sensitivity than mandated by ICAO and in MOPS [2].

The figure below shows the frequency range and centre frequencies used by services and under RR article 4.4.

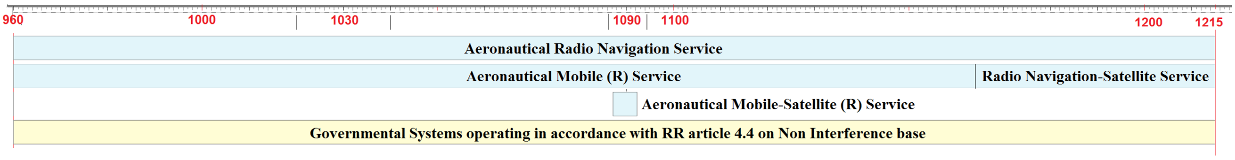

Figure 7: Allocation of services and uses transmit centre frequencies in the band 960- 1215 MHz (2)

A1.2 OVERVIEW OF THE SYSTEMS IN THE BAND 960-1215 MHZ

Initially in 1949, an ICAO standardised Distance Measuring Equipment (DME) system was introduced in this frequency band, and later replaced by DME/N and TACAN. Around the year 1960, SSR Mode A and C, and IFF Modes 1 and 2 were introduced. As depicted in the figure above, a number of aeronautical communication, navigation and surveillance systems and equipment are currently operated in the band.

The Figure 8 below provides a list of equipment, operation modes and uses and indicates if their operation is limited to some states. The technical characteristics of those systems are described in the next chapter.

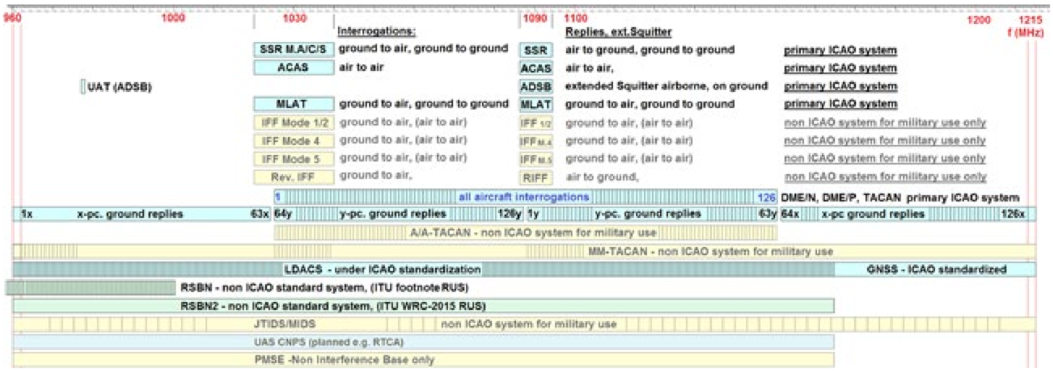

Figure 8: Transmit centre frequencies in the band 960- 1215 MHz

A1.2.1 Overview of DME system operation

DME is an essential aircraft navigation aid, used worldwide, and provides a part of the required navigation equipment on commercial aircraft. DME is used for en-route area navigation as well as departure, approach, landing and missed approach phases of flight. This use will continue and increase well beyond 2030 [83]. In most airspaces it is required to navigate by using multiple DME ground stations for position determination.

The Instrument Landing System (ILS) is used for precision approach and landing of aircraft. This system consists of a Localizer (108-117.975 MHz), Glideslope (328.6-335.4 MHz) and Marker Beacons (74.8-75.2 MHz) or DME for ranging to the Runway threshold. Marker Beacons are generally not used anymore unless there is no available DME frequency, only a few Marker Beacons remain in operation in Europe.

The three facility performance categories of the ILS precision approach (CAT I, CAT II and CAT III) are all certified as integral systems which include DME as a vital component. In real-time, with the accurate azimuth, elevation and the distance to the runway threshold combined, these systems permit coupled auto-pilot and stabilised approaches to runways around the globe.

Many airport ILS/DME installations have been certified at the highest level of precision approach procedures (CAT III) and are authorised to be used for auto-landing operations. Any loss of DME operation in normal or low visibility conditions results in the need for alternative ranging information that require ATC intervention and associated impacts to the operation of that airport, for example flow control being applied with much lower throughput than during normal operations. Any loss of a component part of the ILS requires a demonstration period to be completed, providing fault rectification or resolution to the issue that caused the loss. Depending on the severity of the loss varying periods will be required to prove the stability and operational capability of the facility, for example this could be between 24 and 300 hours or as specified by the air navigation service provider (ANSP) for that aid.

A1.3 PRINCIPLES ON AERONAUTICAL SYSTEMS

Aeronautical systems differ from most other terrestrial systems, in so far that not only their ground components are situated obstacle free to reduce multipath, located as high as terrain and antenna masts permit.

Antenna heights of ground based systems vary typically between ~7 feet (2.1 m) and about 131 feet (40 m) Above Ground Level (AGL).

Locations are not limited to airports with terrain heights of the Airport Reference Point (ARP) of more than 2500 feet (762 m), but can be located on Hills or Mountains with terrain elevation of 10987 feet (3349 m in Corvatsch, Switzerland).

Therefore, the RLOS for ground based equipment in Europe can exceed 172 NM (320 km).

While SSR allows for FL reports of aircraft of up to 126750 ft. Air Traffic Control presently foresees a max. of 66000 feet (20116.8 m) Above Mean Sea Level (AMSL).

The radio line-of-sight (RLOS) between aircraft (airborne and on ground), ground equipment and impact of terrain height is depicted in Figure 9.

While not all signals within RLOS will be sufficiently strong to be processed, also signals well below the defined Minimal Detectable Signal (MDS) or Minimum Triggering Level (MTL) are processed depending on receiver design.

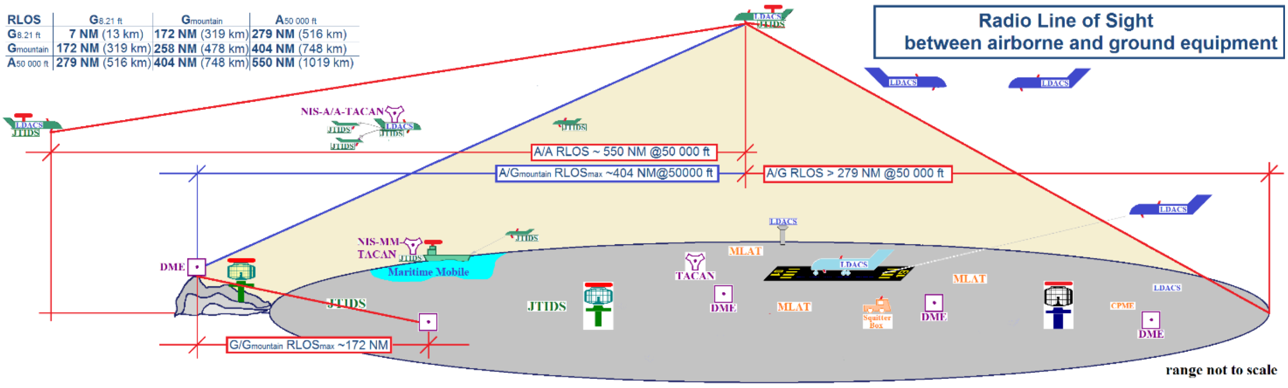

Figure 9: Airborne and Ground RLOS of aeronautical equipment in operation [2]

Note: Antenna height of ground equipment will vary in Europe between 1.8 m (6 ft) AGL and DME at mountain Corvatsch 3349 m (10987 feet) AMSL (Above mean sea Level). Some locations have also negative elevations e.g. Amsterdam Schiphol (airport reference point (ARP) -11 feet).

The number of systems and density of equipment and signal strength received will differ depending on where in the band 960-1215 MHz the receiver is operating on.

For airborne equipment, it is necessary to divide studies in three cases, which are depicted in Figure 10:

- aircraft equipment on ground;
- aircraft during APP (approach), DEP (departure) below 10000 feet to 20000 feet;
- en-route flight up to 66000 feet AMSL.

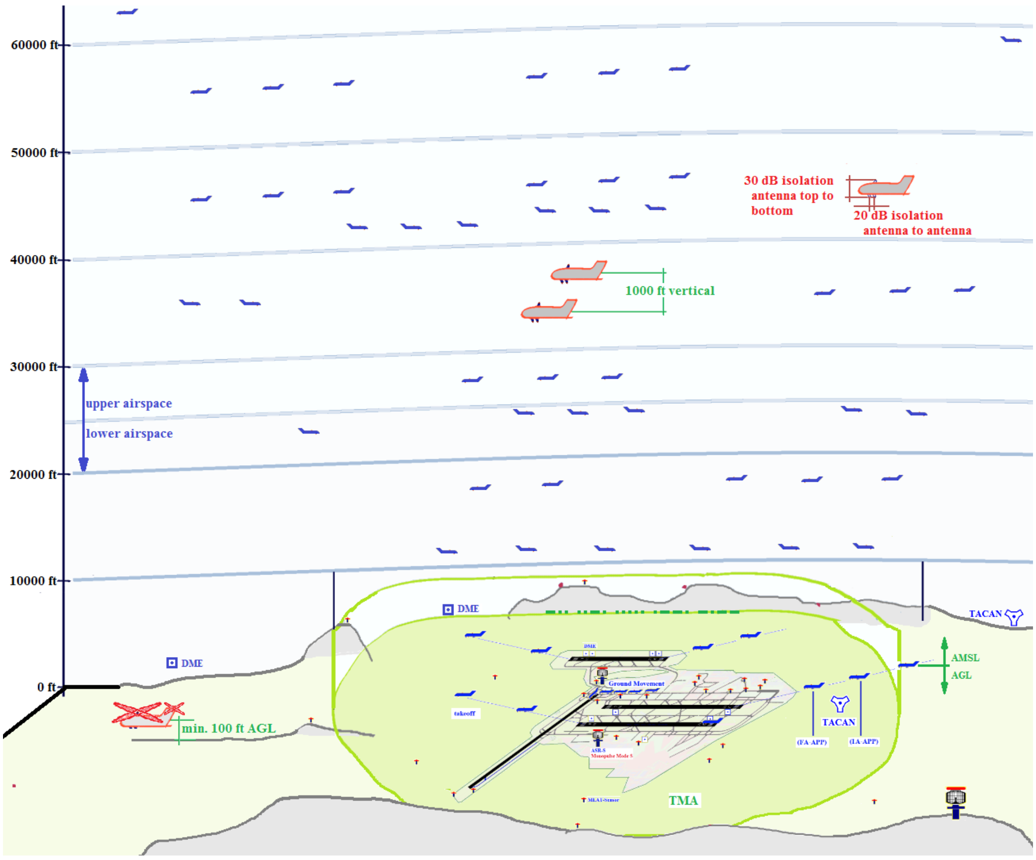

Figure 10: Upper- and Lower airspace ATC operation, Flight Level and altitude for aircraft to be considered in the various phases of a flight [2]

A1.4 INTEGRITY AND CONTINUITY REQUIREMENTS - FADE MARGIN ISSUES

The specific high integrity and continuity requirements (see section A1.5) for aeronautical navigation systems rely on the ratio between the desired and undesired signal level being able to overcome temporal fades and enhancements due to, inter-alia, path obstructions, atmospheric or surface reflection multipath and precipitation. Hence, any compatibility studies involving the aeronautical radionavigation systems need to take into account the increased link budget required to reliably close the link between the radionavigation transmitter and receiver to ensure the required continuity of the service. An example continuity requirement for an ILS and ILS glideslope system providing a CAT I service is 1-4*10-6. For CAT II/III service, the continuity requirement is 1 – 2*10-6.

Although some data and propagation models applicable to aeronautical services already exist, e.g. Recommendation ITU-R P.528-3 (02/2012) "Propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands" [32], they typically do not provide useful temporal characteristics reflecting the particularly high signal availability/continuity requirements of aeronautical radionavigation systems providing a CAT I, II or III service.

Recommendation ITU-R P.2001 "A general purpose wide-range terrestrial propagation model in the frequency range 30 MHz to 50 GHz" [Recommendation ITU-R P.2001-2 (07/2015)] may provide some tools to predict the depth of temporal fades and temporal enhancements due to atmospheric and other effects, as it uses percentages of time in the range of 0.00001% to 99.99999%. However, terrain data would also need to be accounted for as well as the aircraft elevation.

Some L-band (DME band) and C-band (5030-591 MHz band) flight test analyses have been performed by the United States National Aeronautics and Space Agency (NASA) to ascertain fade and required link budget characteristics for Control and Non-Payload Communications used for Unmanned Aircraft Systems. The results of these are available in the document RTCA-DO-362 [65] https://my.rtca.org/NC__Product?id=a1B36000001y1BQEAY.

In summary, the information gathered by the NASA measurement campaign provides, amongst other data points, an evaluation of Excess Path Loss due to multipath and diffraction on the path between an aircraft and ground in a typical scenario which would also apply to DME operations. The figures below, depict the result of a hilly terrain test. The flight path flown was a semi-circle at a constant distance of 35 Nautical Miles (~65 km) and at different flight levels, including 14000 feet (~4300 m), 7500 feet (~2300 m) and 3500 feet (~1100 m) above ground.

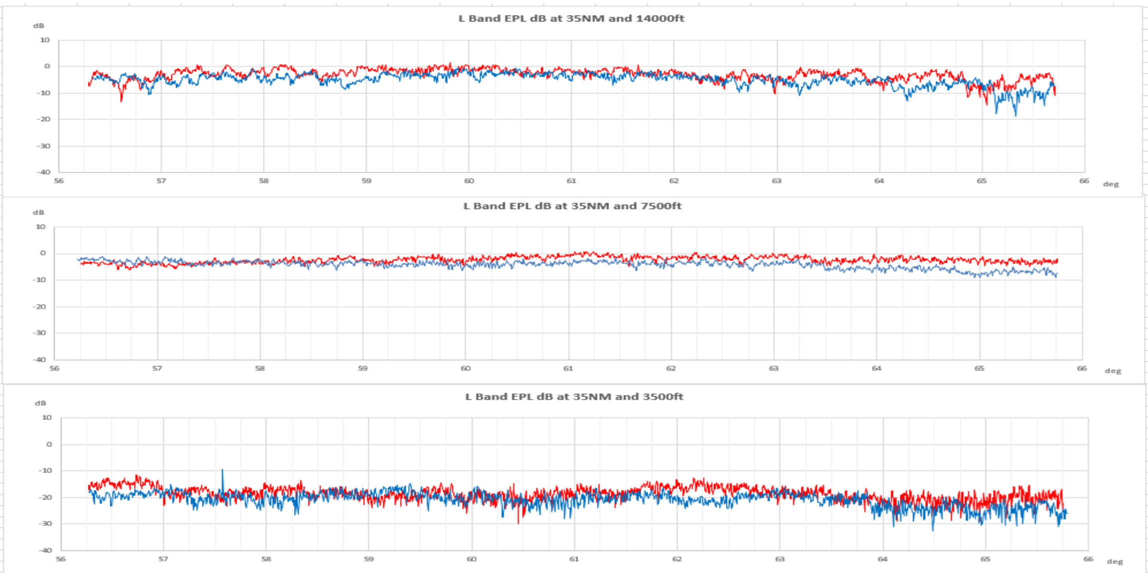

Figure 11: Excess path loss (dB) test results at 35 NM distance with flight levels of 3500 feet, 7500 feet and 14000 feet

As evident from the graphs depicted, the Excess path loss observed during this test flight ranges from 0 up to over 30 dB.

The safe operation of aeronautical navigation systems, in particular ILS CAT I/II/III requires availability and integrity, unlike non safety radio services. Such high availability and integrity can only be achieved by ensuring there is no interference to the various components of the ILS from other systems. In this context, extreme propagation anomalies (temporal fading and enhancement) need to be taken into account, as well as intentional or inadvertent co-sharing of a DME frequency by any other user, including the potential PMSE user. GNSS is not considered reliable enough for ILS precision approach. Integrity and continuity of service

ICAO Annex 10 places an integrity/continuity requirement on DME/N at 1 – 1x10-5. For Category I instrument landing systems, integrity is quoted as 1 – 1x10-7, for Category II and III landing systems, integrity is quoted as 1 – $1x10^{-9}$. For those systems, continuity is quoted as 1 – $2x10^{-6}$. (ref ICAO Annex 10 Vol I [44], table C-2):

- States shall under the ICAO Convention have a Safety Oversight program that serves to ensure the safe design and operation of all airspace procedures, i.e.; airport arrival/departure, and en-route. Ground based navigation facilities are integral components of airspace design;
- Safety case assessments of the airspace procedures take into account the RF operating environment of terrestrial navigation aids and identify potential risks that must be mitigated;
- Airport ILS precision approach procedures are depicted on specifically designed charts that form the legal basis for flight crews to accurately perform the approach using the navigation facilities;
- DME is an integral component of ILS precision approach; DME also provides the threshold distance reference, as an alternative means to Marker Beacons which are not commonly used anymore. DME is a critical component in runway missed approach overshoot procedures, and is used in RNAV procedures;
- GNSS/GPS is not a replacement for DME. The RF environment of GNSS is too vulnerable to place a comparable integrity/continuity requirement as ILS and DME. In addition, GNSS/GPS need an augmentation system in order to be usable for a precision approach;
- Potential introduction of PMSE in the frequency band used by DME and other aeronautical systems would change the RF operating environment of those systems, necessitating a reassessment of the safety cases of the systems supporting the airspace infrastructure;
- Considering the safety critical operation of DME as an integral component of precision ILS and its inclusion in the airspace infrastructure, any I/N compatibility study activity should take into account the integrity/continuity requirements of DME, including temporal fades and enhancements due to atmospheric effects and uneven terrain;
- Given the critical importance of DME as an integral component of precision ILS and the legal framework under which precision approach procedures are authorised, any impact on DME integrity/continuity as a result of a change in the RF operating environment due to introduction of PMSE or similar, should be at least one order of magnitude lower than that of the DME itself, as noted in Annex 10 Volume 1 [44] Table G-15;
- The compatibility studies need to fully recognise the critical operational role of DME in precision ILS approach and landing procedures and hence ensure that any impact of PMSE is sufficiently low to not lower the integrity/continuity of the DME.

A1.5 PMSE USE

For further information on PMSE use see ECC Report 204 [21].

ANNEX 2: USE OF THE BAND 960-1164 MHZ FOR PMSE IN THE UK

A2.1 SUMMARY

Ofcom (UK) has been licensing PMSE equipment in the 960-1164 MHz band since July 2016 using test and development licences. From January 2019 commercial use licences have been available. Trials have taken place by the BBC at Borehamwood, Glasgow, Birmingham, Broadcasting House (London) and by Sky at their studio complex at Osterley, West London plus the Cambridge theatre in central London. In addition, long-term monitoring and some PMSE use has taken place at Edgcott near Oxford and a commercial license was obtained for the site in January 2019. To date, no interference to or from PMSE has been noted, which generally endorses the Ofcom view that for the UK under current conditions this band is viable spectrum for secondary use by PMSE.

The Ofcom spectrum tool has been validated and has proven to identify clear spectrum for PMSE. Licensing continues under both the Test and Development regime and commercial use, licences have been issued or renewed as appropriate.

Trials have predominately been indoors within studios, with a limited number of outdoor deployments. This has been a consequence of practical issues rather than any interference concerns with the DME spectrum. Some additional outdoor trials by the BBC have been made since the initial report, issued in January 2017. External use has using 10 channels has been carried out at Edgcott for days at a time with both Test and Development (T&D) and commercial licences.

During November 2017, an additional 16 channels of Shure and 2 channels of Wisycom equipment have been in use. All equipment has been inspected in the laboratory and found to meet the technical requirements of ETSI EN 300-422-1.

Sufficient confidence was gained by PMSE stakeholders with the scope of this study.

A2.2 SCOPE

PMSE trials using the 960-1164 MHz band for PMSE have been conducted at various sites around the UK in cooperation with the BBC, Sky and London Theatres. This work started in July 2016.

This annex 2 describes the five major locations in depth and shows the environment in which the trials took place, with photos illustrating the clutter which is typical of radio microphone operation. Two racks containing sixteen channels of digital equipment, both hand-held and body-worn units were deployed at the BBC studios. A single rack of 8 channels was deployed at the Sky studios and in November 2017 an additional 16 channels where deployed.

No measurements of interference to DME was carried out during this trial.

A2.3 INTRODUCTION

This annex 2 covers the activities from March 2016 to March 2019.

Following the publication of a statement from Ofcom (UK) on the 10 March 2016 [30], Shure engaged with Ofcom to initiate practical testing and the BBC and Sky were approached as potential future licensees.

The Ofcom statement was the culmination of some three years of work by Ofcom's engineers and its consultants who were seeking to identify long-term access to spectrum for PMSE within the UK which was unlikely to be considered for other services such as mobile broadband.

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[30] https://www.ofcom.org.uk/__data/assets/pdf_file/0021/62481/New-Spectrum-for-Audio-PMSE-statement.pdf

A consultation on "New Spectrum for Audio PMSE"[31] was issued on 23 October 2015 which provides background on the reasoning behind the technical investigations carried out by Ofcom (UK).

This report describes the typical environment where the PMSE equipment has been trialled. High reliability is demanded by PMSE users to achieve the required high quality of service. Typical TV programmes require links operating for duration of up to 10 hours and disruptions to the programme audio are in general not acceptable, and may result in job loss.

A2.4 BACKGROUND TO THE TESTING

The PMSE manufacturers and users welcome the efforts made by Ofcom (UK) in identifying the 960-1164 MHz band for PMSE sharing, as this spectrum band has similar propagation characteristics to the 700 MHz spectrum which will has been reallocated to the mobile service. There are however concerns on a range of issues appertaining to this secondary spectrum allocation.

The objective of the tests described here was to investigate the suitability of the spectrum for uninterrupted PMSE use and test the Ofcom availability tool and coexistence approach that would provide access to the spectrum.

A2.4.1 Period 2016-19 testing in the band 960-1000 MHz

For these tests, Shure used modified ULXD Series digital wireless systems. Four prototype ULXD4 quad receivers, 8 hand-held transmitters, and 8 bodypack transmitters were used, for a total of 16 wireless audio channels. In addition, a Tektronix scanning receiver was made available for initial trials to check spectrum quality. The ULXD systems were modified to operate between 960-1000 MHz, tuneable in 25 kHz steps covering the Distance Measuring Equipment (DME) part of the 960-1164 MHz band, which currently has the greatest amount of available spectrum. Antennas consisted of half wave omnidirectional and paddle-type directional antennas for the receivers.

Following discussions between BBC, Sky and Ofcom (UK), eight Test and Development Licences were issued by Ofcom.

A brief report on each of the initial locations is included within this annex.

A2.4.2 Period 2017 onward Wisycom 960-1164 MHz

Wisycom supplied a dual-channel MRK960 receiver and a pair of MTP40S belt packs. These devices were tuneable across the entire 960-1164 MHz band. Wisycom have indicated that they will market this equipment operating in the 960-1164 MHz with any modifications required by the licencing conditions.

A2.5 EQUIPMENT

A2.5.1 Shure

A2.5.1.1 Antenna

Receiver antennas consisted of paddle-type directional antennas for the receivers. The paddle-type antenna has a gain of 6 dBi and a 3dB-beamwidth of 100 degrees.

[31] https://www.ofcom.org.uk/__data/assets/pdf_file/0023/76352/new-spectrum-audio-pmse-consultation.pdf

Figure 12: Directional receive antenna

A2.5.1.2 Rack containing Receivers

Figure 13: PMSE receivers

A2.5.1.3 Transmitters

Antennas consisted of half wave omnidirectional

Figure 14: Transmitter (microphone)

A2.5.2 Wisycom

The Wisycom equipment uses a traditional FM carrier occupying a nominal bandwidth of 200 kHz. As such, it matches the technical characteristics assumed in the initial Ofcom (UK) technical work.

The equipment comprises a pocket belt pack (Wisycom MTP40S) and a dual channel receiver (Wisycom MKR 960).

Figure 15: Body-worn microphone and dual-channel receiver

A2.6 SPECTRUM IDENTIFICATION

DME can be considered (for spectrum availability) very similar to the situation within the broadcasting band 470-694 MHz in that both DME and a TV transmitter are:

- at a fixed geographical location;
- have a defined coverage area;
- operate on defined frequencies.

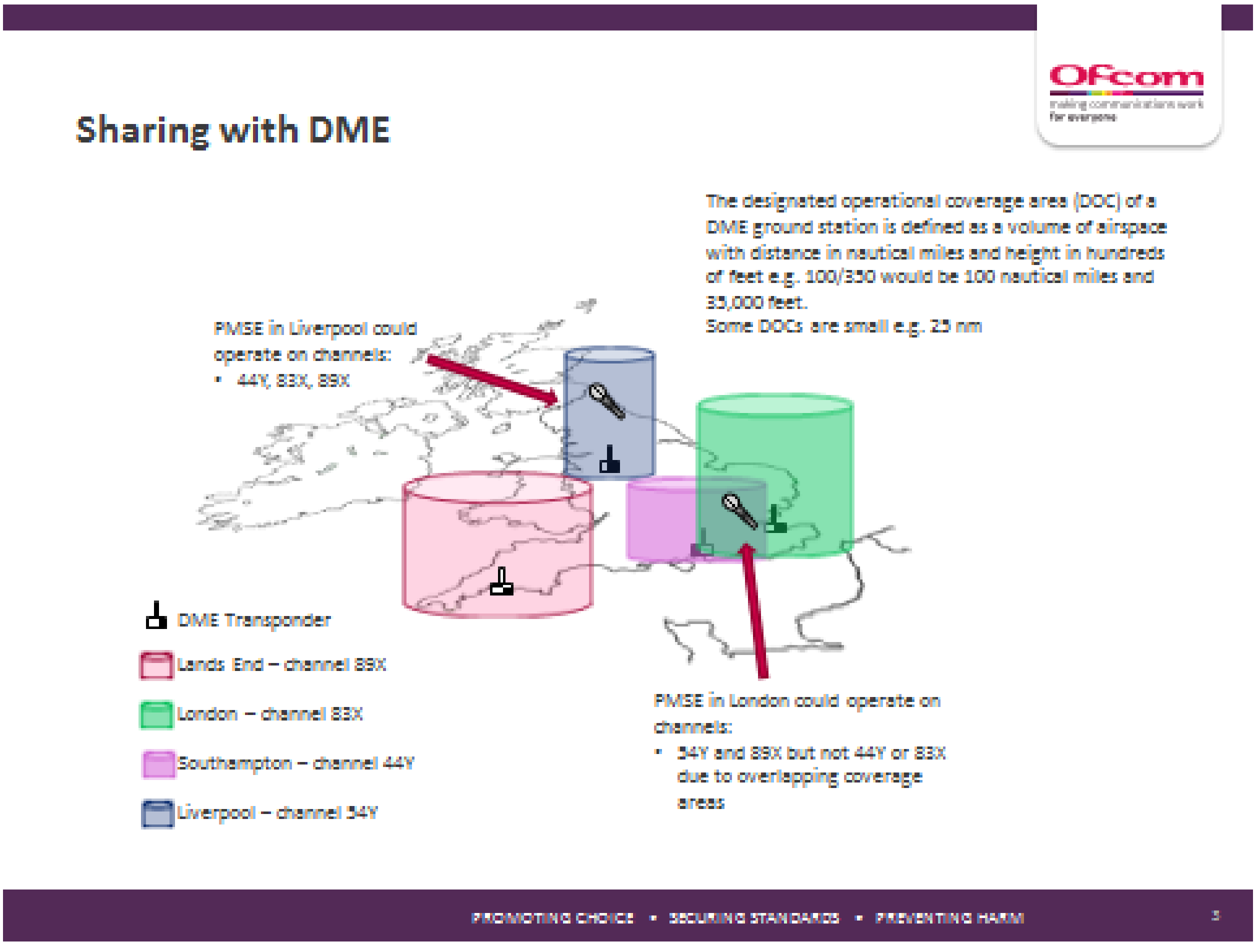


Figure 16: DME designated operational coverage areas and sharing with PMSE

Therefore, the approach by Ofcom (UK) was to generate a “map” of available spectrum at a given location by considering both interference to aeronautical services and to PMSE use over the 960-1164 MHz band. The calculation needs to consider all aeronautical services which may be affected in the UK and elsewhere in the Europe. Channels were then labelled:

- OK;
- Taboo;
- Or showed the potential interference to PMSE.

In addition to an Excel table, the Ofcom (UK) tool can produce graphs that are coloured to indicate spectrum quality and availability:

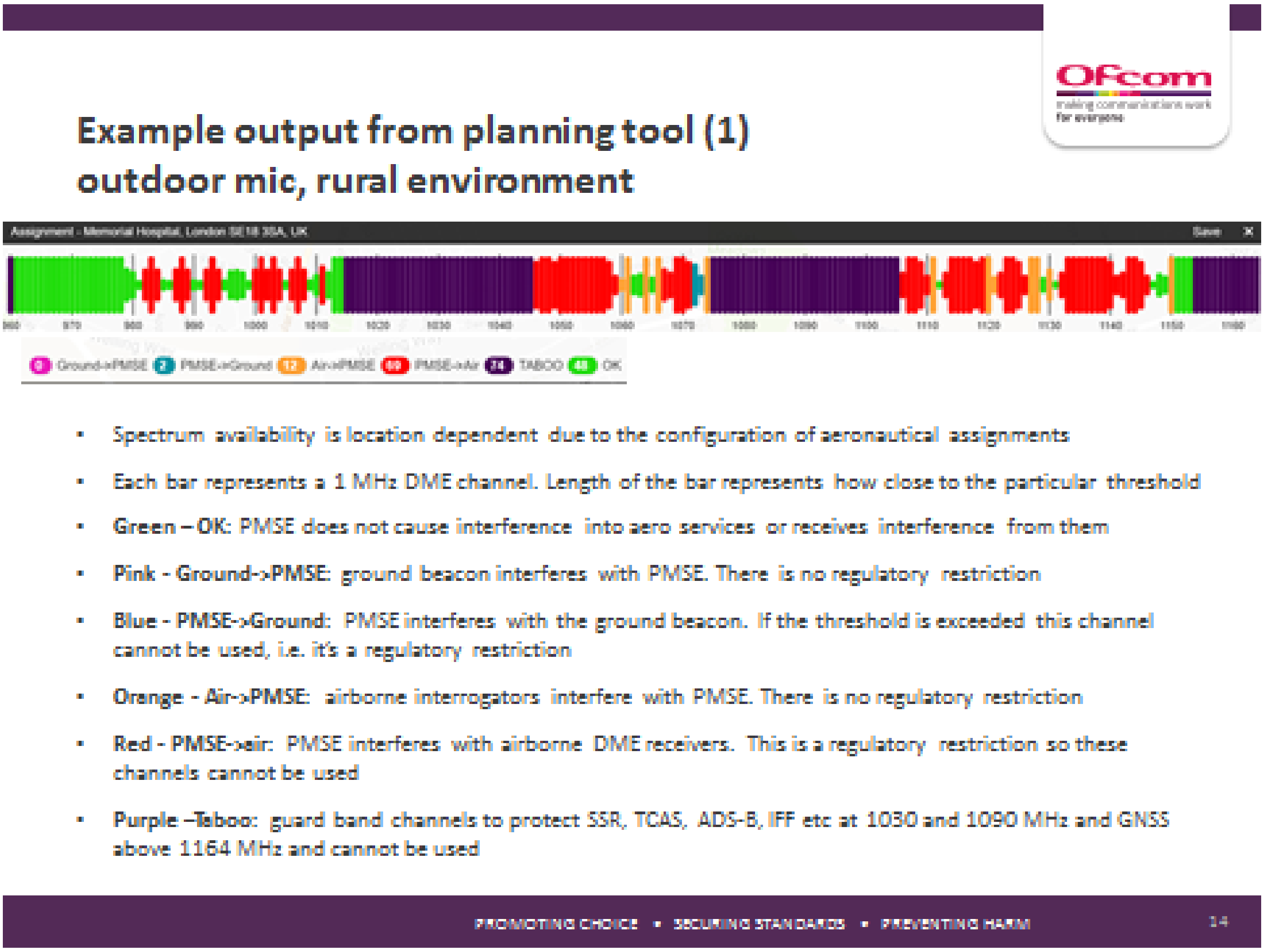


Figure 17: Planning tool example of the availability of PMSE in the DME band

The map below shows the geographical reach of the tool, indicating the various DME stations across Europe that have been considered and protected using the parameters agreed within the UK when calculating the availability of interleaved secondary use spectrum for audio PMSE in the UK. This map does not show all operating DME stations.

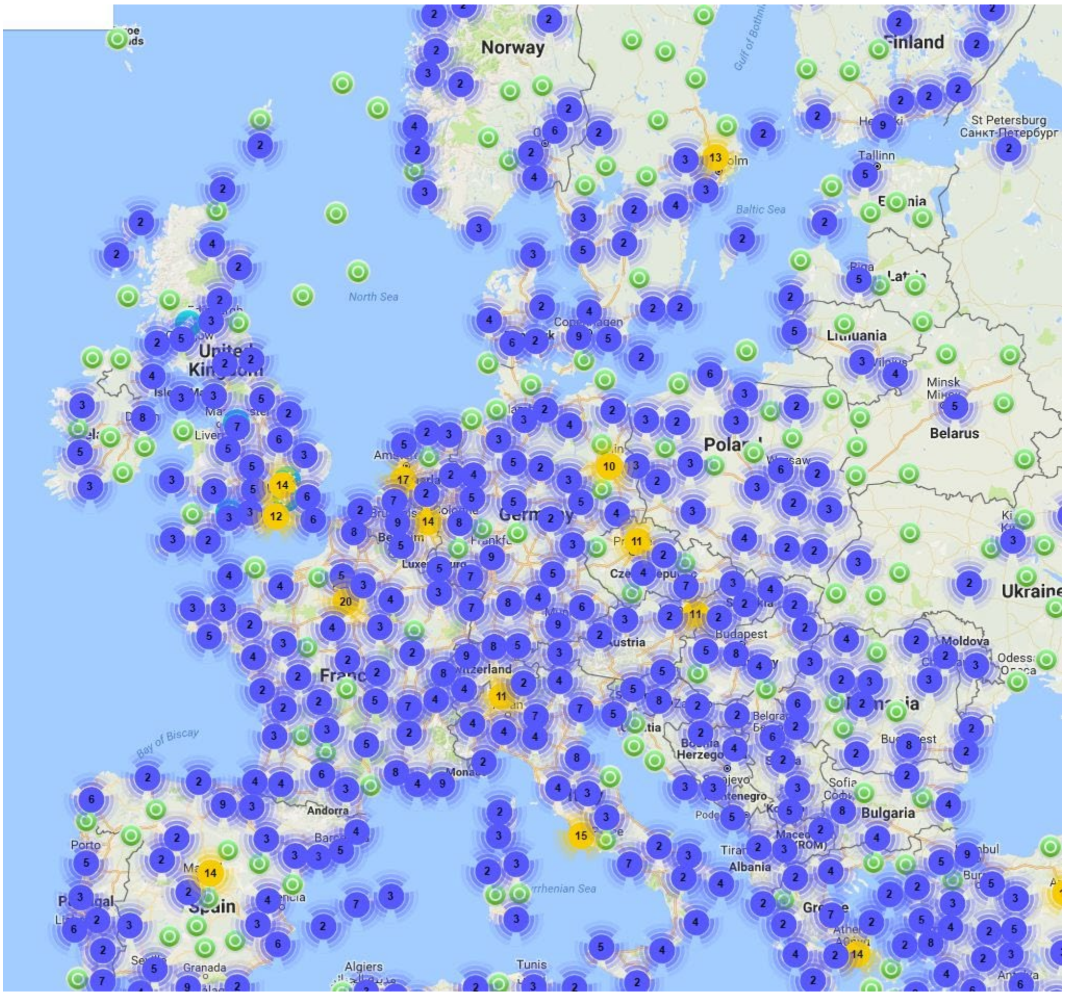


Figure 18: DME stations in Europe taken into account by the planning tool

Spectrum plots – 17 dBm

Mailbox – 78 MHz available of which 15 MHz at risk of interference into PMSE from airborne

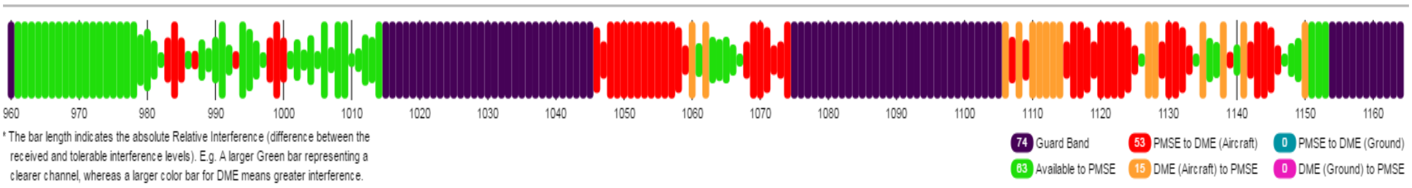


Figure 19: PMSE availability at the BBC studios in Birmingham

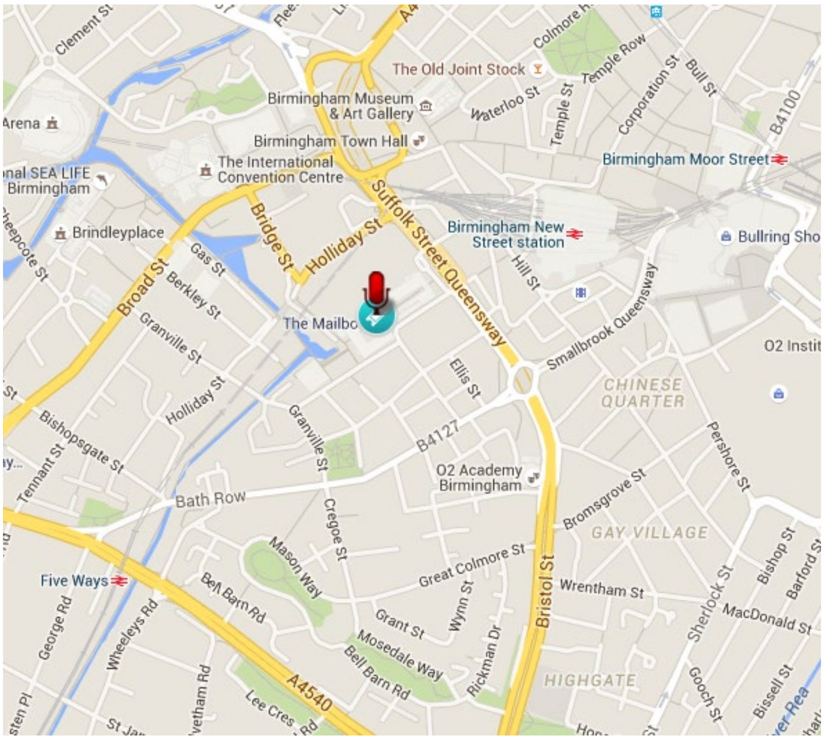


Figure 20: Location of the BBC studios in Birmingham

A2.6.1 Spectrum availability

For these trials Shure prototype equipment was used, which could be tuned over the range 960-1000 MHz. Despite these restrictions, the test and development licences calculated by Ofcom (UK) still had between 24-31 MHz of available spectrum between 960-1000 MHz. The total availability at each site is shown in the graphs attached to each site

Availability Sky studio

Sky, Osterley – 60 MHz available of which 8 MHz was indicated with a risk of interference to PMSE from airborne.

Indoor

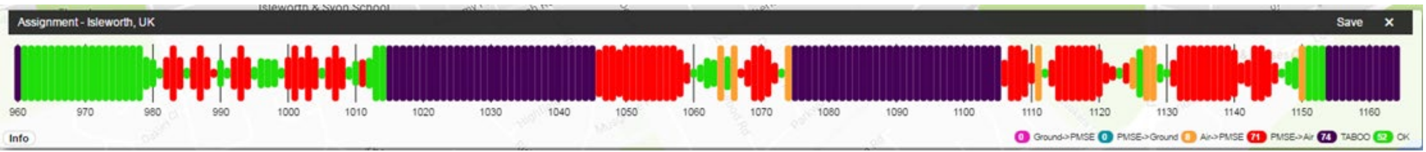


Figure 21: PMSE availability at the Sky studio (indoor) in Osterley

Outdoor

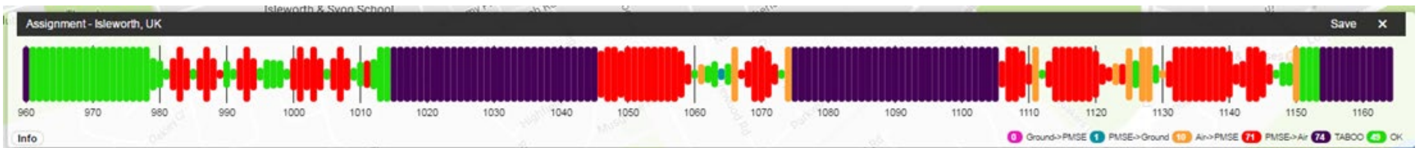


Figure 22: PMSE availability at the Sky studio (outdoor) in Osterley

A2.7 MAILBOX STUDIOS

This was the first location of the trials and the majority of activity was within the studio.

A2.7.1 Conclusions:

DME band noise floors appear comparable to UHF band:

- Lower 40-50 MHz of the 960-1164 MHz band, generally clear of aeronautical airborne transmissions

Indoor use possible at most locations:

- Upper part of band has intermittent transmissions from over flying.

Aircraft which are attenuated indoors:

- Prototype PMSE equipment performance similar to usual UHF-band Equipment;

No interference to the PMSE use.

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

A2.7.2 BBC Studio, "The Mailbox"

The BBC's Birmingham studios are located in a shopping mall in the central part of Birmingham.

Figure 23: BBC's Birmingham studios are located in a shopping mall in the central part of Birmingham

Birmingham is typical of many TV Studios and is a potentially challenging environment for radio microphone use with significant metal clutter required for lighting, air conditioning and camera pedestals.

Figure 24: Interior design of the BBC Mailbox studio

A2.7.3 Mailbox Monitoring Scans

Indoor

This scan shows the 3 radio microphones deployed in the Mailbox regional news TV studio. The measured noise floor is around –93 dBm / 300 kHz (-148 dBm/Hz) which is dominated by the noise figure of the spectrum analyser (pre-amp off). Other discrete spurs are related to EMI within the studio space.

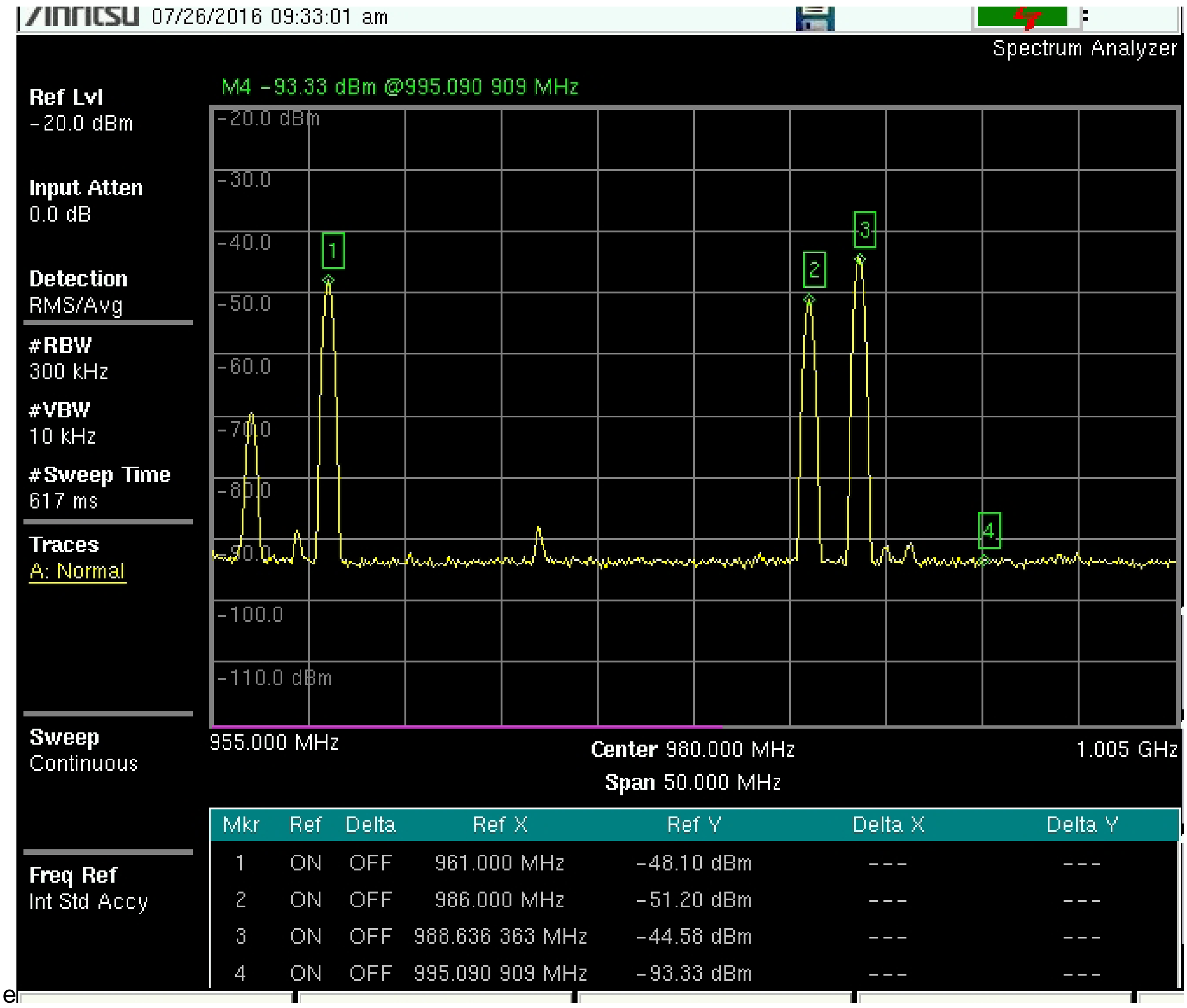


Figure 25: Indoor frequency scan at the BBC Mailbox regional news studio

Outdoor

A scan of the band outdoors reveals a noise floor in the quiet parts of the band of -102 dBm / MHz (-162 dBm/Hz).

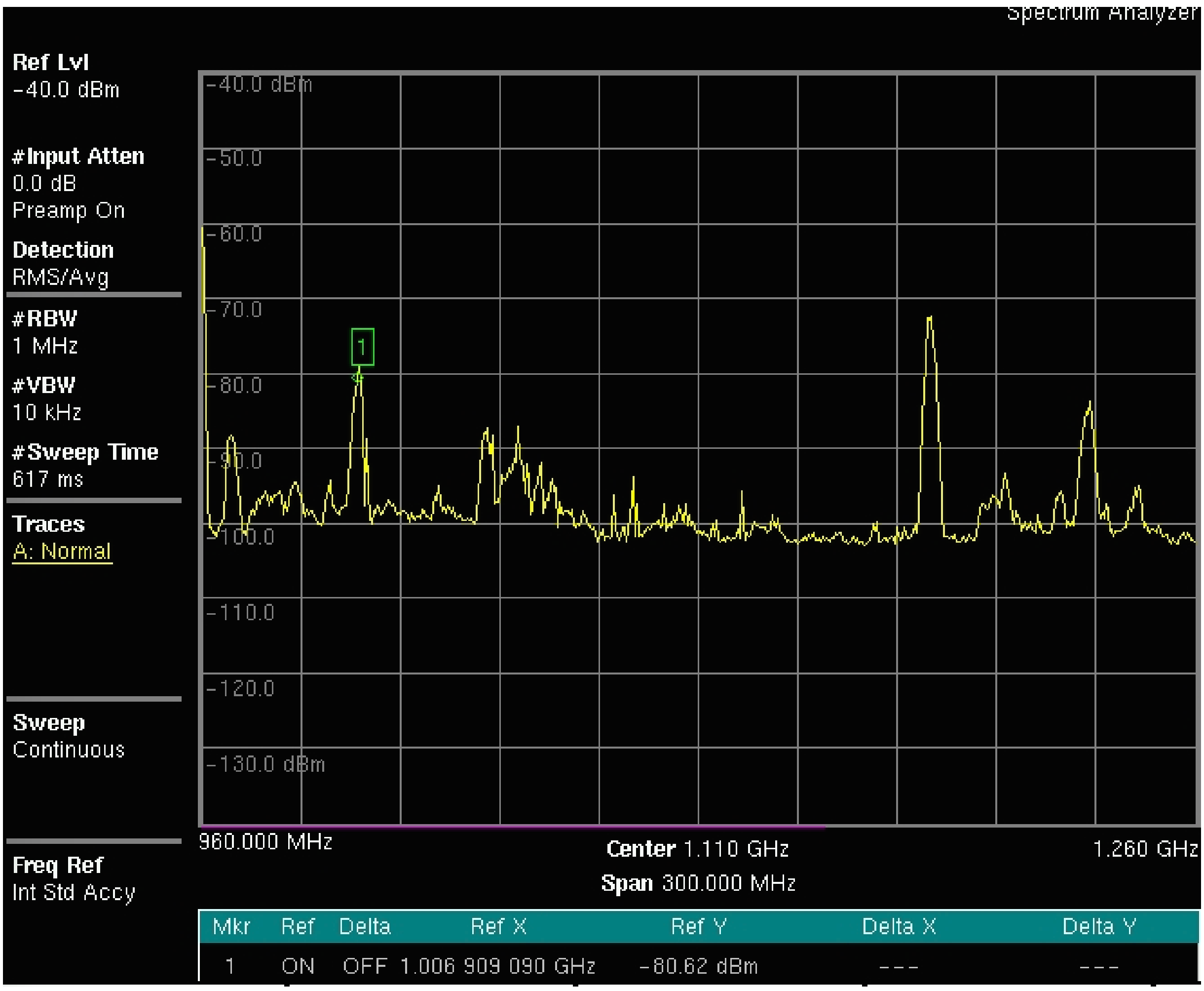


Figure 26: Outdoor frequency scan at the BBC Mailbox regional news studio

A2.7.4 A Scan from Surrey

Max. hold scan (outdoors)

The outdoor scan below was taken in Surrey and reveals little activity in the band 960-1020 MHz.

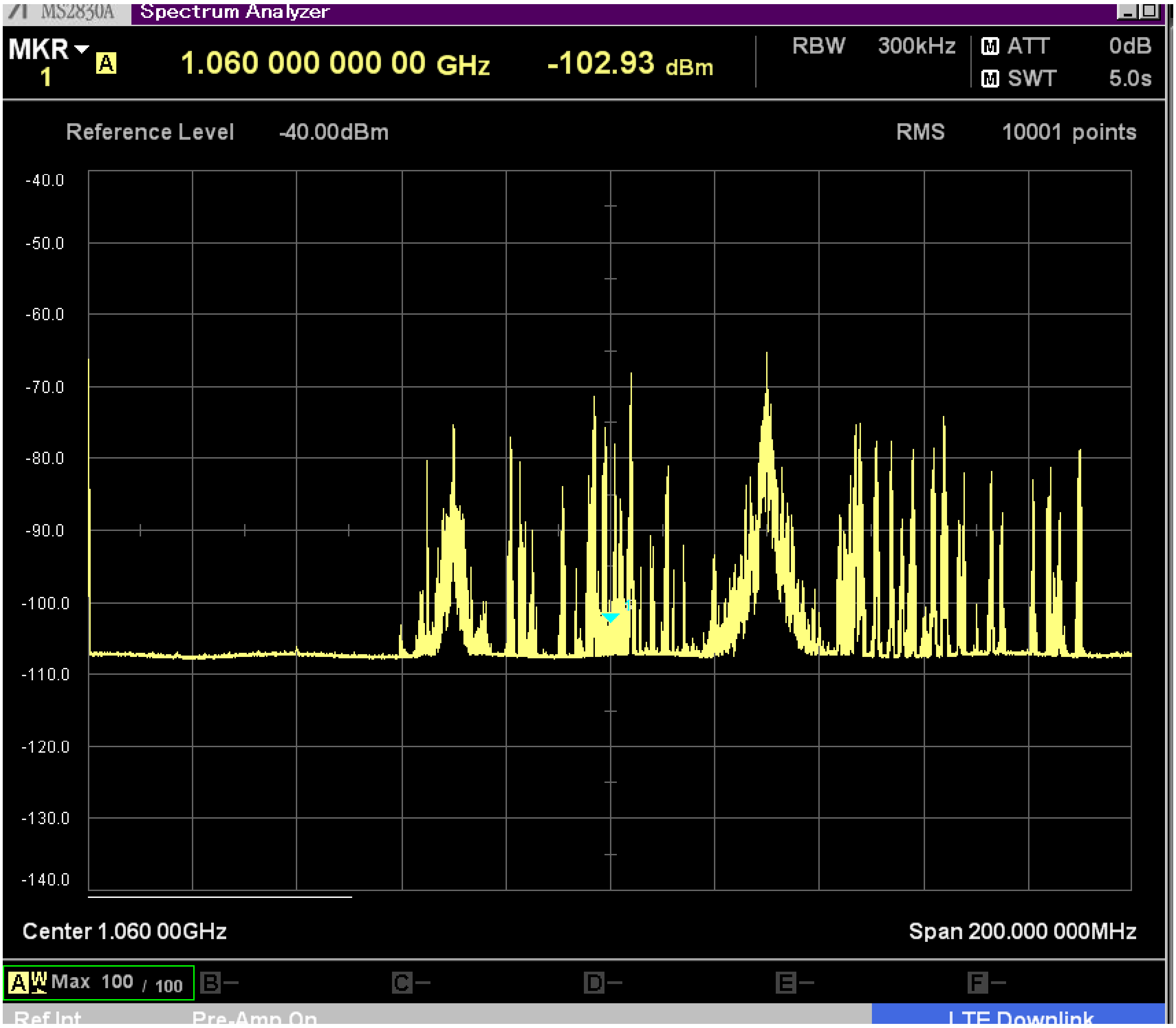


Figure 27: Outdoor frequency scan in Surrey

A2.7.5 Birmingham Airport

Birmingham Airport is situated some 6.3 miles from the studios. It has a passenger count of 10,187,122 per year and is at an elevation of some 100 m. It is the seventh busiest airport in the UK.

The table below identifies the spectrum use for the airport.

Table 9: PMSE availability at the Birmingham airport

Frequency [MHz]	Type	Relative Interference [dB]	Beacon	Channel
995	PMSE->Air	-19.3	BIRMINGHAM/BIRMINGHAM	38X
995	PMSE->Air	-19.3	BIRMINGHAM/BIRMINGHAM	38X
996	OK			

Frequency [MHz]	Type	Relative Interference [dB]	Beacon	Channel
996	PMSE->Air	-10.3	BIRMINGHAM/BIRMINGHAM	38X
996	PMSE->Air	-10.3	BIRMINGHAM/BIRMINGHAM	38X
997	OK			
997	PMSE->Air	-1.3	BIRMINGHAM/BIRMINGHAM	38X
997	PMSE->Air	-1.3	BIRMINGHAM/BIRMINGHAM	38X
998	NO			
998	PMSE->Air	12.7	BIRMINGHAM/BIRMINGHAM	38X
998	PMSE->Air	12.7	BIRMINGHAM/BIRMINGHAM	38X
999	NO			
999	PMSE->Air	51.7	BIRMINGHAM/BIRMINGHAM	38X
999	PMSE->Air	51.7	BIRMINGHAM/BIRMINGHAM	38X
1000	NO			
1000	PMSE->Air	12.7	BIRMINGHAM/BIRMINGHAM	38X
1000	PMSE->Air	12.7	BIRMINGHAM/BIRMINGHAM	38X
1001	OK			
1001	PMSE->Air	-15.8	JERSEY/JERSEY	40X
1001	PMSE->Air	-2.3	BIRMINGHAM/BIRMINGHAM	38X
1001	PMSE->Air	-2.3	BIRMINGHAM/BIRMINGHAM	38X
1002	PMSE->Air	-11.3	BIRMINGHAM/BIRMINGHAM	38X
1002	PMSE->Air	-11.3	BIRMINGHAM/BIRMINGHAM	38X
1002	PMSE->Air	-12.7	ROTTERDAM	41X
1003	OK			
1003	PMSE->Air	-19.3	BIRMINGHAM/BIRMINGHAM	38X
1003	PMSE->Air	-19.3	BIRMINGHAM/BIRMINGHAM	38X
1062	PMSE->Ground	-16.36	BIRMINGHAM/BIRMINGHAM	38X
1062	PMSE->Ground	-16.36	BIRMINGHAM/BIRMINGHAM	38X

A2.7.6 Airport Monitoring

In addition to the spectrum monitoring at The Mailbox, measurements were taken adjacent to the runway at Birmingham airport to investigate the characteristics of the DME signals.

Figure 28: Spectrum monitoring at the Birmingham airport

A2.7.7 Airport Monitoring Antenna

Measurements were made with a broadband log periodic antenna having an antenna gain of approximately 4.5 dBi over the DME band 960-1164 MHz.

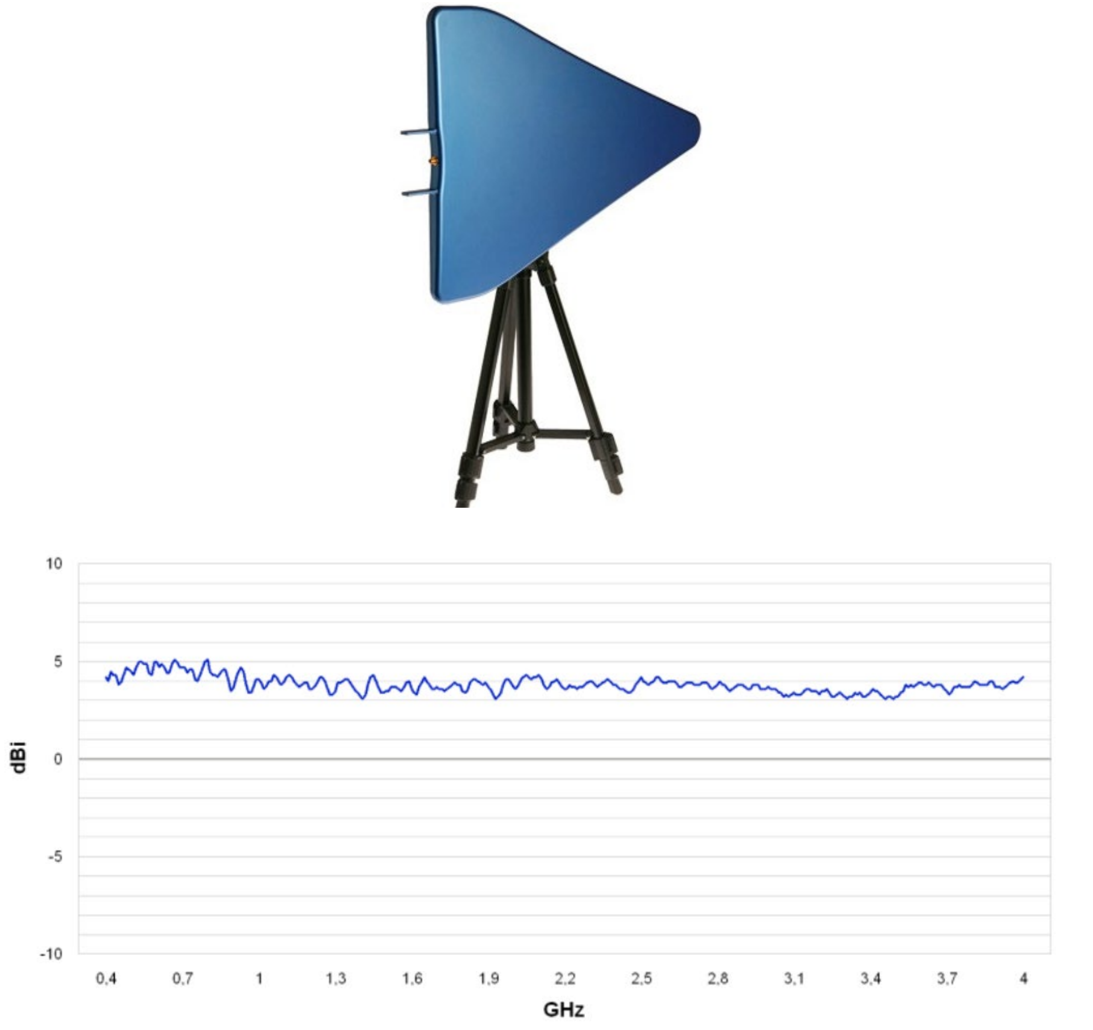


Figure 29: Log periodic measurement antenna and gain over the measurement band

A2.7.8 Airport Monitoring Scans

The trace below was recorded using a zero span sweep with a resolution bandwidth of 1 MHz. It shows the 40 ms pulses from the ground- based DME equipment at the airport.

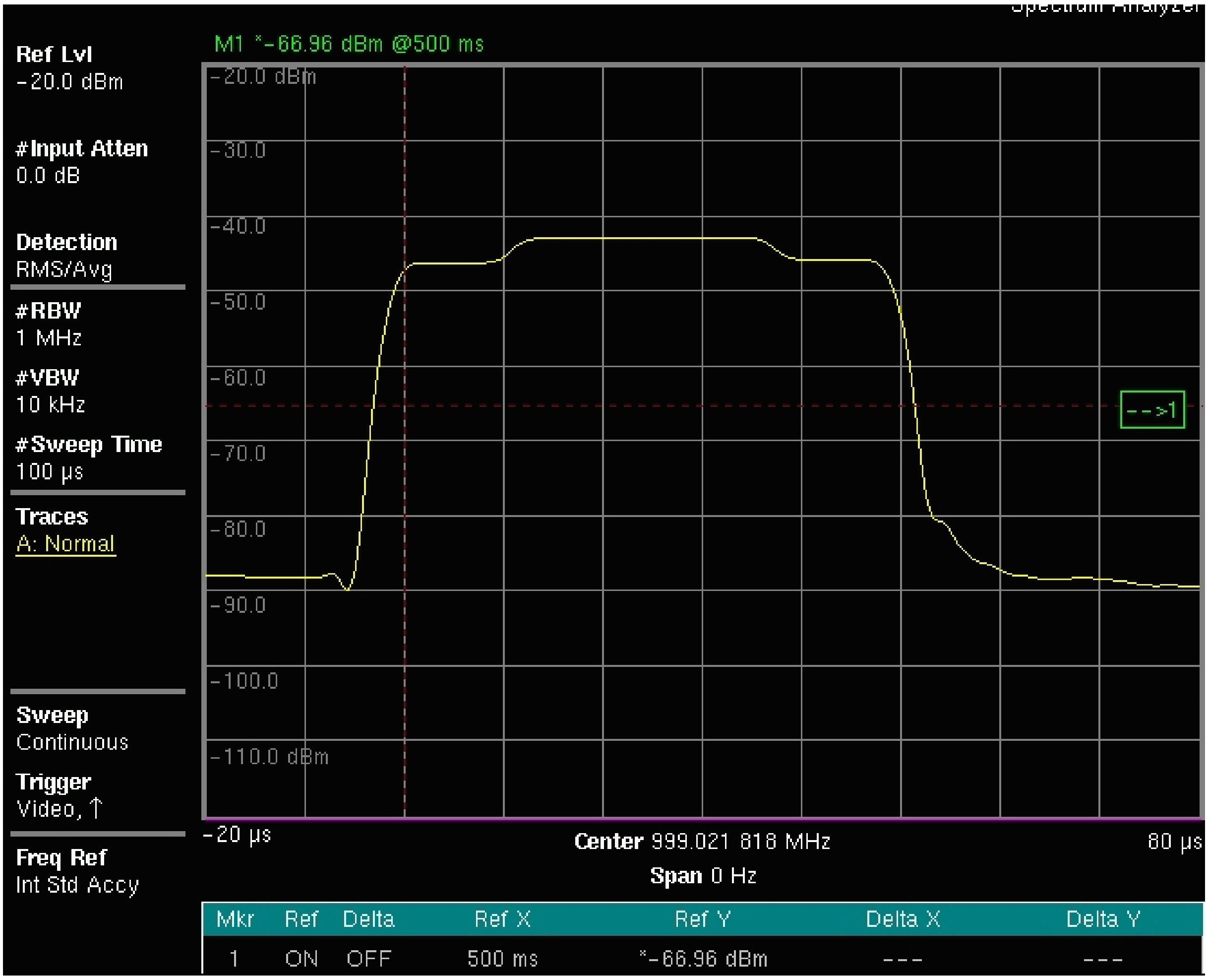


Figure 30: DME ground station pulse shape measurement at the airport

A longer time base shows the DME pulses from the ground-based equipment responding to airborne interrogators with a typical spacing of 1 ms.

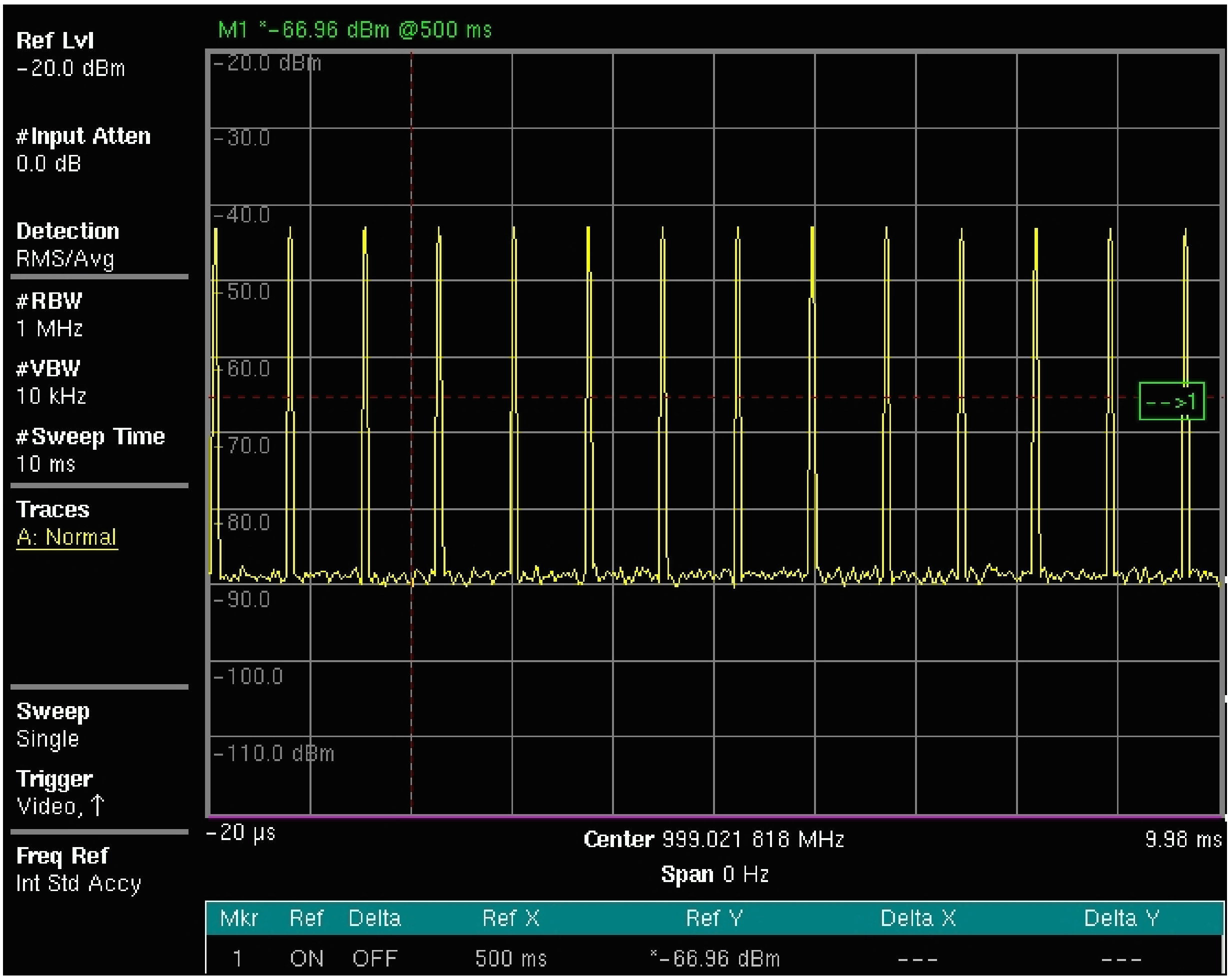


Figure 31: DME ground stations pulse spacing measurement at the airport

A2.8 BBC ELSTREE STUDIO

The studios are located some ten miles north of central London and initially operated as film studios in 1924. They are currently primarily used by the BBC for TV productions including soap operas and light entertainment shows. As can be seen from the studio photo, the construction is concrete walls, typically 0.5 m thick with large steel girders supporting the roof structure.

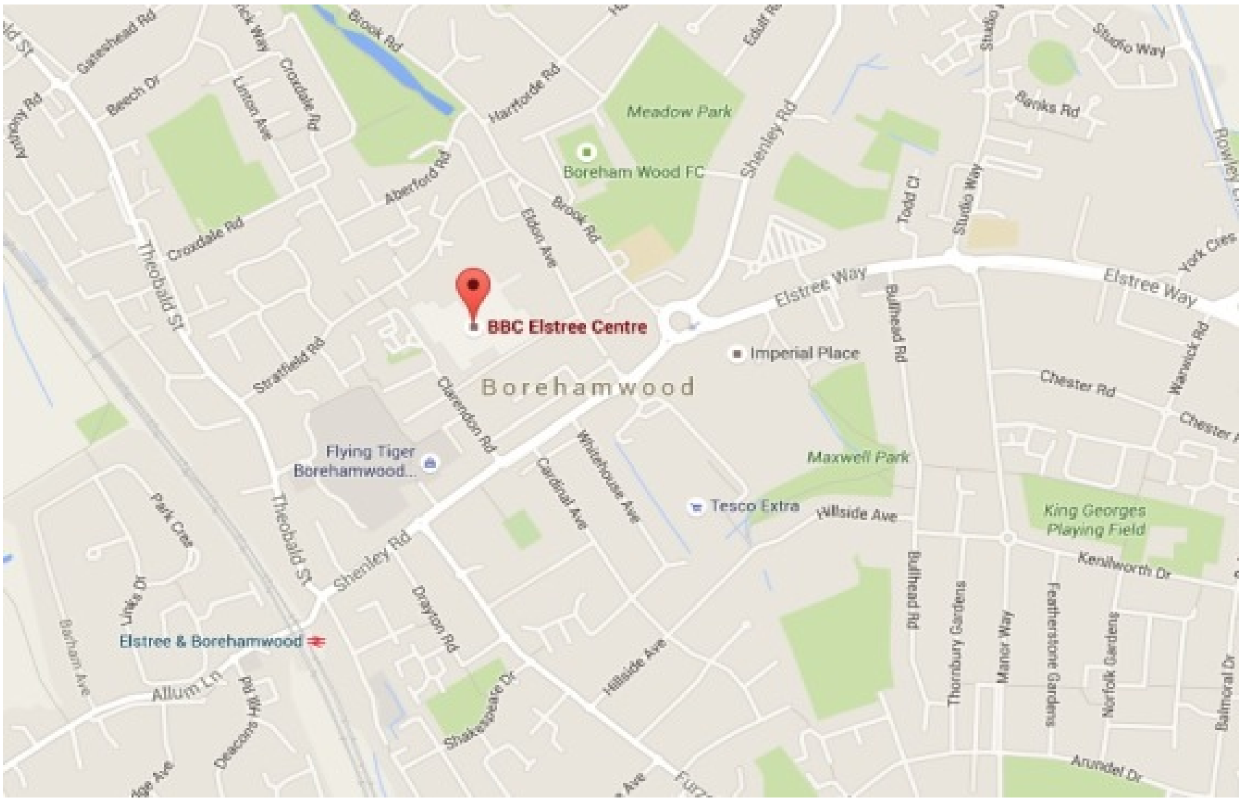


Figure 32: Location of the BBC Elstree studio

Conclusion

The results from the PMSE trials have been favourable. No interference to the PMSE use was noted either in the heavily shielded indoor tests or in outdoor use.

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

A2.8.1 Spectrum Availability

The Elstree plot shows 60 MHz of available spectrum of which 9 MHz is at risk of interference from airborne DME use.

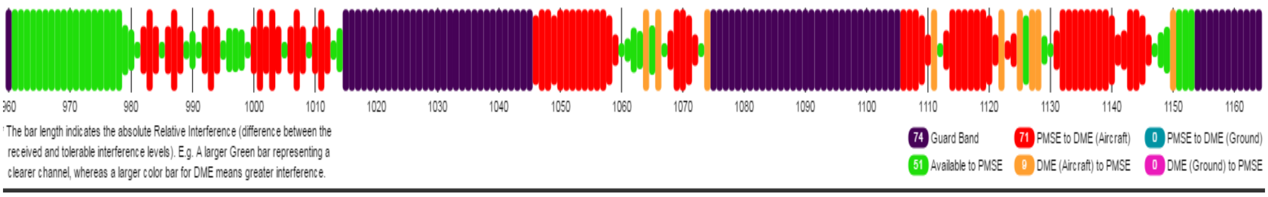


Figure 33: PMSE availability at the BBC Elstree studio

A2.8.2 Studio construction

Figure 34: BBC Elstree studio construction

A2.8.3 Studio used for PMSE Testing

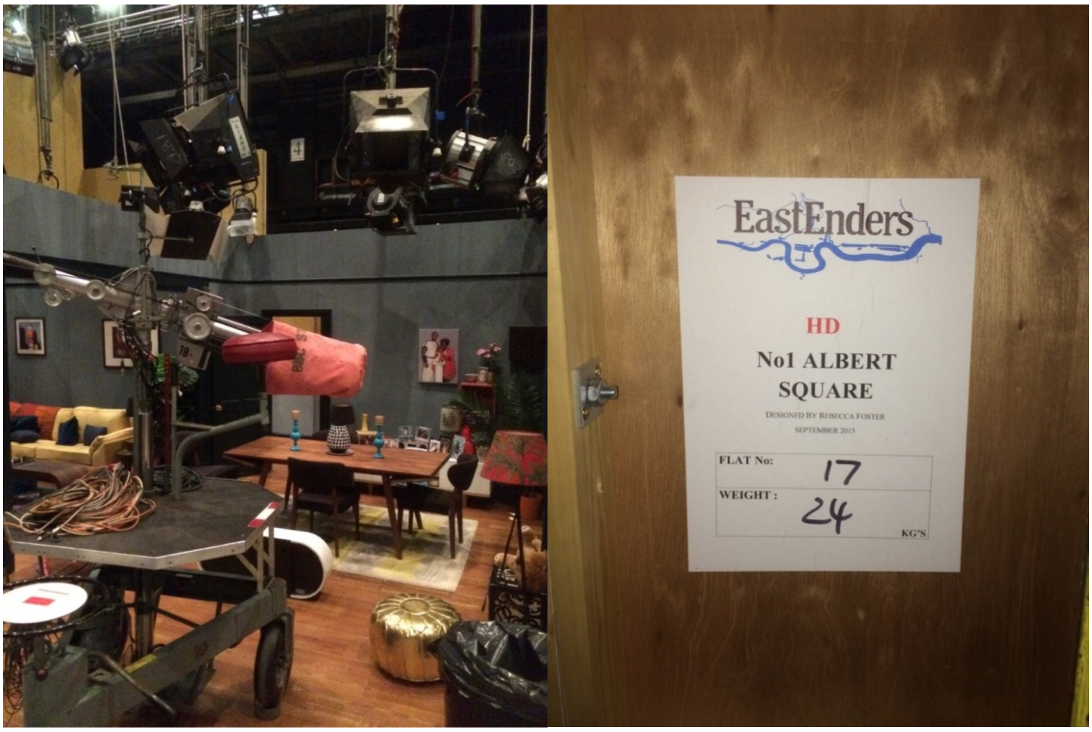


Figure 35: BBC Elstree studio used for the test

The environment for radio propagation in these studios is limited by the lighting and other overhead metal units but helped by the wooden construction of the sets. A studio at Elstree typically contains either a single large set for light entertainment programmers or in this case some 10-20 smaller sets representing various rooms in a house and other locations for a TV soap opera.

Figure 36: BBC Elstree studio lighting and other overhead units

A2.8.4 Equipment Location

The receive equipment was located outside the sets of the soap opera programme.

Note a pair of vertically polarised log periodic antennas was used in a diversity arrangement, which is typical in professional audio PMSE deployments.

Figure 37: Test receiver with two antennas for diversity reception

A2.8.5 Band Scans

The spectrum scan indicated similar noise floors within the DME band to those experienced in the TV band (470-790 MHz). DTT usage from the Crystal Palace transmitter (CP) can be seen at the lower end of the TV band. LTE-800 and GSM-900 mobile signals are also clearly visible.

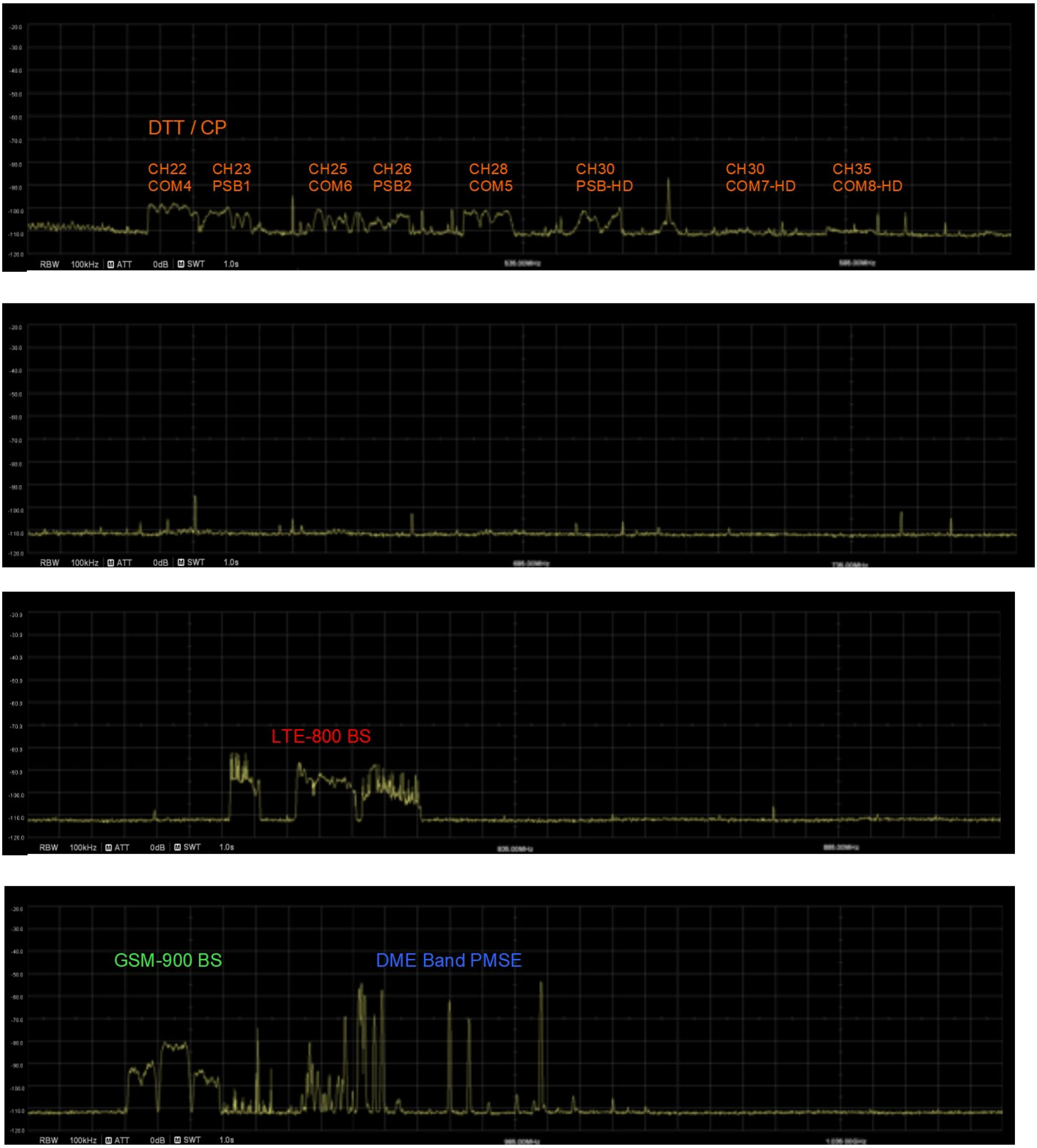


Figure 38: Spectrum scans for the TV, cellular and DME bands

A2.9 CAMBRIDGE THEATRE SEVEN DIALS

Located in the heart of London’s theatre land, this was also the site of Ofcom (UK) testing.

Figure 39: Location of the Cambridge Theatre in London

It is under the Heathrow flight path and the spectrum allocation needs to consider all the surrounding seven airports.

Conclusion

No interference was noted during testing

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

A2.9.1 Spectrum availability

Cambridge Theatre – 61 MHz available of which 10 MHz at risk of interference into PMSE from airborne

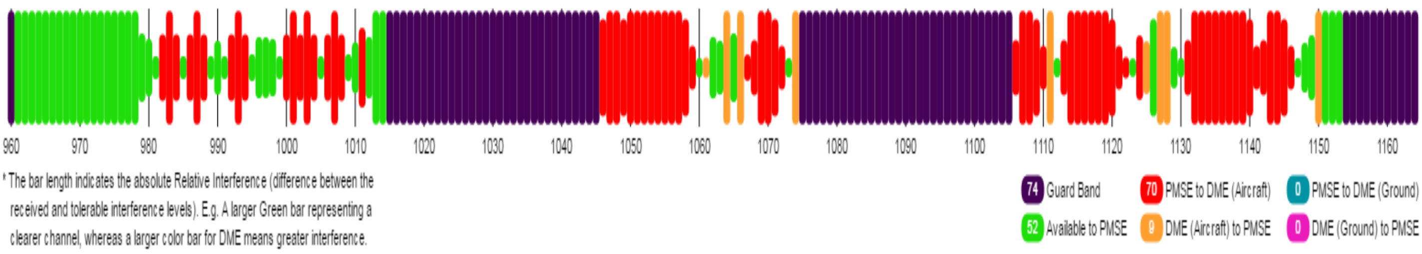


Figure 40: PMSE availability at the Cambridge Theatre in London

A2.9.2 Seating plan of the Theatre

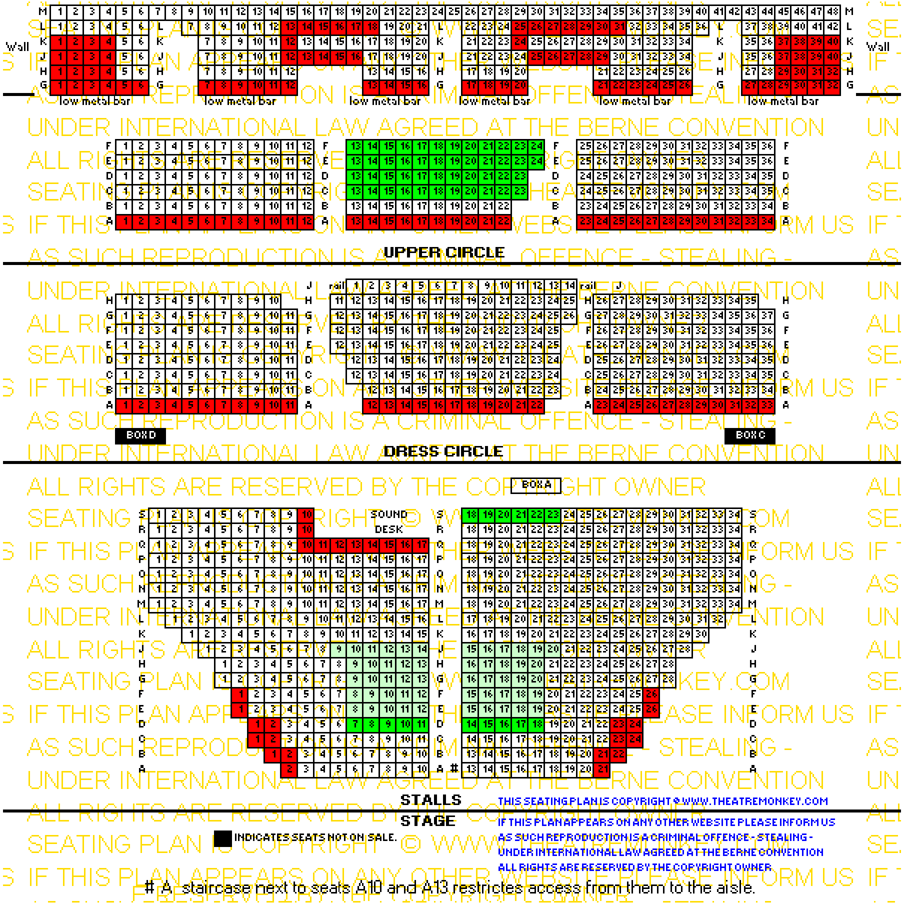


Figure 41: Seating plan of the Cambridge Theatre in London

A2.9.3 Equipment location

Located at row C of the stalls

Figure 42: Receiver location at the Cambridge Theatre

Figure 43: For practical space reasons the equipment was located at row C: Stage of the stalls and in theatre

For practical space reasons the equipment was located at row C of the stalls and in addition to using radio microphones on the stage members of the team walked around the three levels of the theatre to ensure both adequate coverage and a higher link budget which would increase the risk of interference.

Figure 44: Higher transmitting locations of the theatre used in the test

A2.10 SKY STUDIOS

Sky Studios are located some 9 km from Heathrow Airport and dependent on the direction of the wind have aircraft passing at low altitude every 1-3 minutes and is the worst-case site in these trials for aircraft movement

Figure 45: Location of the Sky Studios near Heathrow Airport

Conclusions

No interference experienced:

- DME band noise floor (960-980 MHz) typically < -108 dBm in 300 kHz BW;
- Measurement limited by MS2830A analyzer DANL;
- DTT band noise floor typically higher (-105 -> -90 dBm in 300 kHz);
- Set by intermodulation or IEM / Talkback OOB;
- DME airborne signals attenuated by studio;
- 964-990 MHz very clean, even outdoors.

The lower part of the DME band, especially 961-990 MHz, looks considerably cleaner than UHF PMSE spectrum – although this may be due in part to lower levels of local PMSE activity in the new band.

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

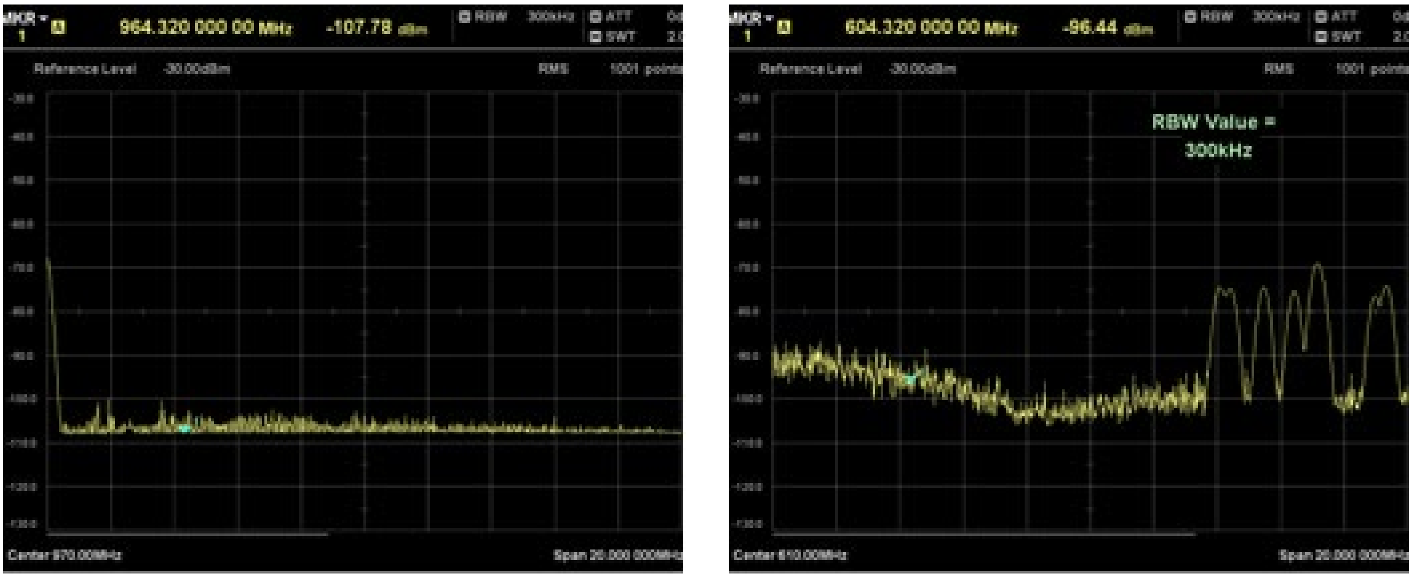


Figure 46: Spectrum scans of the lower DME band and the UHF TV (PMSE) band

The prototype Shure equipment performed well in the tests.

Parts of the new band from 960-1164 MHz are therefore likely to be useful in some circumstances for PMSE use.

Further long-term testing would be beneficial in building confidence in the new band so that a more complete picture of possible interference / use by incumbents can be assimilated.

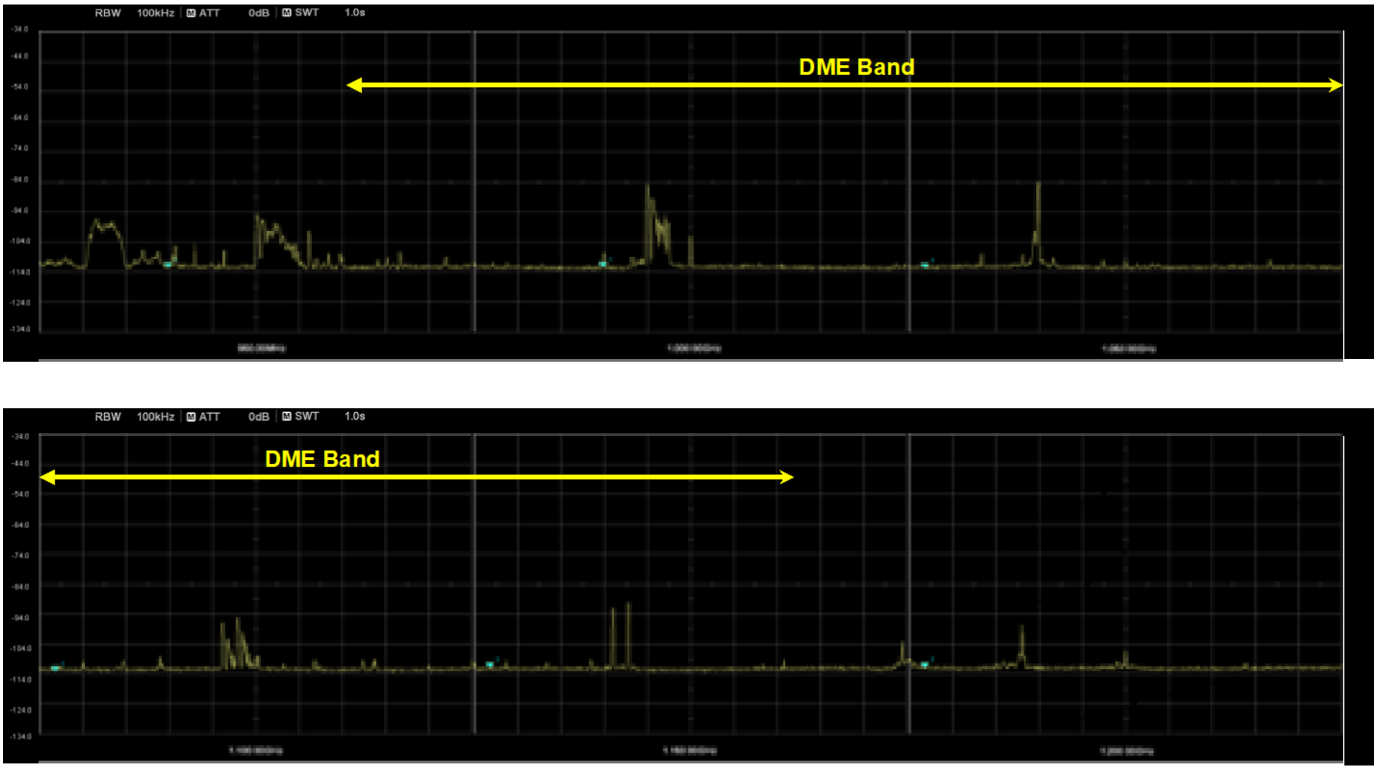


Figure 47: Spectrum scans of the DME band

A2.10.1 Spectrum availability

Sky, Osterley – 60 MHz available of which 8 MHz at risk of interference into PMSE from airborne

Indoor

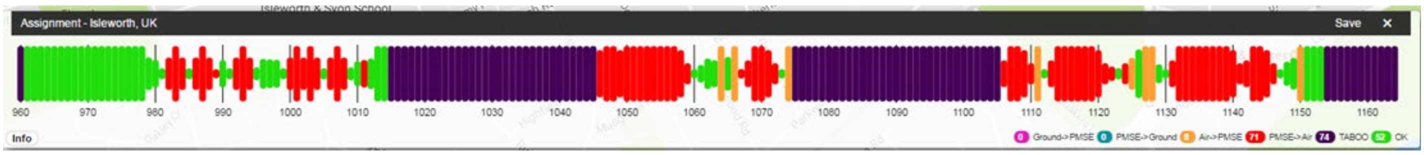


Figure 48: PMSE availability at the Sky studio (indoor) in Osterley

Outdoor: limited by possible interference to PMSE

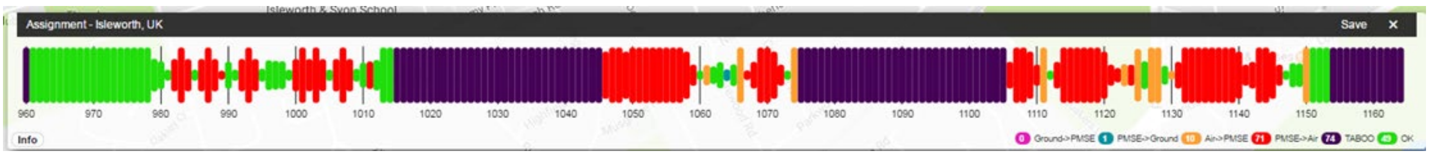


Figure 49: PMSE availability at the Sky studio (outdoor) in Osterley

A2.10.2 Noise floors

A2.10.2.1 Antennas

A broadband bi-cone was used for the logging. The chosen device was a Schwarzbeck BBUK 9139 Biconical + UBAA 9134 Balun. This has a nominal gain of -6 dBi gain over DME band

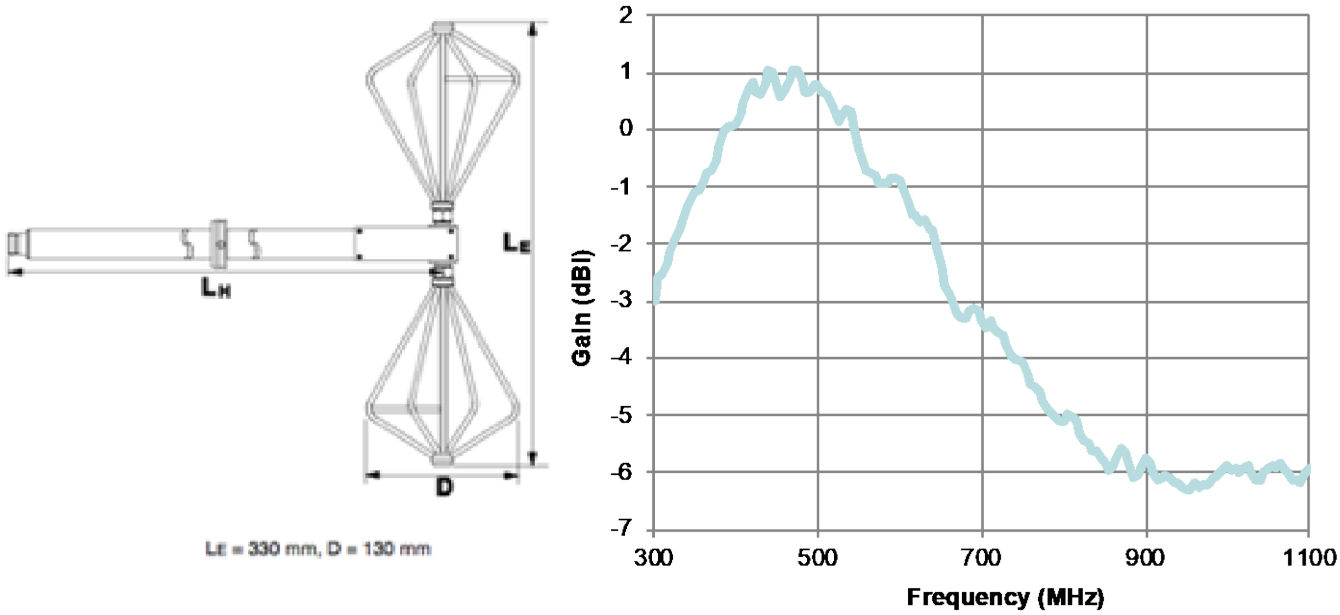


Figure 50: Broadband bi-cone antenna and its gain used in the test

A2.10.2.2 DME Band

Using the max-hold function of the analyser, revealed quiet spectrum in the band 960-1020 MHz. The DME interrogator signals are clearly seen on the right-hand trace with a separation of 1 MHz.

A2.10.2.3 Measurement Noise Floors

Two analysers were used for the measurements and the analyser noise floor parameters are given below. With the pre-amp enabled, the DANL indicated a pre amp noise figure < 12 dB.

Anritsu MS2830A:

- DANL -108 dBm , 300 kHz RBW, Preamp on, 0 dB Att;
- NF = -108 – (-174 + 10* log10(300e3)) = 11.2 dB.

Anritsu MSS2034B:

- DANL = -112 dBm, 100 kHz RBW, Pre-amp on, 0 dB Att;
- NF = -112 – (-174+10*log10(100e3)) = 12 dB.

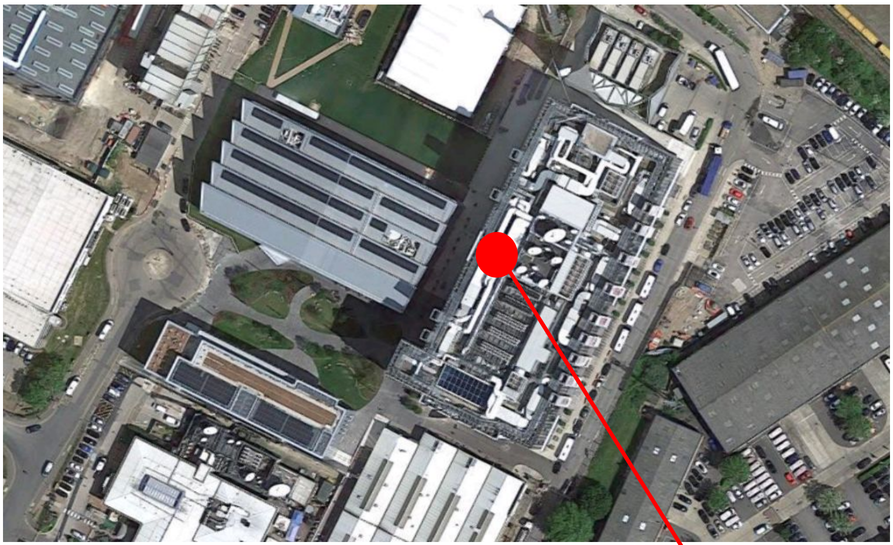
A2.10.3 Test Location

Studio 7

Sky Studios

Sky UK, Osterley

[TQ 163 779]



The studios are located 9km from London Heathrow Airport

Figure 51: Location of the Sky Studios near Heathrow Airport

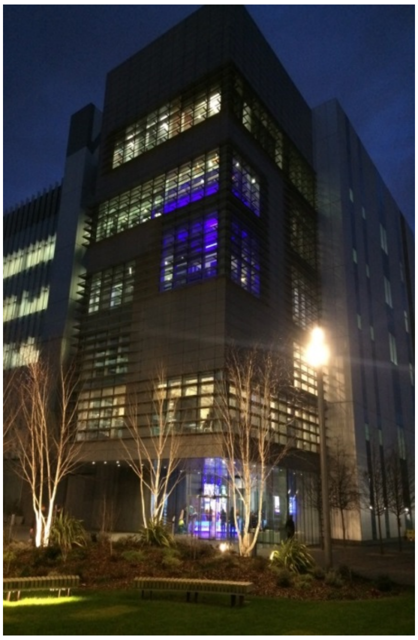


Figure 52: Sky Studios building

Sky Studios Building

Testing took place in Studio 7

Figure 53: Studio 7 of the Sky Studios used for the test

A2.10.4 TEST 1 on 19 December 2016

Investigation into the RF environment at Sky were conducted by Mark Waddell, a lead engineer at the BBC.

Conclusions:

DME band noise floor (960-980 MHz) typically < -108 dBm in 300 kHz BW:

- Measurement limited by MS2830A analyser DANL.

DTT band noise floor typically higher (-105 -> -90 dBm in 300 kHz):

- Set by intermodulation or IEM / Talkback OOB.

DME airborne signals attenuated by studio:

- 964-990 MHz very clean, even outdoors.

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

A2.10.5 TEST 2 on 5 January 2017

Investigation into operational aspects of Shure equipment

Conclusions:

The Shure equipment operating in 961-981 MHz behaves broadly similarly to Sky's existing Sennheiser equipment operating in 682-687 MHz in operational terms.

The Shure equipment can operate at significantly higher channel densities.

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

A2.10.6 Live Broadcast use 2018

Sufficient confidence has now been gained in the viability of the spectrum for live use of the equipment the following programs have been completely produced using the licenced spectrum whilst many others have part used this spectrum in conjunction with other UHF spectrum. Trails continue

Premier League Predictions Friday 2 February 1 hour

The Offload Wednesday 7 February 1 hour

The Debate Wednesday 7 February 1 hour

EFL Matters Thursday 8 February 1 hour

The Debate Thursday 8 February 1 hour

The Offload Wednesday 14 February 1 hour

The Debate Wednesday 14 February 1 hour

EFL Matters Thursday 15 February 1 hour

E Champions 10 May 6 hours

A2.10.7 Overall conclusions:

The lower part of the DME band, especially 961-990 MHz, looks considerably cleaner than UHF PMSE spectrum – although this may be due in part to lower levels of local PMSE activity in the new band.

The prototype Shure equipment performed well in the tests.

Parts of the new band from 960-1164 MHz are therefore likely to be useful in some circumstances for PMSE use.

Further long-term testing would be beneficial in building confidence in the new band so that a more complete picture of possible interference / use by incumbents can be assimilated.

Sufficient confidence has now been gained in the viability of the spectrum that from early in 2018 the equipment has be used in live productions with programs lasting up to six hours without any interruptions or interference, this continues

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

Caveats:

- Operational testing was limited to frequencies not in use for DME;
- Reliable spectrum analysis tools were not available during Test 2;
- The utility of the new band to PMSE equipment users will be determined by a number of factors including availability of suitable, affordable equipment on the market.

A2.11 BBC PACIFIC QUAY STUDIO

BBC Pacific Quay is BBC Scotland's television and radio studio complex at Pacific Quay, Glasgow, Scotland. Opened by then Prime Minister Gordon Brown in August 2007, the studios are home to BBC Scotland's television, radio and online services and the headquarters of the BBC in Scotland.

The studios are located adjacent to the Glasgow Science Centre, across the river from the Scottish Exhibition and Conference Centre and adjacent to the studios of commercial broadcaster STV. The new building is one of the most modern digital broadcasting facilities in the world, complete with the BBC's first HD-capable newsroom.

There are three main television studios based at BBC Pacific Quay.

Studio A is the largest television studio at the complex with 8417 square feet of studio floor space. It can easily accommodate studio audiences of up to 320.

Studio B is the small to medium-sized studio with 2594 square feet of studio floor space. Small studio audiences of up to 100 can be accommodated in Studio B.

Studio C is the smallest studio and is the home to BBC Scotland's flagship news programme "Reporting Scotland". The studio has 1938 square feet of studio floor space. This studio is used for local news, politics and current affairs programming for BBC Scotland and is therefore not usually available for use by other productions.

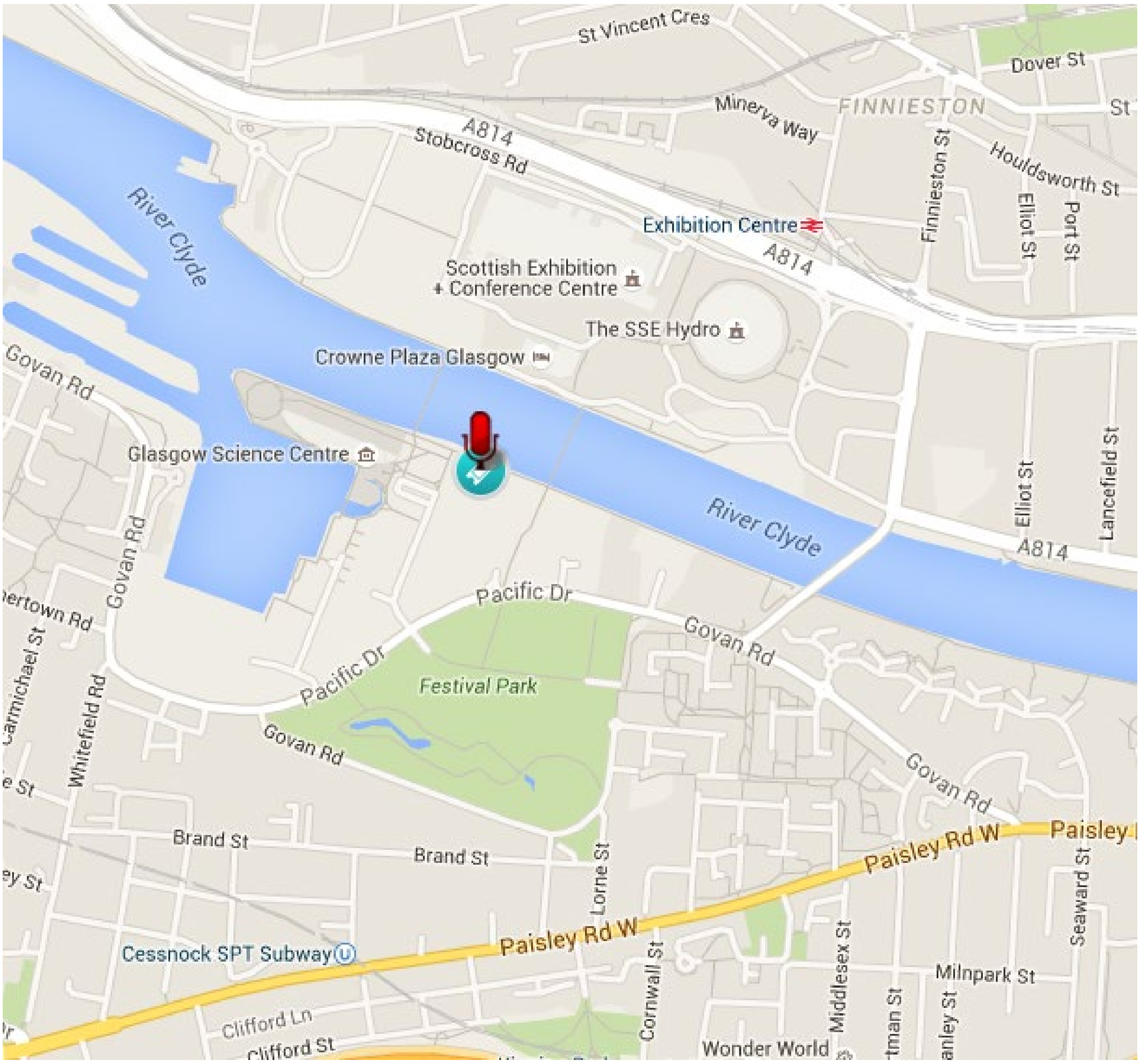


Figure 54: Location of the BCC Pacific Quay studio in Glasgow

Conclusions:

- No interference noted, same comments as previously.

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

A2.11.1 Spectrum Availability

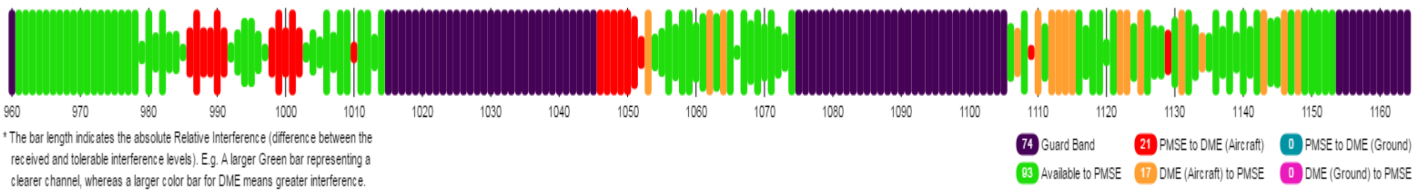


Figure 55: PMSE availability at the BBC Pacific Quay studio in Glasgow

A2.11.2 Spectrum Scan Roof September

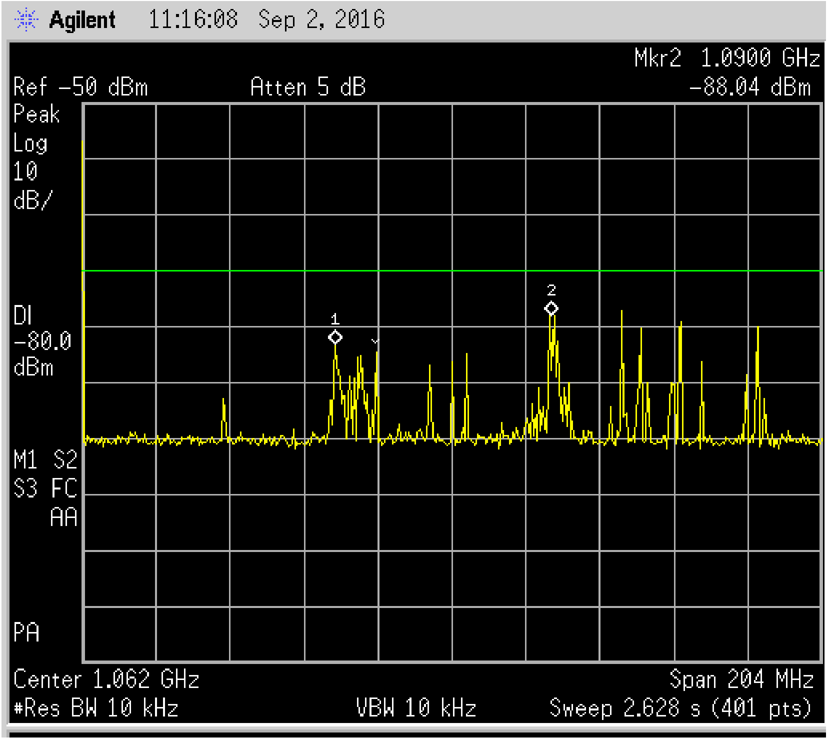


Figure 56: Spectrum scan of the DME band

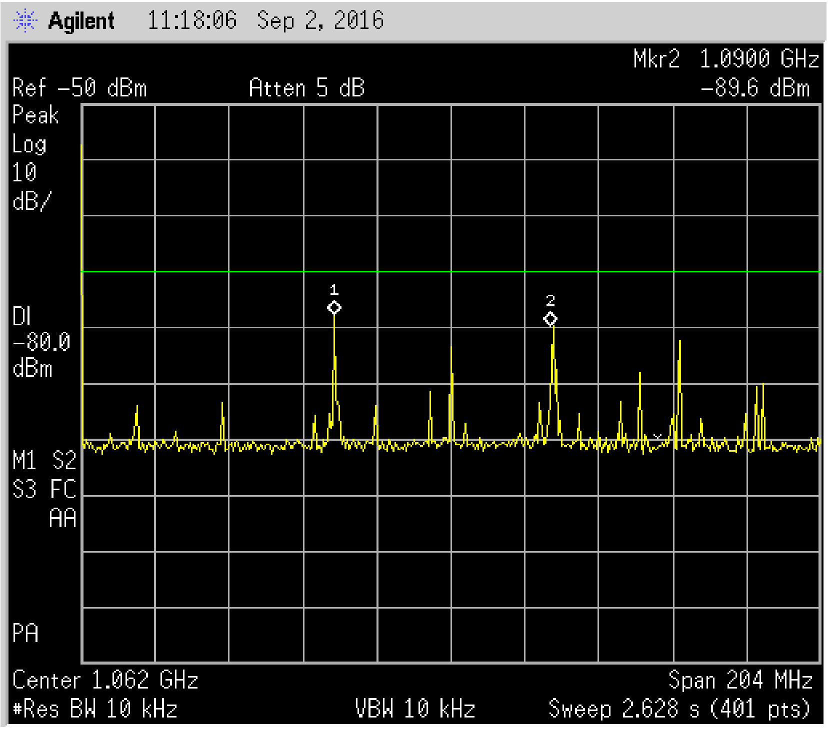


Figure 57: Spectrum scan of the DME band

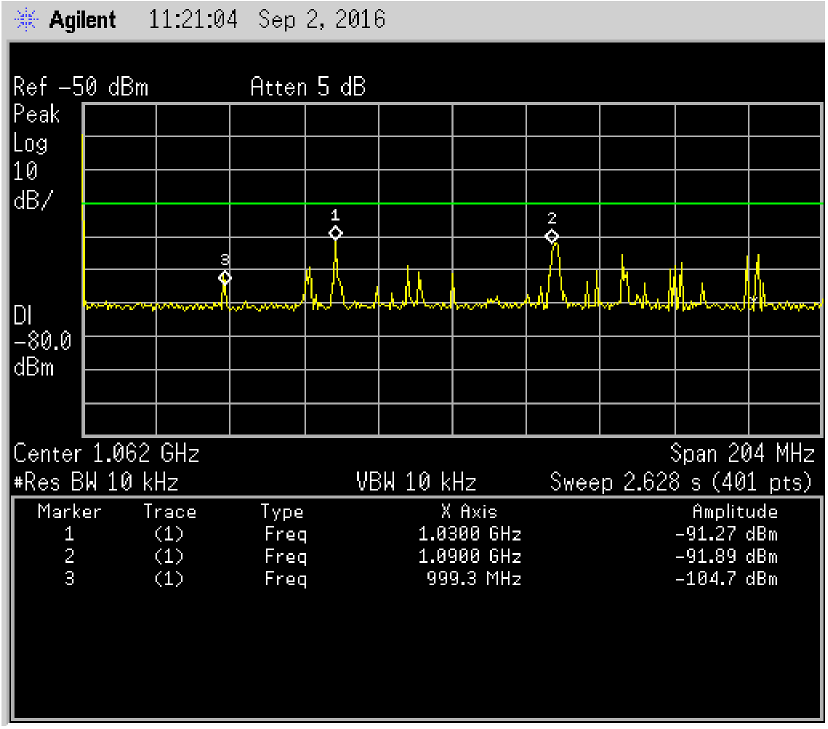


Figure 58: Spectrum scan of the DME band

A2.11.3 PQ Studio C 1 September: 4 Shure mics.GIF

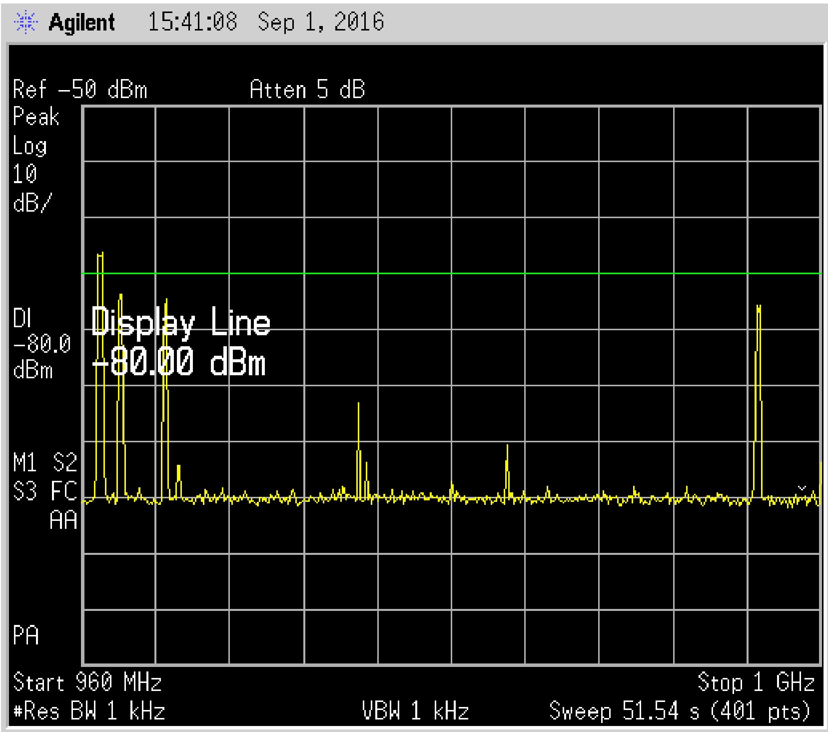


Figure 59: Spectrum scan of the DME band with microphones on

A2.11.4 PQ inside Window

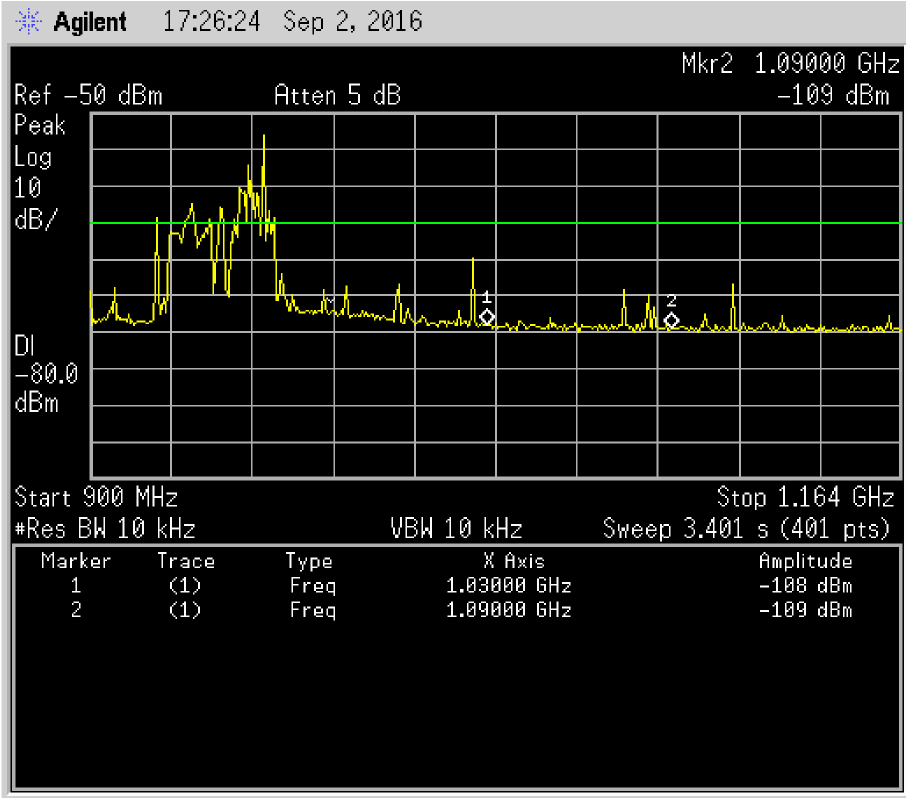


Figure 60: Spectrum scan of the DME band measured inside window

A2.12 MONITORING AND TRANSMISSIONS AT EDGCOTT

Edgcott is located to the west of London and some 20 miles north of Oxford, approximately 50 miles from both Heathrow and Birmingham Airports; it is also on route from a number of military airfields and has acrobatics taking place overhead on a regular basis.

A2.12.1 Spectrum Availability

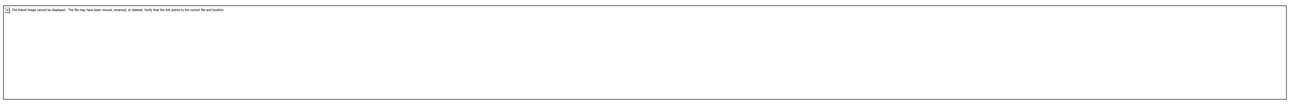


Figure 61: PMSE availability in Edgcott

A2.12.2 Monitoring

From June 2016, monitoring has taken place initially using a Marconi 2390 and a USB spectrum analyser, from mid-2017 adding a Shure UXLD4Q receiver, antennas have been located externally to the building. Time spans have been between a few hours to continuous monthly cycles.

From March 2017, an Ofcom (UK) T&D license has enabled occasional transmissions using the Shure equipment; performance has been similar to equivalent models using the 470-694 MHz band.

Using the Ofcom spectrum plot above, the green spectrum has been interference free and no noticeable interference on the orange spectrum.

Since May 2018, additional Shure transmitters have been in use, no interference or interruptions have been seen for either indoor or outdoor use in spite of often heavy military presence from local airfield.

In January 2019, a commercial license was issued by Ofcom (UK) and the 10 channels identified in the license have been in use both indoor and outdoor. Increased military flights have been noted since February but no interference has been received.

Conclusion:

- Use of PMSE at this location is practical using the Ofcom plot and license;

It has to be noted that the potential impact of a PMSE transmissions into an aeronautical receivers was not considered here.

A2.13 WISYCOM 960-1164 MHZ TESTING

The transmitter equipment was tested for compliance against the ETSI EN 300 422-1 [52] block edge mask that defines the permitted level of out of block emissions. The equipment has a clean spectrum which is compliant with the mask.

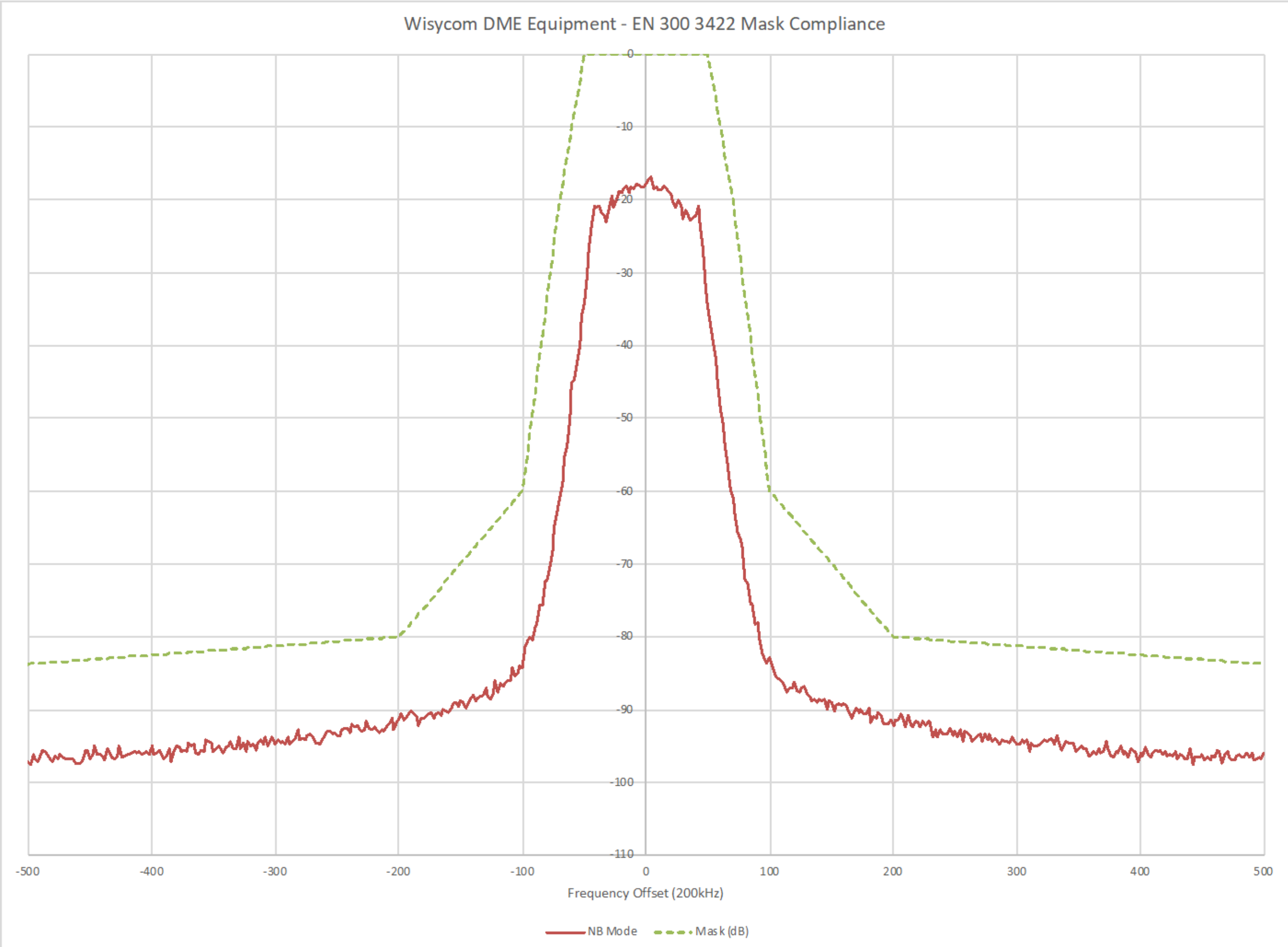


Figure 62: Wisycom microphone transmitter mask (horizontal axis is in kHz) (in dB)

A2.14 SHURE ULXD EQUIPMENT

PERFORMANCE™

Figure 63: Shure ULX-D equipment

Shure ULX-D® Digital Wireless offers uncompromising 24-bit audio clarity and extremely efficient RF performance with single, dual, and quad channel receivers for any size professional sound reinforcement application. Generations ahead of any other available system in its class, ULX-D brings a new level of performance to professional sound reinforcement.

ANNEX 3: IMPACT OF PMSE ON DME FROM APWPT

A3.1 SUMMARY

This study investigates audio PMSE sharing radio spectrum with aeronautical systems; Distance Measuring Equipment (DME) and Tactical Air Navigation System (TACAN) in the spectrum band 960-1164 MHz. Since TACAN provides the same service and has very similar system characteristics to DME, the interference susceptibility will be comparable. Therefore, it can be reasonably assumed that the same protection criteria will apply to both systems, so for convenience and simplicity, only DME is referred to in this annex.

To investigate audio PMSE sharing radio spectrum with aeronautical systems, this study considers several minimum coupling loss calculations.

The types of audio PMSE use investigated are:

- hand-held audio PMSE;
- body-worn audio PMSE.

The study did not consider:

- In Ear Monitors, they transmit with power up to 17 dBm without body loss;
- the aggregated effect of several PMSE

Each of these devices are considered in different environments (urban, sub-urban and rural), in outdoor and indoor cases. Minimum and median values are considered for the body loss. Only the co-frequency case is considered. It should be note that PMSE operated co-frequency with DME/TACAN in close vicinity are expected to be interfered. Therefore, PMSE are not expected to be operated co-frequency in the vicinity of DME/TACAN.

Table 10: Summary

PMSE interference into aeronautical systems	Required co-frequency separation distance (Ground Receiver)	Required co-frequency separation distance (Air Receiver)	Comment
PMSE interference to DME	from* 0.2 to 27.8 km	from* 47.3 to 305.2 km	For hand-held (outdoor)
PMSE interference to DME	from* 0.1 to 15.7 km	from* 11.5 to 96.5 km	For hand-held (indoor)
PMSE interference to DME	from* 0.1 to 22.6 km	from* 28.8 to 192.6 km	For body-worn equipment (outdoor)
PMSE interference to DME	from* 0.1 to 12 km	from* 0 to 60.9 km	For body-worn equipment (indoor)
*Note: the wide ranges reflect the variability in the use cases.			

A3.2 PMSE PARAMETERS

Table 11: Parameters for hand-held audio PMSE

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253 [57]
Antenna transmit height	m	1.5	ECC Report 253
Antenna receive height	m	2	
Body effect	dBd dBi	0 dB (minimum) 6 dB (median)	ECC Report 286 [27]
Modelled e.i.r.p.	dBm	13	ERC/REC 70-03, Annex 10 [28] and ECC Report 253
Antenna polarisation	NA	Vertical	ECC Report 253

Table 12: Parameters for body-worn audio PMSE

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253
Antenna transmit height	m	1.5	ECC Report 253
Antenna receive height	m	2	
Body effect	dBd dBi	8 dB (minimum) 14 dB (median)	ECC Report 286 [27]
Modelled e.i.r.p.	dBm	17	ECC Report 253 and ERC/REC 70-03, Annex 10
Antenna polarisation	NA	Vertical	ECC Report 253

Note: calculations are provided co-frequency and not for IEM, therefore, those parameters are proposed for removal from this annex.

A3.2.1 PMSE receiver Parameters

Table 13: Parameters for audio PMSE receivers

Parameter	Unit	Value	Reference
Interference level to protect PMSE	dBm	-81 dBm	
Selectivity	dB	See curve below	ERC Report 63 [70]

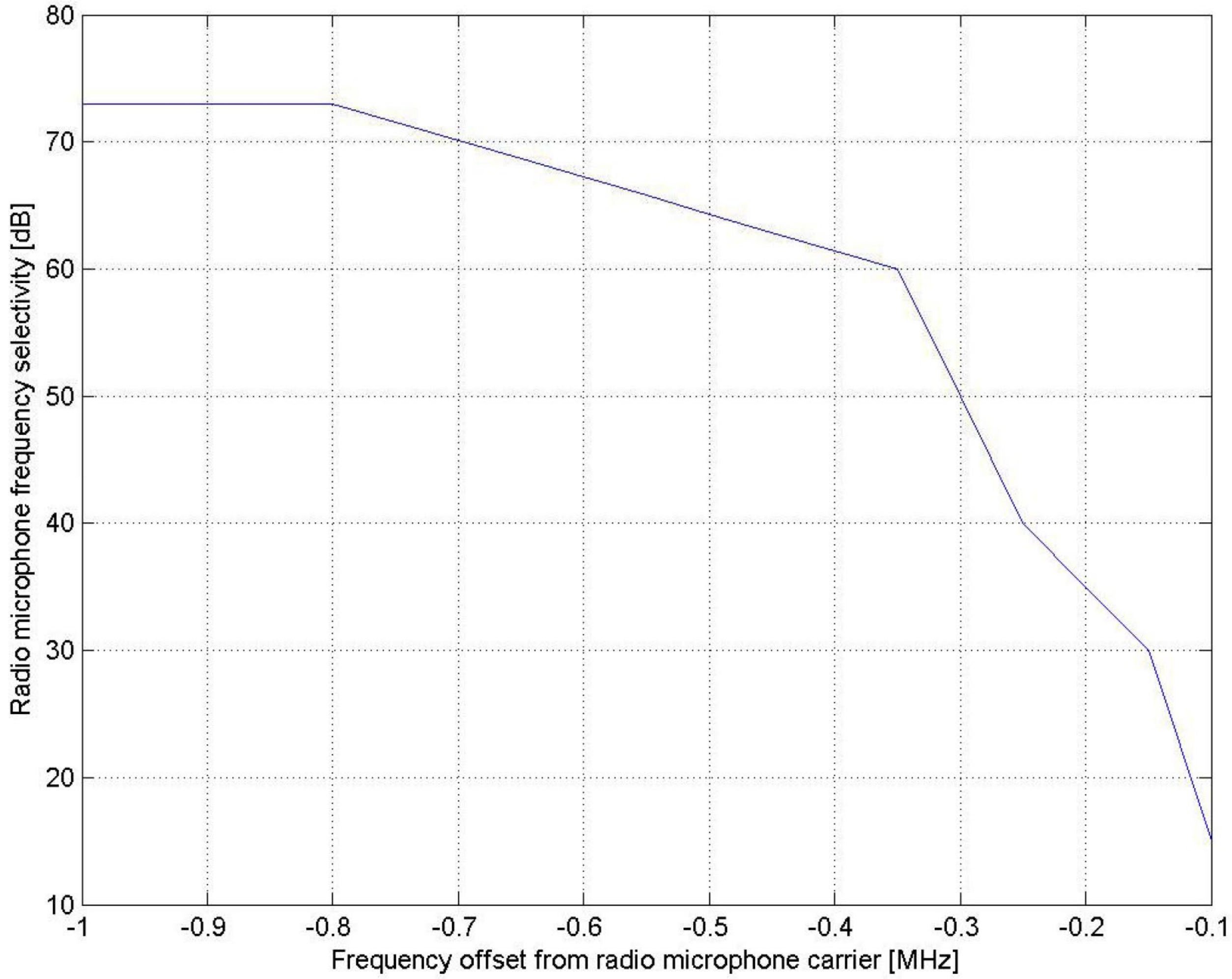


Figure 64: PMSE RF selectivity curves

The receive characteristics, such as antenna receive height, antenna gain and body effect of the body-worn and hand-held audio PMSE are expected to be similar to the transmit characteristics, antenna receive height, antenna gain and body effect of the audio In Ear Monitor (IEM) and vice versa.

A3.2.2 Parameters of body loss

Parameters of body loss are the following:

- For hand-held equipment 0 dB (minimum) and 6 dB (median),
- For body-worn equipment 8 dB (minimum) and 14 dB (median).

A3.2.3 Parameter for building loss

The PMSE equipment is assumed to be deployed outdoor or indoor with 10 dB attenuation as the equipment is inevitably within a congested stage or similar structure.

A3.3 PROPAGATION MODEL

The propagation model which is considered in the calculations for ground to ground case is the Extended Hata model (see ECC Report 252 – SEAMCAT Handbook [62]). For ground to air, free space is currently considered.

A3.4 DME

A3.4.1 DME parameters

Table 14: DME/N, DME/P and TACAN parameters used in study

Parameters	Unit	DME/N ground	DME/N airborne	DME/P ground	DME/P airborne	TACAN ground (civil use)	TACAN airborne (civil use)
Transmitter							
Frequency range	MHz	962-1213	1025-1150	962-1213	1025-1150	962-1213	1025-1150
Bandwidth	MHz	3.5	3.5	3.5	3.5	3.5	3.5
Max. e.i.r.p.	dBm	74	68	75	68	75	69
Mask	N.A.	(see ICAO Annex 10)	(see ICAO Annex 10)	(see ICAO Annex 10)	(see ICAO Annex 10)	(see ICAO Annex 10)	(see ICAO Annex 10)
Receiver							
Frequency range	MHz	1025-1150	962-1213	1025-1150	962-1213	1025-1150	962-1213
Bandwidth	MHz	3.5	3.5	3.5	3.5	3.5	3.5
Noise figure	dB	4	4	4	4	4	4
Protection criteria (I/N) (Note 1)	dB	-10/-20	-10/-20	-10/-20	-10/-20	-10/-20	-10/-20
Antenna gain	dBi	Max. 16 (directional), 12 (omni-directional)	5.4	16	5.4	12	5.4
Selectivity (Note 2)							

Note 1: These values are intended for initial studies only, they need further discussion, especially taking into account secondary service (PMSE) vs safety service (ARNS).
Note 2: ACS: ICAO Annex 10, Volume 1 [44]: Attachment C, Table C.7 and Table C.8.

A3.4.2 Modelling assumptions

Two protection criteria are considered in the studies. I/N of -10 dB and I/N of -20 dB.

Three antenna heights are considered for the DME on the ground: 40 m, 25 m, 2.1 m. For the Airborne case, three altitudes are considered: 100 m, 1000 m, 10000 m.

A3.4.3 Conclusion

Table 15: Results for hand-held audio PMSE (outdoor) – DME ground station

Body loss	I/N	Environment	DME antenna height		
			40	25	2.1
0 dB	-10 dB	Distances (rural) km	15.7	11.8	2.9
		Distances (suburban) km	4.4	3.4	0.8
		Distance (urban) km	2.2	1.7	0.4
	-20 dB	Distances (rural) km	27.8	22.1	5.5
		Distances (suburban) km	8.7	6.6	1.6
		Distance (urban) km	4.3	3.4	0.8
6 dB	-10 dB	Distances (rural) km	10.5	8.0	1.9
		Distances (suburban) km	2.9	2.3	0.5
		Distance (urban) km	1.5	1.1	0.2
	-20 dB	Distances (rural) km	20.3	15.4	3.7
		Distances (suburban) km	5.8	4.5	1.1
		Distance (urban) km	2.9	2.3	0.5

Table 16: Results for hand-held audio PMSE (indoor) – DME ground station

Body loss	I/N	Environment	DME antenna height		
			40	25	2.1
0 dB	-10 dB	Distances (rural) km	8.0	6.1	1.5
		Distances (suburban) km	2.2	1.8	0.4
		Distance (urban) km	1.1	0.9	0.2
	-20 dB	Distances (rural) km	15.7	11.8	2.9
		Distances (suburban) km	4.4	3.4	0.8
		Distance (urban) km	2.2	1.7	0.4
6 dB	-10 dB	Distances (rural) km	5.3	4.1	1.0
		Distances (suburban) km	1.5	1.2	0.2
		Distance (urban) km	0.7	0.6	0.1
	-20 dB	Distances (rural) km	10.5	8.0	1.9
		Distances (suburban) km	2.9	2.3	0.5
		Distance (urban) km	1.5	1.1	0.2

Table 17: Results for Body-worn audio PMSE (outdoor) – DME ground station

Body loss	I/N	Environment	DME antenna height		
			40	25	2.1
8 dB	-10 dB	Distances (rural) km	12.0	9.1	2.2
		Distances (suburban) km	3.4	2.6	0.6
		Distance (urban) km	1.7	1.3	0.3
	-20 dB	Distances (rural) km	22.6	17.5	4.3
		Distances (suburban) km	6.6	5.1	1.2
		Distance (urban) km	3.3	2.6	0.6
14 dB	-10 dB	Distances (rural) km	8.0	6.1	1.5
		Distances (suburban) km	2.2	1.8	0.4
		Distance (urban) km	1.1	0.9	0.2
	-20 dB	Distances (rural) km	15.7	11.8	2.9
		Distances (suburban) km	4.4	3.4	0.8
		Distance (urban) km	2.2	1.7	0.4

Table 18: Results for body-worn audio PMSE (indoor) – DME ground station

Body loss	I/N	Environment	DME antenna height		
			40	25	2.1
8 dB	-10 dB	Distances (rural) km	6.1	4.7	1.1
		Distances (suburban) km	1.7	1.3	0.3
		Distance (urban) km	0.8	0.7	0.1
	-20 dB	Distances (rural) km	12.0	9.1	2.2
		Distances (suburban) km	3.4	2.6	0.6
		Distance (urban) km	1.7	1.3	0.3
14 dB	-10 dB	Distances (Rural) km	4.1	3.2	0.7
		Distances (suburban) km	1.1	0.9	0.2
		Distance (urban) km	0.5	0.4	0.1
	-20 dB	Distances (rural) km	8.0	6.1	1.5
		Distances (suburban) km	2.2	1.8	0.4
		Distance (urban) km	1.1	0.9	0.2

Table 19: Hand-held audio PMSE (outdoor) – Airborne DME - Separation Distances on the ground in km

I/N	Body Loss	DME antenna height (m)		
		100	1000	10000
-10 dB	0 dB	96.5 km	96.5 km	96.0 km
	6 dB	48.3 km	48.3 km	47.3 km
-20 dB	0 dB	305.2 km	305.2 km	305.1 km
	6 dB	153.0 km	152.9 km	152.6 km

Table 20: Hand-held audio PMSE (indoor) – Airborne DME - Separation Distances on the ground in km

I/N	Body Loss	DME antenna height (m)		
		100	1000	10000
-10 dB	0 dB	30.5 km	30.5 km	28.8 km
	6 dB	15.2 km	15.2 km	11.5 km
-20 dB	0 dB	96.5 km	96.5 km	96.0 km
	6 dB	48.3 km	48.3 km	47.3 km

Table 21: Body-worn audio PMSE (outdoor) – Airborne PMSE - Separation Distances on the ground in km

I/N	Body Loss	DME antenna height (m)		
		100	1000	10000
-10 dB	8 dB	60.9 km	60.9 km	60.0 km
	14 dB	30.5 km	30.5 km	28.8 km
-20 dB	8 dB	192.6 km	192.6 km	192.3 km
	14 dB	96.5 km	96.5 km	96.0 km

Table 22: Body-worn audio PMSE (indoor) – Airborne PMSE - Separation Distances on the ground in km

I/N	Body Loss	DME antenna height (m)		
		100	1000	10000
-10 dB	8 dB	19.2 km	19.2 km	16.4 km
	14 dB	9.6 km	9.6 km	0 km
-20 dB	8 dB	60.9 km	60.9 km	60.0 km
	14 dB	30.5 km	30.5 km	28.8 km

A3.5 SSR – 1030-1090 MHZ SYSTEMS

Not studied.

A3.6 UNIVERSAL ACCESS TRANSCEIVER (UAT)

Not studied.

A3.7 CNPC

Not studied.

A3.8 LDACS

Not studied.

A3.9 JTIDS/MIDS

Not studied.

A3.10 GNSS

Not studied.

A3.11 OTHER SYSTEMS

Not studied.

ANNEX 4: MCL STUDY ON THE IMPACT OF THE PMSE ON DME FROM OFCOM, UNITED KINGDOM

A4.1 SUMMARY

This study investigates the audio PMSE sharing radio spectrum with aeronautical systems Distance Measuring Equipment (DME), Tactical air navigation system (TACAN) and Secondary surveillance radar systems (SSR) in the spectrum band 960-1164 MHz. Since TACAN provides the same service and has similar system characteristics compared to DME, also the interference susceptibility will be comparable. Therefore, one can assume that the same protection criteria will apply to both systems, so for convenience we will only refer to DME.

The types of audio PMSE use investigated are:

- hand-held audio PMSE;
- body-worn audio PMSE;
- audio in ear monitor (IEM).

In addition, this study also considers compatibility between PMSE and GNSS above 1164 MHz assuming a 10 MHz guard band from 1154 MHz. Within this study, three GNSS receiver masks are used (which can be referenced) to demonstrate that the separation distances required primarily depend on the assumption of the GNSS receiver mask. It is highlighted that receiver masks performance (across all the range of GNSS equipment) will vary and may not align with those assumed in this study, however, ETSI Standard EN 303 413 specifies a requirement to meet the adjacent frequency signal power level of -75 dBm at 1154 MHz.

To investigate audio PMSE sharing radio spectrum with the aeronautical systems, this study considers several minimum coupling loss calculations. For the interference scenarios of PMSE interference into DME and SSR, neither an aeronautical safety margin nor apportionment have been assumed as explained in section A4.3. For PMSE interference into aeronautical RNSS, 6 dB safety margin has been included in accordance with ITU-R Recommendation M.1903 [69].

The protection criteria used in this study are based on interference thresholds specified in EUROCAE Standards (which have been derived from ICAO Annex 10) and/or other studies, for example ITU-R M.2205 [63]. References for the values used are provided for each case. Aggregate interference (from PMSE) has not been considered, however, it is noted that the practical studies carried out by the UK included four PMSE interferers (three within a DME channel and one adjacent), and these measurements (with aggregated interference) align closely with the values used in the study.

The study did not consider:

- In Ear Monitor with power up to 17 dBm without body loss;
- The aggregated effect of several PMSE;
- The echo suppression of DME (interference threshold instead);
- I/N criteria of aeronautical system (C/I protection criteria instead).

Table 23: Summary

PMSE interference into aeronautical systems	Required co-frequency separation distance (Ground Receiver)	Required co-frequency separation distance (Air Receiver)	Guard band
PMSE interference to DME	~6 km	~23 km	@ 1 MHz separation: for transponder separation distances are 0.6-3.5 km; for interrogator separation distances are 3.6-8.1 km.

PMSE interference into aeronautical systems	Required co-frequency separation distance (Ground Receiver)	Required co-frequency separation distance (Air Receiver)	Guard band
			@ 2 MHz separation: for transponder distances are 0.2-2.7 km; for interrogator distances are insignificant at 2 MHz separation.
PMSE interference to SSR (1030 MHz and 1090) systems	~4 km	~11 km	@ 10 MHz guard band distances are between 200 m to 300 m for both interrogator and transponder. @ 15 MHz guard band separation distances are negligible. As it is not possible to coordinate with airborne receivers, a guard band of 15 MHz is appropriate.
Aeronautical systems interference into PMSE	**Minimum co-frequency separation distance (Ground Transmitter)**	**Minimum co-frequency separation distance (Air Transmitter)**	**Guard band**
DME interference to PMSE	~17 km	~150 km	2-3 MHz
SSR (1030 MHz and 1090 MHz systems) interference to PMSE	~6 km	~35 km	~20 MHz
PMSE interference into GNSS systems	**Minimum separation distance (General Purpose receiver)**	**Minimum separation distance (Airborne Receiver)**	**Guard band**
PMSE interference into GNSS systems	698 m – 4 m depending on Rx mask assumed	930 m – 13 m depending on Rx mask assumed	10 MHz

A4.2 PMSE PARAMETERS

The tables below show parameters for the hand-held and body-worn audio PMSE transmitter. These have been taken from the last published PMSE study from work carried out in SE7, ECC Report 253 [57]. We have applied the same parameters for our study apart from body loss.

For body loss/effect the values from the ECC Report 286 [27] “Body effect of hand-held and body-worn audio PMSE equipment” have been used which is the latest work done within CEPT. The Report gives frequency dependent formulae for use in sharing and compatibility studies.

Table 24: Parameters for hand-held audio PMSE

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253 [57]
Antenna transmit height	m	1.5	ECC Report 253
Antenna receive height	m	2	
Body effect	dBi	-4.85	ECC Report 286 [27]
Modelled e.i.r.p.	dBm	8.15	ERC/REC 70-03, Annex 10 [28] and ECC Report 253
Antenna polarisation	NA	Vertical	ECC Report 253

Table 25: Parameters for body-worn audio PMSE

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253
Antenna transmit height	m	1.5	ECC Report 253
Antenna receive height	m	2	
Body effect	dBi	-6.85	ECC Report 286
Modelled e.i.r.p.	dBm	10.15	ECC Report 253 and ERC/REC 70-03, Annex 10
Antenna polarisation	NA	Vertical	ECC Report 253

Table 26: Parameters for audio IEM

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253
Antenna transmit height	m	2	
Maximum antenna gain	dBi	8	
Maximum e.i.r.p.	dBm	17	
Modelled antenna gain	dBi	0	
Modelled e.i.r.p.	dBm	9	
Antenna polarisation	NA	Vertical	

The usual configuration for IEM transmitter antennas is to mount them above the stage at a height of at least 2 metres. IEM transmitting antennas on the stage are then angled down towards the stage at approximately 45º. This reduces interference to nearby systems as propagation in a horizontal direction is via a combination of the side lobes of the antenna and scatter from the stage. As stated in ECC Report 253 [57], "Considering the pointing downward of the IEM antenna, for the MCL calculations, an E.I.R.P. of 9 dBm is considered (9 dBm output power and 0 dB antenna gain)."

The spectrum masks for analogue and digital audio PMSE systems are given in Figure 65 and Figure 66 below. (ETSI EN 300 422 (V1.5.0 /2015-01).

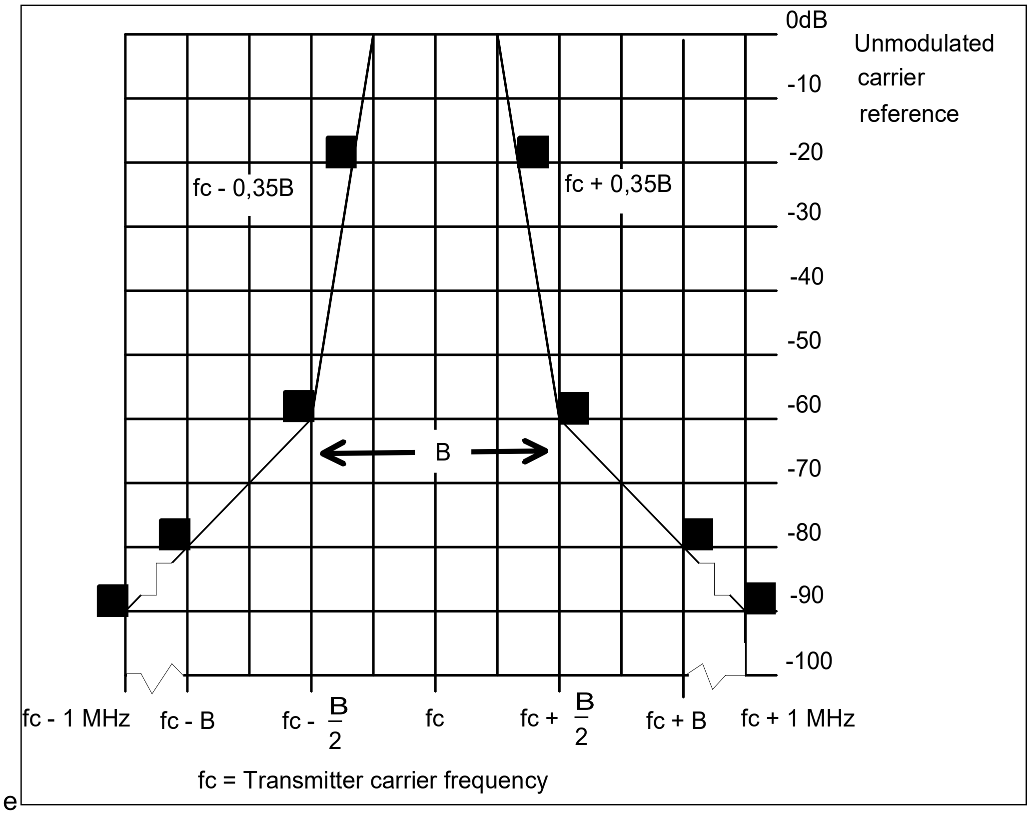


Figure 65: Spectrum mask for analogue systems in all bands (measurement bandwidth is 1 kHz)

Figure 66: Spectrum mask for digital systems below 2 GHz (measurement bandwidth is 1 kHz)

The spectrum mask for digital system has been used in this study. Note, that it can be seen in adjacent channel interference calculations the selectivity of the aeronautical receivers is the significant factor to the calculation and not whether the digital or analogue mask was assumed.

A4.2.1 PMSE receiver Parameters

ERC Report 42 [71] gives various radio microphone system calculations to be used in planning.

This report discusses excess fade margins of 30 dB to overcome multipath. The use of diversity reception, as is frequently the case in professional equipment, means that this fade margin can be further reduced.

Whilst PMSE is often planned to quite high wanted signal levels, a method of analysis that protects the noise floor of PMSE is a very cautious approach which is unnecessary in practice. Accordingly, ERC Report 42 suggests a wanted signal level of -69 dBm to protect radio microphones for the scenario of outside drama and documentary.

The Chester and RRC 06[32] frequency plans consider protecting radio microphones at a level of 68 dBµV/m at 1.5 m with a protection ratio of 12 dB, which is equivalent to -69 dBm at 960 MHz, and the same level in ERC Report 42.

Various process in the PMSE receiver mean that the impact of the E.I.R.P. of an interfering pulsed signal may be averaged over time, which could reduce the impact of the maximum E.I.R.P. of the pulsed system to the audio PMSE (e.g. de-emphasis filtering). A signal with a higher pulse rate may have a higher average power over time, than a pulse signal with a lower pulse rate. This effect can be observed with the JCSys measurement results, where a higher protection is needed with higher pulse rate of the DME signal (see JCSyS [22]) .

JCSys tested radio microphones in the presence of a DME signal. At a minimum interrogation rate of 700 pulse pairs per second (ppps), the PMSE performance, with wanted signal of -64 dBm, fails when DME power is greater than -63.6 dBm for X channel or greater than -62.6 dBm for Y channel.

As a cautious approach to protect audio PMSE, we use the maximum interference level of -81 dBm (-69 dBm - 12 dB protection ratio from RRC06) from the aeronautical pulsed systems. This level of protection gives additional margin than was found needed in practice by the practical tests by JCSys.

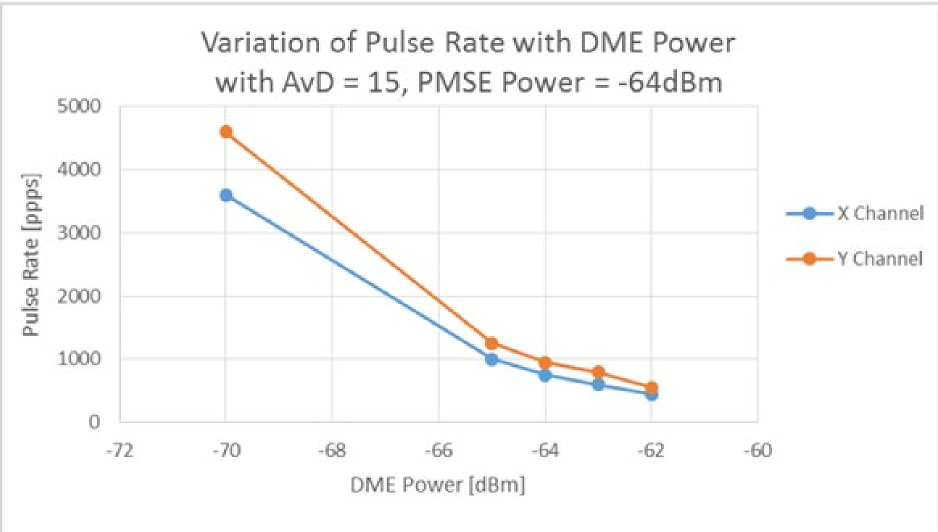


Figure 67: Trade-off of DME Power and Pulse Rate into PMSE

32 Final Acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz

For the purpose of this study the receive characteristics of the body-worn and hand-held audio PMSE are assumed to be similar to the transmit characteristics of the corresponding applications, i.e. the IEM receiver is on the performer so therefore antenna height and body effect of the IEM receive path are assumed to be the same as the body-worn transmitter. This means the IEM receive antenna is at 1.5 m and there is a body effect assumed of -6.85 dBi. Similarly, the microphone receive antenna parameters are assumed to be the same as the IEM transmit antenna, i.e. a height of 2 m and 0 dBi body effect.

Table 27: Parameters for audio PMSE receivers

Parameter	Unit	Value	Reference
Interference level to protect PMSE	dBm	-81 dBm	
Selectivity	dB	See curve below	ERC Report 63 [70]
Antenna receive height	m	2 (for body-worn and hand-held microphones) 1.5 (for IEM)	ECC Report 253 [57]
Body effect	dBi	-6.85 (IEM)	ECC Report 286 [27] (body effect of the IEM receiver close to the human body)

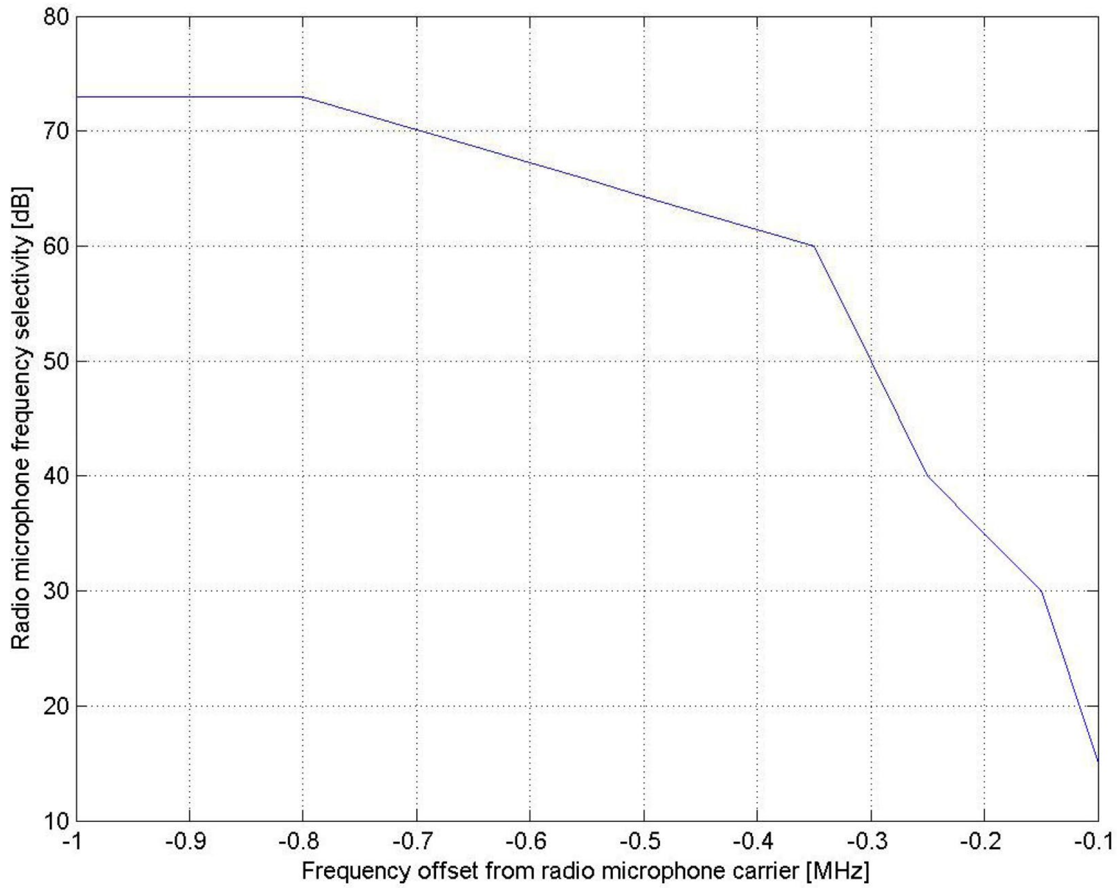


Figure 68: PMSE RF selectivity curves

A4.2.2 Parameters of body loss

Body effect has been assumed based on ECC Report 286 [27]. Values of body effect and the resulting e.i.r.p. are presented in the tables of PMSE transmitter parameters provided in section 2.

A4.2.3 Parameter for building loss

ECC Report 121 [61] measured values of wall loss for the materials tested range from 6 dB to about 34 dB and most wall materials have an attenuation value above 10 dB.

Recommendation ITU-R P.2109-0 [33] also gives a potential wide range of values for building entry loss. Figure 69 gives a CDF of building entry loss for both traditional buildings and thermally efficient building.

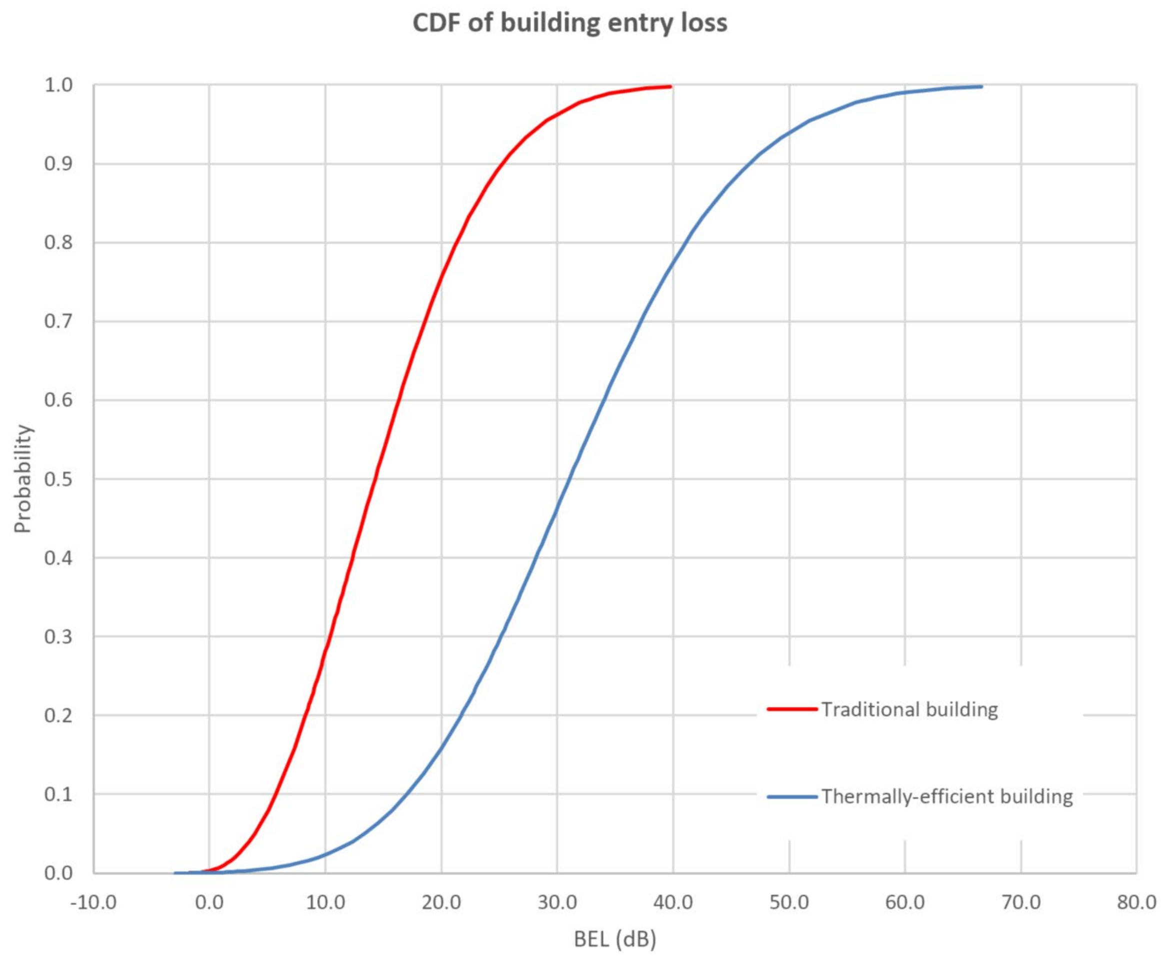


Figure 69: Cumulative distribution function of building entry loss at 960 MHz

This study only considers building entry attenuation in the terrestrial case between audio PMSE and the aeronautical ground stations in the modelled urban environment (building entry attenuation was not considered in our modelled rural environment). The value of 10 dB for building entry attenuation has been assumed in our study and is considered a cautious assumption. It is expected that in practice the actual building entry loss will be greater and in practice also potentially applicable to all scenarios modelled.

A4.3 PROPAGATION MODEL

For the path loss calculation from PMSE to the airborne receivers (at heights 1 km and 10 km), the propagation model ITU-R P.528-3 [32] has been chosen with a time probability of 1%. For the airborne receive height 100 m, the IF-77 algorithm has been used with a time probability of 1%, as the model ITU-R P.528-3 only recommends interpolating the curves, not extrapolating the curves to get results at a height of 100 m. The ICAO planning guidelines proposes a 50%-time probability for propagation modelling for frequency planning (see EUR-Doc-011 [47]). For this study the 1%-time probability was chosen as it incorporates infrequent anomalous propagation effects and an in-built safety margin, which leads to larger protection distances[33]. For cases where the separation distance is less than 1 km, free space path loss was used.

For the path loss calculation from the airborne transmitters (heights 1 km and 10 km) to PMSE, the propagation model with ITU-R P.528-3 [32] with a time probability of 50% is chosen, this is very similar to free space path loss within the radio horizon. For the airborne receive height 100 m, the IF-77 algorithm has been used.

For the path loss calculation from PMSE to the aeronautical ground receiver, the propagation model ITU-R P.452-16 [97] has been chosen with a 1%-time probability and a height gain terminal correction for the Audio PMSE device only and assuming a smooth earth. The height gain terminal correction is based on Recommendation ITU-R P.2108-0 ref. Section 3.1. In an urban environment, an additional clutter loss of 22.6 or 22.9 dB is added depending on the height of the PMSE device (1.5 m or 2 m respectively). In rural and open environments, an additional 15.2 or 17.9 dB clutter loss is added depending on the height of the PMSE device (1.5 m or 2 m respectively).

For the path loss calculation from the aeronautical ground-based transmitter to the PMSE, the propagation model with Recommendation ITU-R P.452-16 with a time probability of 50% is chosen, this is the same time probability chosen as with the other modelling which uses the Okumura Hata propagation model.

As noted in CEPT Report 42 (compatibility between UMTS base stations and DME and LDACS):

- “the apportionment is proposed to model that several sources of interferences may occur simultaneously on the DME devices. However, the pre-requisite is that the interferences are contributing in the same order. Otherwise, if one source of interference is predominant and the others are negligible, then the apportionment factor has no longer to be taken into account.”

Aeronautical systems within the band are pulsed systems and PMSE is a continuous signal, therefore the type of interference is different and do not contribute in the same order. In addition, DME assignments are planned and therefore intra-service interference is addressed within the planning criteria, e.g. co-channel desired-to-undesired protection ratio of 8 dB. A further consideration is that PMSE is not an ‘always on’ interferer, with microphones only transmitting for a few hours at a time. Given these conditions, any apportionment factor (if it exists) will be small and therefore has not been considered in this study.

A4.3.1 Calculating interference at different frequency separations

The interference at different frequency separations was calculated considering the Adjacent Channel Interference Ratio, ACIR.

The Adjacent Channel Interference Ratio (ACIR) is defined as the ratio of the power of an adjacent-channel interferer, to the power measured after a receive filter in the adjacent channel and is a result of both transmitter and receiver imperfections.

Adjacent Channel Leakage Ratio (ACLR) of a signal is defined as the ratio of the signal’s power to the power of the signal when measured centred on an adjacent frequency.

Adjacent Channel Selectivity (ACS) is a measurement of a receiver's ability to process a desired signal while rejecting a strong signal in an adjacent frequency channel.

The combination of these two parameters below gives the ACIR:

---

[33] From ITU-R P.528-3 the difference in path loss between the 1200 MHz/50% and 1200 MHz/1% time curves is between 2.4 dB and 23.1 dB depending on separation distance (92% of distances between 0 km and 1,800 km have a difference of path loss >6 dB).

$$ACIR = \frac{1}{\frac{1}{ACLR} + \frac{1}{ACS}}$$

A4.4 DME

A4.4.1 DME parameters

A4.4.1.1 DME transmitter parameters

Table 28: Parameters for DME airborne interrogator

Parameters	Unit	DME airborne	Reference
Transmit frequency	MHz	1025	
Bandwidth	MHz	0.4	Report ITU-R M.2205 [63]
Antenna (aircraft) height	m	100, 1000 and 10000	
Power	dBm	47-54	Report ITU-R M.2205 and RTCA DO-189 [51], Minimum Operational Performance Standards for Airborne Distance Measuring Equipment (DME) Operating within the Frequency Range of 960-1215 MHz.
Minimum cable loss	dB	1	
Antenna gain	dBi	5.4	
Max. e.i.r.p.	dBm	58.4	Calculated
Antenna polarisation	NA	Vertical	
Mask	N/A	(see ICAO Annex 10)	See below

Table 29: Parameters for DME ground transponder

Parameters	Unit	DME ground	Reference
Transmit Frequency	MHz	960	
Bandwidth	MHz	0.4	
Antenna height	m	40, 25, 2.1	

Parameters	Unit	DME ground	Reference
Max. e.i.r.p.	dBm	70	99% of DME ground stations have an e.i.r.p. of 70 dBm or less from COM3 database
Antenna polarisation	N/A	Vertical	
Mask	N/A	(see ICAO Annex 10)	See below

The spectrum emission mask for the transponder and interrogator has been taken from ICAO Annex 10, and can be seen in the below table.

Table 30: DME emission characteristics

Frequency Offset, MHz	DME emission characteristics, dBc	Reference
0	0	see ICAO Annex 10
0.8	23	see ICAO Annex 10
1	25.5	Interpolated
2	38	see ICAO Annex 10
3	80	Spurious level, see ICAO Annex 10, 3.5.4.1.6.1 and 3.5.4.1.6.2

A4.4.1.2 DME receiver parameters

The interference threshold of -99 dBm is taken from EUROCAE ED-54 [49], the minimum operational performance requirements for DME interrogators. From ITU-R Report M.1639 [72] it is shown that for broadband interference the interference threshold of -99 dBm/MHz can be assumed. Therefore, -99 dBm an appropriate interference protection threshold for narrowband audio PMSE is considered.

Table 31: Parameters for DME airborne interrogator

Parameter	Unit	Value	Reference
Receive Frequency	MHz	960	
Antenna gain	dBi	5.4 (maximum)	
Minimum Cable loss	dB	1	
Interference threshold Note 1	dBm	Sensitivity requirement shall be met for: In-band continuous Carrier Wave up to -99 dBm Out-of-band Carrier Wave up to -40 dBm	EUROCAE ED-54 [49]
DME selectivity	dB	See Table below	Report ITU-R M.2205 [63]
Note 1: For broadband interference the interference threshold of -99 dBm/MHz can be assumed (ITU-R M.1639 [72])			

The airborne DME selectivity values have been considered for frequency separations 1 MHz and 2 MHz. Some values have been linearly interpolated from the tabled values given in Report ITU-R M.2205 [63].

Table 32: Values for airborne interrogator DME receiver selectivity

Frequency Offset, MHz	DME interrogator receiver characteristics, dB	Reference
0.9	6	Report ITU-R M.2205
1	15.3	Interpolated
1.05	20	Report ITU-R M.2205
1.3	40	Report ITU-R M.2205
1.5	60	Report ITU-R M.2205
2	63.3	Interpolated
3	70	Report ITU-R M.2205

Table 33 and Table 34 below show parameters for DME ground based transponders. The interference threshold of -106 dBm is derived from ICAO Annex 10 and EUROCAE ED-57 [50], minimum performance specification for DME ground equipment.

ICAO Annex 10 specifies -103 dBW/m2 as the power density at the transponder antenna required to trigger the transponder. This corresponds to -96 dBm at the terminals of the ground antenna. ED-57 states that the required sensitivity level should be calculated (starting from the Annex 10 figure), taking the real antenna gain and cable losses into account.

ED-57 states that the ground DME receiver should provide a reply efficiency greater than 70% in the presence of in-band Carrier Wave with a minimum C/I = 10 dB. As the ground DME RX handles similar signals as an airborne receiver, it should behave the same way in the presence of an interfering Carrier Wave or broadband noise signal. Therefore, we consider -106 dBm an appropriate interference protection threshold for narrowband audio PMSE.

Table 33: Parameters for ground transponder DME

Parameter	Unit	Value	Reference
Receive Frequency	MHz	1025	
Antenna gain	dBi	12 (omni-directional)	http://www.dbsant.com/5100AD7.php
Minimum cable loss	dB	1	
Interference threshold	dBm	-106	ICAO Annex 10 and EUROCAE ED-57 [50]
DME selectivity	dB	See below	ITU-R Report M 2235 [56].

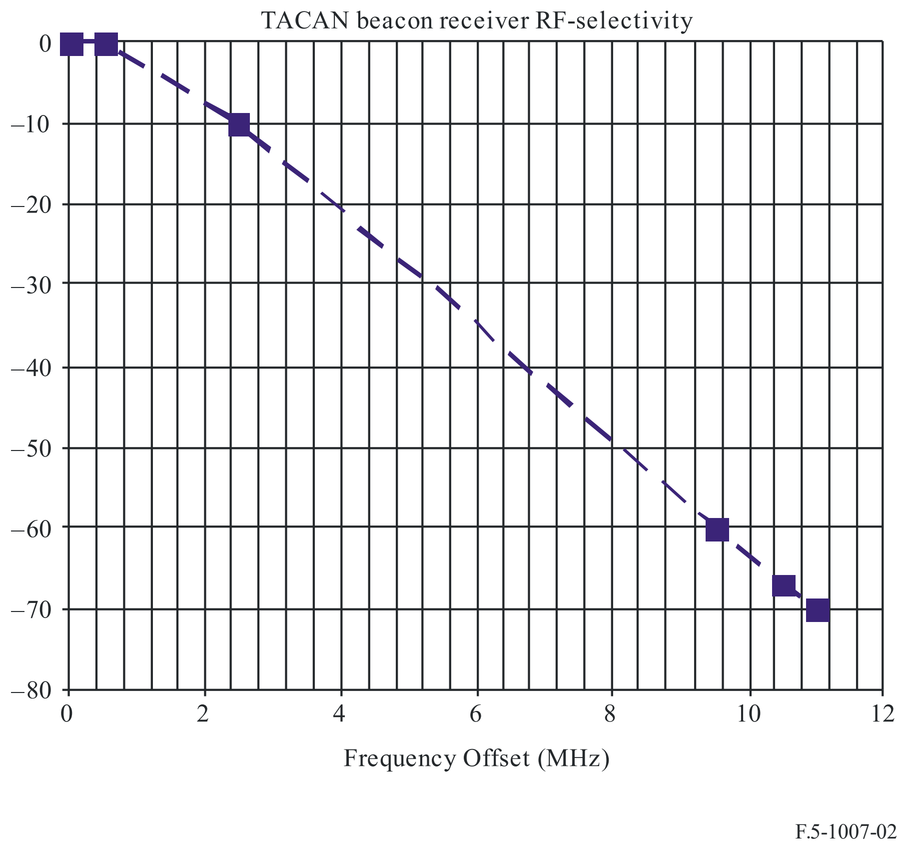


Figure 70: Ground station (beacon) receiver RF selectivity curves

The ground DME selectivity values have been considered for frequency separations 1 MHz and 2 MHz. Some values have been linearly interpolated from the graphed points from the figure above. Measurements taken in the UK suggest that there are significantly better performing DME beacon receivers in practice[34].

Table 34: Values assumed for beacon receiver DME selectivity

Frequency Offset, MHz	Ground station beacon receiver selectivity, dB	Reference
0	0	Recommendation ITU-R M.2013
1	-4.5	Interpolated
2	-9.1	Interpolated
2.2	-10	Recommendation ITU-R M.2013
3	-13.6	Interpolated
9.6	-60	Recommendation ITU-R M.2013

A4.4.2 Modelling assumptions

For full details of modelling approach, see section A4.3. ACIR values for DME are given below.

[34] https://www.ofcom.org.uk/__data/assets/pdf_file/0024/57840/annex6.pdf

Table 35: Values assumed for adjacent channel interference into airborne interrogator DME

Frequency separation from DME centre frequency	0 MHz	1 MHz	2 MHz	3 MHz	Reference
ACLR, dB	0	90	90	90	ECC Report 253 [57] and ETSI EN 300 422 (V1.5.0 /2015-01) [25]
ACS, dB	0	15.3	63.3	70	Report ITU-R M.2205 [63]
ACIR, dB	0	15.3	63.3	70	Calculated

Table 36: Values assumed for adjacent channel interference into ground transponder DME

Frequency separation from DME centre frequency	0 MHz	1 MHz	2 MHz	3 MHz	Reference
ACLR, dB	0	90	90	90	ECC Report 253[57] and ETSI EN 300 422 (V1.5.0 /2015-01)
ACS, dB	0	4.5	9.1	13.6	Recommendation ITU-R M.2013
ACIR, dB	0	4.5	9.1	13.6	Calculated

Table 37: Values assumed for adjacent channel interference into PMSE from DME

Frequency separation from DME centre frequency	0 MHz	1 MHz	2 MHz	3 MHz	Reference
ACLR, dB	0	25.5	38	80	Annex 10 ICAO
ACS, dB	0	74	74	74	ERC Report 63 [70]
ACIR, dB	0	25.5	38	74	Calculated

A4.4.3 Conclusion

A4.4.3.1 Separation distances to protect DME airborne interrogators

Table 38: Co-frequency separation distances to protect airborne interrogator

Parameter	Body-worn	Hand-held	IEM
Tx power	17 dBm	13 dBm	Not considered
Body effect	-6.85 dBi	-4.85 dBi	Not considered
Modelled e.i.r.p	10.15 dBm	8.15 dBm	9 dBm
Building entry loss	0 dB	0 dB	0 dB
PMSE height	1.5 m	1.5 m	2 m
Interference level	-99 dBm		

Parameter	Body-worn	Hand-held	IEM
Antenna gain	Gmax= 5.4 dBi		
Cable loss	1 dB		
Polarisation discrimination	0 dB		
Clutter loss	0 dB		
Path loss to meet the protection criterion	113.55 dB	111.55 dB	112.4 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	8.8 km	7.9 km	9.5 km
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	22.6 km	18.9 km	20.6 km
Separation distances in the main lobe of aircraft antenna at altitude of 10 km	22.7 km	16.3 km	18.8 km

Table 39: Separation distances to protect airborne interrogator at 1 MHz frequency separation

Parameter	Body-worn	Hand-held	IEM
ACIR	15.3		
Path loss to meet the protection criterion	98.25 dB	96.25 dB	97.1 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	3.3 km	2.9 km	3.5 km
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	4.3 km	3.3 km	3.7 km
Separation distances in the main lobe of aircraft antenna at altitude of 10 km	N/A	N/A	N/A

Table 40: Separation distances to protect airborne interrogator at 2 MHz frequency separation

Parameter	Body-worn	Hand-held	IEM
ACIR	63.3		
Path loss to meet the protection criterion	50.25 dB	48.25 dB	49.1 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	N/A		

Parameter	Body-worn	Hand-held	IEM
Separation distances in the main lobe of aircraft antenna at altitude of 1 km			
Separation distances in the main lobe of aircraft antenna at altitude of 10 km			

A4.4.3.2 Separation distances to protect DME ground transponders

Table 41: Co-frequency separation distances to DME ground transponder

Parameter	Body-worn	Hand-held	IEM
Tx power	17 dBm	13 dBm	Not considered
Body effect	-6.85 dBi	-4.85 dBi	Not considered
Modelled e.i.r.p.	10.15 dBm	8.15 dBm	9 dBm
Building entry loss [Outdoor Open environment / Indoor Urban environment]	0 dB; 10 dB		
PMSE height	1.5 m	1.5 m	2 m
Interference level	-106 dBm		
Antenna	Gmax= 12 dBi		
Cable loss	1 dB		
Polarisation discrimination	0 dB		
Clutter loss (rural/urban)	17.9 dB; 22.9 dB	17.9 dB; 22.9 dB	15.2 dB; 22.6 dB
Path loss to meet the protection criterion	109.25 dB; 94.25 dB	107.25 dB; 92.25 dB	110.8 dB; 93.4 dB
Separation distances in the main lobe of DME at 40 m	4.6 km; 1.3 km	4.1 km; 1.0 km	5.9 km; 1.1 km
Separation distances in the main lobe of DME at 25 m	3.6 km; 1.3 km	3.2 km; 1.0 km	4.6 km; 1.1 km
Separation distances in the main lobe of DME at 2.1 m	1.1 km; 0.4 km	0.9 km; 0.4 km	1.4 km; 0.5 km

Table 42: Separation distances to protect DME ground transponder at 1 MHz frequency separation

Parameter	Body-worn	Hand-held	IEM
ACIR	4.5 dB		
Path loss to meet the protection criterion	104.75 dB; 89.75 dB	102.75 dB; 87.75 dB	106.3 dB; 88.9 dB

Parameter	Body-worn	Hand-held	IEM
Separation distances in the main lobe of DME at 40 m	3.5 km; 0.7 km	3.1 km; 0.6 km	4.5 km; 0.7 km
Separation distances in the main lobe of DME at 25 m	2.7 km; 0.7 km	2.4 km; 0.6 km	3.5 km; 0.7 km
Separation distances in the main lobe of DME at 2.1 m	0.8 km; 0.3 km	0.7 km; 0.3 km	1.0 km; 0.4 km

Table 43: Separation distances to protect DME ground transponder at 2 MHz frequency separation

Parameter	Body-worn	Hand-held	IEM
ACIR	9.1 dB		
Path loss to meet the protection criterion	100.15 dB; 85.15 dB	98.15 dB; 83.15 dB	101.7 dB; 84.3 dB
Separation distances in the main lobe of DME at 40 m	2.7 km; 0.4 km	2.1 km; 0.3 km	3.2 km; 0.4 km
Separation distances in the main lobe of DME at 25 m	2.1 km; 0.4 km	1.8 km; 0.3 km	2.7 km; 0.4 km
Separation distances in the main lobe of DME at 2.1 m	0.6 km; 0.2 km	0.5 km; 0.2 km	0.8 km; 0.3 km

A4.4.3.3 Separation distances to protect PMSE from airborne interrogators

Table 44: Co-frequency separation distances to protect PMSE

Parameter	Body-worn/Hand-held	IEM
e.i.r.p	58.4	
Reduction in e.i.r.p. due to bandwidth mismatch	3 dB	
Body effect	Not modelled	-6.85 dBi
Building entry loss	0 dB	0 dB
PMSE receive height	2 m	1.5 m
Interference level	-81 dBm	
Antenna gain	0 dB	Not modelled
Polarisation discrimination	0 dB	
Clutter loss	0 dB	
Path loss to meet the protection criterion	136.4 dB	129.55 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	28.4 km	19.4 km

Parameter	Body-worn/Hand-held	IEM
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	81.0 km	58.0 km
Separation distances in the main lobe of aircraft antenna at altitude of 10 km	149.5 km	68.2 km

Table 45: Separation distances to PMSE at 1 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	25.5 dB	
Path loss to meet the protection criterion	110.9 dB	104.05 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	8.0 km	3.9 km
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	8.1 km	3.6 km
Separation distances in the main lobe of aircraft antenna at altitude of 10 km	N/A	

Table 46: Separation distances to PMSE at 2 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	38 dB	
Path loss to meet the protection criterion	98.4 dB	91.55 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	2.0 km	< 1km
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	N/A	
Separation distances in the main lobe of aircraft antenna at altitude of 10 km		

Table 47: Separation distances to PMSE at 3 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	74 dB	
Path loss to meet the protection criterion	62.4 dB	55.55 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	N/A	

Parameter	Body-worn/Hand-held	IEM
Separation distances in the main lobe of aircraft antenna at altitude of 1 km		
Separation distances in the main lobe of aircraft antenna at altitude of 10 km		

A4.4.3.4 Separation distances to protect PMSE from DME ground transponders

Table 48: Co-frequency separation distances to protect PMSE

Parameter	Body-worn/Hand-held	IEM
e.i.r.p	70 dBm	
Reduction in e.i.r.p. due to bandwidth mismatch	3 dB	
Body effect	Not modelled	-6.85 dBi
Building entry loss	0 dB; 10 dB	
PMSE receive height	2 m	1.5 m
Interference level	-81 dBm	
Antenna gain	0 dB	Not modelled
Polarisation discrimination	0 dB	
Clutter loss	15.2 dB; 22.6 dB	17.9 dB; 22.9 dB
Path loss to meet the protection criterion	132.8 dB; 115.4 dB	123.25 dB; 108.25 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	17.2 km; 6.8 km	9.1 km; 3.9 km
Separation distances in the main lobe aircraft antenna at altitude of at 1 km	13.8 km; 5.5 km	7.3 km; 3.2 km
Separation distances in the main lobe aircraft antenna at altitude of at 10 km	4.7 km; 1.4 km	2.4 km; 1.0 km

Table 49: Separation distances to protect PMSE at 1 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	25.5 dB	
Path loss to meet the protection criterion	107.3 dB; 89.9 dB	97.75 dB; 82.75 dB
Separation distances in the main lobe of DME at 40 m	4.4 km; 0.8 km	1.9 km; 0.3 km
Separation distances in the main lobe of DME at 25 m	3.5 km; 0.8 km	1.7 km; 0.3 km
Separation distances in the main lobe of DME at 2.1 m	1.1 km; 0.4 km	0.7 km; 0.2 km

Table 50: Separation distances to protect PMSE at 2 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	38 dB	
Path loss to meet the protection criterion	94.8 dB; 77.4 dB	85.25 dB; 70.25 dB
Separation distances in the main lobe of DME at 40 m	1.4 km; 0.2 km	0.5 km; N/A
Separation distances in the main lobe of DME at 25 m	1.0 km; 0.2 km	0.5 km; N/A
Separation distances in the main lobe of DME at 2.1 m	0.5 km; 0.2 km	0.3 km; N/A

Table 51: Separation distances to protect PMSE at 3 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	74 dB	
Separation distances in the main lobe of DME at 40 m	N/A	
Separation distances in the main lobe of DME at 25 m		
Separation distances in the main lobe of DME at 2.1 m		

A4.5 SSR – 1030 MHZ AND 1090 SYSTEMS

A4.5.1 SSR 1030 MHz and 1090 MHz parameters

A4.5.1.1 SSR 1030 MHz and 1090 MHz transmitter parameters

Table 52: Transmitter characteristics of SSR airborne transponder

Parameters	Unit	SSR airborne Transponder	Reference
Transmit Frequency	MHz	1090	(RTCA DO-181 §2.2.3.1)
Bandwidth	MHz	4.5 MHz (Mode A and C) 2.3 MHz (Mode S)	Report ITU-R M.2205 [63]
Tx Power	dBm	57 dBm (peak)	(RTCA DO-181 §2.2.3.2) and Report ITU-R M.2205
Cable loss	dB	3	Manual on the Secondary Surveillance Radar (SSR) Systems, ICAO[35]
Antenna gain	dBi	2.8	http://antennaassociates.com/datasheets.php
OOB	N/A	See below	ICAO Annex 10 Vol IV [45], fig. 3.5

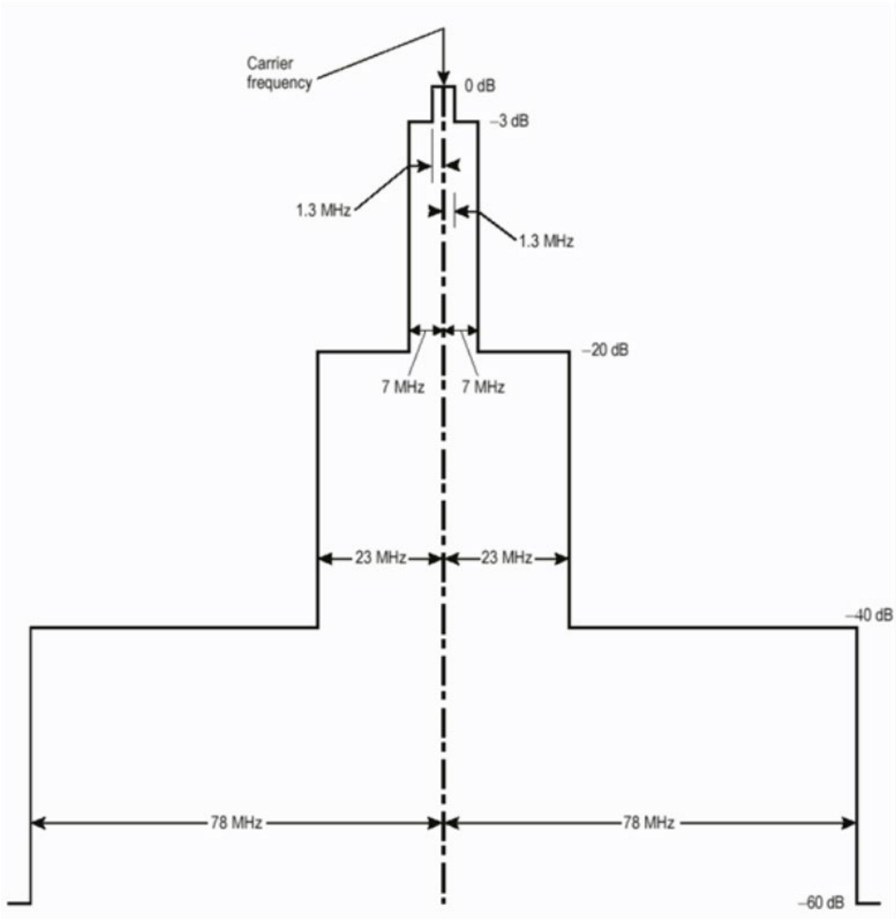


Figure 71: Out-of-band emissions of SSR airborne transponder

[35] http://dgca.gov.in/intradgca/intra/icaodocs/Doc%209684%20-%20Manual%20on%20the%20Secondary%20Surveillance%20Radar%20(SSR)%20Systems%20Ed%203%20Amd%201%20(En).pdf

Table 53: Transmitter characteristics of SSR ground interrogator

Parameters	Unit	SSR ground radar	Reference
Frequency range	MHz	1030	ICAO Annexe 10 Vol4 §3.1.1.1.1
Tx Power (peak)	dBm	62	L-band interference scenarios characterisation, Eurocontrol [88]
Cable loss	dB	3	Compatibility criteria and interference scenarios for SSR systems, Eurocontrol [89] ED-43 §3.2.4.2 [48]
Antenna gain	dBi	27 (max)	https://www.nec.com/en/global/solutions/cns-atm/surveillance/ssr.html
Side lobe gain	dBi	2	https://www.nec.com/en/global/solutions/cns-atm/surveillance/ssr.html and [90].
OOB	N/A	See below	ICAO Annex 10 Vol IV [45], Figure3.2

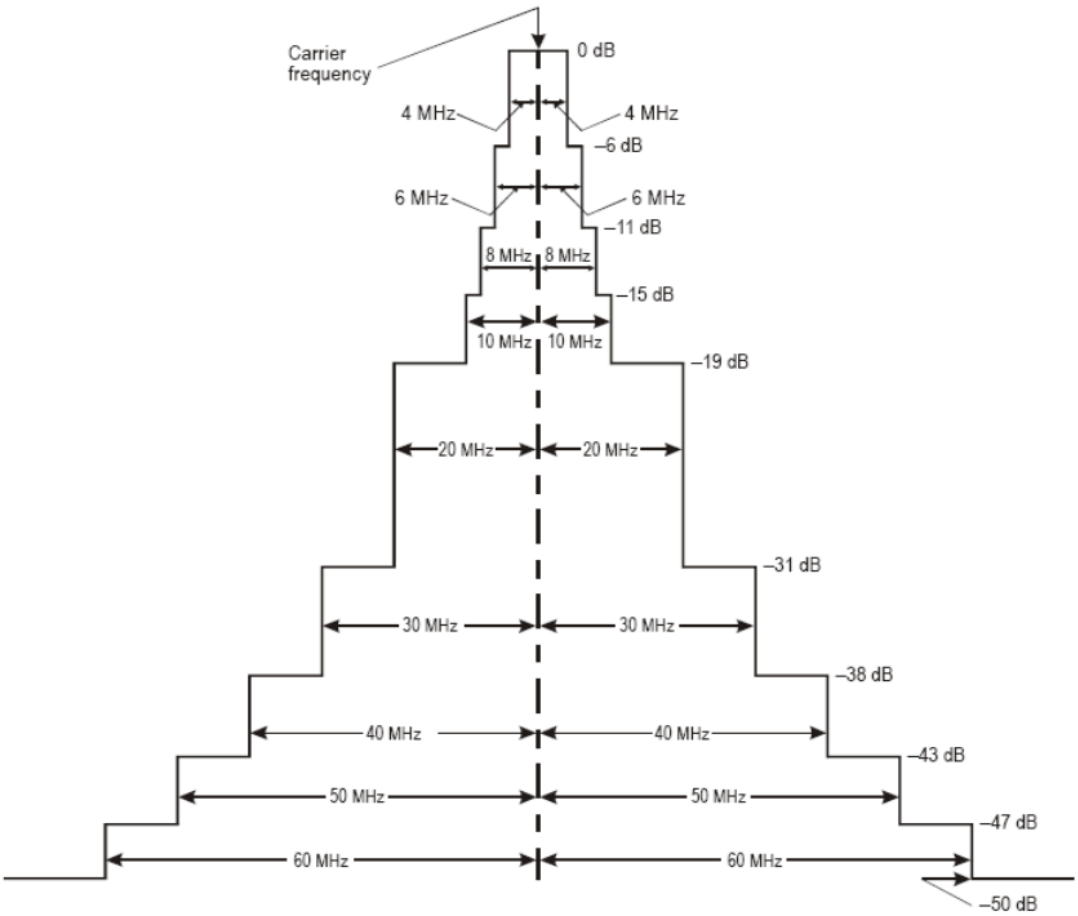


Figure 72: Out-of-band emissions of SSR interrogator ground station

A4.5.1.2 SSR 1030 MHz and 1090 MHz receiver parameters

The value of C/I of 20 dB has been used in our calculations to protect both the transponder and the interrogator from potential PMSE interference. RTCA DO-181C states that the transponder shall reply correctly to at least 90 percent of the interrogations in the presence of non-coherent Continuous Wave interference at signal levels of 20 dB or more below the desired Mode A/C or Mode S interrogation signal level.

The receiver sensitivity of airborne SSR transponders is given as -74 dBm ± 3dB and -73 dBm ± 3dB in Report ITU-R M.2205 [63]. The maximum interference into the transponder receiver is calculated by taking the most conservative value suggested -77 dBm and -20 dB.

The receiver sensitivity of the ground interrogator is given as -90dBm. The maximum interference into the interrogator receiver is calculated by taking -90 dBm considering the C/I of 20 dB.

Table 54: Parameters for SSR airborne transponder receiver

Parameter	Unit	Value	Reference
Receiver Frequency	MHz	1030	
Antenna (aircraft) height	m	100, 1000, 10000	
Antenna gain	dBi	2.8	http://antennaassociates.com/datasheets.php
Antenna polarisation	N/A	Vertical	
Sensitivity	dBm	-77	Worst-case example in Report ITU-R M.2205
Protection criteria, C/I	dB	20	RTCA DO-181C Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/Mode Select (ATCRB/Mode S) Airborne Equipment Compatibility criteria and interference scenarios for SSR systems, Eurocontrol
Cable loss	dB	3	Compatibility criteria and interference scenarios for SSR systems, Eurocontrol[36] ED-43 §3.2.4.2 [48]
Interference threshold	dBm	-97	Calculated
SSR selectivity	dB	See below	Report ITU-R M.2205 and RTCA DO-181C

The airborne SSR selectivity values have been considered for frequency separations 10 MHz and 15 MHz. Some values have been linearly interpolated from the tabled values given in Report ITU-R M.2205.

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Table 55: Values for airborne SSR transponder receiver selectivity

Frequency Offset, MHz	SSR transponder receiver characteristics, dB	Reference
3	3	Report ITU-R M.2205 [63] and RTCA DO-181C
10	24.6	Interpolated
15	40	Report ITU-R M.2205 and RTCA DO-181C

The receiver performance figures for SSR are detailed below.

Table 56: Parameters for ground interrogator SSR receiver

Parameter	Unit	Value	Reference
Receiver frequency	MHz	1090	
Antenna height	M	2.1, 25, 40	
Antenna gain	dBi	27 (max)	https://www.nec.com/en/global/solutions/cns-atm/surveillance/ssr.html
Antenna side lobe gain	dBi	2	-25 dB to -30 dB off peak power, [91] and [92]
Cable loss	dB	3	Compatibility criteria and interference scenarios for SSR systems, Eurocontrol [93] ED-43 §3.2.4.2 [48] Manual on the Secondary Surveillance Radar (SSR) Systems, ICAO [94]
Antenna polarisation	N/A	Vertical	
Sensitivity	dBm	-90	Compatibility criteria and interference scenarios for SSR systems, Eurocontrol
Protection criteria, C/I	dB	20	Assumed same C/I for Continuous Wave like interference as transponder
Sensitivity	dBm	-90	Compatibility criteria and interference scenarios for SSR systems, Eurocontrol
Protection criteria, C/I	dB	20	Assumed same C/I for CW like interference as transponder.
Interference threshold	dBm	-110	Calculated
SSR selectivity	dB	See below	

The antenna side lobe gain has been used for the calculations of the SSR interrogator as it is assumed the geometry of an SSR interrogator will be pointing towards an aircraft in the air. The side lobe antenna gain is typically 25 to 30 dB off the main gain, we have chosen the lower value 25 dB for our modelling.

The ground SSR interrogator selectivity values have been taken from the values given in Report ITU-R M.2205 [63] for the transponder. In the UK, we previously have measured the SSR characteristics [95] and the values given within Report ITU-R M.2205 for the transponder are also a good fit for the interrogator.

Table 57: Values for airborne SSR interrogator receiver selectivity

Frequency Offset, MHz	SSR interrogator receiver characteristics, dB	Reference
3	3	Report ITU-R M.2205 and RTCA DO-181C
10	24.6	Interpolated
15	40	Report ITU-R M.2205 and RTCA DO-181C

A4.5.2 Modelling assumptions

For full details of modelling approach, see section 3. ACIR values for SSR (1030 MHz and 1090 MHz systems) are given below.

Table 58: Values assumed for adjacent channel interference into SSR

Frequency separation from SSR centre frequency	0 MHz	3 MHz	10 MHz	15 MHz	Reference
ACLR, dB	0	90	90	90	ECC Report 253 [57] and ETSI EN 300 422 [25]
ACS, dB	0	3	24.6	40	Report ITU-R M.2205
ACIR, dB	0	3	24.6	40	Calculated

Table 59: Values assumed for adjacent channel interference into PMSE from SSR airborne transponder

Frequency separation from SSR centre frequency	0 MHz	7 to 10 MHz	23 MHz	Reference
ACLR, dB	0	20	40	ICAO Annex 10 Vol IV [45], fig. 3.5
ACS, dB	0	74	74	ERC Report 63 [70]
ACIR, dB	0	20	40	Calculated

Table 60: Values assumed for adjacent channel interference into PMSE from SSR ground interrogator

Frequency separation from SSR centre frequency	0 MHz	10 MHz	20 MHz	Reference
ACLR, dB	0	15	19	ICAO Annex 10 Vol IV, Figure 3.2
ACS, dB	0	74	74	

Frequency separation from SSR centre frequency	0 MHz	10 MHz	20 MHz	Reference
ACIR, dB	0	15	19	Calculated

A4.5.3 Conclusion

A4.5.3.1 Separation distances to protect SSR airborne transponders

Table 61: Co-frequency separation distances to protect airborne transponder

Parameter	Body-worn	Hand-held	IEM
Tx power	17 dBm	13 dBm	Not considered
Body effect	-6.85 dBi	-4.85 dBi	Not considered
Modelled e.i.r.p	10.15 dBm	8.15 dBm	9 dBm
Building entry loss	0 dB;	0 dB;	0 dB;
PMSE height	1.5 m	1.5 m	2 m
Interference level	-97 dBm		
Antenna gain	2.8 dB		
Cable loss	3 dB		
Polarisation discrimination	0 dB	0 dB	0 dB
Clutter loss	0 dB	0 dB	0 dB
Path loss to meet the protection criterion	106.95 dB	104.95 dB	105.8 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	6.0 km	5.0 km	5.9 km
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	11.3 km	8.8 km	9.9 km
Separation distances in the main lobe of aircraft antenna at altitude of 10 km	N/A	N/A	N/A

Table 62: Separation distances to protect airborne transponder at 10 MHz frequency separation

Parameter	Body-worn	Hand-held	IEM
ACIR	24.6 dB		
Path loss to meet the protection criterion	82.35 dB	80.35 dB	81.2 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	0.3 km	0.2 km	0.3 km

Parameter	Body-worn	Hand-held	IEM
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	N/A		
Separation distances in the main lobe of aircraft antenna at altitude of 10 km			

Table 63: Separation distances to protect airborne transponder at 15 MHz frequency separation

Parameter	Body-worn	Hand-held	IEM
ACIR	40		
Path loss to meet the protection criterion	66.95 dB	64.95 dB	65.8 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	N/A		
Separation distances in the main lobe of aircraft antenna at altitude of 1 km			
Separation distances in the main lobe of aircraft antenna at altitude of 10 km			

A4.5.3.2 Separation distances to protect SSR ground interrogators

Table 64: Co-frequency separation distances to SSR ground interrogators

Parameter	Body-worn	Hand-held	IEM
Tx power	17 dBm	13 dBm	Not considered
Body effect	-6.85 dBi	-4.85 dBi	Not considered
Modelled e.i.r.p	10.15 dBm	8.15 dBm	9 dBm
Building entry loss [Outdoor Open environment / Indoor Urban environment]	0 dB; 10 dB		
PMSE height	1.5 m	1.5 m	2 m
Interference level	-110 dBm		
Antenna gain towards horizon	2 dBi		
Cable loss	3 dB		
Polarisation discrimination	0 dB		
Clutter loss (rural/urban)	17.9 dB; 22.9 dB	17.9 dB; 22.9 dB	15.2 dB; 22.6 dB

Parameter	Body-worn	Hand-held	IEM
Path loss to meet the protection criterion	103.25 dB; 88.25 dB	101.25 dB; 86.25 dB	104.8 dB; 87.4 dB
Separation distances to SSR at 40 m	3.2 km; 0.6 km	2.8 km; 0.5 km	4.1 km; 0.5 km
Separation distances to SSR at 25 m	2.5 km; 0.6 km	2.2 km; 0.5 km	3.2 km; 0.5 km
Separation distances to SSR at 2.1 m	0.7 km; 0.3 km	0.7 km; 0.3 km	0.9 km; 0.3 km

Table 65: Separation distances to protect SSR ground interrogator at 10 MHz frequency separation

Parameter	Body-worn	Hand-held	IEM
ACIR	24.6		
Path loss to meet the protection criterion	78.65 dB; 63.65 dB	76.65 dB; 61.65 dB	80.2 dB; 62.8 dB
Separation distances to SSR at 40 m	0.2 km; N/A	0.2 km; N/A	0.2 km; N/A
Separation distances to SSR at 25 m	0.2 km; N/A	0.2 km; N/A	0.2 km; N/A
Separation distances to SSR at 2.1 m	0.2 km; N/A	0.2 km; N/A	0.2 km; N/A

Table 66: Separation distances to protect SSR ground interrogator at 15 MHz frequency separation

Parameter	Body-worn	Hand-held	IEM
ACIR	40		
Path loss to meet the protection criterion	63.25 dB; 48.25 dB	61.25 dB; 46.25 dB	64.8 dB; 47.4 dB
Separation distances to SSR at 40 m	N/A		
Separation distances to SSR at 25 m			
Separation distances to SSR at 2.1 m			

A4.5.3.3 Separation distances to protect PMSE from SSR airborne transponders

Table 67: Co-frequency separation distances to protect PMSE

Parameter	Body-worn/Hand-held	IEM
e.i.r.p	56.8 dBm	

Parameter	Body-worn/Hand-held	IEM
Reduction in e.i.r.p. due to bandwidth mismatch	13.5 dB [37]	
Body effect	Not modelled	-6.85 dBi
Building entry loss	0 dB	
PMSE receive height	2 m	1.5 m
Interference level	-81 dBm	
Antenna gain	0 dB	Not modelled
Polarisation discrimination	0 dB	
Clutter loss	0 dB	
Path loss to meet the protection criterion	124.3 dB	117.45 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	16.5 km	10.2 km
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	35.3 km	13.4 km
Separation distances in the main lobe of aircraft antenna at altitude of 10 km	34.5 km	12.7 km

Table 68: Separation distances to PMSE at 7 to 10 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	20 dB	
Path loss to meet the protection criterion	104.3 dB	97.45 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	3.6 km	1.7 km
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	3.4 km	1.3 km
Separation distances in the main lobe of aircraft antenna at altitude of 10 km	N/A	

Table 69: Separation distances to PMSE at 23 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	40 dB	
Path loss to meet the protection criterion	84.3 dB	77.45 dB
Separation distances in the main lobe of aircraft antenna at altitude of 100 m	0.4 km	0.2 km

[37] Assuming that the power is over 4.5 MHz bandwidth.

Parameter	Body-worn/Hand-held	IEM
Separation distances in the main lobe of aircraft antenna at altitude of 1 km	N/A	
Separation distances in the main lobe of aircraft antenna at altitude of 10 km		

A4.5.3.4 Separation distances to protect PMSE from SSR ground interrogators

Table 70: Co-frequency separation distances to protect PMSE

Parameter	Body-worn/Hand-held	IEM
e.i.r.p	61 dBm	
Reduction in e.i.r.p. due to bandwidth mismatch	13.5 dB[38]	
Body loss	Not modelled	-6.85 dBi
Building entry loss [Outdoor Open environment / Indoor Urban environment]	0 dB; 10 dB	
PMSE receive height	2 m	1.5 m
Interference level	-81 dBm	
Antenna gain	0 dB	Not modelled
Polarisation discrimination	0 dB	
Clutter loss (rural/urban)	15.2 dB; 22.6 dB	17.9 dB; 22.9dB
Path loss to meet the protection criterion	113.3 dB; 95.9 dB	103.75 dB; 88.75 dB
Separation distances in the main lobe of SSR at 40 m	6.1 km; 1.4 km	3.0 km; 0.7 km
Separation distances in the main lobe of SSR at 25 m	4.9 km; 1.4 km	2.2 km; 0.6 km
Separation distances in the main lobe of SSR at 2.1 m	1.5 km; 0.5 km	0.8 km; 0.3 km

Table 71: Separation distances to protect PMSE at 10 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	15 dB	
Path loss to meet the protection criterion	98.3 dB; 80.9 dB	88.75 dB; 73.75 dB
Separation distances in the main lobe of SSR at 40 m	1.9 km; 0.3 km	0.7 km; 0.1 km

[38] Assuming the same reduction as the transponder.

Parameter	Body-worn/Hand-held	IEM
Separation distances in the main lobe of SSR at 25 m	1.9 km; 0.3 km	0.6 km; 0.1 km
Separation distances in the main lobe of SSR at 2.1 m	0.6 km; 0.2 km	0.3 km; 0.1 km

Table 72: Separation distances to protect PMSE at 20 MHz frequency separation

Parameter	Body-worn/Hand-held	IEM
ACIR	19 dB	
Path loss to meet the protection criterion	94.3 dB; 76.9 dB	84.75 dB; 69.75 dB
Separation distances in the main lobe of SSR at 40 m	1.2 km; 0.2 km	0.4 km; N/A
Separation distances in the main lobe of SSR at 25 m	1.2 km; 0.2 km	0.4 km; N/A
Separation distances in the main lobe of SSR at 2.1 m	0.5 km; 0.2 km	0.2 km; N/A

A4.6 UNIVERSAL ACCESS TRANSCEIVER (UAT)

Not studied

A4.7 CNPC

Not studied

A4.8 LDACS

Not studied

A4.9 JTIDS/MIDS

Not studied.

A4.10 GNSS

A4.10.1 Parameters

A4.10.1.1 PMSE parameters

This study only considers body-worn PMSE as the worst-case scenario. The PMSE parameters in this study are provided in the table below.

Table 73: Parameters for body-worn audio PMSE

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253 [57]
Antenna transmit height	m	1.5	ECC Report 253
Antenna receive height	m	2	
e.i.r.p.	dMm	17	ECC Report 253
Body effect	dBi	-7.25 (@ 1154 MHz)	ECC Report 286 [27]
Modelled e.i.r.p	dBm	9.75	ECC Report 253 and ERC/REC 70-03, Annex 10 [28]
Antenna polarisation	NA	Vertical	ECC Report 253

A4.10.1.2 GNSS parameters

The parameters for the protection criteria have been taken from Table 2-1 of ITU-R Recommendation M.1905, Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1164-1215 MHz.

The interference thresholds assumed are those given for acquisition mode threshold power level of aggregate narrowband interference at the passive antenna output for air navigation receiver 1 and the general purpose receiver as defined in Table 2-1. Note 6 to the table states:

- The continuous RFI threshold value applies to airborne receiver operations above 6096 m (20000 feet) altitude above MSL. The acquisition mode values for airborne operations below 610 m (2000 feet) altitude above ground are -143.1 dBW (narrow-band) and -133.1 dB(W/MHz) (wideband)

Three GNSS receiver masks were considered. Two are from ITU-Report M.2235 Aeronautical mobile (route) service sharing studies in the frequency band 960-1164 MHz [56]:

- non pulsed interference levels at the aeronautical radionavigation satellite receiver antenna port (Figure 8 of Report ITU-R M.2235);
- relative non pulsed interference attenuation referenced to the non-aeronautical high-precision (Figure 9 of Report ITU-R M.2235).

In addition to the two receiver masks from ITU-R M.2235, a further mask from Characterization of L5 receiver performance using digital pulse blanking. In: Proceedings of the ION GPS-2002. 2002.[99] Figure 3 of the "Characterization of L5 Receiver Performance Using Digital Pulse Blanking" has been used in the study (see Figure 76).

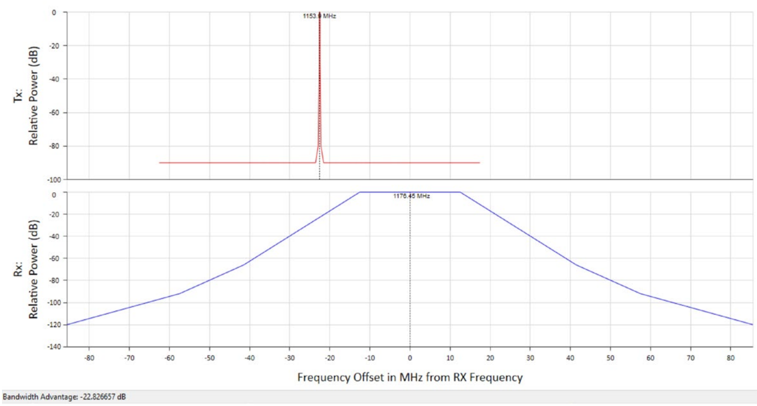


Figure 73: GNSS receiver mask (Figure 9 of Report ITU-R M.2235)

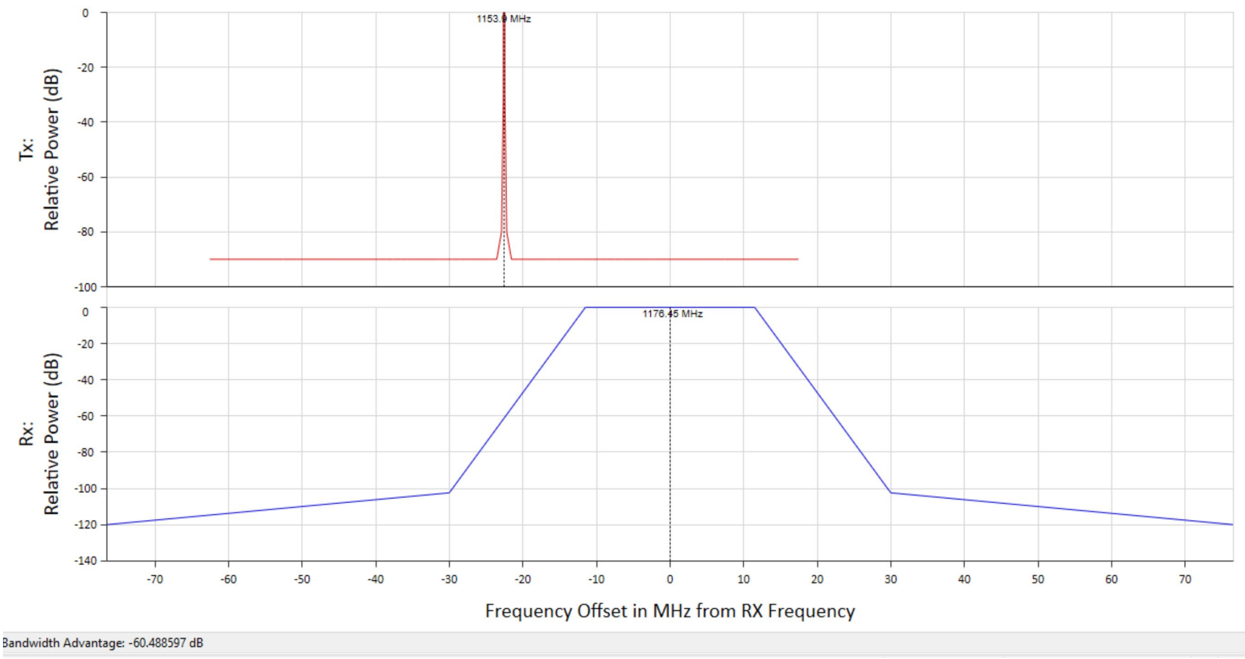


Figure 74: GNSS receiver mask (Figure 8 of Report ITU-R M.2235)

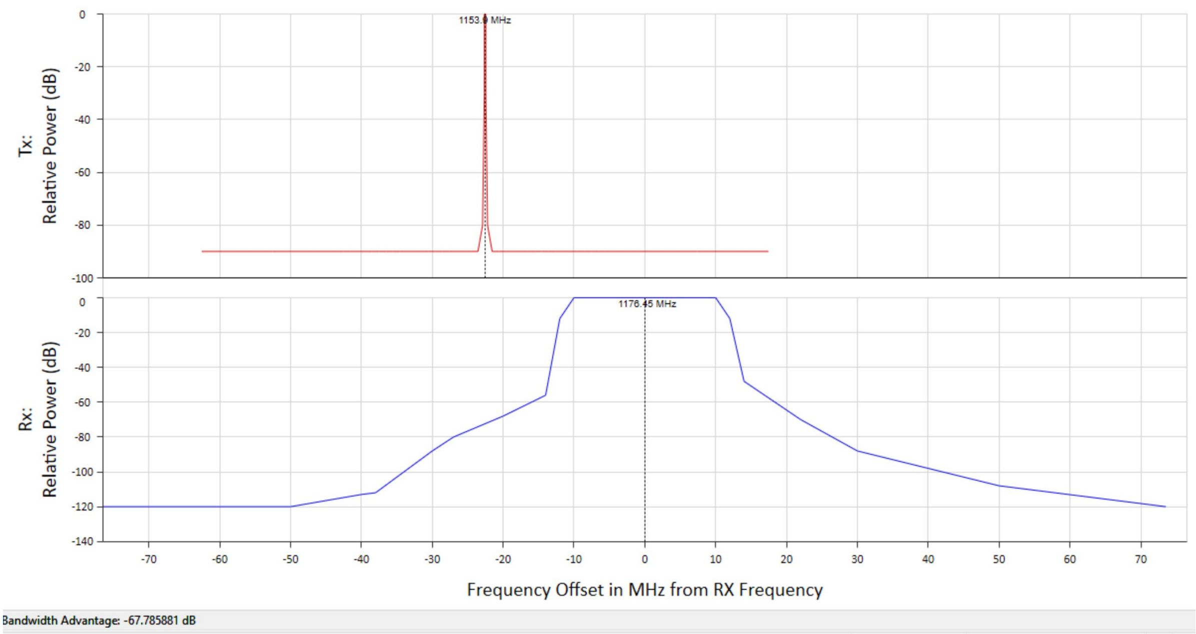


Figure 75: GNSS receiver mask (Figure 3 of Characterisation of L5 Receiver Performance Using Digital Pulse Blanking [99])

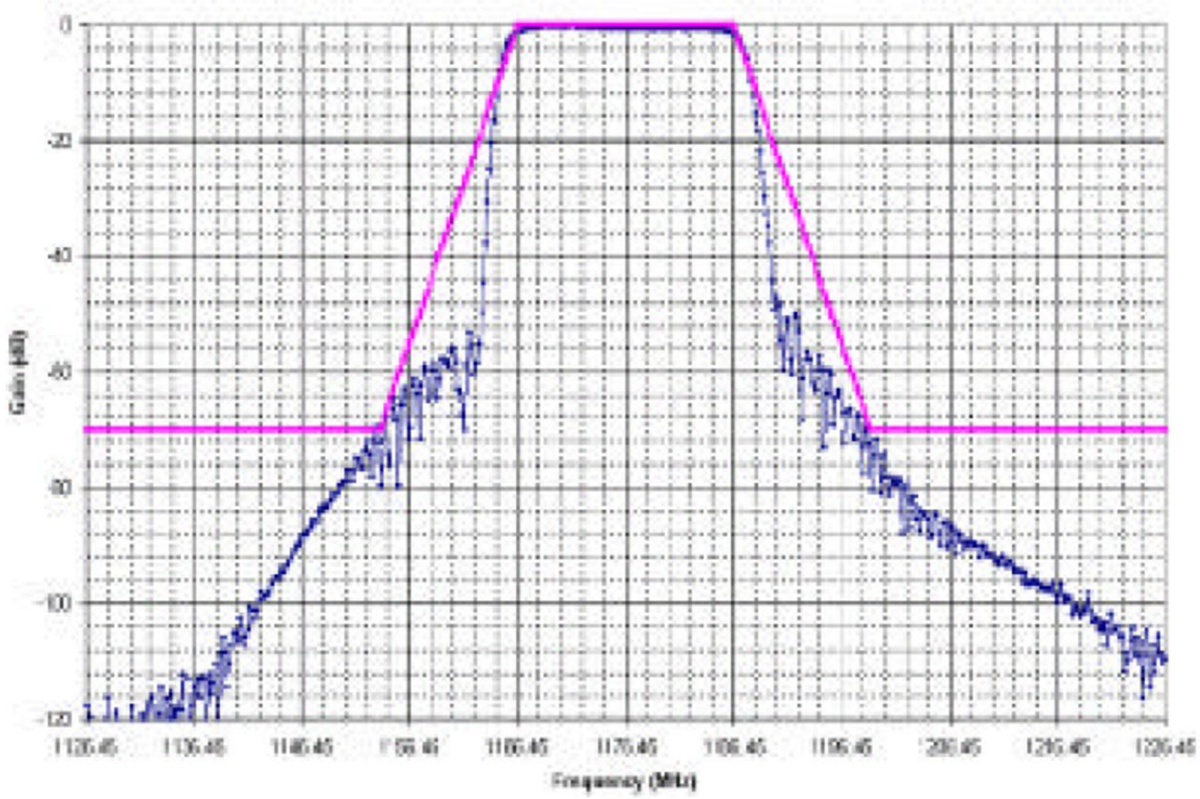


Figure 76: Characterisation of L5 Receiver Performance Using Digital Pulse Blanking [99]

A4.10.2 Modelling assumptions

Table 74: Modelling assumptions

Parameter	Unit	Value	Reference
Frequency	MHz	1154 MHz	Assuming 10 MHz guard band to protect GNSS above 1164 MHz
Number of PMSE interferers		5	
Safety margin	dB	6	Only in the aeronautical case
Interference threshold (aero)	dBW	-149.1 (incl. safety margin)	Recommendation ITU-R M.1905
Interference threshold (general purpose)	dBW	-156	Recommendation ITU-R M.1905
Antenna gain (aero)	dBi	-10	Recommendation ITU-R M.1905 for angles below -30°
Antenna gain (general)	dBi	-10	Recommendation ITU-R M.1905
Polarisation discrimination	dB	3 (for aero only)	GNSS signals are circularly polarised whereas PMSE is linearly polarised. Only applied in aero case as receive antenna is free from clutter

Parameter	Unit	Value	Reference
Building loss	dB	0	Only outdoor PMSE studied
Clutter loss (rural)	dB	17.9	Only rural considered as worst-case scenario

A4.10.3 Conclusion

Table 75: Separation distances for outdoor PMSE to airborne GNSS

Separation distances for outdoor PMSE to airborne GNSS	
Report ITU-R M.2235 [56] Figure 9 receiver mask	930 m
Report ITU-R M.2235 Figure 8 receiver mask	22 m
Mask GPS L5 real receiver mask	13 m

Table 76: Separation distances for outdoor PMSE to general purpose GNSS

Separation distances for outdoor PMSE to general purpose GNSS	
Report ITU-R M.2235 Figure 9 receiver mask	698 m
Report ITU-R M.2235 Figure 8 receiver mask	8 m
Mask GPS L5 real receiver mask	4 m

A4.11 OTHER SYSTEMS

- Not studied.

ANNEX 5: IMPACT OF PMSE ON DME FROM BNETZA

A5.1 SUMMARY

A MCL sharing study has been performed on audio PMSE interfere the co-frequency DME equipment.

For Line of Sight (LoS) configuration, the free space model can be used. For Non LoS (NLoS) other models are more appropriate. The time probability is relevant for long radio paths (e.g. >100 km) but could be neglected for short radio paths and low antenna height of the wireless microphone. A general assumption in the study is the "smooth earth model"; therefore no terrain information and relative antenna heights were used in the study. The radio horizon was considered. Further the common safety margins for aeronautical services and TACAN systems were not taken into account. The flight orientation was not taken into account.

The protection criteria used in this study are based on interference thresholds.

This is a minimum coupling loss analysis. There are margins because some of the assumptions, e.g. on the penetration loss or clutter loss, are very conservative. In reality these losses will be higher. The polarization loss was not considered. The elevation antenna patterns are not taken into account, the maximum gain was used. Any probabilities that the antennas are pointing to each other with the maximum in azimuth and elevation are not considered (e.g. the flight orientation). Under these assumptions the conclusion is as follows: If the audio PMSE will be used in densely built-up areas (cities) and/or indoor, no interferences are likely to occur. Audio PMSE should not be used in a Radio Line of Sight and an open area of at least 3 km around the ground DME station. The required protection distance between audio PMSE used in a large open area and the airborne DME receiver depends on flight altitude and could reach up to 63 km - see summary table 30.

An effective mitigation technique is the selection of adjacent frequencies and not the co-frequency band. If the PMSE carrier is 500 kHz away from DME carrier, the Carrier-to-Interference ratio can be as low as -27 dB. This has been determined in the measurement campaign with DFS Germany, see in A10.6.5 and the figure 123 and table 131. In this case, a smaller separation distance is necessary to ensure the compatibility.

The Radionavigation Service in the frequency band 960-1164 MHz is a safety-of-life service. The full protection of these radio systems has to be ensured. Before accepting other radio applications in that band, e.g. low power audio PMSE, very careful compatibility and sharing studies with conservative assumptions and protection criteria have to be performed to determine the technical condition for new radio application while ensuring the full protection of the incumbent systems.

Table 77: Summary of separation distance

PMSE interference into aeronautical systems	Required co-frequency separation distance (Gnd Receiver)	Required co-frequency separation distance (Air Receiver)	Comment (Propagation Model)
PMSE (Hand-held outdoor) interference to DME	134 km (only P.525 free space)	from 18 km to 63 km	Basic transmission loss (P.525 free space, P.452)
PMSE (Hand-held indoor) interference to DME	13.4 km (only P.525 free space)	from 0.0 km to 0.9 km	Basic transmission loss (P.525 free space, P.452) with building / body / clutter loss
PMSE (Hand-held outdoor) interference to DME	from 0.6 km to 3 km	Not determined	Basic transmission loss (P.1546)
PMSE (Hand-held indoor) interference to DME	from 0.4 km to 0.9 km	Not determined	Basic transmission loss (P.1546) with building / body / clutter loss

A5.2 PMSE PARAMETERS

A5.2.1 PMSE parameters

Table 78:Hand-held audio PMSE

Parameter	Unit	Value	Reference
Bandwidth ($B_{IF,PMSE}$)	MHz	0.2	ECC Report 253 [57]
Antenna height (h_{PMSE})	m	1.5	ECC Report 253
Body loss (L_{body})	dB	7 dB (minimum)	ECC Report 286 [27]
Transmit Power (P_{PMSE}) e.i.r.p	dBm	17	ERC/REC 70-03 Annex 10 [28] and ECC Report 253
Antenna polarisation		Vertical	ECC Report 253

A5.2.2 Body loss

ECC Report 286 contains the body effect of hand-held and body-worn audio PMSE equipment and is based on previous studies including measurements and simulations.

The body loss at 1 GHz can be estimated for hand-held microphones between 7 and 11 dB. The chosen value is 7 dB.

A5.2.3 Building loss

This Recommendation ITU-R P.2109 [33] provides a method for estimating building entry loss at frequencies between about 80 MHz and 100 GHz. The method is not site-specific, and it is primarily intended for use in sharing and compatibility studies. This is a rather new Recommendation, adopted in 2017.

The penetration loss at 1000 MHz is about 13 dB for traditional houses and 28 dB for thermally efficient houses. The chosen value is 13 dB.

A5.3 PROPAGATION MODELS

In the following various, commonly used propagation models are briefly analysed with regard to the application for this study (shortcomings and parameter ranges).

A5.3.1 Free space attenuation

The free-space propagation is a fundamental reference for radio-engineering. The basic calculation of the free-space attenuation is provided in Recommendation ITU-R P.525. The basic transmission loss is referred to free-space attenuation between isotropic antennas and is a function of the frequency and the distance between the isotropic antennas.

Noting that the free space attenuation is independent of the antenna heights and is depending only on the frequency and direct radio path considered, i.e. no multi-path propagation is addressed.

It is obvious that the application is limited to LoS propagation, i.e. limited by the radio horizons d1, d2 , which are a function of the antenna height h_1, h_2 above ground (sea level, respectively) and the effective Earth radius k R with k=4/3 considering the refractivity of the lower atmosphere:

$d_1 = 4.12\sqrt{h_1}$ with d_1 in km and h_1 in m.

The radio horizons for the antenna heights used in this contribution are listed below:

h_1 / m	1.5	2.1	25	40	100	1000	10000
d_1 / km	5	6	20.6	26	41.2	130	412

For the LoS condition both antenna heights have to be considered: $d \ll d_1 + d_2$. Noting, if $d \approx d_1 + d_2$, then the 1st Fresnel zone touches the spherical Earth surface and additional attenuation has to be taken into account.

A5.3.2 Recommendation ITU-R P.528

This Recommendation contains propagation curves for aeronautical mobile and radionavigation services using the VHF, UHF and SHF bands. It contains a method for predicting basic transmission loss in the frequency range 125-15500 MHz, antenna heights of h_1 between 1.5 m and 20 km and of h_2 between 1 and 20 km and time probability between 1 and 95%. The method uses an interpolation method on basic transmission loss data from sets of curves. These sets of curves are valid for ground-air, ground-satellite, air-air, air-satellite, and satellite-satellite links. The Recommendation does not take into account the terrain (only flat) and land-usage around the transmitter (e.g. buildings).

For frequencies around 1000 MHz, very low time percentage of 1% and antenna height of h_1 = 1.5 m, the predicted basic transmission loss is slightly less than the related free space loss. This may be caused by multi-path propagation and/or atmospheric effects, like ducting. Significant contribution due to multi-path propagation could be an issue over very smooth surfaces, e.g. sea or lake, but is not an issue in rough terrain or urban area. For anomalous atmospheric conditions, stable atmospheric layers are required and a small angle of wave incident is required. These pre-conditions will not be found over cities where the atmosphere is mixed and can be described well by the standard atmosphere corresponding to k=4/3 and very low antenna height surrounded by obstacles.

Therefore, for Europe and over land, the assumption of the time probability of 50% is a very reasonable assumption for the estimation. By the way, comparing 1% with 50 or 95% for short distances, let say less than 50 km, the extension of the distance is negligible.

A5.3.3 Recommendation ITU-R P.452

This Recommendation contains a prediction method for the evaluation of interference between stations on the surface of the Earth at frequencies from about 0.1 GHz to 50 GHz, accounting for both clear-air and hydrometeor scattering interference mechanisms.

The propagation model was developed originally for point-to-point prediction for fixed service with antennas above roof tops. Later on it was amended for other frequency ranges and lower antenna heights. The models contained within Recommendation ITU-R P.452 work from the assumption that the interfering transmitter and the interfered-with receiver both operate within the surface layer of atmosphere. Use of exceptionally large antenna heights to model operations such as aeronautical systems is not appropriate for these models.

The model predicts the basic transmission loss to less (compared with free space) for short distances (on Earth) and large antenna height differences because the two-dimensional distance between the antennas is not taken into account.

For large distances and LoS, the predicted transmission loss is approaching the free space value. For beyond the radio horizon and NLoS the path loss is increased by diffraction loss due to the spherical Earth surface. The consideration regarding the time probability of the atmosphere is similar to above (see above). All terrain heights used in this model are set to 0 m, i.e. smooth Earth surface.

A5.3.4 Recommendation ITU-R P.1546 [98]

This Recommendation describes a method for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 MHz to 3000 MHz. It is intended for use on tropospheric radio circuits over land paths, sea paths and/or mixed land-sea paths up to 1000 km length for effective transmitting antenna heights less than 3000 m. The method is based on interpolation/extrapolation from empirically derived field-strength curves as functions of distance, antenna height, frequency and percentage time. The calculation procedure also includes corrections to the results obtained from this interpolation/extrapolation to account for terrain clearance and terminal clutter obstructions.

The model was developed originally for VHF/UHF broadcasting. It was later extended for receiving antenna heights lower than 10 m and transmitting antenna heights lower than 30 m and, of course, the frequency range was extended significantly. It is a very commonly used model for point-to-area prediction taking into account the different environments such as rural, suburban or urban and seems therefore appropriate to be used for the estimation of the radio path loss for the radio path PMSE to the ground DME station. In the model, the clutter height used for rural and suburban is 10 m and for urban is 20 m.

It is distinguished between time and location probability. For the time probability, the same consideration is valid as above. The location probability is typically set to 50% and the loss limited by free space.

A5.3.5 Recommendation ITU-R P.2108 on clutter loss

This Recommendation provides methods for estimating loss through clutter at frequencies between 30 MHz and 100 GHz. This is a rather new Recommendation, adopted in 2017, and driven by the studies for IMT.

The clutter loss depends on the frequency, type of environment and extension of the area. For about 1000 MHz with homogeneous built-up area of about 100 m around the PMSE transmitter, the additional loss is in the range of 17 dB. Extending the range of the built-up area up to 1 km, then the loss increases to about 25 dB.

The clutter loss will be used together with the Recommendations (P.525, P.452 [97], and P.528 [32]) to consider the impact of build-up area. The model P.1546 [98] contains already different environments.

The chosen value for clutter loss: 17 dB.

A5.3.6 Propagation models considered

For impact of PMSE on the airborne DME receiver the basic transmission loss is determined by free space, Recommendation ITU-R P.528 and Recommendation ITU-R P.452.

For impact of PMSE on the ground DME receiver the basic transmission loss is determined by free space and P.1546.

Body loss, clutter and penetration losses are added as appropriate.

A5.4 DME

A5.4.1 DME parameters

Table 79:DME/P Airborne interrogator

Parameter	Unit	Value	Reference
Frequency range	MHz	962-1213	[66]
Bandwidth (BIF,DME)	MHz	3.5	
Antenna height (h2)	m	100, 1000, 10000	

Parameter	Unit	Value	Reference
Antenna gain (GDME) Note 1	dBi	5.4 (maximum)	
Antenna polarisation		Vertical	
Interference threshold (IDME) Note 2, 3	dBm/MHz	Sensitivity requirement shall meet in-band Continuous Wave up to -99 dBm	EUROCAE ED-54 [49]
Note 1: The antenna pattern is not taken into account in the study. Note 2: For broadband interference the interference threshold of -99 dBm/MHz can be assumed (Recommendation ITU-R M.1639 [72]). Note 3: The threshold referred to one PMSE channel of 200 kHz results in -106 dBm.			

Table 80:DME Ground transponder

Parameter	Unit	Value	Reference
Frequency range	MHz	1025-1150	[66]
Bandwidth (BIF,DME)	MHz	3.5	
Antenna height (h2)	m	40, 25, 2.1	
Antenna gain (GDME)	dBi	12 (omnidirectional)	
Antenna polarisation		Vertical	
Interference threshold (IDME)	dBm	-106	ICAO Annex 10, EUROCAE ED-57 [50]

A5.4.2 Modelling assumptions

The sharing studies related to hand-held microphones interfere with the co-frequency airborne and ground DME receivers are picked up to discuss the impact of different propagation models. The required protection distance is determined for various environments around the PMSE. Additionally, the indoor use of PMSE is studied.

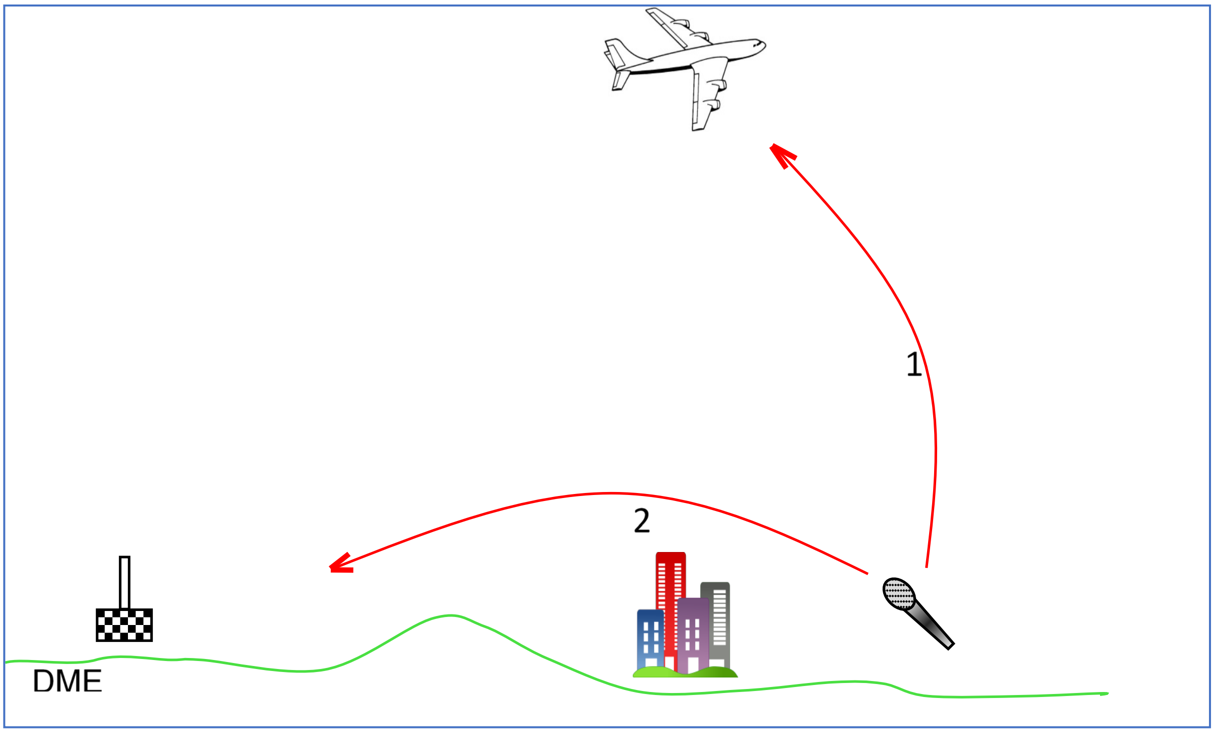


Figure 77: Audio PMSE sharing radio spectrum with DME systems

In this study, the following interference scenarios are considered:

- Audio PMSE transmitter to DME airborne interrogator receiver;
- Audio PMSE transmitter to DME ground transponder receiver.

The direction of DME interfere with audio PMSE is not addressed because it could be assumed the PMSE systems in the band 960-1164 MHz are operated by professional operators and the selected radio spectrum and geographic location were identified by the regulator, in order to ensure that PMSE does not interfere any aviation system.

The audio PMSE system is designed in such a way that each wireless microphone use an exclusive channel, i.e. two microphones will use two different frequency bands.

To simplify the consideration, the following (worst-case) assumptions are taken in this study:

- audio PMSE device with the highest transmitted power: hand-held audio PMSE;
- co-frequency use with the frequency of 1000 MHz;
- PMSE device is in the main antenna lobe of the DME equipment.

A5.4.3 MCL Analysis

The interference on DME is estimated with MCL methodology. The basic transmission loss can be determined by

$$L_b = P_{PMSE} + G_{DME} - I_{DME}$$

Where

- Lbbasic transmission path loss in dB;
- PPMSE transmitted power (e.i.r.p.) in dBm;
- GDME maximum of antenna gain in dBi of the DME equipment;
- IDME Interference threshold referred to the PMSE channel bandwidth in dBm.

The required distance to protect DME is determined for various propagation models.

Then transmission loss is increased step-by-step

by body loss of the microphone, Lbody

by clutter in the vicinity of PMSE to take into account buildings (urban area), Lclutter

by penetration loss, Lbuilding for PMSE use indoor only

The detailed MCL analysis for airborne DME receiver is contained in Table 81. The results are summarised in the following table.

Table 81: Required protection distance for Airborne DME receiver

	Flight height		
	100 m	1000 m	10000 m
Open area	18 km	63 km	62 km
+ body loss	28 km	28 km	26 km
+ clutter loss	4 km	4 km	0 km
+ building entry loss	0 km	0 km	0 km

The worst case is when the PMSE device is used in open area with LoS to the airplane and the antennas are pointing to each other, then the separation distance results in about 18 (P.452) to 63 (P.525) km depending on the flight height.

Taking into account the additional body loss, the required range is reduced to 13(P.452) to 28 km (P.525).

Assuming that PMSE is applied usually in cities, the required distance is less than 4 km for low flight heights.

If PMSE is used in cities indoor only, no interference is likely to occur. An additional margin of about at least 13 dB is given.

The detailed MCL analysis for Ground DME receiver is contained in Table 82. All considered cases (rural, suburban or urban) are below 3 km due to the low antenna heights. The worst case is rural. Ground DME stations are somewhere in the area of an airport. The required protection distance should be ensured easily in all cases by the responsible authorities.

A5.4.4 PMSE (hand-held) interfere with airborne DME receiver

A5.4.4.1 Required transmission loss

Table 82: Required protection distance for Airborne DME receiver

		Propagation model, km			Transmission Loss L/dB
		P.525	P.528	P.452	
DME_Airborne (VLR): h2 = 100 m					
Lb / dB	0	62.8	NA	18	128.4

		Propagation model, km			Transmission Loss L/dB
		P.525	P.528	P.452	
+ Lbody / dB	7	28	NA	12.6	121.4
+ Lclutter / dB	24	4	NA	4	104.4
+ Lbuilding / dB	37	0.9	NA	0.9	91.4
DME_Airborne (VLR): h2 = 1000 m					
Lb / dB	0	62.8	53.5	56.4	128.4
+ Lbody / dB	7	28	27.7	27.4	121.4
+ Lclutter / dB	24	3.6	3.8	4	104.4
+ Lbuilding / dB	37	0	0	0	91.4
DME_Airborne (VLR): h2 = 10000 m					
Lb / dB	0	62.0	61	60	128.4
+ Lbody / dB	7	26.2	26	27.4	121.4
+ Lclutter / dB	24	0	0	0	104.4
+ Lbuilding / dB	37	0	0	0	91.4

A5.4.4.2 Discussion

The required distance for protection of the airborne DME receiver against interference can be estimated well by the free space model. There are three exceptions:

For non LoS, e.g. low flight altitude (e.g. 100 m), the radio path is touching the Earth surface or is even diffracted at the spherical Earth. In that case the model Recommendation ITU-R P.452 [97] is more appropriate.

If the calculated path length is considerably larger than the height difference of the antennas, then the horizontal distance is about the calculated path length, otherwise the antenna height difference has to be taken into account for the determination of the horizontal path length.

The calculated distance is less than the flight height, i.e. there is no interference but a margin. The values are set to 0 in the Table 81.

The worst case is when the PMSE device is used in open area with LoS to the airplane and the antennas are pointing to each other, then the separation distance results in about 18 to 63 km depending on the flight height.

Taking into account the additional body loss, the required range is reduced to 13 to 28 km.

Assuming that PMSE is applied usually in cities, the required distance is less than 4 km for low flight heights.

If PMSE is used in cities indoor only, no interference is likely to occur. An additional margin of about at least 13 dB is given.

A5.4.5 PMSE (hand-held) interfere with ground DME receiver

A5.4.5.1 Required transmission loss

Table 83: Required protection distance for ground DME receiver

		Propagation model, d/km				Transmission Loss L/dB
		P.525	P.1546 rural	P.1546 suburban	P.1546 urban	
DME_Ground (VLR): h2 = 2.1 m						
Lb / dB	0	134	1.70	1.6	0.6	135
+ Lbody / dB	7	60	1.1	1.1	0.5	128
+ Lbody + Lbuilding / dB	20	13.4	0.74	0.71	0.35	115
DME_Ground (VLR): h2 = 25 m						
Lb / dB	0	134	2.5	2.35	1.55	135
+ Lbody / dB	7	60	1.6	1.5	1	128
+ Lbody + Lbuilding / dB	20	13.4	0.84	0.8	0.67	115
DME_Ground (VLR): h2 = 40 m						
Lb / dB	0	134	3	2.74	1.8	135
+ Lbody / dB	7	60	1.8	1.70	1.1	128
+ Lbody + Lbuilding / dB	20	13.4	0.88	0.84	0.71	115

A5.4.5.2 Discussion

The required distance for protection of the ground DME receiver against interference can be estimated well by the point to area model P.1546 [98]. The use of the free space model not appropriate because the LoS is not possible over this distance with these low antenna heights.

All considered cases (rural, suburban, urban) below 3 km. Ground DME stations are somewhere in the area of an airport. The required protection distance should be ensured easily in all cases by the responsible authorities.

A5.4.6 Conclusion

A MCL sharing study has been performed on audio PMSE interfere the co-frequency DME equipment.

For LoS configuration, the free space model can be used. For non LoS other models are more appropriate. The time probability is relevant for long radio paths (e.g. >100 km) but could be neglected for short radio paths and low antenna height of the wireless microphone.

If the audio PMSE is used in densely built-up areas (cities) and/or indoor, no interference is likely to occur.

Audio PMSE should not be used in an open area of about 3 km around the ground DME station.

The required protection distance between audio PMSE used in a large open area and the airborne DME receiver depends on flight altitude and could reach up to 63 km.

This is a minimum coupling loss analysis. There are margins because some of the assumptions, e.g. on the penetration loss or clutter loss, are very conservative. In reality, these losses will be higher. The polarisation loss was not considered. The elevation antenna patterns are not taken into account, the maximum gain was used. The probability that the antennas are pointing to each other with the maximum in azimuth and elevation is not considered. An effective mitigation technique is the selection of adjacent frequencies and not the co-frequency band.

ANNEX 6: IMPACT OF PMSE ON IN-BAND ARNS AND ADJACENT BAND GNSS SYSTEMS FROM ANFR

A6.1 SUMMARY

A6.1.1 Executive Summary

This study investigates the possible use of audio PMSE in the frequency band 960-1164 MHz currently allocated to aeronautical mobile en-route and radionavigation services.

The study took into account existing aviation systems (civil aviation DME, 1030 MHz and 1090 MHz frequency, GNSS in the adjacent band and military JTIDS/MIDS) as well as on-going projects (short-term Universal Access Transceiver (UAT), mid-term LDACS and CNPC for drones, long-term CNS). The band 960-1164 MHz being already saturated with these security systems, the adequate propagation model is Free Space Loss between aircrafts and PMSE devices, and an I/N = -6 dB criterion was used:

- Regarding PMSE transmitters, they are considered with omnidirectional e.i.r.p. Due to lack of scenarios, the study considered aggregated interference in co-channel with up to 3 PMSE per one MHz, with a body loss of 0 dB;
- Regarding PMSE receivers, the interference level ensuring protection considered is -105 dBm;
- The resulting separation distances range from 225 km to 587 km for outdoor use of audio PMSE.

A6.1.2 Overall criterion

The protection criterion I/N of -6 dB have been considered in this study.

This I/N protection criteria is commonly used for various terrestrial systems at ITU-R level and in many studies at CEPT.

In order to protect the high availability and integrity requirement for the aeronautical radionavigation, the value of the protection criteria of I/N -10 dB is also considered in this study. The safe operation of aeronautical systems into the band 960-1164 MHz requires availability and integrity in particular for the aeronautical radionavigation service, unlike other radio services.

A6.1.3 Status

An additional factor to recognize the status of the service under which aeronautical systems are operated compared to the one for PMSE is not considered in this study, although the frequency. The band 960-1164 MHz is not allocated to the mobile service. Therefore, PMSE will have to operate under ITU RR No. 4.4, whereas all the aeronautical systems operate on a primary basis in this band.

A6.1.4 Safety margin consideration

ICAO handbook DOC 9718 [101] defines the safety, as following:

Aeronautical safety applications are required to have continued operation through worst-case interference, so all factors which contribute to harmful interference should be considered in analyses involving those applications. An aviation safety margin is included in order to address the risk that some such factors cannot be foreseen (for example impacts of differing modulation schemes). This margin is applied to the system protection criteria to increase the operational assurances to the required level. Traditionally for aviation systems/scenarios an aviation safety margin of 6-10 dB is applied. Until established on the basis of further study on a case-by-case basis, an aviation safety margin of not less than 6 dB should be applied.

Aeronautical systems of civil aviation operated in the frequency band 960-1164 MHz are for safety of life purpose, therefore a safety margin of 6 dB to comply with ITU RR No. 4.10 and ICAO handbook [2] is considered appropriate for this study.

A6.1.5 Aggregated effect and deployment scenario

So far, no much material was provided regarding a possible deployment scenario of audio PMSE in the band 960-1164 MHz.

Nevertheless, according to ETSI TR 102 546 [58], during outdoor show, such as 14 July in France, around 150 wireless microphones can be at the same place.

The aggregated effect has been taken into account although no much material was provided. Due to PMSE inter-system interferences, it appears relevant to consider a use of three wireless audio PMSE within one MHz bandwidth.

A6.1.6 Summary

All the incumbent systems into the band 960-1164 MHz were considered. This includes the current applications (such as DME, UAT, and all the 1030-1090 MHz frequencies systems) and also the future systems that are expected in Europe and in France in the short, middle and long term (CNPC for drones, LDACS and the long term CNS system).

For the compatibility studies, the main objective is to ensure security for the aeronautical systems, therefore they are considered as a victim and only the receivers parameters are shown below. The worst case considered is airborne systems and outdoor PMSE, with no building attenuation or body attenuation.

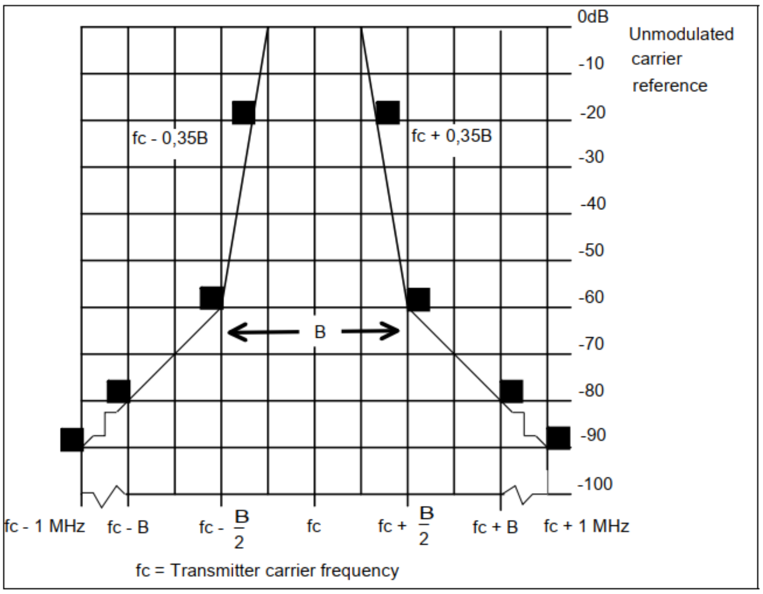
Table 84: Summary

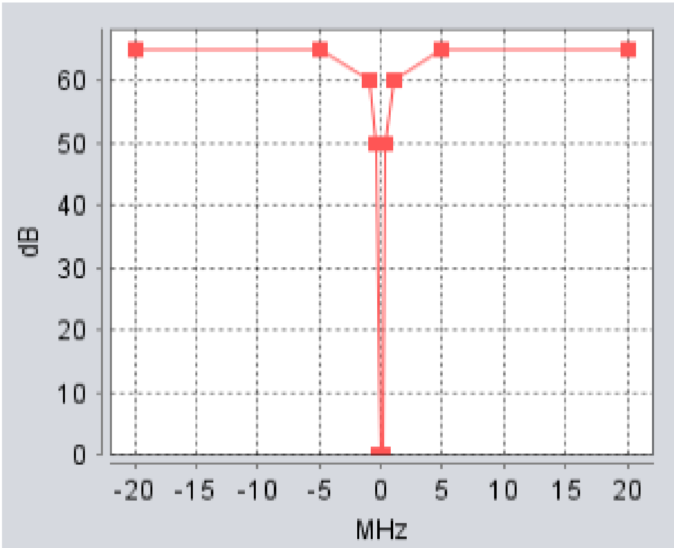
PMSE interference into aeronautical systems	Frequency Band (MHz)	Minimum co-frequency separation distance (Air Receiver)	Guard band (note 1)
DME	962-1164	571 km	1.59 MHz
UAT	978	419 km	10.8 MHz
1030-1090 MHz frequencies	1030 1090	Not applicable	23.1 MHz 21.4 MHz
CNPC	960-1164	432 km	486 kHz
LDACS	1110-1156	287 km	>500 kHz
GNSS	1176.45	Not applicable	30 MHz
Integrated CNS	960-1164	Unknown	Unknown
Aeronautical systems interference into PMSE	**Frequency Band (MHz)**	**Minimum co-frequency separation distance (Air Receiver)**	**Guard band**
DME	962-1164	587 km	Not studied
UAT	978	587 km	Not studied
CNPC	960-1164	225 km	Not studied
LDACS	964-1010	298 km	Not studied
Link 16 (JTIDS/MIDS emitters)	969-1008 1053-1065 1113-1206	587 km (note 2)	Not studied
Integrated CNS	960-1164	Unknown	Not studied

PMSE interference into aeronautical systems	Frequency Band (MHz)	Minimum co-frequency separation distance (Air Receiver)	Guard band (note 1)
Note 1: This separation frequency should be respect considering a minimum separation distance between aeronautical systems and PMSE Note 2: Even assuming an indoor use with the maximum wall attenuation of 20 dB, the separation distance would remain more than 80 km for 200 W and 150 km for 1 kW).			

A6.2 PMSE PARAMETERS

Table 85: Parameters PMSE

Parameters	Unit	Value	Comments
Hand-held audio, body-worn and IEM (In Ear Monitoring) PMSE transmitter			
Bandwidth (BW)	MHz	0.2	
Antenna height	m	1.5	
Maximum e.i.r.p.	dBm	17 (RMS) / 21 (Peak)	The RMS value will be considered in this study.
Out-of-band emission			
Receiver			
Bandwidth (BW)	MHz	0.2	ETSI EN 300 422 [25], Section 5.1.1. Table 1, Designator "R"

Parameters	Unit	Value	Comments
Reference Sensitivity	dBm	-90	ETSI TR 102 546 [58] Section B.4.1.3
Blocking Response	dB		see ETSI EN 300 422 [25] Attachment 2, Applicable Receiver Parameter for PWMS below 1 GHz.
Antenna height	m	3	
Antenna gain	dBi	0	Omni directional

A6.2.1 PMSE receiver Parameters

Table 86: Parameters for audio PMSE receivers

Parameter	Unit	Value	Reference
Interference level to protect PMSE	dBm	-115 (RMS) -105 (peak)	ETSI TR 102 546 [58]for the level of -115 dBm.
Selectivity	dB	See curve below	ERC Report 63 [70]

A6.2.2 Parameters of body loss

A body loss value of 0 dB has been considered in this study to reflect the Intra Ear Monitoring configuration and to be considered for the worst-case configuration hand-held/body-worn system, the applicability of ECC Report 286 [27] being not agreed for this study.

Therefore, the e.i.r.p. considered for PMSE devices is omnidirectional.

A6.2.3 Parameter for building loss

The aeronautical systems involve aircrafts as mobiles in the air and PMSE devices on the ground. Outdoor use of PMSE is not excluded and it has to be noted that the level of attenuation due to building could be extremely variable. No building attenuation has been taken into account in the sharing scenarios.

A6.3 PROPAGATION MODEL

The worst-case scenario requires the Free Space Loss as the propagation model between the aircraft (mobile) and the PMSE (outdoor, without indoor or building entry considerations).

A6.4 DME

A6.4.1 DME parameters

A6.4.1.1 Regular DME

Table 87:Regular DME

Parameters	Unit	DME/N airborne
Transmitter		
Frequency range	MHz	1025-1150
Bandwidth	MHz	0.9
Max. e.i.r.p.	dBm	68
Minimum cable loss	dB	1
Receiver		
Frequency range	MHz	962-1213
Bandwidth	MHz	1.8
Noise figure	dB	4
Antenna gain	dBi	5.4
Minimum cable loss	dB	1

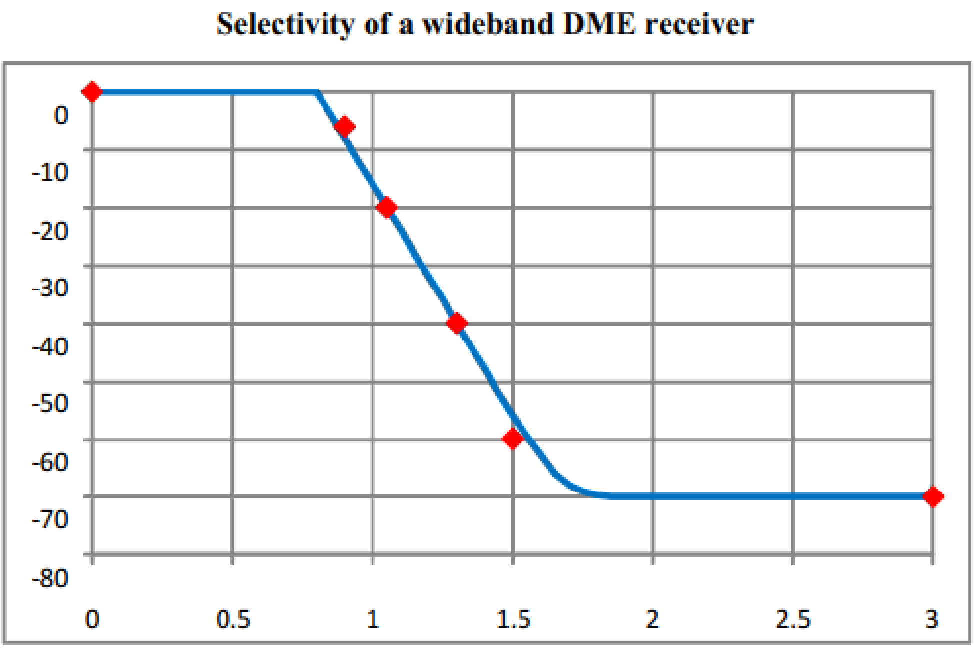


Figure 78: Airborne selectivity of a 442 DME receiver (Bandwidth of 1.8 MHz at 3 dB)

A6.4.1.2 Transportable DME

Per operational requirement, there are 2 DME channels reserved for French Civil Aviation Authority that can be unannounced deployed and used anywhere at any time in all the French territory.

Table 88: Channels reserved for transportable DME in France

Channel	Interrogation Frequency	Reply Frequency
97Y	1121 MHz	1058 MHz
119X	1143 MHz	1206 MHz

Each of these frequencies requires, for the reply towards DME airborne receivers, a reserved access and a guard band of at least 2 MHz in order to be protected from PMSE inferences (see dedicated sections above – this guard band is the figure that sets the separation distance to 1000 feet).

A6.4.1.3 Other military frequencies in band 962-1164 MHz

Per operational requirement, there are 5 TACAN channels reserved for NATO and French Military for TACAN that can be unannounced used anywhere at any time in all the French territory.

Table 89: Channels reserved for TACAN (in France)

Channel	Interrogation Frequency	Reply Frequency
26Y	1050 MHz	1113 MHz
34X	1058 MHz	995 MHz
54X	1078 MHz	1015 MHz
98X	1122 MHz	1185 MHz
112Y	1136 MHz	1073 MHz

There are also 16 pairs of Air-To-Air channels dedicated to NATO use over European and American skies in order to ensure protection missions regarding non-allied nations as well as training purposes. They can be activated without notice to the civil aviation authorities. Similarly, there are 4 channels dedicated for exclusive use by NATO naval units.

Table 90: Reserved frequencies for TACAN (European territory)

Air-To-Air channels	Navy channels
20&83X/Y	1X
25&88X/Y	16X
30&93X/Y	1Y
35&98X/Y	16Y
40&103X/Y	
45&108X/Y	
50&113X/Y	
55&118X/Y	

The military use for TACAN leads to similar considerations as Civil Aviation DME in the studies.

Each of these reply frequencies requires, for the reply towards TACAN airborne receivers, a reserved access and a guard band of at least 2 MHz in order to be protected from PMSE inferences (see dedicated sections below – this guard band is the figure that sets the separation distance to 1000 feet).

A6.4.2 Modelling assumptions

The propagation model is Free Space Loss between an airborne platform and PMSE devices used in open-air conditions, therefore omnidirectional without building loss and body loss.

A6.4.3 Conclusion and compatibility studies

A6.4.3.1 DME Study for protection of the airborne receiver (between 962 and 1164 MHz)

This section presents the MCL DME study conducted in order to evaluate the necessary separation distance and the associated guard band to protect the DME airborne receiver between 962 and 1164 MHz.

A6.4.3.2 Impact of audio PMSE transmitter on airborne receiver

The DME receivers are likely to receive interference from PMSE, which is computed with the hypothesis as follows:

Table 91: Calculation of separation distance to protect airborne DME receiver from PMSE interference

Parameters	Parameter value
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (3 PMSE within 1 MHz Bandwidth) (dB)	7.32 dB
DME receiver Noise (dBm)	-107.38 dBm
DME antenna gain (dBi)	5.4 dB
Cable loss (dB)	1 dB
Safety Margin (dB)	6 dB
Interference Level allowed (dBm)	-123.78 dBm (I/N=-6dB) / -127.78 dBm (I/N=-10dB)
Requested Attenuation (dB)	148.10 dB (I/N=-6dB) / 152.10 dB (I/N=-10dB)
FSL Distance Separation required at 1062 MHz	571,44 km (I/N=-6dB) / 905,68 km (I/N=-10dB)
Radio Horizon (Flight level 600)	587 km

According to the study, a separation distance of 571,44 km (I/N=-6 dB) or 905,68 km (I/N=-10dB) is needed in order to protect the DME/N receivers from audio PMSE.

As this distance is very important, the practical separation distance will be limited by the radio horizon. As a plane can flight up to 60000 feet, the separation distance is then 587 km (I/N=-10 dB).

A6.4.3.3 Guard Band to protect DME Channels (between 960 and 1164 MHz)

As it is shown by the precedent table, cohabitation between PMSE and DME on co-channel is not feasable because of the separation distances are too much important (571 km and 587 km, respectively for I/N = -6 dB and I/N = -10 dB).

In order to protect both systems, it is important to define a guard band. In this study we will consider that the closest distance between an airborne and an outdoor PMSE will be 1000 feet (around 330 m).

Table 92: Calculation of guard band to protect DME receiver from PMSE interference

Parameters	Parameter value
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (3 PMSE near the bandwidth edge victim) (dB)	4.77 dB
DME receiver Noise (dBm)	-107.38 dBm
DME antenna gain (dBi)	5.4
Cable loss (dB)	1
Safety Margin	6 dB
Interference Level allowed (dBm)	-123.78 dBm (I/N = -6 dB) / -127.78 dBm (I/N = -10 dB)
Requested Attenuation (dB)	145.55 dB (I/N = -6 dB) / 149.55 dB (I/N = -10 dB)
FSL Attenuation for 330 m at 1062 MHz (dB)	83.34 dB
Receiver Selectivity Required (dB)	62.21 dB (I/N = -6 dB) / 66.21 dB (I/N = -10 dB)
Guard band to reach the receiver selectivity (MHz)	1.59 MHz (I/N = -6 dB) / 1.75 MHz (I/N = -10 dB)

According to the receiver mask from an 442 DME receiver, a guard band of +/-1.59 MHz (I/N = -6 dB) or 1.75 MHz (I/N = -10 dB) is needed in order to protect the DME receivers from audio PMSE.

A6.4.3.4 DME Study to protect PMSE receiver (between 960-1164 MHz)

The MCL DME study was conducted in order to assess the required separation distance to protect PMSE receivers between 960-1164 MHz. As the CNPC signal is a TDD pulsed signal, the protection criteria for PMSE is assumed to be -105 dBm for pulsed interferences. It has to be noted that no additional margin has been included here, therefore this value should be considered as a threshold and not diminished.

Table 93: Calculation of separation distance to protect PMSE from airborne DME interference

Parameters	Impact of DME airborne transmitter on PMSE receiver
DME Airborne e.i.r.p. (dBm) for 900 KHz	68 dBm / 900 kHz
DME Airborne e.i.r.p. (dBm)	64.47 dBm / 200 kHz
PMSE protection criteria (dBm)	-105 dBm
Requested Attenuation (dB)	166.46 dB

Parameters	Impact of DME airborne transmitter on PMSE receiver
FSL Distance Separation required (F=1062 MHz)	4734 km (in co-channel)
Radio Horizon (Flight level 600)	587 km

A separation distance of 4734 km is needed in order to protect the audio PMSE from the CNPC airborne transmitters.

As this distance is very important, the practical separation distance will be limited by the radio horizon. As a plane can flight up to 60000 feet, the separation distance is then 587 km).

A6.5 1030 MHZ AND 1090 MHZ SYSTEMS

A6.5.1 1030 MHz and 1090 MHz parameters

In order to consider the worst-case scenario, we only study airborne SSR receiver for the 1030 MHz frequency and the airborne ABSB receiver for the 1090 MHz frequency.

Table 94: SSR airborne transponder characteristics

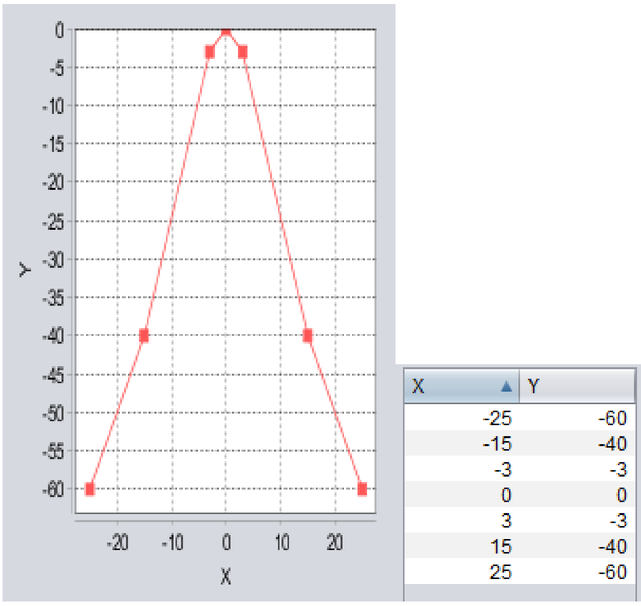
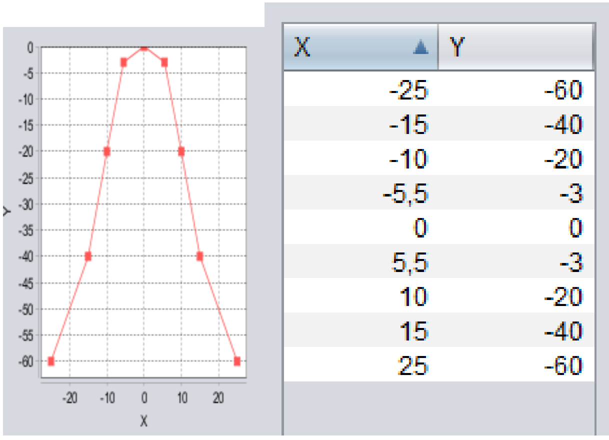
Parameters	Unit	SSR airborne Transponder Receiver
Frequency range	MHz	1030 (RTCA DO-181 §2.2.2.2)
Antenna Gain	dBi	5.4
Cable loss	dB	3 (ED-43 §3.2.4.2 [48])
Bandwidth	MHz	6 (RTCA DO-181 §2.2.2.3)
Noise figure	dB	5
Selectivity for the Airborne (Mode S replies)	dBc	 (RTCA DO-181 §2.2.2.3) Spurious Rejection : 70 dBc

Table 95: Airborne ADS-B airborne receiver characteristics

Parameters	Unit	ADS-B airborne receiver
Frequency range	MHz	1090 (RTCA DO-260 §1.2.2)
Antenna Gain	dBi	2 to 5 dBi (RTCA DO-260 M.4.1)
Cable loss	dB	3 (RTCA DO-260 §P2.1.1)
Bandwidth	MHz	11 MHz (RTCA DO-260 Table 2-82)
Noise figure	dB	5
Selectivity (RTCA DO-260 Table 2-82)	dBc	

A6.5.2 Modelling assumptions

The propagation model is Free Space Loss between an airborne platform and PMSE devices used in open-air conditions, therefore omnidirectional without building loss and body loss.

A6.5.3 conclusion

The MCL 1030 MHz and1090 MHz frequencies study aims to define the relevant guard band. Therefore it is considered that the closest distance between an airborne and an outdoor PMSE will be 1000 feet (around 330 meters).

A6.5.3.1 Guard band to protect the 1030 MHz frequency

The system that has the widest receiver for the 1030 MHz frequency is the airborne SSR receiver (RTCA DO-181 §2.2.2.3).

In this section, we only study the impact of audio PMSE to airborne SSR receiver as it is wider than the PMSE receiver.

The airborne antenna gain is up to 5.4 dBi with a receiver bandwidth of 6 MHz.

Table 96: Calculation of guard band to protect airborne SSR receiver from PMSE interference

Parameters	Impact of audio PMSE transmitter on SSR airborne receiver
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (3 PMSE near the bandwidth edge victim) (dB)	4.77 dB

Parameters	Impact of audio PMSE transmitter on SSR airborne receiver
SSR receiver Noise (dBm)	-101.15 dBm
SSR antenna gain (dBi)	5.4
Cable loss (dB)	1
Safety Margin (dB)	6
Interference Level allowed (dBm)	-117.55 dBm (I/N = -6 dB) / -121.55 dBm (I/N = -10 dB)
Requested Attenuation (dB)	139.32 dB (I/N = -6 dB) / 143.32 dB (I/N = -10 dB)
FSL Attenuation for 330 meters at 1030 MHz (dB)	83.07 dB
Receiver Selectivity Required (dB)	56.25 dB (I/N = -6 dB) / 60.25 dB (I/N = -10 dB)
Guard band to reach the receiver selectivity (MHz)	23.1 MHz (I/N = - 6 dB) / >25 MHz (extrapolation) (I/N = -10 dB)

According to the SSR Selectivity from the study, a guard band of 23,1 MHz (I/N = -6 dB) or >25 MHz (I/N = -10 dB) is needed in order to protect the 1030 MHz frequency from audio PMSE.

A6.5.3.2 Guard band to protect the 1090 MHz frequency

The system that has the widest receiver for the 1090 MHz frequency is the airborne ADS-B receiver (Table 2-82 DO-102A).

In this section, only the impact of audio PMSE to airborne ABSB receiver as it is wider than the PMSE receiver is studied.

The airborne antenna gain is up to 5 dBi with a receiver bandwidth of 11 MHz.

Table 97: Calculation of guard band to protect airborne ADS-B receiver from PMSE interference

Parameters	Impact of audio PMSE transmitter on ADS-B airborne receiver
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (3 PMSE near the bandwidth edge victim) (dB)	4.77 dB
ADSB receiver Noise (dBm)	-98.52 dBm
ADSB antenna gain (dBi)	5 dBi
Cable loss (dB)	1 dB
Safety Margin (dB)	6 dB
Interference Level allowed (dBm)	-114.52 dBm (I/N = -6 dB) / -118.52 dBm (I/N = -10 dB)
Requested Attenuation (dB)	136.29 dB (I/N = -6 dB) / 140.29 dB (I/N = -10 dB)
FSL Attenuation for 330 m at 1090 MHz (dB)	83.57 dB
Receiver Selectivity Required (dB)	52.72 dB (I/N = -6 dB) / 56.72 dB (I/N = -10 dB)
Guard band to reach the receiver selectivity (MHz)	21.40 MHz (I/N = -6 dB) / 23.40 MHz (I/N = -10 dB)

According to the ADS-B Selectivity from the study, a guard band of +/-21.40 MHz (I/N = -6 dB) or 23.40 MHz (I/N = -10 dB) is needed in order to protect the ADS-B receivers from audio PMSE.

A6.5.4 Overall results

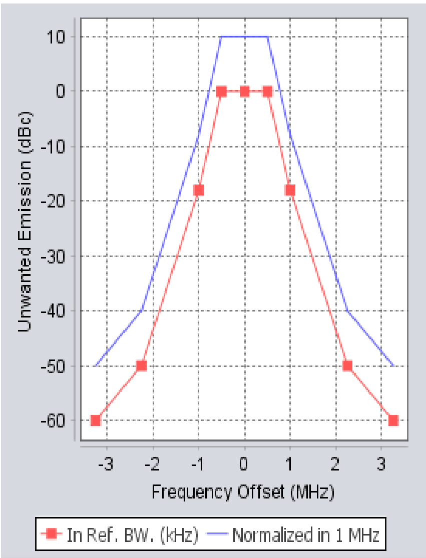
Any interference into the frequencies 1030 or 1090 is unacceptable for safety reasons (e.g. no co-channel with SSR and above all TCAS and ADS-B). Therefore, the guard bands presented above are essential, hence mandatory.

A6.6 UNIVERSAL ACCESS TRANSCEIVER (UAT)

A6.6.1 UAT parameters

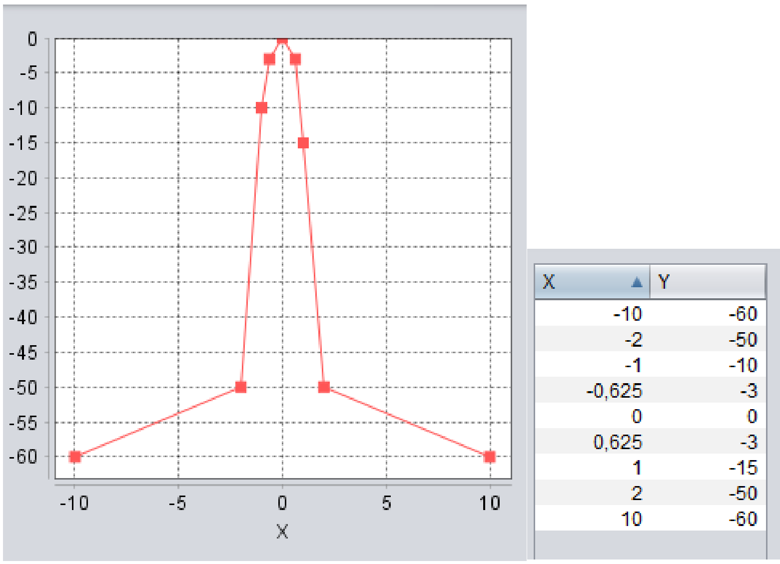
Table 98: UAT characteristics

<table>
<tr><th>Parameters</th><th>Unit</th><th>UAT airborne</th></tr>
<tr><td colspan="3">Transmitter</td></tr>
<tr><td>Frequency range
§12.1.2.1</td><td>MHz</td><td>978 (+/- 0.002%)</td></tr>
<tr><td>Bandwidth
§12.1.2.3.3</td><td>MHz</td><td>1.3 MHz (-20 dB)</td></tr>
<tr><td>e.i.r.p.
§12.1.2.3.2</td><td>dBm</td><td>58 dBm</td></tr>
<tr><td>OOB
§12.1.2.3.3</td><td>N.A.</td><td>



<table>
<tr><th>Offset</th><th>Mask</th><th>Ref. BW</th></tr>
<tr><td>-3,25</td><td>-60</td><td>100</td></tr>
<tr><td>-2,25</td><td>-50</td><td>100</td></tr>
<tr><td>-1</td><td>-18</td><td>100</td></tr>
<tr><td>-0,5</td><td>0</td><td>100</td></tr>
<tr><td>0</td><td>0</td><td>100</td></tr>
<tr><td>0,5</td><td>0</td><td>100</td></tr>
<tr><td>1</td><td>-18</td><td>100</td></tr>
<tr><td>2,25</td><td>-50</td><td>100</td></tr>
<tr><td>3,25</td><td>-60</td><td>100</td></tr>
</table>

</td></tr>
<tr><td colspan="3">Receiver</td></tr>
<tr><td>Frequency range
§12.1.2.1</td><td>MHz</td><td>978 (+/- 0.002%)</td></tr>
<tr><td>Antenna Gain</td><td>dBi</td><td>0 to 4 dBi (RTCA DO-282B)
Assumed Omnidirectional</td></tr>
</table>

Parameters	Unit	UAT airborne
Cable loss	dB	1-3 dB (DOC 9861 [59])
Bandwidth (RTCA DO-282B)	MHz	1.3 MHz (-3 dB)
Noise figure	dB	6 dB
Selectivity For Airbornes	dB	

A6.6.2 Modelling assumptions

The propagation model is Free Space Loss between an airborne platform and PMSE devices used in open-air conditions, therefore omnidirectional without building loss and body loss.

A6.6.3 CONCLUSION

A6.6.3.1 UAT Study to protect the airborne receiver (978 MHz)

The MCL UAT studies investigate the separation distance required and the associated guard band to protect the UAT airborne receiver at 978 MHz.

A6.6.3.2 Impact of audio PMSE transmitter on UAT airborne receiver

The UAT receivers are likely to receive interference from PMSE, which is computed with the hypothesis as follows:

Table 99: Calculation of separation distance to protect airborne UAT from PMSE interference

Parameters	Parameter values
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (3 PMSE within 1 MHz Bandwidth) (dB)	5.91 dB
UAT receiver Noise (dBm)	-106.79 dBm
UAT antenna gain (dBi)	4 dB

Parameters	Parameter values
Cable loss (dB)	1 dB
Safety Margin (dB)	6
Interference Level allowed (dBm)	-121.79 dBm (I/N = -6 dB) / -127.79 dBm (I/N = -10 dB)
Requested Attenuation (dB)	144.70 dB (I/N = -6 dB) / 148.70 dB (I/N = -10 dB)
FSL Distance Separation required at 968 MHz	419,53 km (I/N = -6 dB) / 664,91 km (I/N = -10 dB)
Radio Horizon (Flight level 600)	587 km

According to the study, a separation distance of 419.53 km (I/N=-6 dB) or 664.91 km (I/N = -10 dB) is needed in order to protect the LDACS receivers from audio PMSE.

As this distance is very important, the practical separation distance will be limited by the radio horizon. As a plane can flight up to 60000 feet, the separation distance is then 587 km (I/N = -10 dB).

A6.6.3.3 Guard band to protect UAT (978 MHz)

As it is shown by the two precedent tables, cohabitation between PMSE and UAT on the same frequency (978 MHz) is not feasible because of the distance separation which are too much important (419 km and 587 km, respectively for I/N = -6 dB and I/N = -10 dB).

In order to protect both systems, it is important to define a guard band. In this study we will consider that the closest distance between an airborne and an outdoor PMSE will be 1000 feet (around 330 m).

Table 100: Calculation of guard band to protect airborne UAT from PMSE interference

Parameters	Parameter values
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (3 PMSE near the bandwidth edge victim) (dB)	4.77 dB
UAT receiver Noise (dBm)	-106.79 dBm
UAT antenna gain (dBi)	4 dB
Cable loss (dB)	1 dB
Safety Margin (dB)	6
Interference Level allowed (dBm)	-121.79 dBm (I/N = -6 dB) / -127.79 dBm (I/N = -10 dB)
Requested Attenuation (dB)	143.56 dB (I/N = -6dB) / 147.56 dB (I/N = -10 dB)
FSL Attenuation for 330 m at 978 MHz (dB)	82.62 dB
Receiver Selectivity Required (dB)	60.94 dB (I/N = -6 dB) / 64.94 dB (I/N = -10 dB)
Guard band to reach the receiver selectivity (MHz))	10.8 MHz (extrapolation) (I/N = -6 dB) / 14 MHz (extrapolation) (I/N = -10 dB)

According to the receiver selectivity from the study, a guard band of +/-10,8 MHz (I/N = -6 dB) or 14 MHz (I/N = -10 dB) is needed in order to protect the UAT receivers from audio PMSE.

A6.6.3.4 Universal Access Transceiver (UAT) Study to protect PMSE receivers (978 MHZ)

The MCL UAT Study was conducted in order to assess the required separation distance to protect the PMSE receiver at 978MHz.

As the UAT signal is a pulsed signal, the protection criteria for PMSE is assumed to be -105dBm for pulsed interferences. It has to be noted that no additional margin has been included here, therefore this value should be considered as a threshold and not disminished.

Table 101: Calculation of separation distance to protect PMSE from airborne UAT interference

Parameters	Impact of UAT airborne transmitter on PMSE receiver
UAT Airborne e.i.r.p. (dBm) for 1.3 MHz	58 dBm / 1.3 MHz
UAT Airborne e.i.r.p. (dBm) for 0.2 MHz	49.87 dBm / 200 kHz
PMSE protection criteria (dBm)	-105 dBm
Requested Attenuation (dB)	154.87 dB
FSL Distance Separation required (F=978 MHz)	1352 km (in co-channel)
Radio Horizon (Flight level 600)	587 km

According to the study, a separation distance of 1352 km is needed in order to protect the audio PMSE from the UAT transmitters.

As this distance is very important, the practical separation distance will be limited by the radio horizon. As a plane can flight up to 60000 feet, the separation distance is then 587 km.

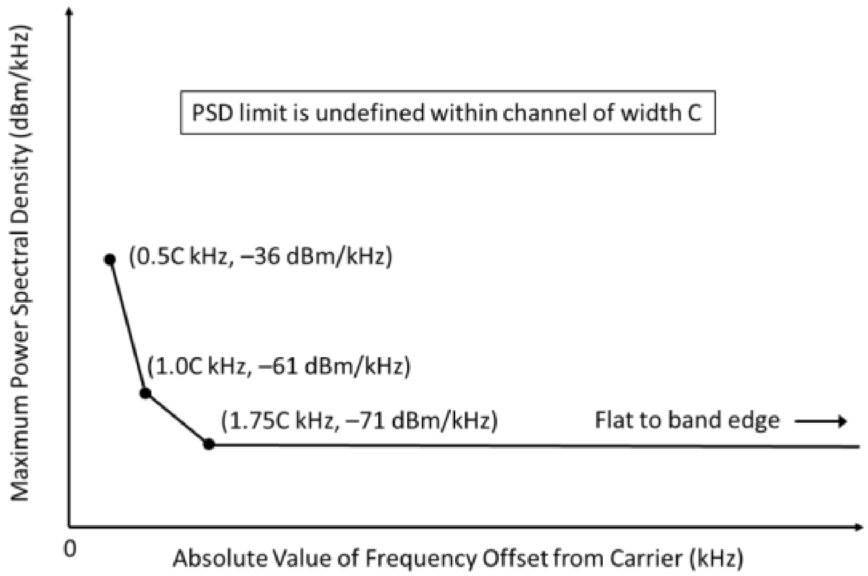
A6.7 CNPC

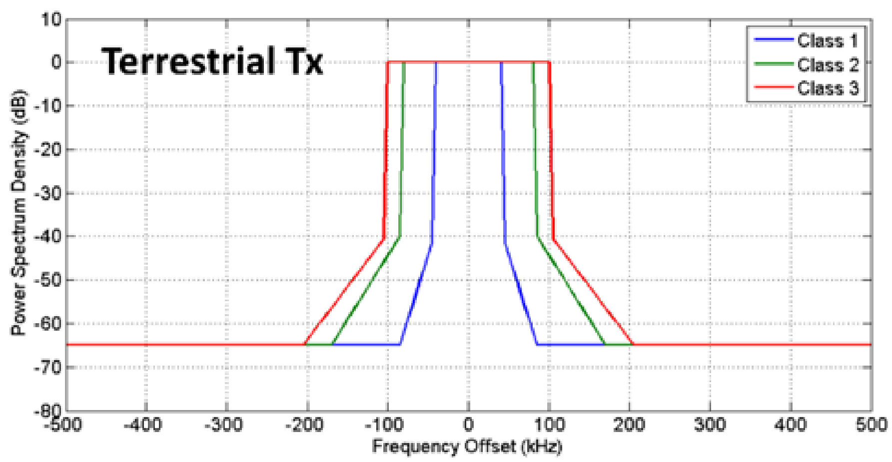
A6.7.1 CNPC parameters

All the parameters come from the RTCA document (DO-362) [65].

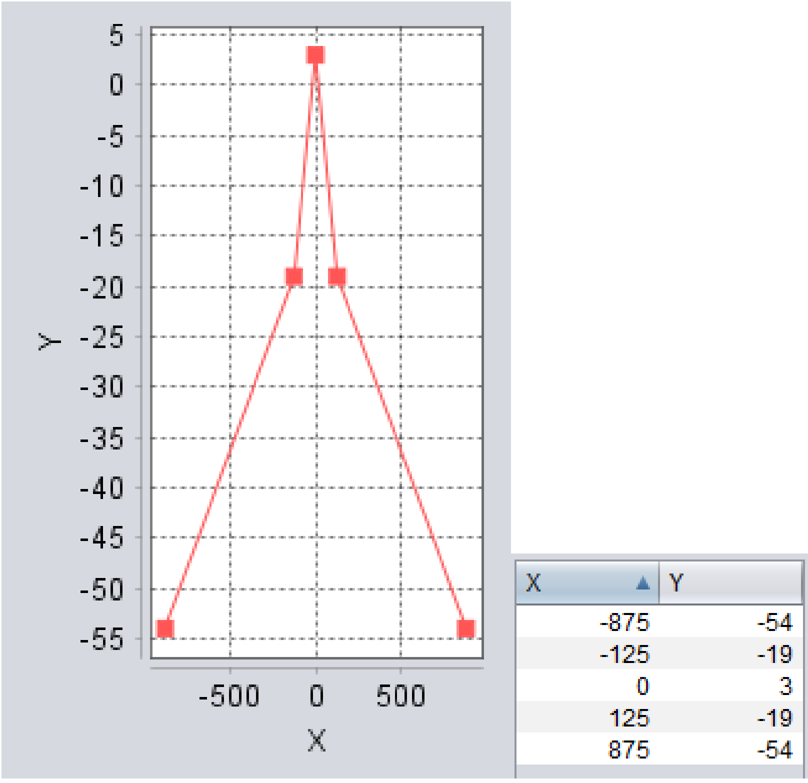
Table 102: UAV CNPC characteristics

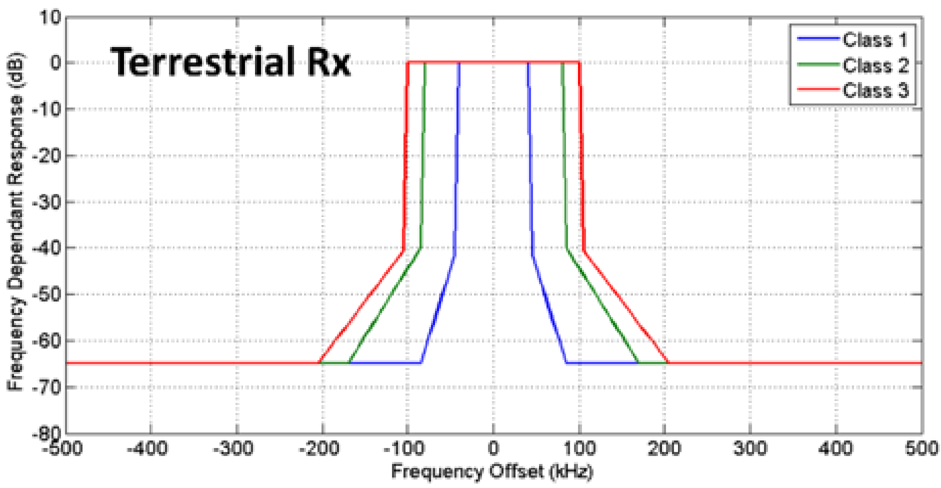
Parameters	Unit	UAV CNPC airborne
Transmitter		
Frequency range	MHz	960-1164
Bandwidth	MHz	0.500
e.i.r.p.	dBm	Range From 15 up to 30 with directional ground antennas Range From 15 up to 37 dBm with omnidirectional ground antennas +/-10% (average during 1 second) [see DO-362 §2.2.2.1.1.1

<table>
<tr><th>Parameters</th><th>Unit</th><th>UAV CNPC airborne</th></tr>
<tr><td>OOB</td><td>N.A.</td><td>




§2.2.1.7.2</td></tr>
<tr><td colspan="3">Receiver</td></tr>
<tr><td>Frequency range</td><td>MHz</td><td>960-1164 (§1.5)</td></tr>
<tr><td>Antenna Gain</td><td>dBi</td><td>Omnidirectional 3 dBi (see DO-362 §2.2.1.6.2.1.1 [65])</td></tr>
<tr><td>Cable loss</td><td>dB</td><td>1 (see DO-362 Table G-8)</td></tr>
<tr><td>Bandwidth</td><td>MHz</td><td>0.500</td></tr>
<tr><td>Noise figure</td><td>dB</td><td>4 (see DO-362 §L.1 4)</td></tr>
</table>

<table>
<tr><th>Parameters</th><th>Unit</th><th>UAV CNPC airborne</th></tr>
<tr><td>Selectivity
§2.2.1.7.2</td><td>dBc</td><td>




</td></tr>
</table>

A6.7.2 Modelling assumptions

The propagation model is Free Space Loss between an airborn platform and PMSE devices used in open-air conditions, therefore omnidirectional without building loss and body loss.

A6.7.3 CONCLUSION

A6.7.3.1 CNPC Study to protect the airborne receiver (between 960-1164 MHz)

The MCL CNPC study aims at establishing the required separation distance to protect the CNPC airborne receiver between 960-1164 MHz.

A6.7.3.2 Impact of audio PMSE transmitter on CNPC airborne receiver

Table 103: Calculation of separation distance to protect airborne UAV CNPC from PMSE interference

Parameters	Value
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (3 PMSE within 1 MHz Bandwidth) (dB)	1.76 dB
CNPC receiver Noise (dBm)	-112.94 dBm
CNPC antenna gain (dBi)	3 dBi
Cable loss (dB)	1 dB
Safety Margin (dB)	6
Interference Level allowed (dBm)	-126.94 dBm (I/N = -6 dB) / -130.94 dBm (I/N = -10 dB)
Requested Attenuation (dB)	145.70 dB (I/N = -6 dB) / 149.70 dB (I/N = -10 dB)
FSL Distance Separation required at 968 MHz	432,67 km (I/N = -6 dB) / 685,74 km (I/N = -10 dB)
Radio Horizon (Flight level 600)	587 km

According to the RTCA document (DO-362) [65], a separation distance of 432.67 km (I/N = -6 dB) or 685.74 km (I/N = -10 dB) is needed in order to protect the CNPC receivers from audio PMSE.

As this distance is very important, the practical separation distance will be limited by the radio horizon. As a plane can flight up to 60000 feet, the separation distance is then 587 km (I/N = -10 dB).

A6.7.3.3 Guard band to protect CNPC (between 960 and 1164 MHz)

As it is shown by the two precedent tables, cohabitation between PMSE and CNPC on co-channel is not feasible because of the distance separation (280 km and 70 km).

In order to protect both systems, it is important to define a guard band. In this study we will consider that the closest distance between an airborne and an outdoor PMSE will be 1000 feet (around 330 m).

Table 104: Calculation of guard band to protect airborne UAV CNPC from PMSE interference

Parameters	Impact of audio PMSE transmitter on UAV airborne
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (2 PMSE near the bandwidth edge victim) (dB)	3 dB
CNPC receiver Noise (dBm)	-112.94 dBm
CNPC antenna gain (dBi)	3 dBi
Cable loss (dB)	1 dB
Safety Margin (dB)	6
Interference Level allowed (dBm)	-126.94 dBm (I/N = -6 dB) / -130.94 dBm (I/N = -10 dB)
Requested Attenuation (dB)	146.94 dB (I/N = -6 dB) / 150.94 dB (I/N = -10 dB)
FSL Attenuation for 330 m at 1062 MHz (dB)	83.34 dB

Parameters	Impact of audio PMSE transmitter on UAV airborne
Receiver Selectivity Required (dB)	63.60 dB (I/N = -6 dB) / 67.60 dB (I/N = -10 dB)
Guard band to reach the receiver selectivity (MHz)	486 kHz (I/N = -6 dB) / 526 kHz (extrapolation) (I/N = -10 dB)

According to the RTCA document (DO-362) [65], a guard band of +/-486 kHz (I/N = -6 dB) or 526 kHz (I/N = -10 dB) is needed in order to protect the CNPC receivers from audio PMSE.

A6.7.3.4 CNPC Study to protect PMSE receiver (between 960-1164 MHz).

The MCL CNPC Study was conducted in order to assess the required separation distance to protect the PMSE receiver between 960-1164 MHz.

As the CNPC signal is a TDD pulsed signal, the protection criteria for PMSE is assumed to be -105 dBm for pulsed interferences. It has to be noted that no additional margin has been included here, therefore this value should be considered as a threshold and not disminished.

Table 105: Calculation of separation distance to protect PMSE from airborne UAV CNPC interference

Parameters	Impact of CNPC airborne transmitter on PMSE receiver
CNPC Airborne e.i.r.p. (dBm) for 500 KHz	39 dBm
CNPC Airborne e.i.r.p. (dBm) for 200 KHz	35.02 dBm
PMSE protection criteria (dBm)	-105 dBm
Requested Attenuation (dB)	140.02 dB
FSL Distance Separation required (F=1062 MHz)	225.39 km (in co-channel)

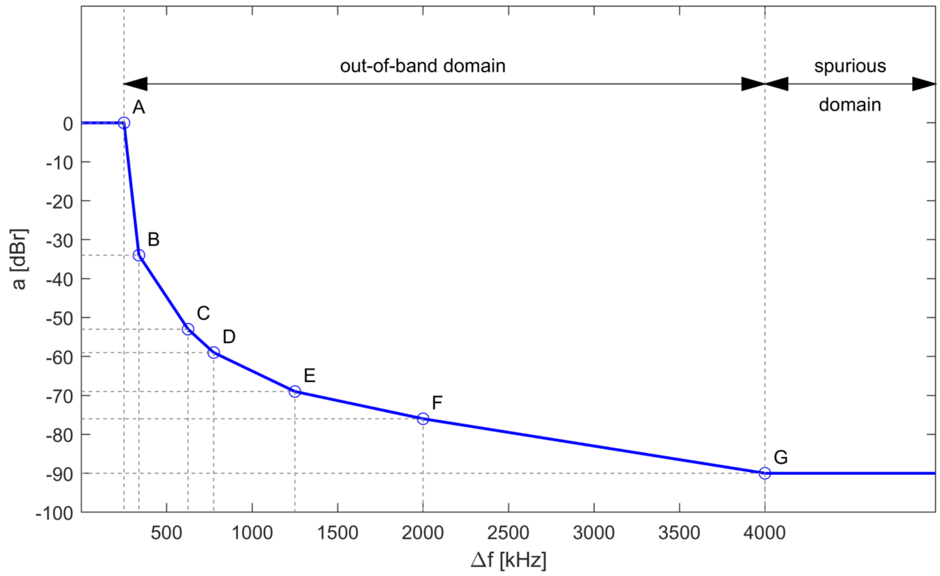
According to the RTCA document (DO-362) [65], a separation distance of 225.39 km is needed in order to protect the audio PMSE from the CNPC airborne transmitters.

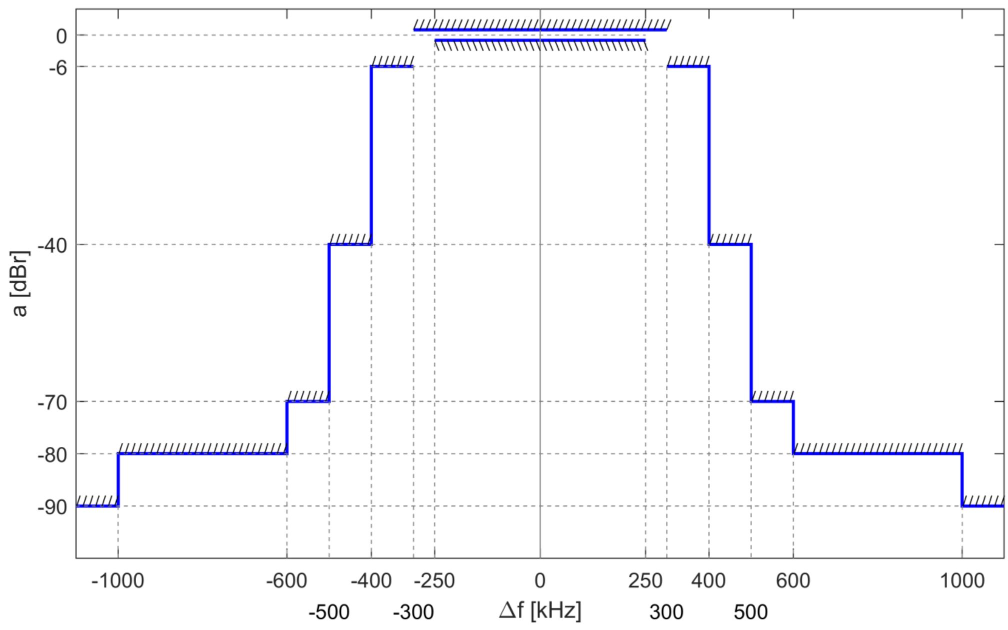
A6.8 LDACS

A6.8.1 LDACS UNDER ICAO CONSIDERATION parameters

Table 106: LDACS characteristics

Parameters	Unit	LDACS airborne receiver and Transmitter
Transmitter		
Frequency range	MHz	964-1010 MHz
Bandwidth	MHz	0.500
e.i.r.p.	dBm	42 dBm

<table>
<tr><th>Parameters</th><th>Unit</th><th>LDACS airborne receiver and Transmitter</th></tr>
<tr><td>OOB</td><td>N.A.</td><td>
</td></tr>
<tr><td colspan="3">Receiver</td></tr>
<tr><td>Frequency range</td><td>MHz</td><td>1110-1156 MHz</td></tr>
<tr><td>Antenna Gain</td><td>dBi</td><td>3</td></tr>
<tr><td>Cable loss</td><td>dB</td><td>3</td></tr>
<tr><td>Dupplexer Loss</td><td>dB</td><td>1</td></tr>
<tr><td>Bandwidth</td><td>MHz</td><td>0.5</td></tr>
<tr><td>Noise figure</td><td>dB</td><td>6</td></tr>
<tr><td>Selectivity</td><td>dB</td><td><table>
<tr><td>Passband Ripple (±250 kHz)</td><td>within ± 1 dB</td></tr>
<tr><td>Attenuation @ ±300 kHz</td><td>> 6 dB</td></tr>
<tr><td>Attenuation @ ±400 kHz</td><td>> 40 dB</td></tr>
<tr><td>Attenuation @ ±500 kHz</td><td>> 70 dB</td></tr>
<tr><td>Attenuation @ ±600 kHz</td><td>> 80 dB</td></tr>
<tr><td>Attenuation @ ±1000 kHz</td><td>> 90 dB</td></tr>
</table></td></tr>
</table>

Parameters	Unit	LDACS airborne receiver and Transmitter
		

A6.8.2 Modelling assumptions

The propagation model is Free Space Loss between an airborne platform and PMSE devices used in open-air conditions, therefore omnidirectional without building loss and body loss.

A6.8.3 CONCLUSION

A6.8.3.1 Impact of PMSE to protect airborne receivers of LDACS between 1110-1156 MHz

The PMSE equipments are assumed to be deployed outdoor, then the free space propagation model is considered.

The airborne antenna gain is up to 3 dBi, the receiver bandwidth is 0.5 MHz and the cable loss is 2 dB (including duplexer loss).

A6.8.3.2 Separation distance to protect the LDACS airborne receiver

Table 107: Calculation of separation distance to protect airborne LDACS receiver from PMSE interference

Parameters	Impact of audio PMSE transmitter on LDACS airborne receiver
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (3 PMSE within 1 MHz Bandwidth) (dB)	1.76 dB
LDACS receiver Noise (dBm)	-110.94 dBm

Parameters	Impact of audio PMSE transmitter on LDACS airborne receiver
LDACS antenna gain (dBi)	3
Cable loss (Duplexer included) (dB)	2
Safety Margin	6 dB
Interference Level allowed (dBm)	-123.94 dBm (I/N = -6 dB) / -127.94 dBm (I/N = -10 dB)
Requested Attenuation (dB)	142.70 dB (I/N = -6 dB) / 146.70 dB (I/N = -10 dB)
FSL Distance Separation required (F=1133 MHz)	287.65 Km (I/N = -6 dB) / 455.90 km (I/N = -10 dB)
Radio Horizon (Flight level 600)	587 km

According to the study, a separation distance of 287.65 km (I/N = -6 dB) or 455.90 km (I/N = -10 dB) is needed in order to protect the LDACS airborne receivers from audio PMSE.

A6.8.3.3 Guard band to protect LDACS airborne receiver

As shown above, cohabitation between PMSE and LDACS on co-channel is not feasable because of the distance separation which are too much important (287 km and 455 km, respectively for I/N = -6 dB and I/N = -10 dB).

In order to protect both systems, it is important to define a guard band. In this study we will consider that the closest distance between an airborne and an outdoor PMSE will be 1000 feet (around 330 m).

It has to be noted that in absence of the PMSE emission mask, this guard band will have to be reviewed.

Table 108: Calculation of guard band to protect airborne LDACS receiver from PMSE interference

Parameters	Impact of audio PMSE transmitter on LDACS airborne receiver
PMSE e.i.r.p (dBm)	17 dBm
Aggregated Effect (2 PMSE near the bandwidth edge victim) (dB)	3 dB
LDACS receiver Noise (dBm)	-110.94 dBm
LDACS antenna gain (dBi)	3
Cable loss (Duplexer included) (dB)	2
Safety Margin	6 dB
Interference Level allowed (dBm)	-123.94 dBm (I/N = -6 dB) / -127.94 dBm (I/N = -10 dB)
Requested Attenuation (dB)	142.70 dB (I/N = -6 dB) / 146.70 dB (I/N = -10 dB)
FSL Attenuation for 330 m (F=1133 MHz) (dB)	83.90 dB
Receiver Selectivity Required (dB)	58.80 dB (I/N = -6 dB) / 62.80 dB (I/N = -10 dB)
Guard band to reach the receiver selectivity (MHz).	>500 kHz (I/N = -6 dB & -10 dB)

According to the ICAO SARPS document, a guard band of >500 kHz (I/N = -6 dB & -10 dB) is needed in order to protect the LDACS receivers from audio PMSE.

A6.8.3.4 LDACS Study to protect PMSE receiver (between 964 and 1010 MHz).

The MCL LDACS Study was conducted in order to assess the required separation distance to protect the PMSE receiver between 964 and 1010 MHz.

As the LDACS signal is a FDD pulsed signal, the protection criteria for PMSE is assumed to be -105 dBm for pulsed interferences. It has to be noted that no additional margin has been included here, therefore this value should be considered as a threshold and not diminished.

Table 109: Calculation of separation distance to protect PMSE from airborne LDACS interference

Parameters	Impact of LDACS airborne transmitter on PMSE receiver
LDACS Airborne e.i.r.p. (dBm) for 500 kHz	42 dBm
LDACS Airborne e.i.r.p. (dBm) for 200 kHz	38.02 dBm
PMSE protection criteria (dBm)	-105 dBm
Requested Attenuation (dB)	143.02 dB
FSL Distance Separation required (F=1062 MHz)	298.42 km (in co-channel)

According to the RTCA document (DO-362) [65], a separation distance of 298.42 km is needed in order to protect the audio PMSE from the LDACS airborne transmitters.

A6.9 JTIDS/MIDS

A6.9.1 Link 16 parameters

Table 110: JTIDS/MIDS (Link 16) characteristics

Parameters	Unit	JTIDS/MIDS ground	JTIDS/MIDS airborne
Transmitter			
Frequency range	MHz	969-1008, 1053-1065, 1113-1206	969-1008, 1053-1065, 1113-1206
Bandwidth	MHz	3	3
Max. TX peak power	dBm	53-60	53-60
Antenna gain	dBi	12 omni 16 directional	5.4
Minimum cable loss	dB	1	1
OOB	N.A.	See below Figure 79	

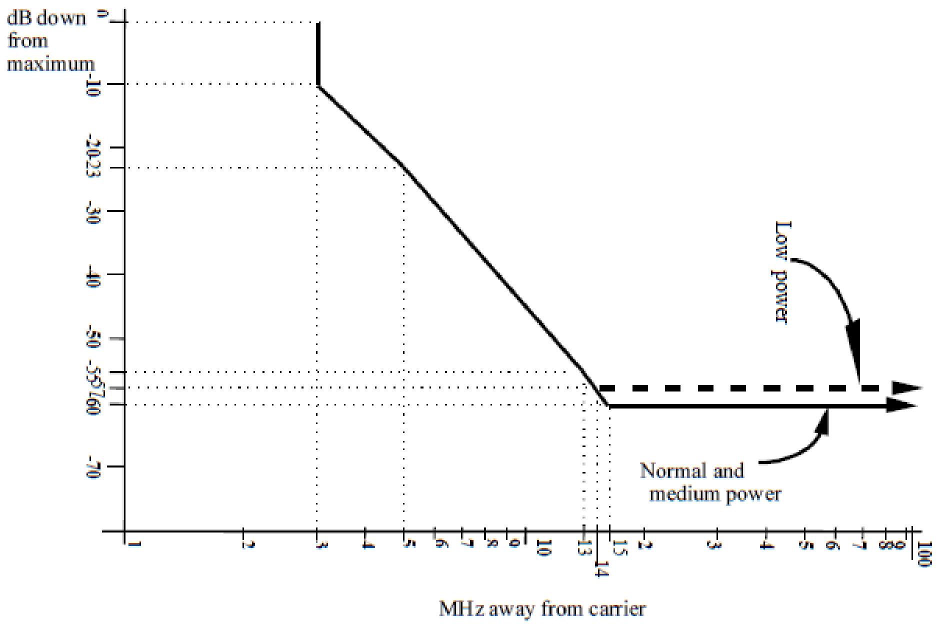


Figure 79: JTIDS/MIDS OOB emission mask

A6.9.2 Modelling assumptions

The propagation model is Free Space Loss between an airborne platform and PMSE devices used in open-air conditions, therefore omnidirectional without building loss and body loss.

A6.9.3 CONCLUSION

A6.9.3.1 Link 16 Study to protect PMSE receiver (969-1008, 1053-1065, 1113-1206)

The MCL Link 16 Study was conducted in order to assess the required separation distance to protect the PMSE receiver between in the three sub-bands operated by military.

In this scenario the only source of interference considered is the JTIDS/MIDS terminal for the military datalink “Link 16” between aircrafts and between aircrafts and ground stations. This conveys tactical orders and short messages for orders, reports and tracking of other mobiles.

As the Link 16 signal is a TDD pulsed signal, the protection criteria for PMSE is assumed to be -105 dBm for pulsed interferences. It has to be noted that no additional margin has been included here, therefore this value should be considered as a threshold and not diminished.

A6.9.3.2 For airborne transmitter of 200 W power for ordinary configuration:

Table 111: Calculation of separation distance to protect PMSE from airborne JTIDS/MIDS (200 W) interference

Parameters	Impact of Link 16 airborne transmitter on PMSE receiver
Link 16 Airborne peak power (dBm) for 3 MHz	53 dBm / 3 MHz
Link 16 Airborne antenna gain (dBi)	5.4 dBi
Cable loss (dB)	1 dB

Parameters	Impact of Link 16 airborne transmitter on PMSE receiver
Link 16 Airborne e.i.r.p. (dBm) for 3 MHz	57.40 dBm
Link 16 Airborne e.i.r.p. (dBm) for 200 KHz	45.63 dBm
PMSE protection criteria (dBm)	-105 dBm
Requested Attenuation (dB)	150.64 dB
FSL Distance Separation required (F=1000 MHz)	>800 km (in co-channel)
Radio Horizon (Flight level 600)	587 km

According to the RTCA document (DO-362) [65], a separation distance greater than 800 km is needed in order to protect the audio PMSE from the Link 16 ordinary airborne transmitters. As this distance is very important, the practical separation distance will be limited by the radio horizon. As a plane can flight up to 60000 feet, the separation distance is then 587 km.

A6.9.3.3 For airborne transmitter of 1000 W power for specific configuration:

Table 112: Calculation of separation distance to protect PMSE from airborne JTIDS/MIDS (1000 W) interference

Parameters	Impact of Link 16 airborne transmitter on PMSE receiver
Link 16 Airborne peak power (dBm) for 3 MHz	60 dBm / 3 MHz
Link 16 Airborne antenna gain (dBi)	5.4 dBi
Cable loss (dB)	1 dB
Link16 Airborne (dBm) for 3 MHz	64.40 dBm
Link16 Airborne E.I.R.P. (dBm) for 200 KHz	52.63 dBm
PMSE protection criteria (dBm)	-105 dBm
Requested Attenuation (dB)	157.64 dB
FSL Distance Separation required (F=1000 MHz)	>1500 km (in co-channel)
Radio Horizon (Flight level 600)	587 km

According to the RTCA document (DO-362) [65], a separation distance greater than 1500 km is needed in order to protect the audio PMSE from the Link16 specific airborne transmitters. As this distance is very important, the practical separation distance will be limited by the radio horizon. As a plane can flight up to 60000 feet, the separation distance is then 587 km.

A6.9.3.4 Impact of JTIDS/MIDS on Audio PMSE

Even assuming an indoor use with the maximum wall attenuation of 20 dB, the separation distance would remain more than 150 km for 1 kW and more than 80 km for 200 W.

Based on the results in the previous table covering a large range of parameters, and considering that JTIDS/MIDS operates in fast frequency hopping mode all over the frequency band 960-1164 MHz (except 1030/1090 guards), the protection of audio PMSE cannot be ensured from JTIDS/MIDS on aircraft.

A6.10 GNSS

A6.10.1 Parameters

Table 113: RNSS Parameters

RNSS Receive typeee	Air-navigation	General-purpose
RNSS Receive mask	Report ITU-R M.2235 [56] Figure 8 (Aeronautical receiver)	Gaussian Filter Bandwidth 20.5 MHz
RNSS Centre frequency (MHz)	1176.45	1176.45
RNSS Bandwidth (MHz)	24	24
RNSS Gain (dBi)	-5	3
RNSS Receiver temperature (K)	727	330

A6.10.2 Modelling assumptions

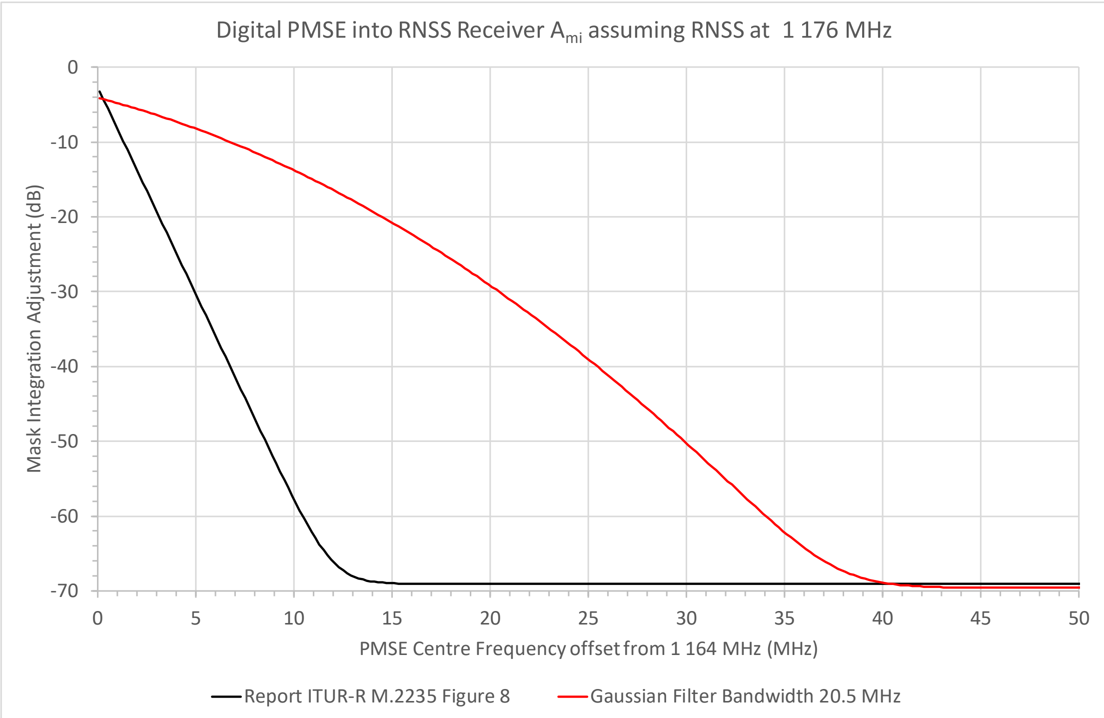


Figure 80: Integration of PMSE Digital Mask with RNSS Receiver Mask

A6.10.3 Conclusion

Table 114: Results - Required Guard Band (MHz)

RNSS Receiver Type	Guard Band
General-purpose	31 MHz
Air-navigation	12 MHz

The conclusion is that a guard band of 30 MHz would be required to protect RNSS receivers (for both General purpose and air navigation).

A6.11 OTHER SYSTEMS (LONG-TERM CNS)

CNS system are planned to be developed under ICAO standards to cover the following functions: Communication, Navigation and Surveillance.

There are currently no technical details about this future system but it is planned to be used in all the width of the frequency band 960-1164 MHz.

ANNEX 7: PMSE SELECTIVITY IN PRESENCE OF JTIDS/MIDS PULSES FROM NARFA DEU

A7.1 SUMMARY

This contribution investigates the possible use of low power audio PMSE (excluding airborne use) in the aeronautical frequency band 960-1164 MHz, considering the influence on PMSE receivers of incumbent systems' emissions, in this case: JTIDS/MIDS.

Because of being focused on the impact on PMSE, only PMSE receiver's parameters become relevant, no user equipment's parameters have to be taken into account.

PMSE's standard[39] signal power level was determined by measuring each PMSE receiver's sensitivity and increase it by +3 dB, yielding -90 dBm for two devices and -91 dBm for the third.

Although the scenario is based on outdoor use, a theoretical interpretation of the results has also been done for indoor use assuming a building entry loss (BEL) of 20 dB.

Additionally, a theoretical interpretation of the results has also been done for PMSE operating with a +20 dB higher signal power level than the above PMSE's standard[40] signal power level.

Owing to poor availability of professional PMSE equipment operating at the focused band, professional PMSE equipment operating in frequency bands near that band had to be used. In doing so it was kept in mind that the equipment had to operate with comparable parameters.

The results as shown in Table 115 indicate – regarding the impact of JTIDS/MIDS only – that it would be possible to use PMSE equipment sharing JTIDS/MIDS systems in co-channel or adjacent channel scenarios as long as a minimum separation distance to those JTIDS/MIDS systems is assured.

With respect to a single JTIDS/MIDS channel a minimum frequency separation can be calculated for sharing the band.
In the case of PMSE complying with the minimum frequency separation and in conjunction with the distributed use of channels by JTIDS/MIDS it would require PMSE to operate near 1030 MHz or 1090 MHz.
But in an overall view on the band's utilization, including the defined guard bands and other application's frequency usage, no appropriate frequency is left for selection.

Table 115: Summary

PMSE, interferred by JTIDS/MIDS		Option 1	Option 2
Scenario	Parameter	Minimum separation distance (LoS)	Minimum frequency separation
PMSE outdoor	Standard signal power level (-90 dBm / -91 dBm)	300 km (analogue) 400 km (digital)	7 MHz, but no appropriate frequency in an overall view, due to band's heavy utilization
	+20 dB signal power level (-70 dBm / -71 dBm)	30 km (analogue) 40 km (digital)	

39 "Standard" in the meaning of "used as reference within this study"

40 "Standard" in the meaning of "used as reference within this study"

PMSE, interferred by JTIDS/MIDS		Option 1	Option 2
Scenario	Parameter	Minimum separation distance (LoS)	Minimum frequency separation
PMSE indoor	Standard signal power level (-90 dBm / -91 dBm)	30 km (analogue)[41] 40 km (digital)	
BEL=20 dB	+20 dB signal power level (-70 dBm / -71 dBm)	3 km (analogue) 4 km (digital)Error! Bookmark not defined.	

A7.2 PMSE PARAMETERS

The interference of the PMSE links depend on the PMSE receiver's selectivity, i.e. to recognize the wanted signal and to be able to process it without misinterpretation, but not on the parameters of the wanted signal's transmitter.

Therefore, the PMSE user equipment (with respect to its parameters, e.g. body loss) has not been taken into account. Furthermore, no IEM - even though containing a receiver - has been taken into account, too.

PMSE links are recognised as undisturbed if a SINAD of at least 40 dB is assured (see A7.2.4).

There is a poor availability of PMSE equipment operating at 960-1160 MHz.
Thus, professional PMSE systems operating in other frequency bands near to 960-1164 MHz were chosen to be studied instead (see Table 116).

Table 116: PMSE equipment used for measurement

PMSE device under test (DUT)	Modulation	Frequency	
Sennheiser G4	FM	823-865 MHz	tested at 864.5 MHz
Sennheiser D6000/9000	PI/4-QPSK; 64-DAPSK	630-718 MHz	tested at 630.0 MHz
Shure QLX-D	8-PSK	823-865 MHz	tested at 864.5 MHz

A7.2.1 PMSE receiver Parameters

The devices under test (DUT) have been measured for their reception threshold (see A7.9.3.6.).

It was decided to use a SINAD threshold of 40 dB (see A7.2.3) and an integration duration of 2 ms for determining the SINAD. For comparison, also the SINAD for an integration duration of 1 ms is calculated.

For the measurement (see A7.9.3 a wanted signal level has been used corresponding to a level 3 dB above the threshold of the DUT's receiver. These low signal levels in the range of -90 dBm will occur for short time spans in real situations, e.g. due to shadowing from moving persons or fading effects of the radio channel.

---

[41] Theoretical distance only, some buildings comply to assumed BEL, others not.
'LoS' between interferer and building rather than the victim.

A7.2.2 Parameters of body loss

No body loss has been taken into account.

A7.2.3 Parameter for building loss

Building loss has been assumed neither for the PMSE link itself nor for the interference measurement which is based on an outdoor scenario!

Nevertheless, for interpretation purpose the separation distances may be recalculated for indoor use. Considering ITU-R publication [34] for the indoor use scenario a median building entry loss (BEL) at frequencies around 1000 MHz of 13 dB (traditional buildings) or 28 dB (thermally-efficient buildings) could be taken into account. For the recalculation a value for the BEL of 20 dB has been assumed.

A7.2.4 Criteria for audio transmission error

There are different threshold criteria used at which a PMSE link is said to be disturbed:

- Referring to ETSI, a SINAD value of 30 dB is demanded generally to satisfy the needs of professional audio applications (see SE7(18)121 [35], Table 12.2: Continuous phenomena, minimum performance criteria).
- The APWPT demands a value of at least 40 dB for professional audio.
  This value has been used in SINAD calculation on the measured data (see A7.9.3.6 . And A7.9.3.9).
- From the activities of CEPT SE7 regarding PMSE a proposal of a SINAD value of more than 50% of the undisturbed link was derived (see Table 117, where this was used to determine the undisturbed SINAD).

Table 117: Devices under test (DUT) and their undisturbed SINAD value

PMSE radio link	RF-level at RX	SINAD without interferer
DUT-A (digital)	-91 dBm	68 dB
DUT-B (digital)	-90 dBm	78 dB
DUT-C (analogue)	-91 dBm	60 dB

Note: The PMSE radio links have different SINAD values in the undisturbed state. As even under ideal transmission conditions, the SINAD value of the tested analogue DUT is 8 dB / 18 dB below that of the examined digital DUTs, setting the threshold to 50% of the undisturbed case favours the analogue system.

As the deciding factor for disturbance is the ratio between the levels of the wanted and the interfering signal, the results can easily be scaled to situations where the wanted signal is stronger. To cause the same disturbances, the level of the interfering signal has to be increased by the same factor as the wanted signal.

A7.3 PROPAGATION MODEL

Both, JTIDS/MIDS (interferer) and PMSE (victim) are assumed to be used outdoor.

Airborne JTIDS/MIDS transmitters are considered as focal point, because of their unpredictable occurrence and emission's impact on PMSE.

In doing so, the propagation model for aeronautical mobile and radionavigation services using the UHF band (ITU-R P.528) would be suitable.
For the line-of-sight scenario a more simplified approach is free space propagation (ITU-R P.525,253 which has been used.

A7.4 DME

Not studied.

A7.5 SSR – 1030 MHZ AND 1090 MHZ SYSTEMS

Not studied.

A7.6 UNIVERSAL ACCESS TRANSCEIVER (UAT)

Not studied.

A7.7 CNPC

Not studied.

A7.8 LDACS

Not studied.

A7.9 JTIDS/MIDS

Data transfer with JTIDS/MIDS yields a pulsed emission using frequency hopping.

A7.9.1 Parameters

A7.9.1.1 Pulse and emission characteristics.

Each JTIDS/MIDS pulse contains a continuous phase shift modulated (CPSM) carrier during 6.4 µs followed by a dead time during 6.6 µs as shown in Figure 81 (see [39], page 2-48).

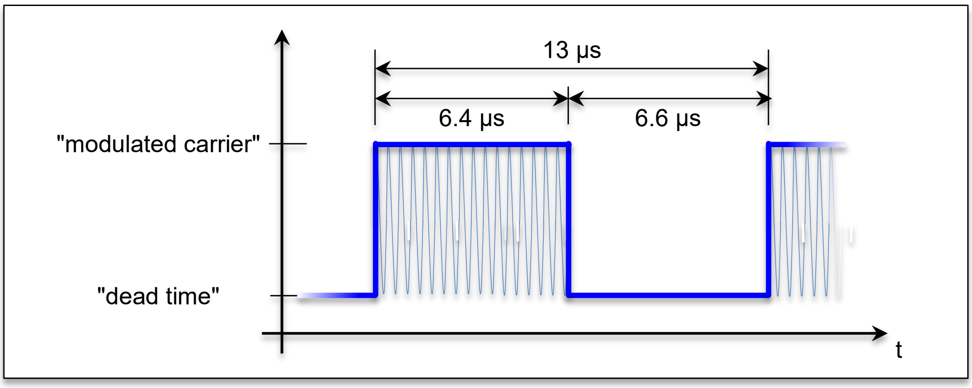


Figure 81: JTIDS/MIDS pulse, basic characteristics

As a requirement (see [38], AP1.3.5.1.) every JTIDS/MIDS pulse must comply with the spectral mask (in-band) featuring a -10 dB signal level at ± 3 MHz to its carrier frequency, a -23 dB level at ± 5 MHz , a -55 dB level at ± 13 MHz and a -60 dB level at ± 15 MHz (see [39]). These requirements shall apply between 920 MHz and 1266 MHz.

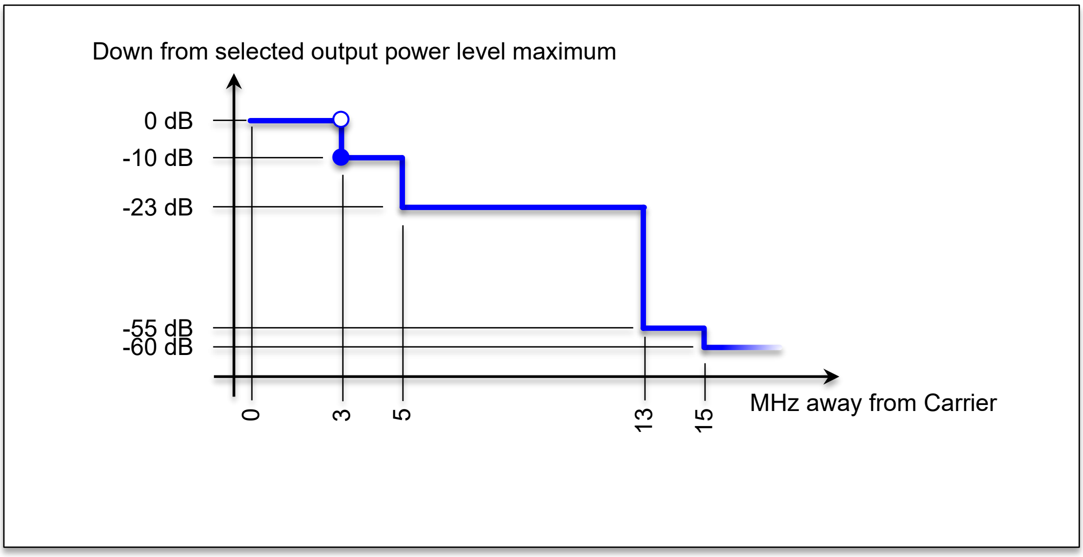


Figure 82: JTIDS/MIDS pulse, power spectral mask requirement (in-band)

In [38] AP1.3.6., out-of-band-emission characteristics are defined: "Except for the second and the third harmonics, the OOB harmonics and all other spurious emission below 920 MHz and above 1266 MHz shall be at least 80 dB down from the level at the fundamental. The second and third harmonics shall be suppressed 50 + 10 log p (where p = peak power output in watts at the fundamental) or 80 dB, whichever requires less suppression. These out-of-band emission requirements shall apply for each selected power level."

A7.9.1.2 Frequency usage

As summarised in [39] on page 2-51 "Link 16 operates in the 960-1215 MHz band, with JTIDS/MIDS frequencies occurring every 3 MHz between 969 and 1206 MHz."
To protect IFF at 1030 MHz and TCAS at 1090 MHz these frequencies are excluded for the use by JTIDS/MIDS (see Understanding Voice Data Link Networking, Northrop Grumman [38], AP1.4.2.1.2. and also [39] page 2-51) leaving 51 frequencies in the band segments 969 MHz to 1008 MHz, 1053 MHz to 1065 MHz and 1113 MHz to 1206 MHz to be assigned to JTIDS/MIDS.

Frequency hopping, which is an essential part of every operational JTIDS/MIDS link, is done after each pulse (see [39], page 2-48.).

JTIDS/MIDS systems have to ensure a uniform distribution of all transmitted pulses over the 51 assigned frequencies within a so called 'JTIDS/MIDS frame' with a duration of 12 s (see Understanding Voice Data Link Networking, Northrop Grumman [38] AP1.4.2.1.4.).

A7.9.1.3 Transmitters

With regard to the output power several possible modes and relating restrictions are mentioned in [38] (AP1.3.2. and 1.3.3.). Power levels of more than 200 W are allowed as long as all EMC requirements are met. There are products available with output power up to 1 kW.
For calculation of separation distances in a co-channel and adjacent channel scenario, an output power of 400 W (as stated in the German FCA [40], chapter 2.2.2) has been taken into account.
For peak output power of up to 1 kW the appropriate increase in power has to be applied to upscale the separation distances provided in this document.

Additionally, the ground station's transmit power differs slightly only and so does not change the situation significantly.

A7.9.2 Modelling assumptions

A7.9.2.1 Propagation model for JTIDS/MIDS transmission

Since this study shall provide information about the possibilities of using audio PMSE in erratic vicinity of JTIDS/MIDS transmitters, the ground stations of JTIDS/MIDS have not been taken into account. This is because of the ground stations not being mobile and thus their interference direction being predictable.

"You certainly know where it is… only you don't know exactly at what time and frequency it emits."

Airborne JTIDS/MIDS transmitters are truly erratic interferers, because they may emit from any point in space (APIS) and with nearly every orientation with respect to the PMSE victim.
Furthermore due to mission requirements the interferer's course mustn't be assumed to be straight, hence interferer's signal strength has to be expected very variable and thus unpredictable.

"You certainly don't know where it is nor do you know at what time or frequency it emits."

And so, free space propagation is used.

A7.9.2.2 Pseudo JTIDS/MIDS – interferer signal

Two different interferer signals were generated for the sensitivity tests.

- Interfering signal 1 "all slots" represents a theoretical worst-case scenario.
  - All available "pulse slots" (13 µs duration, see Figure 81) are occupied by pseudo JTIDS/MIDS pulses without any guard intervals (theoretical TSDF of 233%).
  - There is no frequency hopping.
  - The pulse sequence contains 65536 (216) random JTIDS/MIDS pulses and is about 0.82 s long.
- The interference signal 2 "1in30 slots" emulates a more realistic JTIDS/MIDS signal.
  Although no real frequency hopping takes place here either, the hopping is taken into account by reducing the pulse density.
  - The number of JTIDS/MIDS channels (bandwidth: approx. 5 MHz, channel spacing: 3 MHz) that can have an impact on a 200 kHz wide PMSE channel is determined. It can be assumed that only four of the 51 JTIDS/MIDS channels are relevant (see e.g. Figure 95). Therefore, the number of pulses from the interfering signal 1 can be reduced by a factor of 4/51.
  - Furthermore, the interfering signal 1 also has an unrealistic Time Slot Duty Factor (TSDF) of 233%. This circumstance is taken into account by reducing the number of pulses to a TSDF of 100%.
    Remark: The TSDF is formally calculated over one frame of length 12 s. Transmitting airborne terminals will usually send one packet within one time-slot of length 7,8125 ms and then switch to receive mode for the following time-slots, resulting in an average TSDF of less than 100%. As the frames of digital PMSE systems are typically in the range of 1 ms to 2 ms, however, the relevant interference energy is occurring within one JTIDS/MIDS time-slot, and here the temporary TSDF is 100% for standard packets.
  - The total number of pulses can therefore be reduced by a factor of 30 (4/51 * 100/233 → 1/30).
  - In order to generate such a signal, blocks with 30 pulse slots each were used. For each block, exactly one random pulse was placed in a random pulse slot. If the pulse by chance falls into the first pulse slot, it is dropped, because in a real hopping pattern the direct neighbouring channel is never used. The finally generated signal contains about 2100 random JTIDS/MIDS pulses and is also about 0.82 s long.

A7.9.2.3 Further modelling aspects

By using TDMA only one transmitter is allowed to emit at a time within a JTIDS/MIDS net. Hence overlay of a single net's signals need not to be taken into account.

Overlay of different JTIDS/MIDS nets may occur. Ground stations of those additional JTIDS/MIDS nets are ordinarily not placed in vicinity. Thus impact of the net nearer to the PMSE victim will dominate and the

influence of the one more far away may be neglected.
A possible overlay of airborne JTIDS/MIDS systems using different JTIDS/MIDS nets would enlarge the impact on PMSE, but has also not been taken into account.

JTIDS/MIDS systems use frequency hopping, which in reality leads to an occupancy of each JTIDS/MIDS channel every now and then, but by definition having a uniform distribution over all used JTIDS/MIDS channels within each 'JTIDS/MIDS frame' (duration of 12 s).

A7.9.3 Test Method

A7.9.3.1 SINAD Measuremente

The SINAD (Signal to Noise and Distortion) measurement is a common method for evaluating transmission quality.

$$SINAD = \frac{P_{signal}+P_{noise}+P_{distortion}}{P_{noise}+P_{distortion}}$$

However, standard implementations are not directly suitable for pulsed interferers like the JTIDS/MIDS signal with pulse durations in the microsecond range. For example, measuring equipment like the Rohde&Schwarz Audioanalyzer UPV cannot measure the SINAD precisely for audio durations significantly below one second.

Thus, Dr. Müller from DFS has developed a modified version of the SINAD measuring method. The integration duration for the SINAD calculations is in the range of the frame length of PMSE (1 ms / 2 ms). It is suitable for digital and analogue systems ([37]).

A single SINAD value is calculated here by fitting an ideal sine signal to a segment of the recorded audio signal, where the segment length corresponds to the integration time. Only the amplitude is taken into account, but not a possible frequency drift.

The algorithm is based on QR decomposition and requires an audio recording of any length and the expected frequency of the sine tone (typically: 1 kHz) as input.

Figure 83shows exemplary a recorded test signal in black and the fitted reference signal in grey color. The difference between the two signals is shown in red.

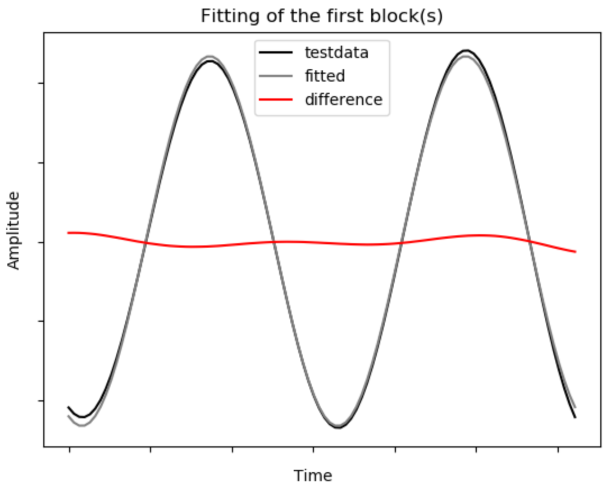


Figure 83: Fitting of recorded sine tone

A7.9.3.2 Criteria for audio transmission error

For details about the assumptions defining a disturbed PMSE link, see A7.9.3.2 Interferer signal

For details about the creation of the JTIDS/MIDS signal, see A7.9.2.2.

A7.9.3.3 Test Setup

The measurements were made in a shielded chamber to avoid external influences.

The R&S UPV Audio Analyzer generates a test tone of 1 kHz and feeds it into the audio input of the DUT's transmitter (TX). The transmitter generates a PMSE radio signal that is transmitted via coaxial cable.

A variable attenuator allows fine tuning of the signal level. This allows, among other things, to determine the reception threshold of the receiver.

In the following combiner, the interfering signal from the pseudo JTIDS/MIDS generator is added to the wanted PMSE signal. The combined signal is split up in order to forward it to the PMSE receiver (RX) and to a Spectrum- and Signal Analyzer for monitoring purposes. Because of the PMSE RX being directly connected to the combiner, no diversity mechanism within the RX is able to r7educe the interference.

The receiver generates an audio signal from the radio signal, which is recorded in the UPV. Subsequently, an evaluation takes place on a remote control computer.

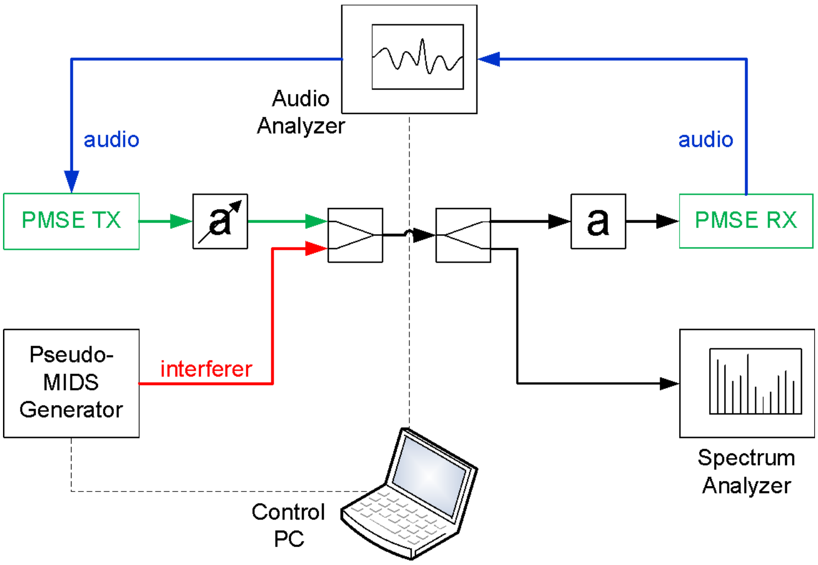


Figure 84: Test setup block diagram

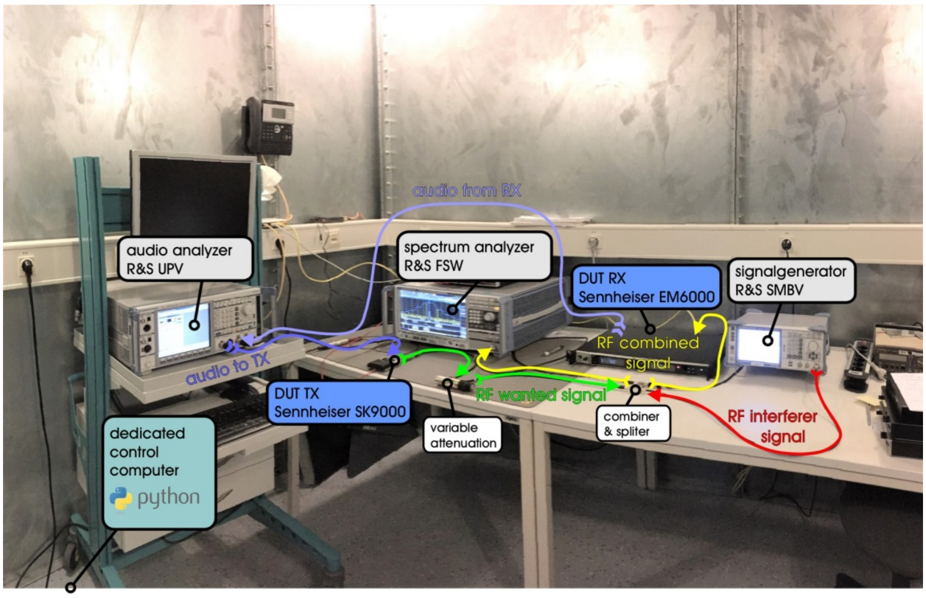


Figure 85: Test chamber

A7.9.3.4 Test procedure

A7.9.3.5 Step 1 - determining reception threshold

For the tests, the reception threshold of the respective DUT is determined. To determine the reception threshold, the variable attenuation in the test setup is continuously reduced, starting from a very high value, until the SINAD value is above the threshold of 40 dB for 60 minutes. During this procedure no explicit interferer is present. The reception is limited only due to thermal noise at room temperature.

A7.9.3.6 Step 2 - setting level for wanted signal

When the reception threshold for the DUT is found, the wanted signal level for the measurements is set to 3 dB above this threshold for digital systems and 10 dB for analogue systems according to [36]. For this, the variable attenuation is reduced by 3 dB or 10 dB, respectively.

A7.9.3.7 Step 3 - testing

The selectivity test begins with an orientation test, for which one second long measurements are done for the entire parameter space.

The frequency of the interferer is varied in the range of ± 11 MHz around the PMSE signal's center frequency of in steps of 1 MHz. The interferer level is then increased from practically zero in steps of 3 dB.

Note: The interferer level of the pseudo JTIDS/MIDS generator is subsequently related to a 200 kHz wide PMSE channel. The conversion factor between a 5 MHz wide JTIDS/MIDS signal and a 200 kHz wide PMSE signal used here is -14 dB (= 10*log10(200/5000)). The components used between the pseudo JTIDS/MIDS generator using an Rohde&Schwarz SMBV and the DUT receiver were calibrated in advance so the offset between the generator level reading and the interferer level directly at the receiver is determined.

The audio signal from the DUT receiver is then recorded and stored as a file for following calculations.

A7.9.3.8 Step 4 - calculating based on measured data

For each generated audio file, the SINAD values are calculated for an integration time of 1 ms (SBerr = Single Block Error) and 2 ms (MBerr = Multi Block Error). An example is shown in Figure 86

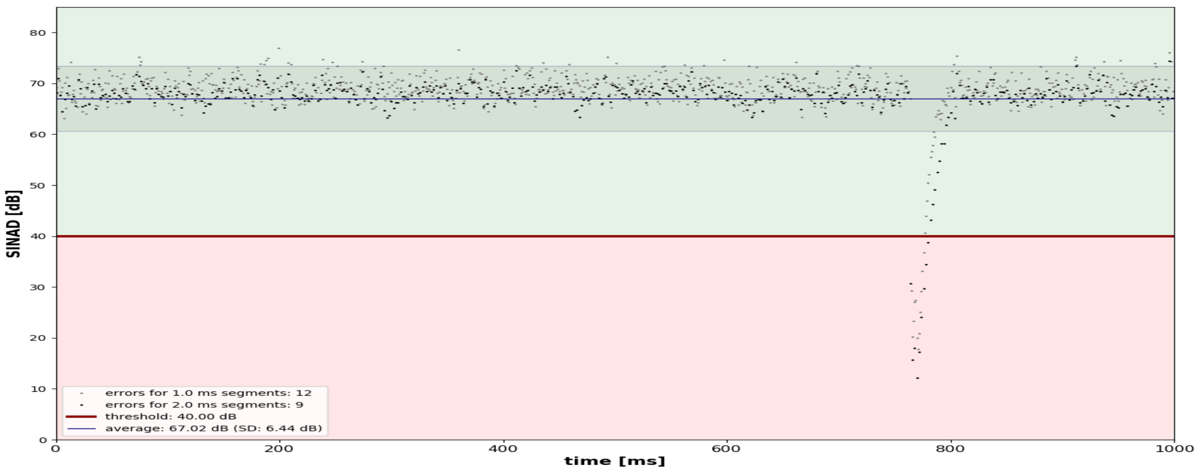


Figure 86: Exemplary SINAD plot

A7.9.3.9 Step 5 - aggregating the results

In a further processing step, the results of the individual measurements are combined to form a selectivity plot as shown in the Figure 87

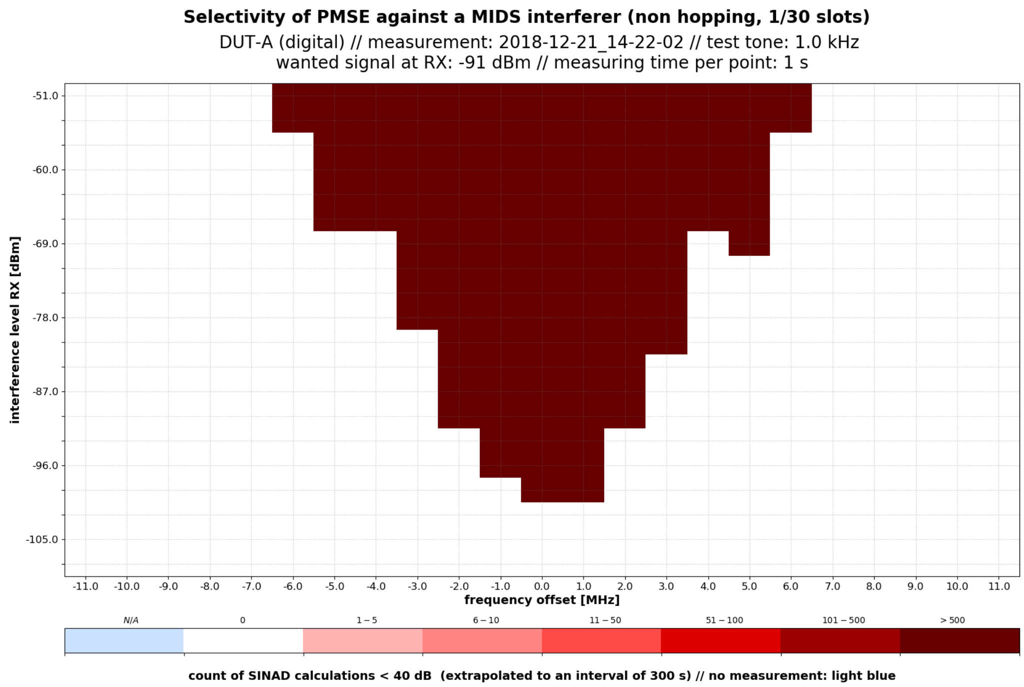


Figure 87: Exemplary result within the orientation test

A7.9.3.10Step 6 - repeat the testing steps making the precision test

In order to obtain reliable results, the measurement duration must be increased significantly from the one second for the orientation test. Measurements with different measurement durations have shown that measurement durations of 10 minutes represent a good compromise between precision and time expenditure.[42]

[42] Note that during the tests it happened that an audio error occurred only after a measurement duration more than 3 hours, meaning that to ascertain an absolute error-free PMSE link, 10 minutes measurement duration is not sufficient.4

For the precision test, the step size for increasing the interferer level was reduced to 1 dB. The generated file from the orientation test with the rough position of the interference threshold makes it possible to significantly reduce the test time during precision testing, as a large number of measurements in the parameter space can be omitted because the expected result corridor can be estimated before the test. The procedure for the precision test is the same as for the orientation test. The generated result files have the same format, so a precision test can be used as the basis for an even more precise test.

shows an example of the results of the precision tests.

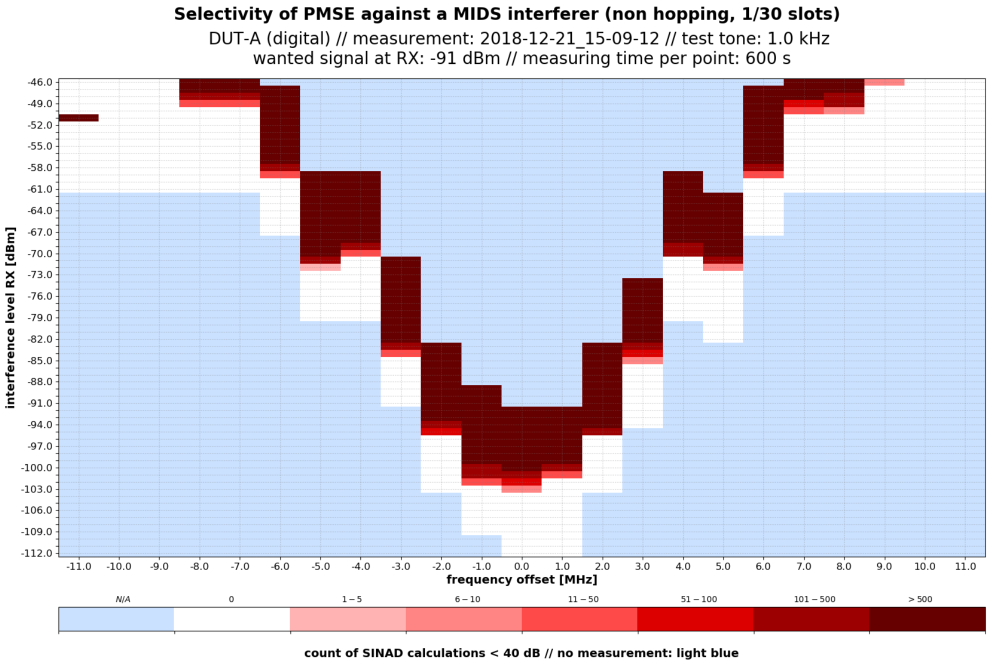


Figure 88: Exemplary result within the precision test

A7.9.4 Test Results

A7.9.4.1 DUT audio behavior

It has been found that errors (SINAD values below the threshold of 40 dB) often occur time-correlated as disturbance events. It is assumed that this is because the digital systems detect transmission errors and mute their audio output accordingly, to slowly increase the audio level again afterward. This usually leads to several low SINAD values in series, becoming continuously better. Figure 89 shows the audio recording and Figure 90 the corresponding SINAD plot for such a disturbance event.

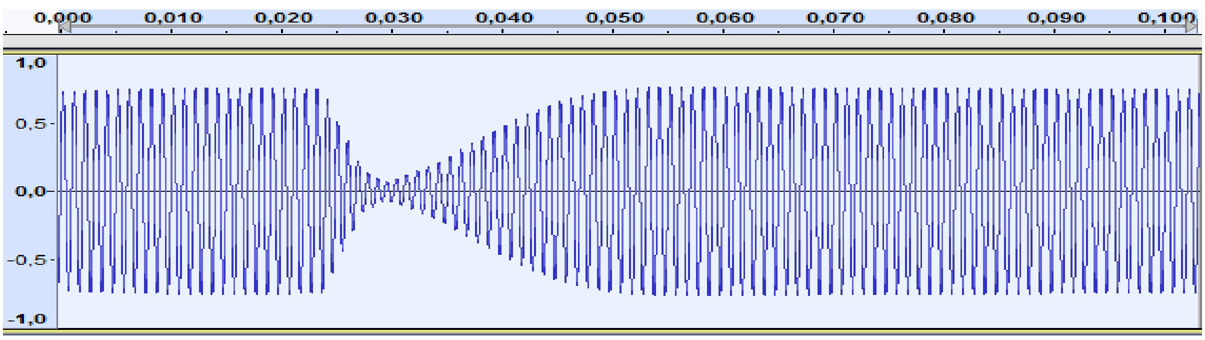


Figure 89: Audio recording during a disturbance event

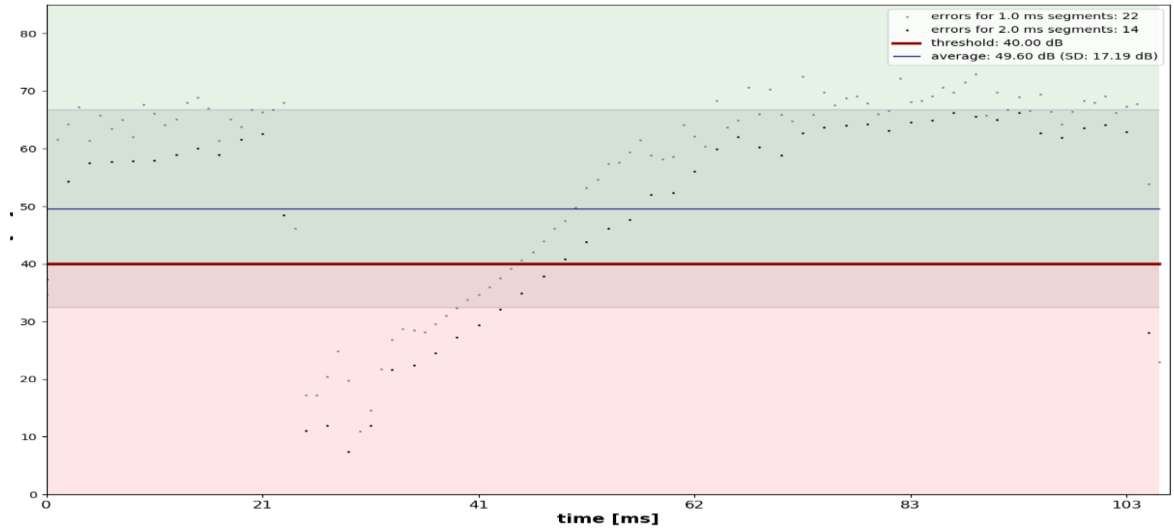


Figure 90: SINAD values during the disturbance event from the above figure

A7.9.4.2 Dependency on measurement duration

The graphs in Figure 91 show a selectivity plot for the DUT-A (digital) for different measurement durations. The signal 1 "all slots" is used as interference signal.

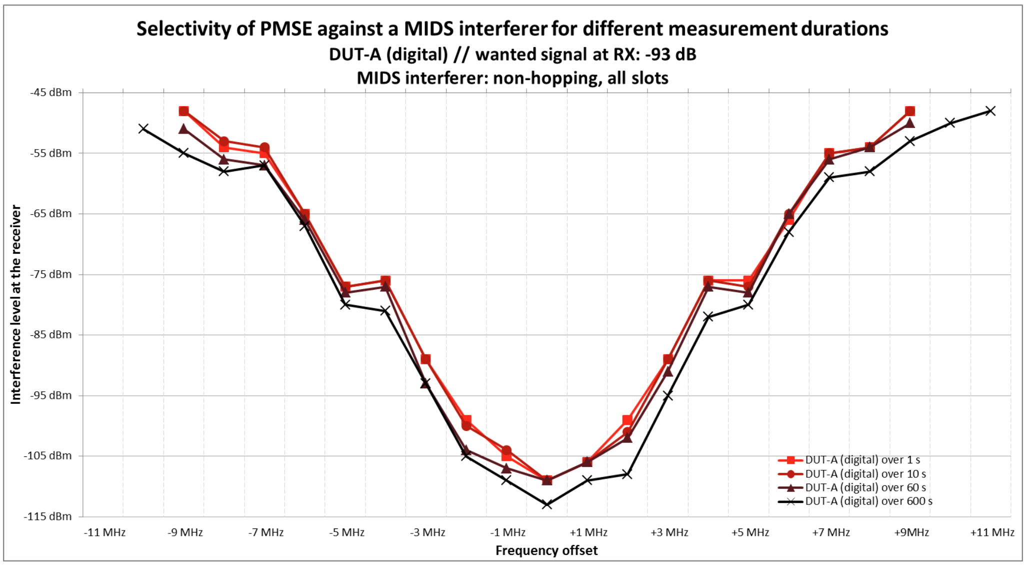


Figure 91: Selectivity of PMSE depending on measurement duration

The difference between a measurement duration of 1 s and 10 s is negligible. Between 1 s and 1 min the difference is about 2 dB. A longer measurement duration leads to a higher sensitivity against interference. The comparison between a measurement duration of 1 s and 10 min results in a difference of 4 dB.

A7.9.4.3 Dependency on pulse density

In the following, the DUTs are examined with regard to their sensitivity for different pulse densities.

As shown in the following figure, the DUT-A (digital) is more sensitive to the all-slots signal than the 1in30 signal by 7 dB with the same measurement duration of 10 min. If the measurement duration for the all-slots signal is shortened to 20 s, the number of pulses is identical for the signal 1in30 with 10 min measurement duration. However, it turns out that the sensitivity of the DUT-A (digital) to the short all-slots interferer signal is also 5 dB higher than that of the 1in30 signal.

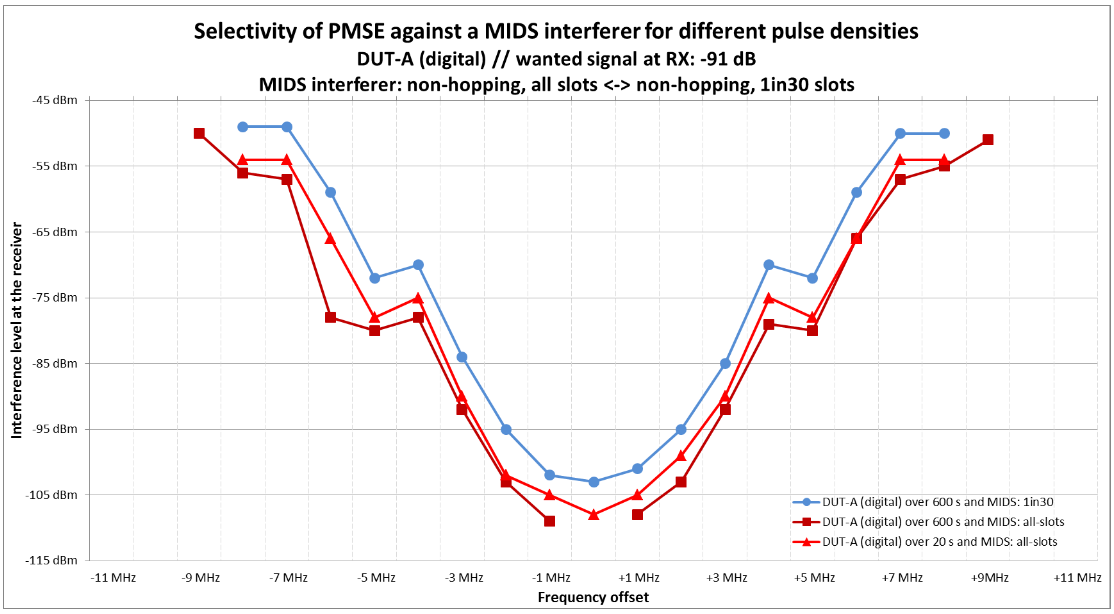


Figure 92: Selectivity of the DUT-A (digital) depending on pulse density

The interferer sensitivity of the DUT-B (digital), on the other hand, is largely independent of pulse density. The sensitivity of the DUT-B (digital) to the all-slots signal is only 1 dB higher than that to the 1in30 signal with the same measurement duration of 10 min.

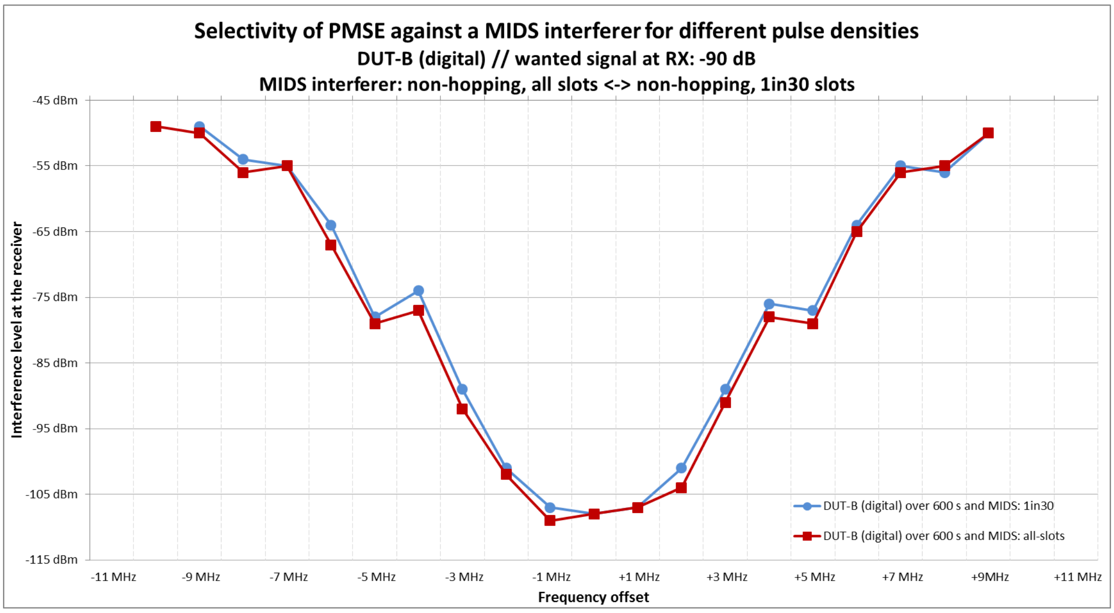


Figure 93: Selectivity of the DUT-B (digital) depending on pulse density

For the DUT-C (analogue), the pulse density has no effect on the selectivity. In total, the difference between the two tested pulse sequences is 0 dB.

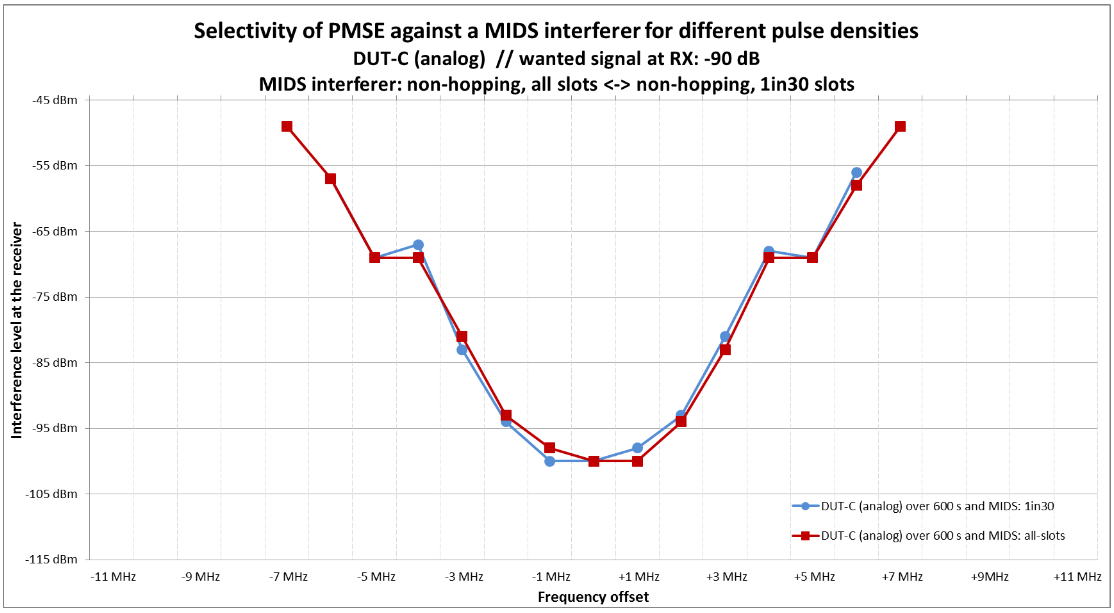


Figure 94: Selectivity of the DUT-C (analogue) depending on pulse density

A7.9.4.4 Comparison of DUTs

Figure 95 shows, for different DUTs, the level of a JTIDS/MIDS interferer, referenced to a bandwidth of 200 kHz, at which the first disturbances of the PMSE link occur, versus the frequency offset between the PMSE link and the interferer (signal 1in30 slots). It can be seen that:

- the DUT-B (digital) is the most sensitive; the difference to DUT-A (digital) is 3 dB,
- the DUT-C (analogue) proves to be the most robust; the difference to the DUT-B (digital) is 8 dB.

Note that the wanted signal level for the different DUTs varies by 1 dB.

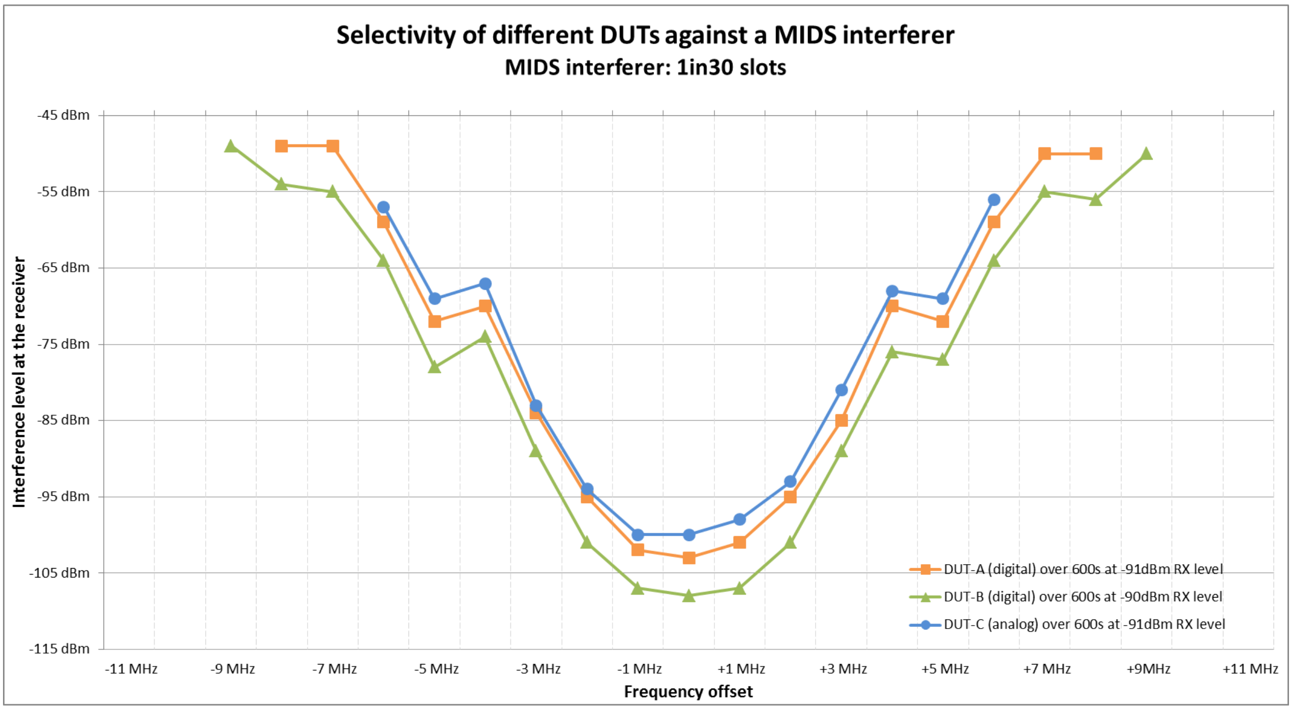


Figure 95: Selectivity of DUTs against a JTIDS/MIDS interferer

A7.9.4.5 Interferer level and distance

The next diagram shows the interference levels from Figure 95 converted into distances. For calculation of the corresponding distance the following parameters are assumed:
Interferer TX power: 400 W e.i.r.p., free space propagation loss at 1 GHz, PMSE RX antenna gain: 0 dBi

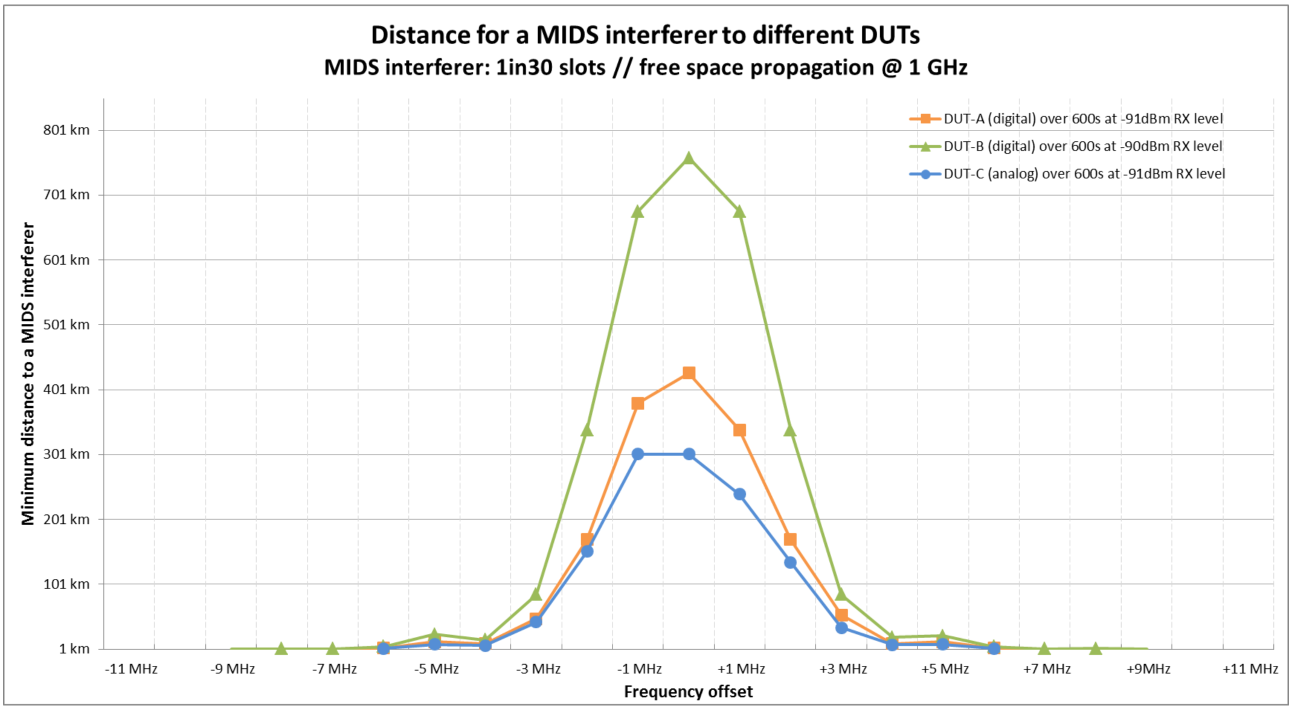


Figure 96: Distance between a JTIDS/MIDS interferer and DUTs corresponding to the interferer levels the above figure

A7.9.4.6 Summary of observations

The results are dependent of the measuring duration. duration of 10 minutes represents a good compromise between accuracy and effort. It is slightly optimistic though as there is some probability that an error would occur after the 10 minute measurement duration.

The different DUTs behave differently towards a JTIDS/MIDS interferer.

The interference sensitivity of the DUT-B (digital) is higher than that of the DUT-A (digital). Most robust is the DUT-C (analogue).

The DUT-A (digital) responds more sensitively to a higher pulse density than the DUT-B (digital).
In contrast, the DUT-C (analogue) behaves almost independent of the pulse density.

No analysis was done if, or to what extent, the manufacturer's techniques of error concealment have an influence on the tests carried out.

A7.9.5 Interpretation

The following interpretations are based on the plots from Figure 95 and Figure 96:

- The digital PMSE links are rather sensitive to interference. First disturbances in the PMSE link occur at a signal-to-interference ratio (in 200 kHz bandwidth) of 12 dB for the DUT-A (digital) and 18 dB for the DUT-

B (digital), corresponding to JTIDS/MIDS levels 12 dB and 18 dB below the wanted PMSE signal level at the receiver[43];

- This means that, assuming free space propagation with a clear line-of-sight to an aircraft with an active JTIDS/MIDS and 400 W e.i.r.p., the PMSE link gets disturbed already from a distance of about 300 km for the analogue DUT and of about 400 km and 750 km respectively for the digital ones (see Figure 96);
- For most cases, in this distance range there will be no direct line-of-sight to aircraft at usual flight levels. However, if there is an aircraft with an active JTIDS/MIDS within line-of-sight to a PMSE link, the PMSE will get disturbed with a very high probability;
- The curves of Figure 95 are measured using a wanted signal level of -91 dBm (DUT-A, digital) and -90 dBm (DUT-B, digital), corresponding to a level 3 dB above the threshold of the PMSE receiver. In practice, the PMSE links are operated at higher signal levels.
  According to the APWPT, though, these low signal levels in the range of -90 dBm will occur for short time spans also in real situations, e.g. due to shadowing from moving persons or fading effects of the radio channel.
  If one assumes nevertheless that the wanted signal level always is maintained at 20 dB above the value assumed for Figure 95, thus at -71 dBm and -70 dBm respectively, the interference level also has to be correspondingly higher to cause disturbance.
  With free space propagation, that change of +20 dB for the signal level means reducing the distance by factor 10. Instead of 300 km, 400 km and 750 km, the first disturbances would occur at distances of 30 km, 40 km and 75 km respectively.
  In practice this also means that generally every aircraft in line-of-sight with an active JTIDS/MIDS will cause disturbance of the PMSE link;
- Disregarding a potential frequency remapping[44], there are no frequency ranges within the Air Band which are not used by the hopping JTIDS/MIDS waveform except the protection zones around the SSR frequencies 1030 MHz (transponder interrogation) and 1090 MHz (transponder reply). Omitting those, the optimum frequencies for a PMSE link are the ones exactly between the JTIDS/MIDS channels with their 3 MHz spacing, thus at 1.5 MHz offset to the JTIDS/MIDS centre frequencies.

  In the curves of Figure 95and Figure 96, this offset corresponds to points between 1 MHz and 2 MHz frequency offset. The interference level for disturbance at this offset is about -98 dBm and -104 dBm, respectively for the digital DUTs, the distance about 272 km and 500 km.

  Again, with a reduction by factor 10 for a PMSE link operating at 20 dB more wanted signal level, the distances are around 27 km and 50 km.
  Thus, due to the broadband nature of the JTIDS/MIDS signals, using frequencies exactly between the JTIDS/MIDS channels for PMSE links improves only marginally on the interference liability.
  Also in this case, any aircraft with active JTIDS/MIDS in line-of-sight means disturbance of the PMSE;
- When trying to ensure that an aircraft within line-of-sight and a flight altitude above e.g. 1500 m does not cause disturbances, according to Figure 95 a frequency separation of at least 7 MHz is required. This would require PMSE to operate in the defined guard bands between 960 MHz to 962 MHz, 1015 MHz to 1045 MHz or 1075 MHz to 1105 MHz.

  As documented in the measurements by DFS [37] the segments between 1045 MHz and 1075 MHz and 1105 MHz to 1150 MHz have to be considered entirely in use by DME- and (A/A-) TACAN-interrogators (and -transponders), because aircraft operate and transmit at any time, at any place down to 100 feet AGL as mission requires. Signal strength up to and exceeding -40 dBm outdoor and -50 dBm indoor have been measured, which also requires that the wide spectrum of SSR and IFF transmissions centred on 1030 MHz and 1090 MHz ± 3 MHz are taken into account.

  Hence, this frequency separation can hardly be achieved;
- The situation is different when the PMSE link is operated indoors. The additional attenuation however is strongly dependent of the building properties and can range from nearly 0 dB (uncoated glass windows)

[43] Note: The signal-to-interference level can be read from the curves in Figure 95 by subtracting the interference level at a certain frequency offset from the signal level of the wanted signal as stated in the plot legend.

[44] JTIDS/MIDS frequency remapping is simplified a manually defined set of JTIDS/MIDS channels, that have to be omitted by a certain JTIDS/MIDS net.

to more than 40 dB (steel reinforced concrete over several floors).
Assuming a median BEL of 20 dB would reduce the found separation distances by factor 10.
In practice, it can probably not be ensured that the BEL is always sufficient to prevent disturbances.

A7.9.6 Conclusion

It has to be assumed that PMSE links using equipment investigated here, or similar, get disturbed as soon as an aircraft with active JTIDS/MIDS is within line-of-sight.
This is also the case for JTIDS/MIDS ground stations, whose slightly different transmit power and antenna pattern does not change the situation significantly.

With respect to JTIDS/MIDS interferer only, a separation by a frequency offset by ± 7 MHz or more to JTIDS/MIDS centre frequencies would require PMSE to operate near the SSR channels 1030 MHz and 1090 MHz.

In an overall view a separation by a frequency offset by ± 7 MHz or more to JTIDS/MIDS centre frequencies in the Air Band is not possible because such frequencies for PMSE would be in the defined guard bands. Transmission from aircraft DME-, (A/A-) TACAN-interrogator (and -transponder) and the wide spectrum of SSR and IFF transmissions centered on 1030 MHz and 1090 MHz ± 3 MHz are additional signals that need to be taken into account, since aircraft signal strength up to and exceeding -40 dBm outdoor and -50 dBm indoor have been measured [37].

A7.10 GNSS

Not studied.

A7.11 OTHER SYSTEMS

Not studied.

ANNEX 8: IMPACT OF PMSE IN THE BAND 960-1164 MHZ ON RNSS ABOVE 1164 MHZ FROM TRANSFINITE

A8.1 SUMMARY

This study investigates the adjacent band sharing scenario of PMSE operating within the band 960-1164 MHz with Radio Navigation Satellite Service (RNSS) receivers above 1164 MHz. This document describes the Galileo RNSS system, the parameters assumed for each system, the methodology used and the results.

The analysis suggests that a guard band of 30 MHz below 1164 MHz would be required to protect the RNSS from out-of-band emissions from PMSE operating in the band 960-1164 MHz.

This Annex investigates the adjacent band sharing scenario of PMSE operating within the band 960-1164 MHz with Radio Navigation Satellite Service (RNSS) receivers above 1164 MHz. This scenario is shown graphically in the figure below:

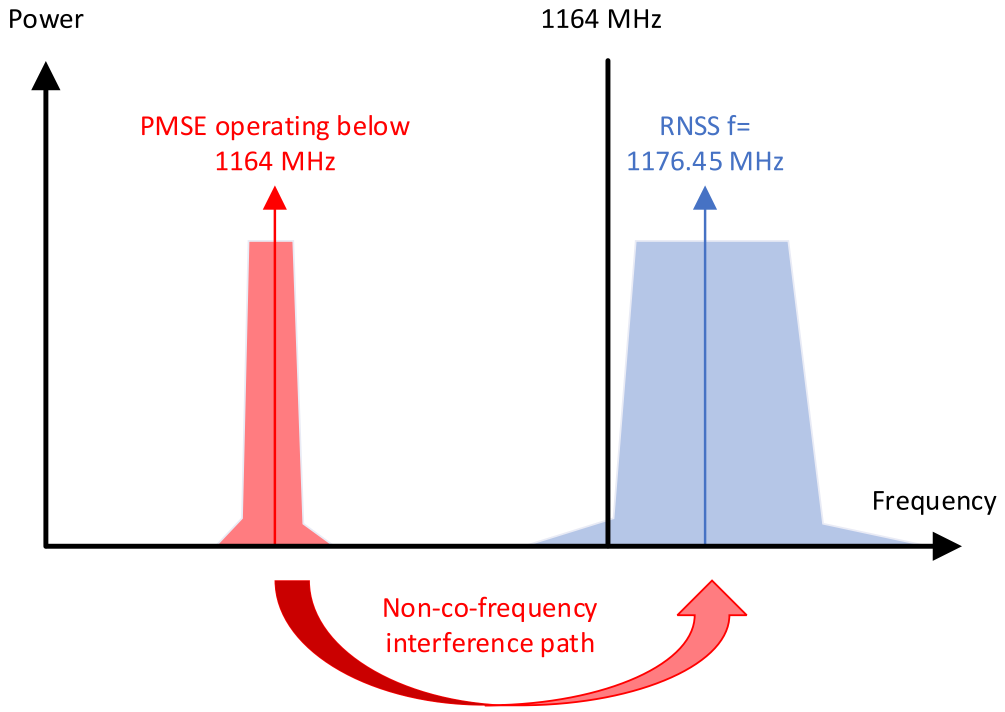


Figure 97: PMSE in 960-1164 MHz Adjacent Band Sharing Scenario with RNSS operating above 1164 MHz

RNSS satellites operate at altitudes of over 20000 km and hence the received signal is extremely weak with a threshold value of -155.25 dBW. Therefore, even though PMSE transmitters are relatively low power, there is the potential for harmful interference unless spectrum management techniques such as a guard band are employed.

RNSS has become essential for a very wide range of services, user groups and communities with many business and operations relying on its ubiquitous and continuous availability. This has been achieved by spectrum managers ensuring that this band is relatively clear of interference, so it can be used for the designated purpose.

This study analysed what spectrum measures would be required to continue to ensure that RNSS can provide a continuous and ubiquitous service to a range of user communities.

The analysis suggests that a guard band of 30 MHz below 1164 MHz would be required to protect the RNSS from out-of-band emissions from PMSE operating in the band 960-1164 MHz.

Table 118: Summary

PMSE interference into RNSS systems	Minimum co-frequency separation distance (Ground Receiver)	Minimum co-frequency separation distance (Air Receiver)	Guard band
PMSE interference to RNSS	n/a	n/a	30 MHz

This study did not consider the potential for interference due to intermodulation or the impact of PMSE on GNSS repeaters.

A8.2 PMSE PARAMETERS

The tables below show parameters for the PMSE assumed for this study. Four types were considered, namely:

- Body-worn;
- Hand-held;
- IEM with downtilt;
- IEM without downtilt.

It was noted that a key assumption of this study was that the bandwidth of the PMSE would be 200 kHz rather than other bandwidths (e.g. wideband). Use of wideband systems would result in a significant increase in adjacent band interference and hence require larger guard bands.

Table 119: Parameters for hand-held audio PMSE

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253 [57]

Table 120: Parameters for body-worn audio PMSE

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253 [57]
Antenna transmit height	m	1.5	ECC Report 253
Antenna receive height	m	n/a	
Body effect	dB	9.4	ECC Report 286 [27]
Modelled e.i.r.p	dBm	17	ERC/REC 70-03, Annex 10 [28]
Antenna polarisation	NA	n/a	ECC Report 253[57]

Table 121: Parameters for audio IEM with downtilt

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253
Antenna transmit height	m	2	

Parameter	Unit	Value	Reference
Maximum antenna gain	dBi	8	
Maximum e.i.r.p.	dBm	17	
Modelled antenna gain	dBi	0	
Modelled e.i.r.p	dBm	9	
Antenna polarisation	NA	n/a	

Table 122: Parameters for audio IEM with no downtilt

Parameter	Unit	Value	Reference
Bandwidth (BW)	MHz	0.2	ECC Report 253 [57]
Antenna transmit height	m	2	
Maximum antenna gain	dBi	8	
Maximum e.i.r.p.	dBm	17	
Modelled antenna gain	dBi	8	
Modelled e.i.r.p	dBm	17	
Antenna polarisation	NA	n/a	

The source of parameters was in most cases ECC Report 253.

Note that the transmit power and gain were not used: all the calculations were based upon e.i.r.p.

It was noted that ECC Report 253 stated that:

"The usual configuration for IEM transmitter antennas is to mount them above the stage at a height of at least 2 metres. IEM transmitting antennas on the stage are then angled down towards the stage at approximately 45º."

The phrase "usual configuration" implies that in other configurations there could be other geometries. Hence to ensure that all configurations have been studied a separate IEM option without this downtilt was also considered.

The body loss was calculated from ECC Report 286 [27] using a central frequency of 1154 MHz and the following equations as the proposed methodology (discussed later) was to be minimum coupling loss (MCL):

Hand-held Audio PMSE: Min. Body Effect [dB] = 0.0015 dB/MHz * F [MHz] – 8.5239 dB

Body-worn Audio PMSE: Min. Body Effect [dB] = -0.0049 dB/MHz * F [MHz] - 3.7769 dB

The body loss was used for horizontal paths but not high elevation paths as the data in ECC Report 286 was based upon measurements in the horizontal plane not vertical plane.

Note that the body loss in ECC Report 286 [27] was defined as being the difference between a dipole and PMSE equipment in the presence of a human body. To use this directly would require information about the transmit power and gain pattern of the PMSE device. However, during type approval (and this study) the typical constraint is the maximum permitted e.i.r.p. Hence a range of transmit powers and gains could be feasible while remaining consistent with this e.i.r.p. constraint. In order to use the Report 286 data, it was assumed that the hand-held and body-worn PMSE devices had antennas that could be modelled as dipole and hence the body loss gain could be added to the e.i.r.p.

The spectrum masks for analogue and digital audio PMSE systems are given in the figure below taken from ETSI EN 300 422 [25].

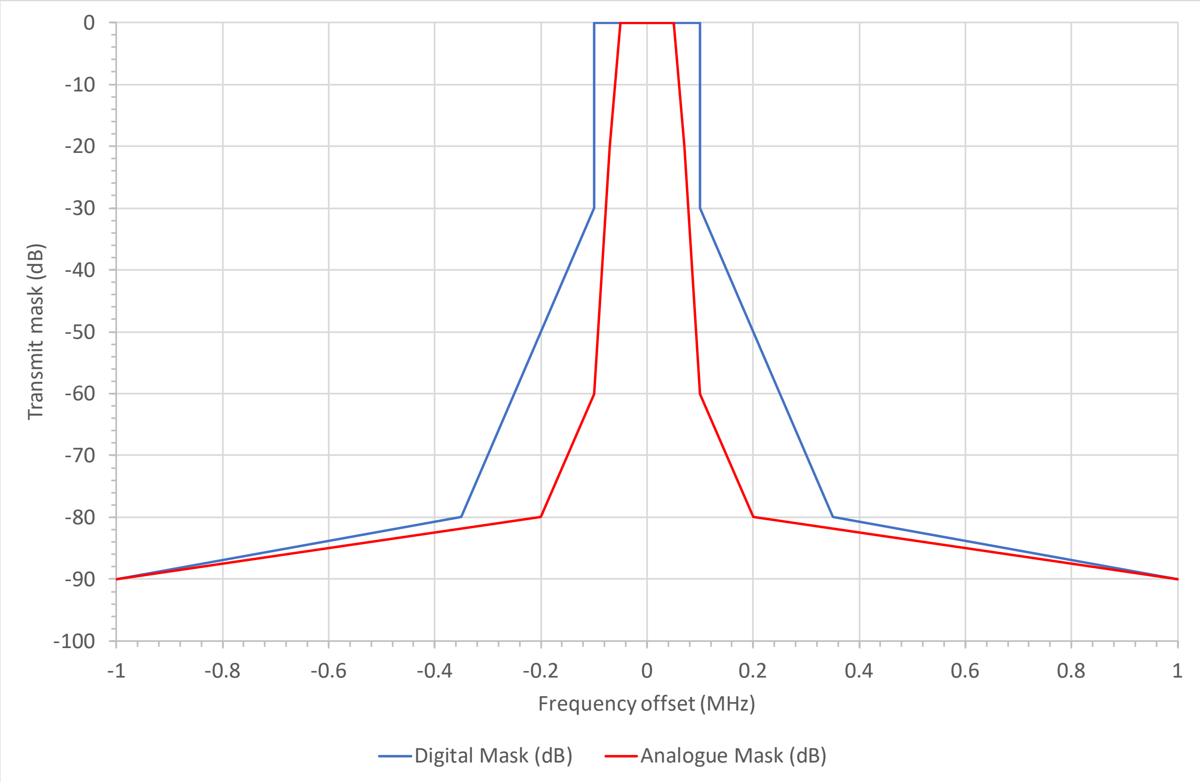


Figure 98: PMSE Transmit Spectrum Masks The digital mask was used in this study

It was noted that the spurious emission level in ETSI EN 300 422 appeared to be higher than the edge of the mask values (e.g. -54 dB vs. -90 dB) but it was assumed for the mask integration (described below) that the mask continued into the spurious domain with value as at the edge of the mask (e.g. -90 dB). It was felt that this was a valid assumption given the bandwidth of the RNSS signal was over 20 MHz and typically spurious emissions are narrow-band spikes.

A8.2.1 PMSE receiver Parameters

Not applicable for this study.

A8.2.2 Parameters of body loss

The body loss information is given in the tables above on PMSE parameters.

A8.2.3 Parameter for building loss

The building loss is given in the propagation section below.

A8.3 PROPAGATION MODEL

The scenarios considered (as described in the Modelling Assumptions section) all involved short distances, which is typical for adjacent band sharing scenarios. For these paths the appropriate propagation model is free space path loss with the potential for additional losses such as:

- Building entry loss (where applicable): 10 dB;
- Rural clutter loss (where applicable): 11.6 dB;
- Urban clutter loss (where applicable): 23.3 dB.

The clutter loss was calculated using Recommendation ITU-R P.2108 using the height-gain model with rural obstruction height = 5 m and urban = 15 m.

A8.4 DME

Not studied.

A8.5 SSR – 1030 MHZ AND 1090 MHZ SYSTEMS

Not studied

A8.6 UNIVERSAL ACCESS TRANSCEIVER (UAT)

Not studied

A8.7 CNPC

Not studied

A8.8 LDACS

Not studied

A8.9 JTIDS/MIDS

Not studied

A8.10 GNSS

Galileo is the European global satellite-based navigation system. Until now, radionavigation satellite service (RNSS) users around the world have had to depend on American GPS or Russian Glonass signals. Galileo gives users a new and reliable alternative, run by civil, not military authorities.

Satellite positioning is now an essential tool for all forms of transportation; if RNSS signals were switched off tomorrow, truck and taxi drivers, ship and aircraft crews, and millions of average citizens around the world would be lost – literally.

As the use of satellite-based navigation systems continues to expand, the implications of potential signal failure become even greater. Such an event, whether accidental or intentional, would jeopardise financial and communications activities, public utilities, security and humanitarian operations and emergency services.

As far back as the early 1990s, the European Union saw the need for a European-controlled global satellite navigation system. The decision to build one was taken in the spirit of other well-known European endeavours, such as the Ariane launcher and Airbus. A defining characteristic of Galileo is that, unlike GPS and GLONASS, it was conceived and developed and will always remain under civilian control.

While European independence has been a key goal behind the creation of the new system, Galileo is nevertheless 100% interoperable with GPS and Glonass, making it a fully integrated new element in the worldwide global navigation satellite system, a powerful cornerstone that will allow more accurate and more reliable positioning, even in high-rise cities where buildings can obscure signals.

GPS, and to some extent Glonass, have opened up the markets for accurate positioning and timing, Galileo will take that further by working interoperably with GPS (and other RNSS systems) to offer even more reliable positioning, navigation and timing (PNT). This increased reliability and availability in areas such as city centres with tall buildings is likely to open up a range of new business opportunities for equipment manufacturers, application developers and providers of ‘reliability-critical' services.

The ubiquitous continuous operation of RNSS such as Galileo has led to a large number of services and users being dependent upon its availability. In additional to traditional pedestrians, bikes, aircraft, boat, road vehicle etc. navigation, new services and user communities continue to be developed that use RNSS navigation services, such as proposed driver-less cars and bike & scooter hire companies which allow the vehicles to be returned at any time and at any locations using RNSS positioning information. Many PMR devices can determine their location using RNSS and report back to a central office using polling. These PMR units could be used for security applications.

The value of RNSS to general society is extremely large and any degradation in its availability as a ubiquitous continuously available service would have extremely large costs, and in some cases, involve safety of life implications.

The Galileo system consists of a constellation of 30 satellites operating at an altitude of 23 600km. Each satellite transmits navigation signals on three carrier frequencies, in particular in the frequency band 1164-1215 MHz.

Galileo provides an open, free of cost, positioning, navigation and timing (PNT) service, enabling a wide range of applications particularly those aimed at the general public and civil aviation. The frequency band 1164 - 1215 MHz provides signals for safety related applications (particularly aviation) and will enable reliable, accurate and precise navigation fixes.

A8.10.1 Parameters

The RNSS is used to provide navigation and timing services with continuous ubiquitous global coverage, typically provided by satellites in medium Earth orbit (MEO). An overview of the frequency arrangements for the Galileo, Glonass and GPS systems are shown in the figure below:

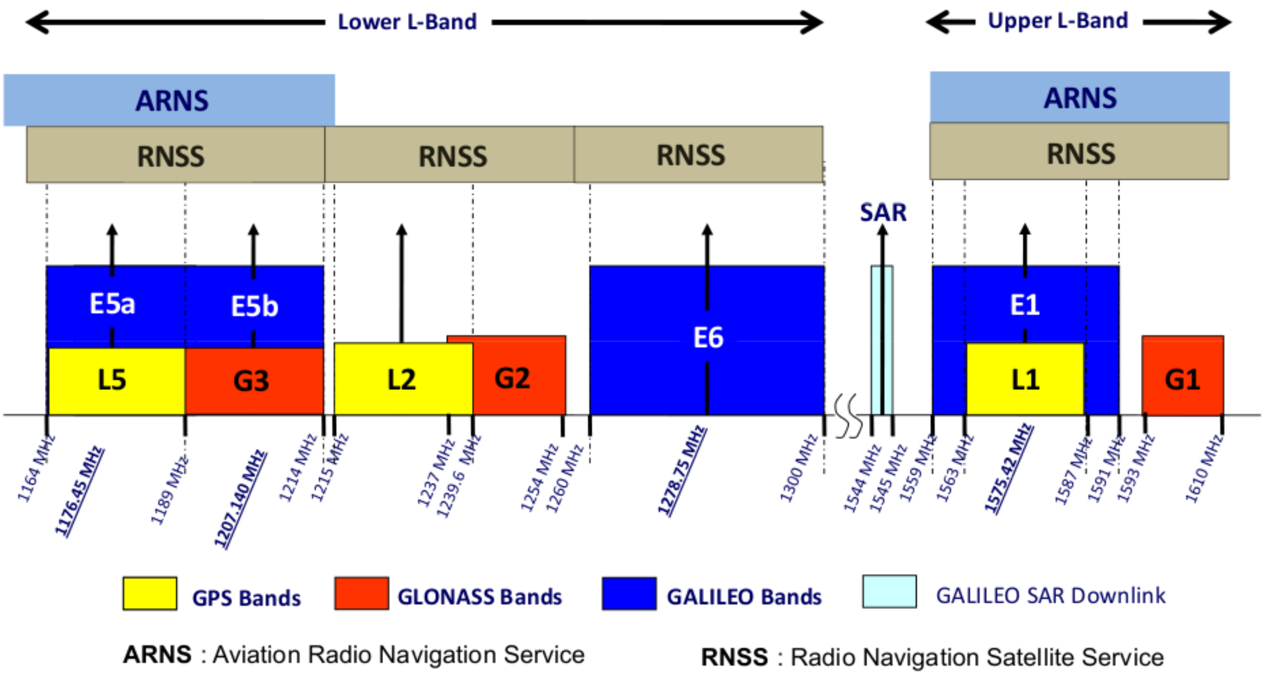


Figure 99: RNSS Use of Frequency bands above 1164 MHz

It can be seen that just above the 1164 MHz boundary are the E5a Galileo and L5 GPS bands.

The following Recommendations were used as the source of information for parameters:

- Recommendation ITU-R M.1318-1 – Evaluation model for continuous interference from radio sources other than in the radionavigation-satellite service to the radionavigation-satellite service systems and networks operating in the 1164-1215 MHz, 1215-1300 MHz, 1559-1610 MHz and 5010-5030 MHz bands;
- Recommendation ITU-R M.1787 - Description of systems and networks in the radionavigation-satellite service (space-to-Earth and space-to-space) and technical characteristics of transmitting space stations operating in the bands 1164-1215 MHz,1215-1300 MHz and 1559-1610 MHz;
- Recommendation ITU-R M.1905-0 – Characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (space-to-Earth) operating in the band 1164-1215 MHz;
- Report ITU-R M.2235 [56] - Aeronautical mobile (route) service sharing studies in the frequency band 960-1164 MHz.

These Recommendations included a number of options which were summarised into two configurations, one for air-navigation and another general purpose:

Table 123: RNSS Parameters

RNSS Receive type	Air-navigation	General-purpose
RNSS Receive mask	M.2235 Figure 8 (Aeronautical receiver)	Gaussian Filter Bandwidth 20.5 MHz
RNSS Centre frequency (MHz)	1176.45	1176.45
RNSS Bandwidth (MHz)	24	24
RNSS Gain (dBi)	-5	3
RNSS Receiver temperature (K)	727	330

Recommendation ITU-R M.1905 gives two gain values, a minimum and maximum. For the air-navigation case the minimum was used assuming the maximum was pointing at the sky and minimum towards the ground. For the general-purpose case the maximum gain was used.

The threshold metric used was T(I/N)[45] calculated using the parameters from Recommendation ITU-R M.1905 and the methodology in Recommendation ITU-R M.1318 and is shown in the following table:

Table 124: RNSS Interference Threshold

RNSS Receive type	Air-navigation	General purpose
Acquisition mode threshold power density level of aggregate wideband interference at passive antenna output (dBW/MHz)	-148.7	-146
Receiver noise temperature (K)	727	330
Noise (dBW/MHz)	-140.0	-143.4
Safety of life margin (dB)	6	0
Service apportionment factor	4	4
Aggregate T(I/N) before safety of life margin (dB)	-8.7	-2.6
Aggregate T(I/N) after safety of life margin (dB)	-14.7	-2.6
Single service T(I/N)	-20.7	-8.6

Note that the thresholds quoted are the ones for wideband interference rather than those for narrowband which are about 10 dB more stringent. Recommendation ITU-R M.1905 definitions are:

"Narrow-band continuous interference is considered to have a bandwidth less than 700 Hz. Wideband continuous interference is considered to have a bandwidth greater than 1 MHz. Thresholds for interference bandwidths between 700 Hz and 1 MHz are under study."

This could require further consideration at a later stage.

It was noted that the interference thresholds in Recommendation ITU-R M.1905 were aggregate over all systems and services. Hence to determine a threshold to use for a specific scenario, namely one system (service) of PMSE (mobile) into RNSS an apportionment factor was used. In this case an apportionment factor of 4 was used. An example of the other services could be {other RNSS, Aeronautical, PMSE/mobile, other non-co-frequency}.

The receive filter masks for the two configurations considered are shown in the figure below:

[45] Where the notation T(X) implies the threshold of metric X

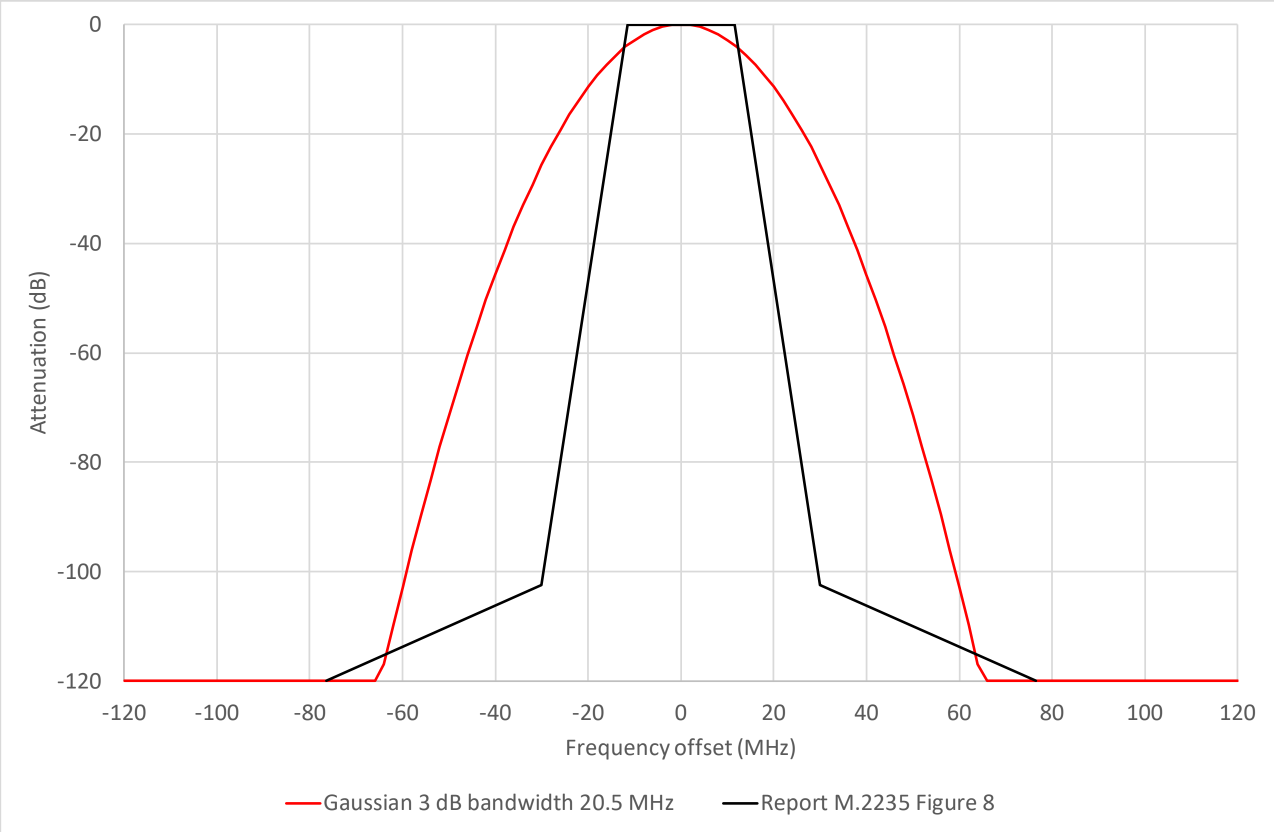


Figure 100: RNSS Receive Filter Masks

The receive noise of a receive mask with Gaussian bandwidth was calculated using N = kT.bandwidth as that gives a value very close to that calculated using integration.

It should be emphasised that the RNSS received signal is extremely weak. For example, Recommendation ITU-R M.1787 gives a minimum receive power level of -155.25 dBW. This is significantly below the noise floor and gives an indication of why PMSE, while sometimes considered a low power service, could cause harmful interference if located within the vicinity of an RNSS receiver. An implication of this is that RNSS operation will be mostly outdoors.

It also should be noted that generic RNSS devices such as smartphones have limited space available (e.g. chips millimetres in size) and hence will operate with less attenuation than the filter characteristics of equipment that meets the Report M.2235 [56] Figure 8 curve. There is significant benefit to citizens and consumers that generic RNSS devices are highly portable and hence there is little scope to provide greater attenuation.

Analysis of a typical RNSS network suggests that an operating signal would be close to this level with little margin available. Unlike PMSE receivers, the transmitter is many thousands of kilometres away and the link budget does not have a large fade margin within it. An example of an RNSS operation can be seen in the following screenshot of a simulation where the resulting wanted signal is only just above the threshold of -155.25 dBW:

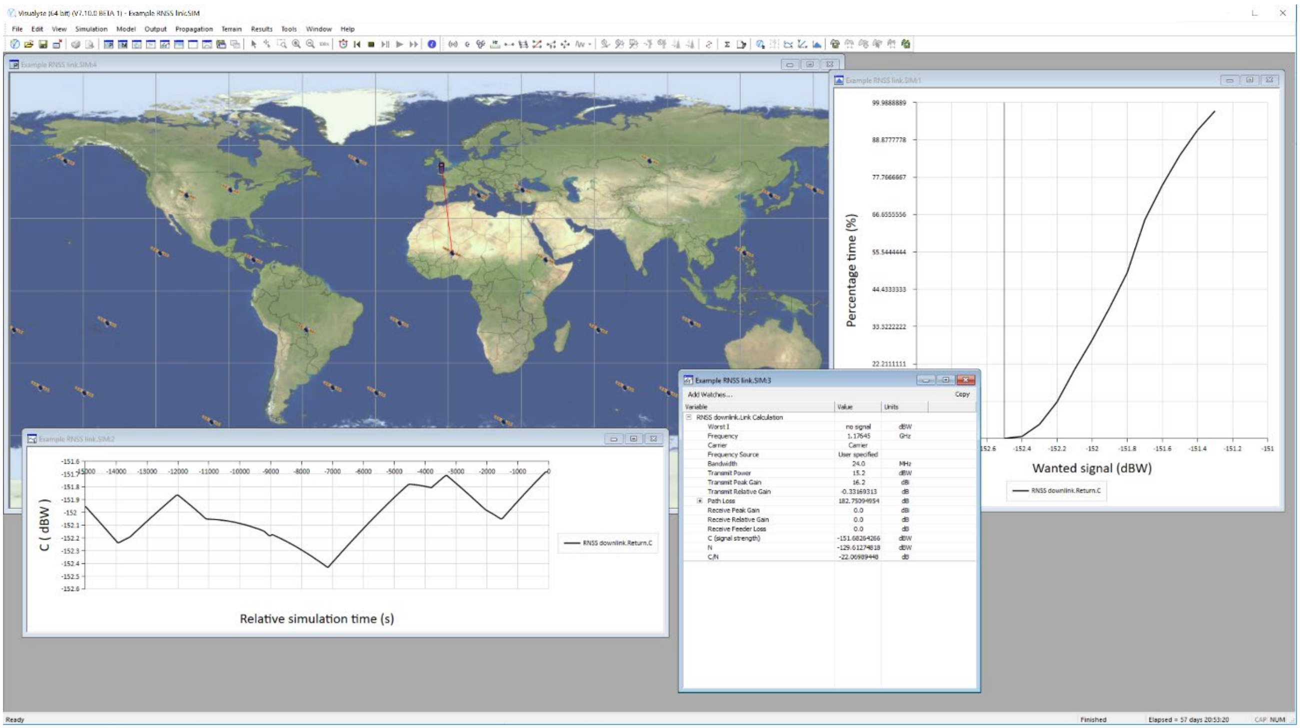


Figure 101: Example RNSS Constellation Simulation

A8.10.2 Modelling Assumptions

This section describes the modelling methodology used, including how the transmit and receiver masks were integrated, the propagation models, the equation used to calculate I/N and the various scenarios used to derive the required guard band.

A8.10.2.1 Transmit and Receive Mask Integration

The interference at the RNSS receiver was calculated by integrating the transmit PMSE spectrum mask with the RNSS receiver filter mask using:

$$A_{MI} = \frac{p_{rx}}{p_{tx}} = \frac{\int_{f=0}^{f=\infty} m_{tx}(f) m_{rx}(f)\, df}{\int_{f=0}^{f=\infty} m_{tx}(f)\, df}$$

The integration range for the top integral was over the receive filter bandwidth with the assumption that the last value of the transmit spectrum mask continued outside the defined range. The integration range of the lower integral was over the transmit mask bandwidth.

The resulting plot of AMI vs frequency offset is shown in the figure below:

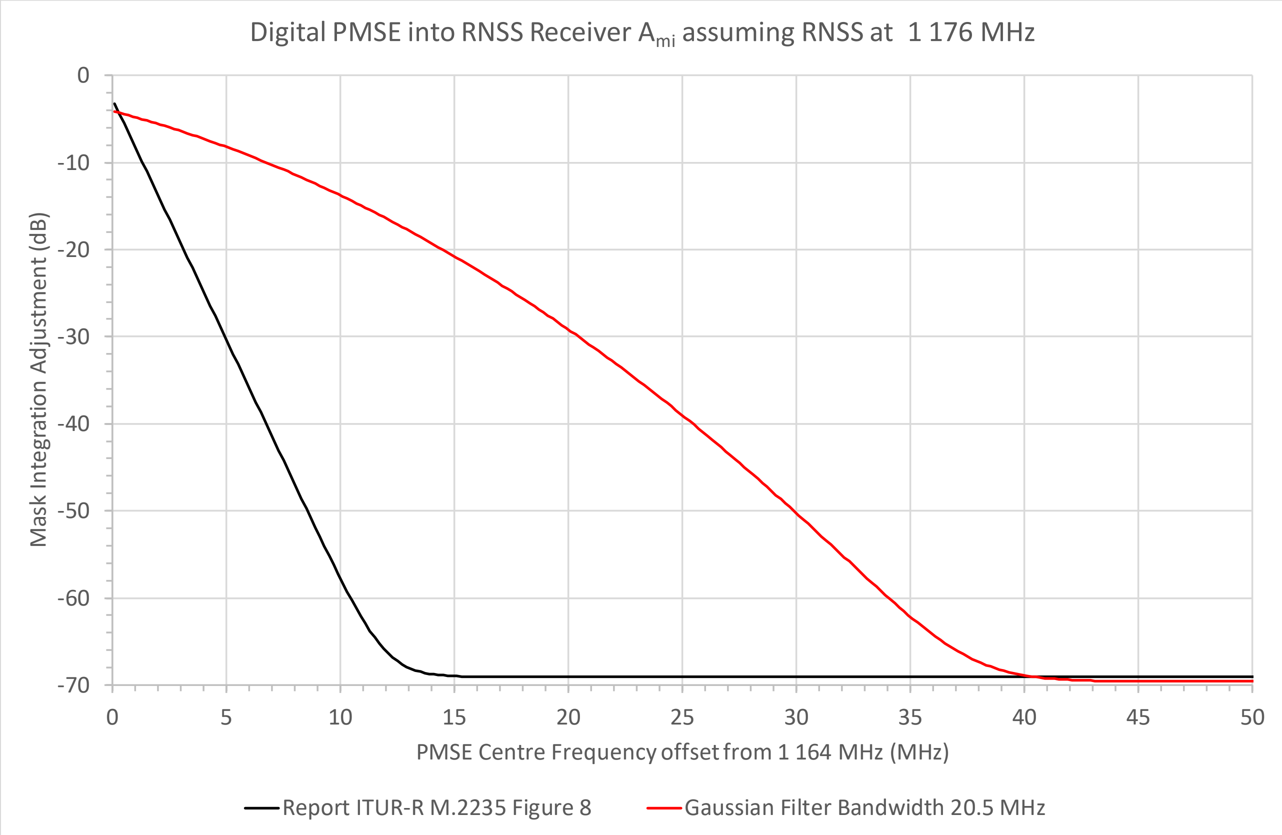


Figure 102: Integration of PMSE Digital Mask with RNSS Receiver Masks

A8.10.2.2Modelling Methodology

The I/N was calculated using the following equation:

$$\frac{I}{N} = EIRP + G_{tx,rel} - L_{body} - L_{fs}(f,d) - L_{clutter} - L_{BEL} + G_{rx} + A_{MI}(\delta f) - 10log_{10}(kTB)$$

Where:

- e.i.r.p. = PMSE transmit E.I.R.P. (dBW)
- $G_{tx,rel}$ = PMSE transmit relative gain (dB)
- L_{body} = PMSE body loss (dB)
- L_{fs}= free space path loss (dB) dependent upon frequency f and distance d
- $L_{clutter}$ = clutter loss on radio path (dB)
- L_{BEL} = building entry loss (dB) (if applicable)
- G_{rx} = RNSS receive gain (dBi)
- A_{MI} = Mask integration adjustment for given difference in frequency f (dB)
- T = RNSS receive temperature (K)
- B = RNSS receive bandwidth (Hz)

It can be seen that the I/N calculated depends upon separation distance d and frequency offset f. The distance was defined by the scenarios (as described below) and then the frequency offset varied until the calculated I/N met the required T(I/N). From the frequency offset the necessary guard band could be determined.

Polarisation loss is not considered as there is unlikely to be main-beam to main-beam alignment and hence significant de-polarisation affects.

A8.10.2.3 Scenarios

A number of scenarios were defined, namely:

- Theatre General: a generic RNSS receiver is operating outside a theatre where PMSE devices are being used inside. An example of this would be the West End of London.
- Urban General: a generic RNSS receiver is operating on a location where PMSE devices are being used outdoors. An example of this would be the Boat Race in London or bike / scooter hire company in the Olympic Park.
- Rural General: a generic RNSS receiver is being operated in a rural area with many PMSE devices are being used outdoors. Examples would include music festivals such as Glastonbury and sporting events such as Silverstone.
- Theatre Air: an aircraft RNSS receiver is operating over an area where many theatres are using PMSE devices indoors. An example would be an aircraft over London which has a large number of theatres.
- Urban Air: an aircraft RNSS receiver is operating over an area where PMSE devices are being used outdoors. An example of this would be the Boat Race in London or an event at the Olympic Park.
- Rural Air: an aircraft RNSS receiver is operating at lower altitude over a rural area where PMSE devices are being used outdoors. Examples would include music festivals such as Glastonbury and sporting events such as Silverstone, both of which have high use of PMSE and have high helicopter traffic.

The parameters for these scenarios are defined in the table below:

Table 125: Scenario Parameters

Scenarios	Building entry loss (dB)	Clutter loss (dB)	Distance (m)	Site aggregation factor (dB)
Theatre General	10	0	50	0
Urban General	0	23.3	20	0
Rural General	0	11.6	50	0
Theatre Air	10	0	1000	20
Urban Air	0	0	100	10
Rural Air	0	0	50	10

The aggregation factor takes account of the number of PMSE interfering sites that have an impact on the aggregate interference. For short range paths this is 1 (i.e. 0 dB) but for aircraft over an area where there could be large numbers of sites using PMSE that contribute to the aggregate interference a factor of 10 dB or 20 dB was included (i.e. 10 or 100 sites).

At each site it was assumed there were 3 PMSE devices transmitting in the three channels nearest the RNSS receiver taking into account the guard band assumed, as shown in the figure below:

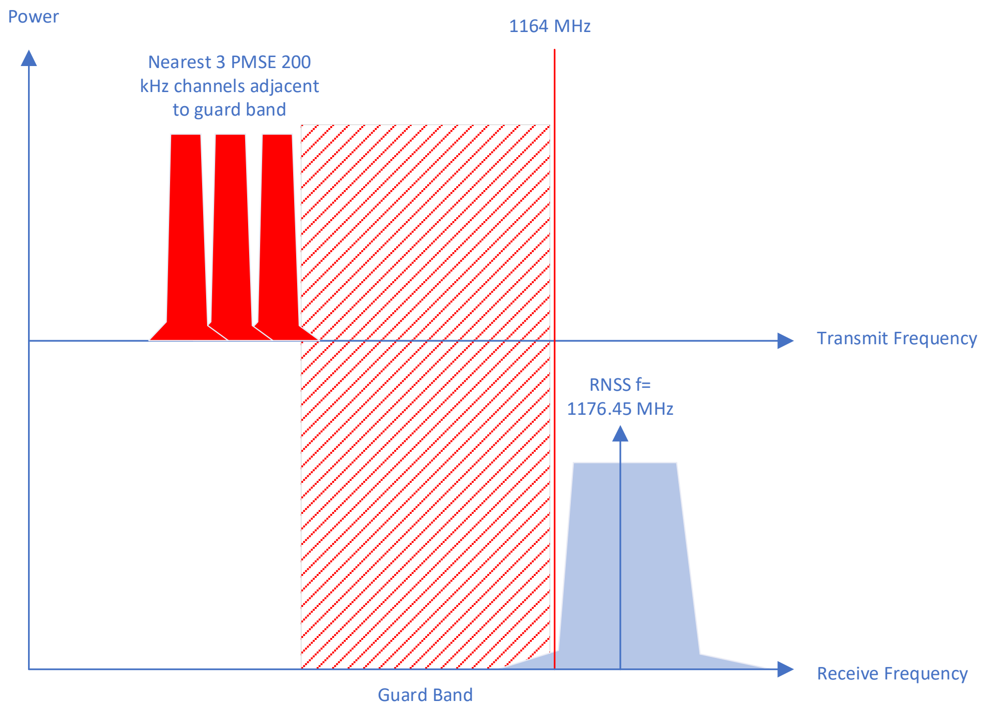


Figure 103: PMSE Channels, guard band and RNSS receive frequency

A8.10.2.4 Sensitivity Analysis

A number of variations to the input parameters were considered, including:

- Using a tighter threshold for the general case of T(I/N) = -6 dB as per ETSI EN 303 413;
- Considering more PMSE adjacent band channels (e.g. 5 rather than 3);
- Consideration of air-navigation receiver No. 2 in Table 2.1 of Recommendation ITU-R M.1905 or the low height parameters;
- Consideration of actual masks of general-purpose receivers taken from receiver specifications.

In general, it was found that these changes make only a minor impact on the resulting guard bands required, and it was concluded that scenarios and parameters proposed in the main study were a representative set.

A8.10.3 Conclusion

For each of the scenarios, for each of the PMSE types, the necessary guard band was calculated as in the table below:

Table 126: Required Guard Band Required to Meet T(I/N) (MHz)

RNSS Receiver Type	Scenario	Body-worn	Hand-held	IEM with downtilt	IEM no downtilt
General	Theatre	28	29	28	32
General	Urban	25	27	26	30
General	Rural	27	28	28	31
Air	Theatre	5	5	3	5
Air	Urban	10	10	9	10
Air	Rural	12	12	10	12

In each case the guard band was increased in 1 MHz steps until the I/N was below the T(I/N). For example, a plot of the first case (Theatre General / body-worn) would be as in the figure below.

Scenario = Theatre General / PMSE type = body-worn

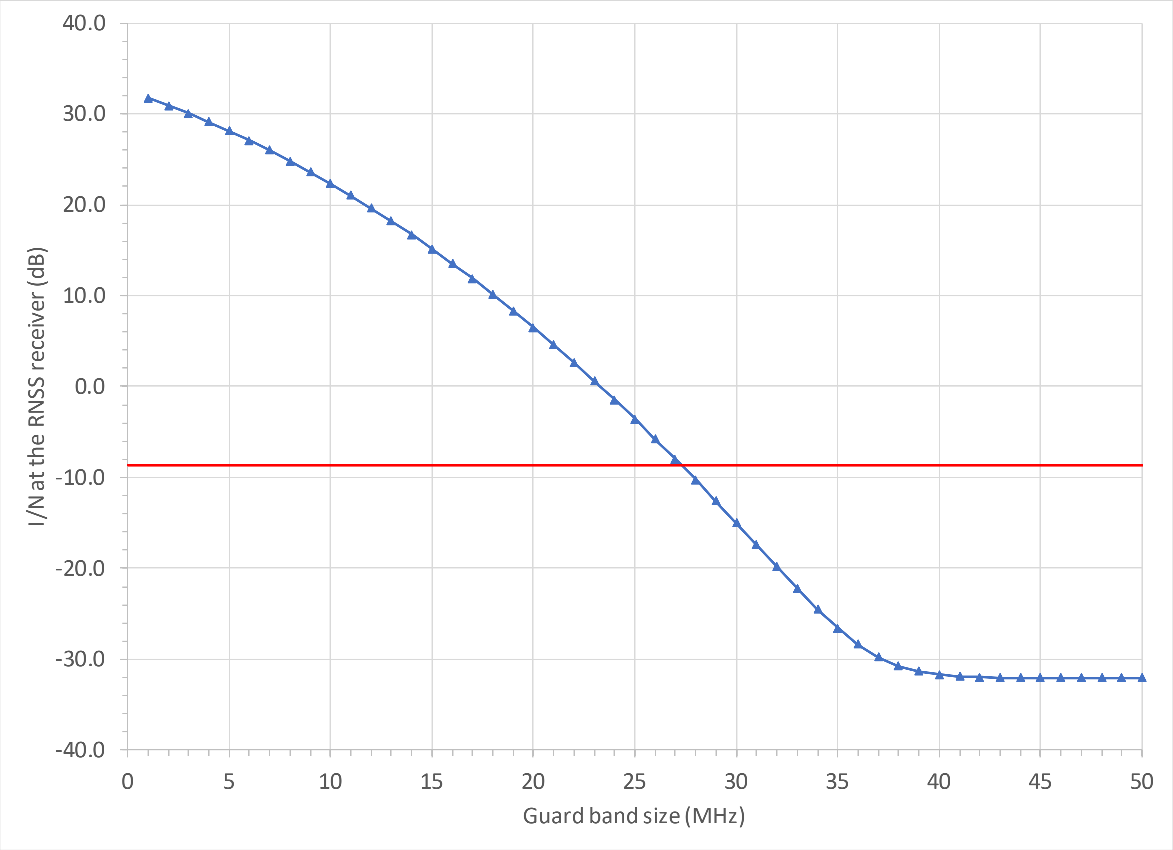


Figure 104: PMSE Channels, guard band and RNSS receiver frequency

It was noted that the largest guard band was 32 MHz for the IEM with no downtilt case. As it is possible there could be some discrimination at the IEM transmitter, it was concluded that a 30 MHz guard band could be sufficient. This would also protect all other scenarios.

This study investigates the impact of PMSE operating in the band 960-1164 MHz on RNSS receivers in the adjacent bands above 1164 MHz. The study considered a number of PMSE types, RNSS receiver types and scenarios.

The conclusion was that a guard band of 30 MHz would be required to protect RNSS receivers.

A8.11 OTHER SYSTEMS

Not studied.

ANNEX 9: GUIDANCE FOR PRACTICAL TESTS OF DME AND TACAN OPERATIONS, THE EFFECTS OF MULTIPATH AND SIGNAL STRENGTH VARIATION FROM DFS GERMANY

A9.1 SUMMARY

This Annex discusses the loading of the DME channel as perceived by DME/TACAN receivers, the effects of multipath and indicates the need for compatibility with PMSE to be determined with the Echo Suppression capabilities of transponders receiver enabled.

Note: This multipath aspect has not been addressed in the PMSE compatibility studies/measurements contained in this report.

A9.2 INTRODUCTION

While DME and TACAN pulses are normally depicted in literature to have only a width of 3.5 µs ±0.5 µs, this is only true at the 50% amplitude points of the pulses. Below the 50% amplitude points width can be up 8 µs.

Echos and multipath can occur at most locations, especially since aeronautical pulses may be received at a signal level higher than -40 dBm. Multipath will increase the pulse width, or increase the number of pulses received above receiver thresholds, thus increasing apparent duty cycle.

In extreme cases, DME pulse trains that originate from a single interrogation pulse pair due to multiple echoes with decreasing signal strength will occur. Such pulse trains have been measured to last for 150 µs or longer. DME and TACAN transponder receivers are therefore equipped with Short- and Long-Distance Echo-Suppression circuits (SEDS and LDES) which can provide protection for up to 350 µs after the initial interrogation pulse pair was received.

A9.3 INCREASE OF DME AND TACAN PULSE WIDTH WITH AMPLITUDE AND PULSE FORM

DME/TACAN aeronautical pulses are often depicted as Gaussian shaped pulses in literature.

The definitions for DME pulses in ICAO Annex 10 Volume I [44] are:

- - pulse-width of 3.5 µs ±0.5 µs at 50% amplitude points;
- - max. pulse rise time between 10% and 90%;
- - max. pulse decay time between 90% and 10% amplitude points;
- - pulse drop not to fall below >95% amplitude.

Note: TACAN pulse characteristics are similar to DME with the addition of pulse amplitude modulation.

This has direct impact on the spectrum emission mask which is 200 mW measured in 500 kHz centred ±0.8 MHz above and below centre frequency and 2 mW measured in 500 kHz centred ±2.0 MHz above and below centre frequency.

Below the -10 dB points a Gaussian pulse becomes wider as shown in measurements below. Manufactures are free to implement any waveform that meets the above criteria. The equipment measured are fully ICAO compliant, and are the result of different interrogator designs and technology.

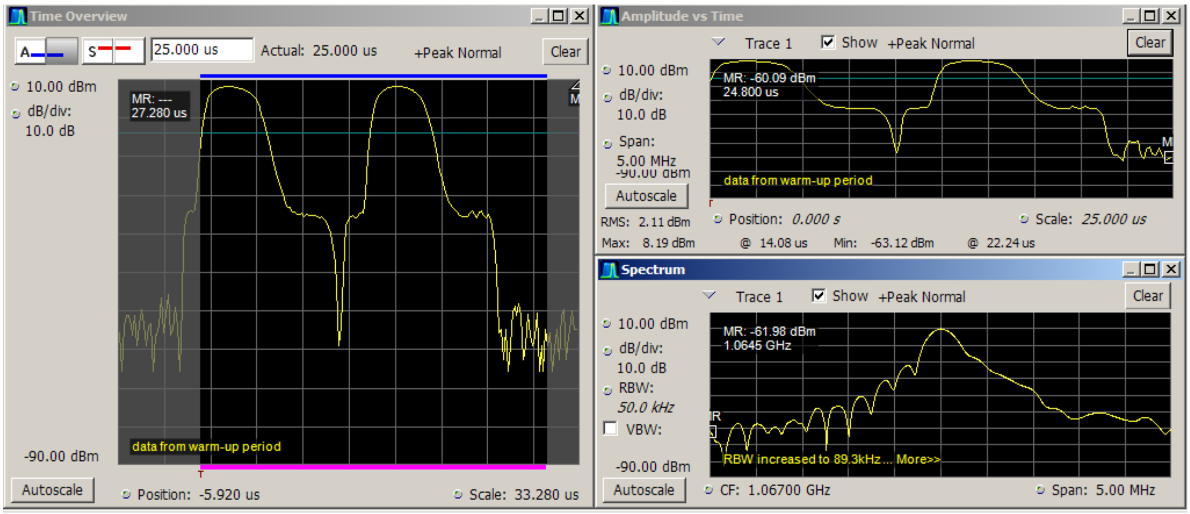


Figure 105: Measured pulse form DME-40 (Collins)

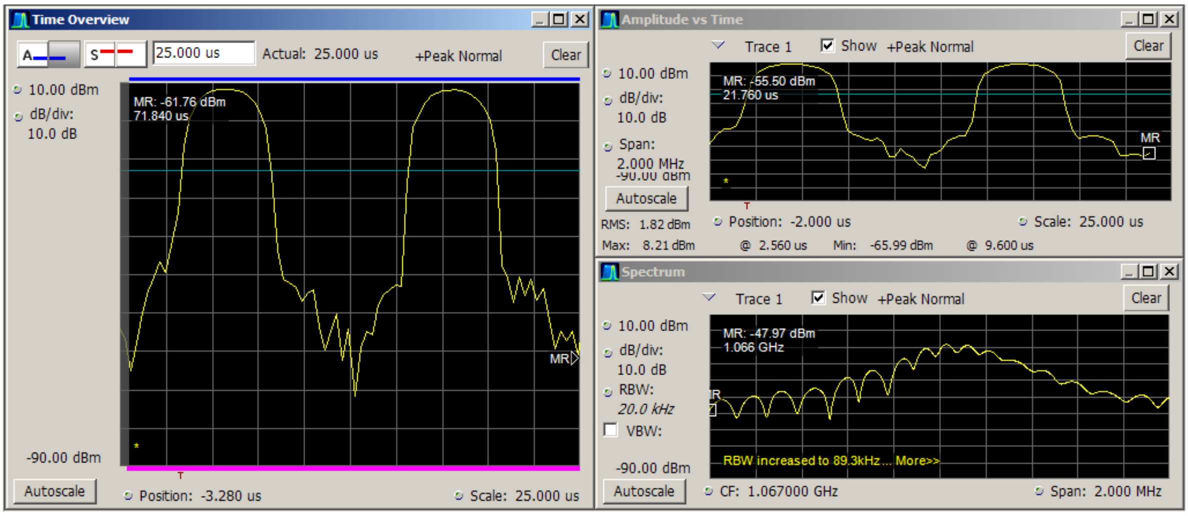


Figure 106: Measured pulse form KTU-709 (Bendix)

A9.4 INCREASE OF DME AND TACAN PULSE COUNT AND AGGREGATE DUTY CYCLE IN PRESENCE OF MULTIPATH

Multipath is generated by strong aircraft DME and TACAN interrogations (see figure 3). A more detailed description of DME and TACAN multipath can be found in FAA-6820.10.

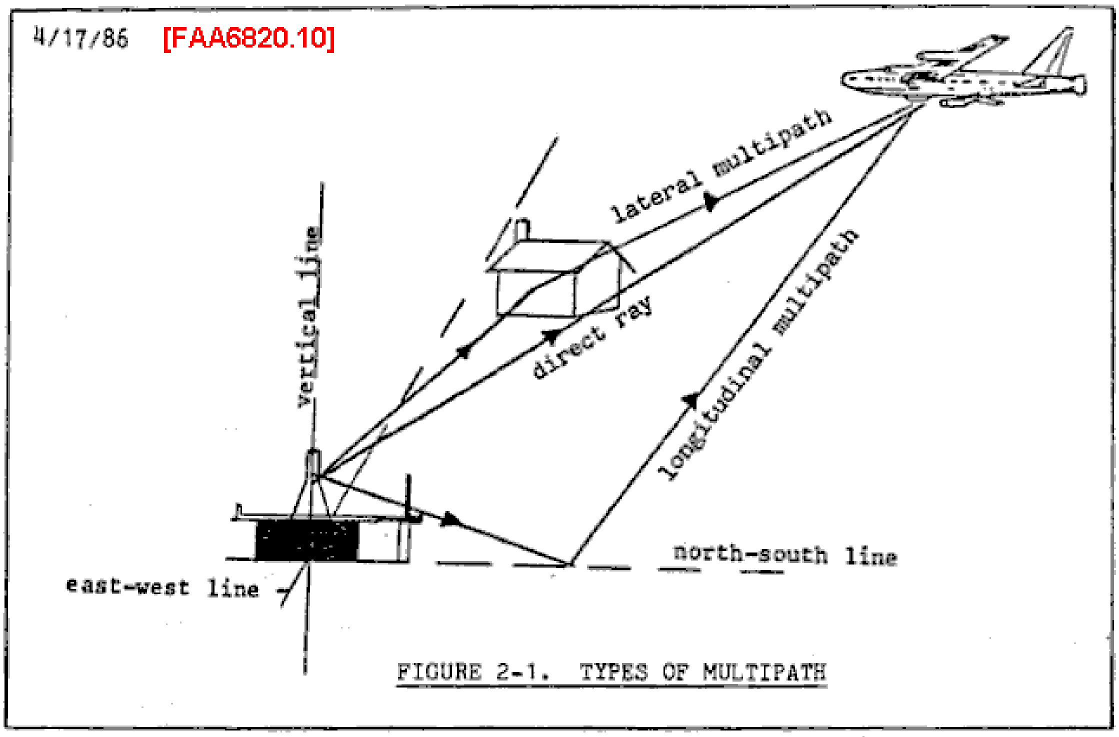


Figure 107: longitudinal- and or lateral-echos/-multipath [FSS-6820.10]

A9.4.1 Short Distance Multipath

An echo that falls between two interrogation pulses is considered as short distance multipath (see figure below).

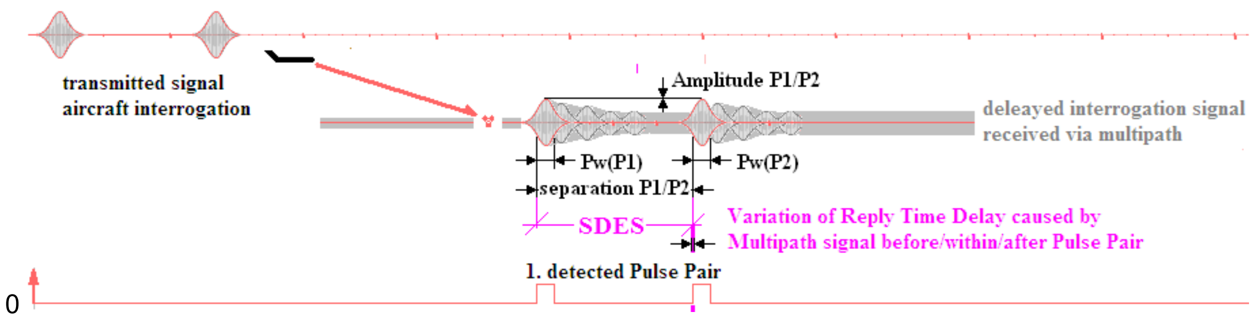


Figure 108: Short distance-echos/-multipath

A9.4.2 Long Distance Multipath

An echo arriving after the initial interrogation pulses is called a Long Distance Multipath echo.

Multiple replies from the Frankfurt/Main TACAN were observed in 1969 during a flight inspection by BFS (Bundesanstalt für Flugsicherung). In addition to the transponder reply to the interrogation received via the direct path. A second and a third replies were generated by the transponder. The interrogation pulse pair were received via multiple reflections in the airport vicinity. Observation of the output signal of the logarithmic amplifier of the transponder identified a dense pulse train generated which was received as long as 150 µs after the initial interrogation pulse, before the amplitude of the multipath signals dropped below the set Minimum Triggering Level (MTL) of the TACAN receiver. US-FAA had identified similar occurrences. In consequence modifications to existing transponder, called echo traps, were made. Furthermore, input material to ICAO lead to an amendment of ICAO Annex 10 with provisions countering multipath effects. Today DME and TACAN transponder have LDES and SDES circuits to counter multipath interference for up to 350 µs duration.

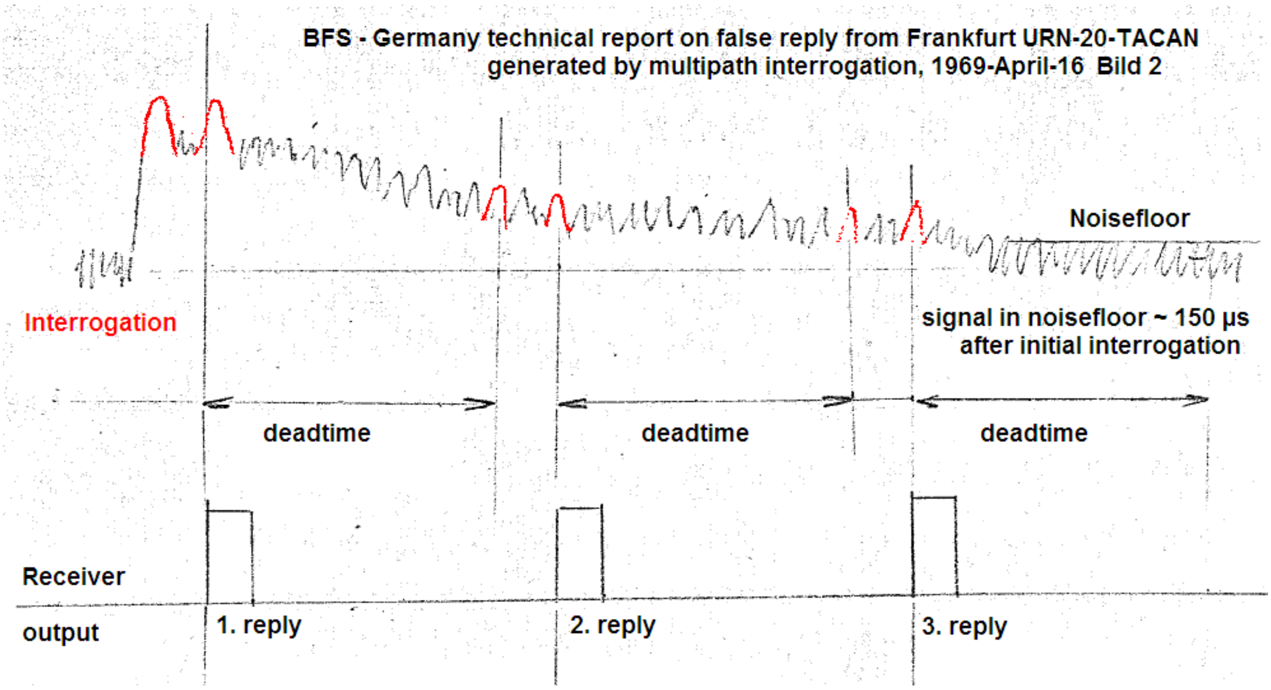


Figure 109: Long distance-echos/-multipath [BFS-RD-1969]

A9.5 CONCLUSION

The measurements introduced in this Annex demonstrated that aeronautical pulses, e.g. from DME and TACAN, produce multipath echoes at most transponder locations, thus negatively affecting the reception of weaker DME/TACAN signals. Due to this, when assessing compatibility with PMSE, testing of DME/TACAN performance should be conducted with the Echo Suppression enabled to be representative of normal use of DME/TACAN. Echo suppression was not used in the DME-PMSE compatibility studies/measurements reported.

ANNEX 10: PMSE INTERFERENCE MEASUREMENTS ON DME/TACAN FROM BNETZA AND DFS GERMANY

A10.1 SUMMARY

This Annex describes the laboratory measurements of DME and TACAN on-board equipment and DME ground stations interfered by digitally modulated PMSE signals. Special consideration was paid to the performance and interference behaviour of different DME and TACAN equipment of various designs and from different manufacturers. It should be noted that due to time constraints, the measurement campaign is not considered to be conclusive in terms of identifying accurate compatibility criteria.

A10.2 INTRODUCTION

The impact of only one of the possible digital waveforms for PMSE signal on the performance of DME/TACAN systems was measured at the laboratories of the DFS Germany, together with the Federal Network Agency Germany (BNetzA). DME and TACAN interrogator and DME transponder were conducted in separate measurements.

In a first step, the behaviour of the on-board and ground station equipment under test (EUT) in a non-interfered situation at low wanted signal levels was investigated. The main purpose of this measurement was to establish a failure (or performance) criterion for the DME/TACAN system, and to determine the system sensitivity.

In a second step, a digitally modulated PMSE signal was injected in the signal path with increasing level at different frequency offsets and the performance of the DME/TACAN equipment was recorded.

Each measurement was repeated multiple times to consider also statistical behaviour of the EUTs.

A10.3 SYSTEM DESCRIPTION

The distance measuring equipment (DME) system consists of an on-board interrogator and a ground station transponder. The on-board interrogator sends out a series of unmodulated double pulses in a random time sequence. These pulses are received by the ground station receiver, delayed by a fixed time and re-transmitted to the aircraft on a different frequency. The aircraft equipment can then calculate the distance to the ground station by measuring the time between sent and received double-pulses.

The on-board interrogator transmits between 1025 and 1150 MHz (1 MHz channel steps) and the ground transponder transmits between 962 and 1213 MHz (63 MHz above or below the interrogator channel).

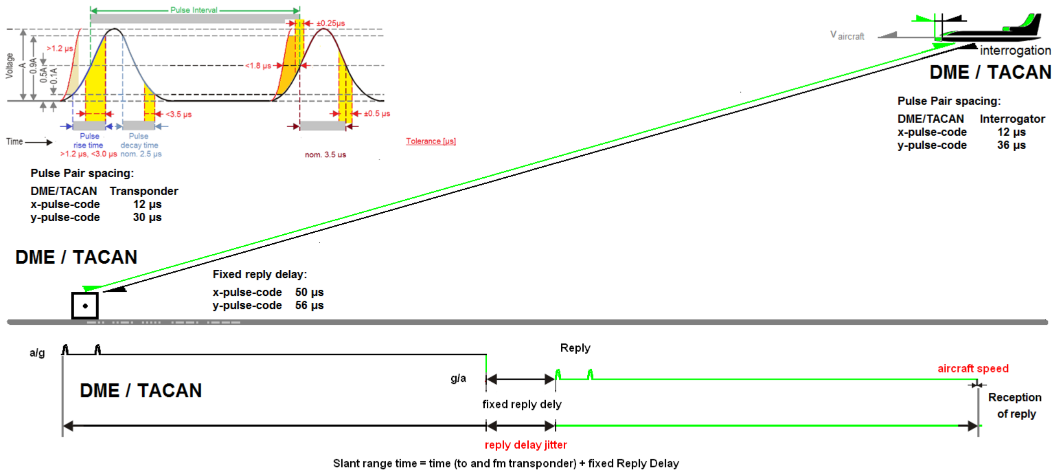
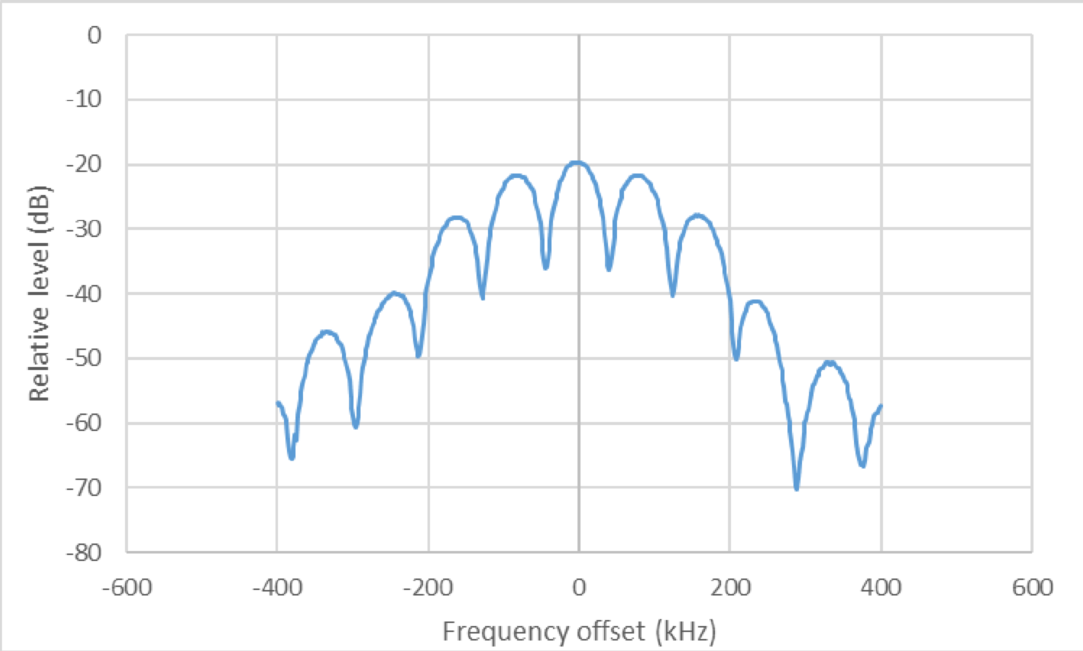


Figure 110: DME/TACAN interrogation and reply timing



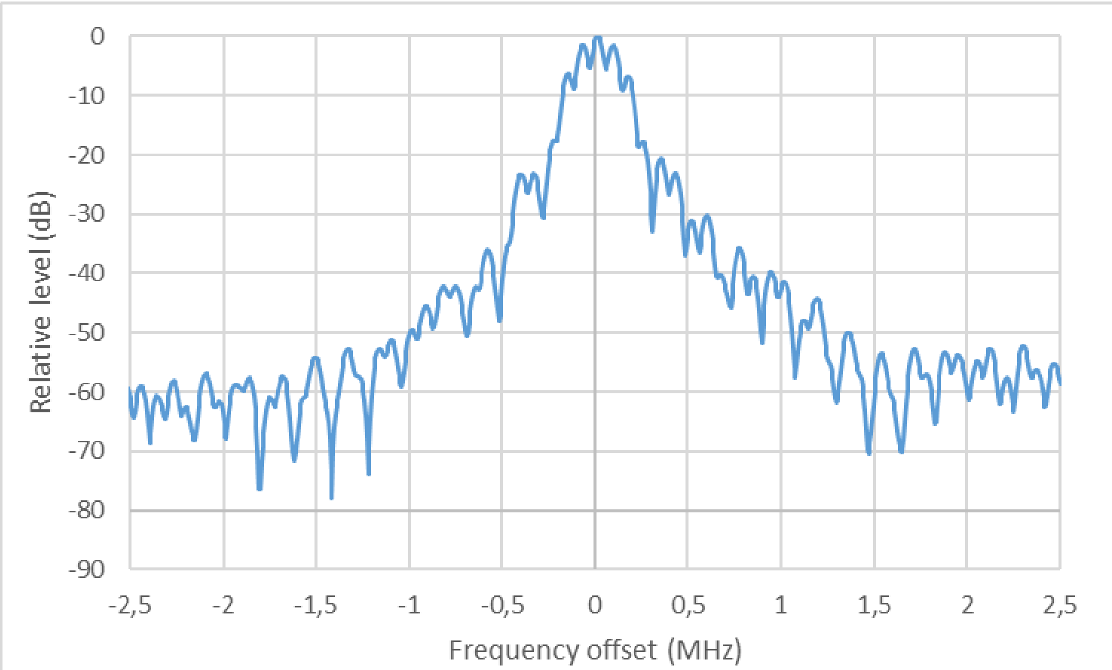


Figure 111: DME spectrum

In addition to determining the slant range distance to the ground station and the identification in Morse-Code (1350 Hz tone), TACAN systems also allow determination of the bearing referenced to/from magnetic north, under which the ground station is seen from the aircraft. To facilitate this function, the TACAN ground station sends out 900 additional pulses pairs, forming Reference Pulse Groups (RPG). All pulses are transmitted via a mechanically or electronically rotating antenna. This antenna produces a Pulse Amplitude Modulation (PAM) in space across all transmitted pulses see SE7(18)182 and SE7(19)183. The level of the pulses, when received by the on-board receiver, are amplitude modulated with 15 and 135 Hz having 12% to 55% Depth of Modulation (DOM). The bearing angle to the ground station can then be calculated by evaluating the phase of the two AM-tones relative to the TACAN-RPG

The spectra of DME and TACAN are principally equal, but transponder and interrogator differ in width and requirement as specified in ICAO Annex 10-I **Error! Reference source not found.**. However, the maximum amplitude of the pulses from the TACAN ground transponder is changing due to the PAM. The following figure shows the pulse amplitudes of DME and TACAN over 85 ms time. The depth of modulation is 50%. As specified in ICAO Annex 10, the DME/TACAN levels are always referenced to the maximum peak amplitude of the pulses.

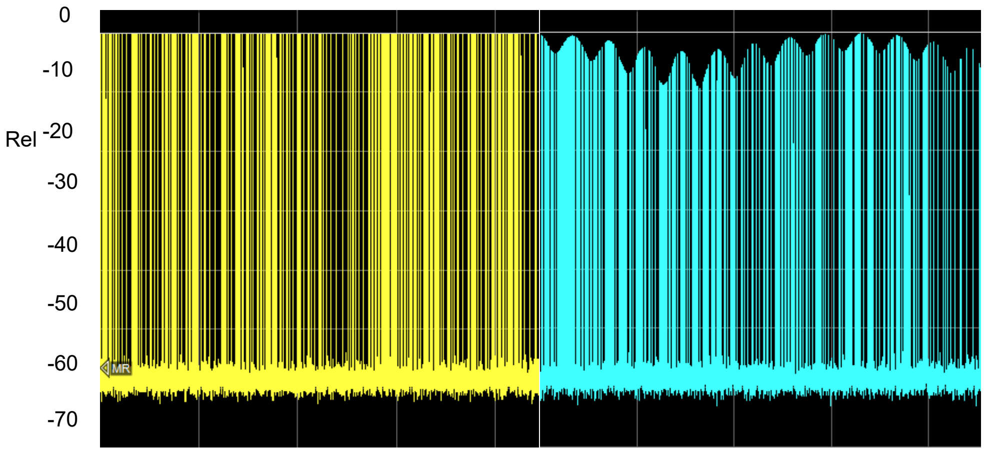


Figure 112: DME (left) and TACAN with PAM (right) amplitude vs. time

Compared to DME, decoding of TACAN pulse pairs generally requires higher signal levels at the on-board receiver, because only very few pulses actually reach the peak power level due to the PAM.

To receive all pulses, the peak level of a TACAN transponder signal needs to be approximately 9 dB higher than a DME signal. Hence, also the required C/I may need to be higher.

In "search mode", the on-board interrogator sends out up to 150 pulse pairs per second (pp/s) and tries to synchronize/lock-on with the ground transponder. If acquisition/lock-on is successful, the interrogator changes to "track mode" where it transmits below 30 pp/s. The time needed for synchronisation is called acquisition, Lock-on or Time to acquire" (TTA).

Ground DME and TACAN transmit up to 5400 pp/s and additional 900 pp/s during identification in Morse code. To enable identification of the specific ground station, an ID consisting of two to four characters is sent every 30 to 40 seconds as Morse Code, The Morse Code dots and dashes are generated by a series of pulses to sustain a 1350 Hz audio tone. The aircraft equipment decodes the ID into an audible tone or provides it as digital data word via the ARINC-429 aircraft bus.

A10.4 INTERFERING SIGNAL

For these measurements, the signal interfering from one available a digital wireless microphone using QPSK was analysed. The following figure shows the spectrum of the PSME signal, recorded with RMS detector in 1 kHz resolution bandwidth. The power was set to maximum to create the highest possible unwanted emissions.

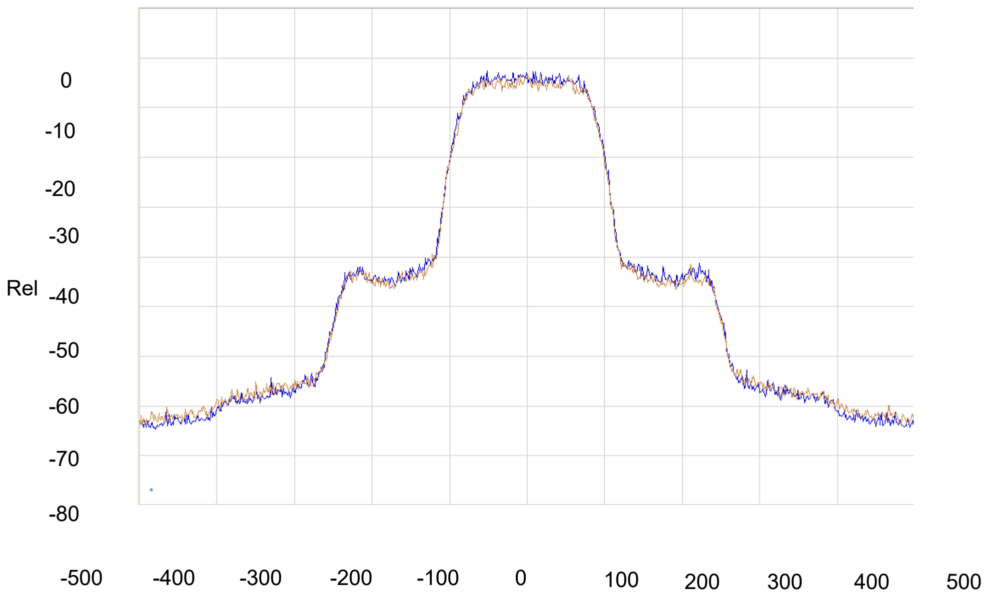


Figure 113: PSME signal from a typical wireless microphone

In order to be able to freely adjust frequency and level of the PMSE signal, it was decided to use a vector signal generator to produce the interfering signal for these measurements. The relevant RF parameters are:

- Bandwidth: 180 kHz;
- Modulation: QPSK;
- PAPR (peak to average power ratio): 3.5 dB.

The following figure shows the resulting spectrum of the interfering PMSE signal used.

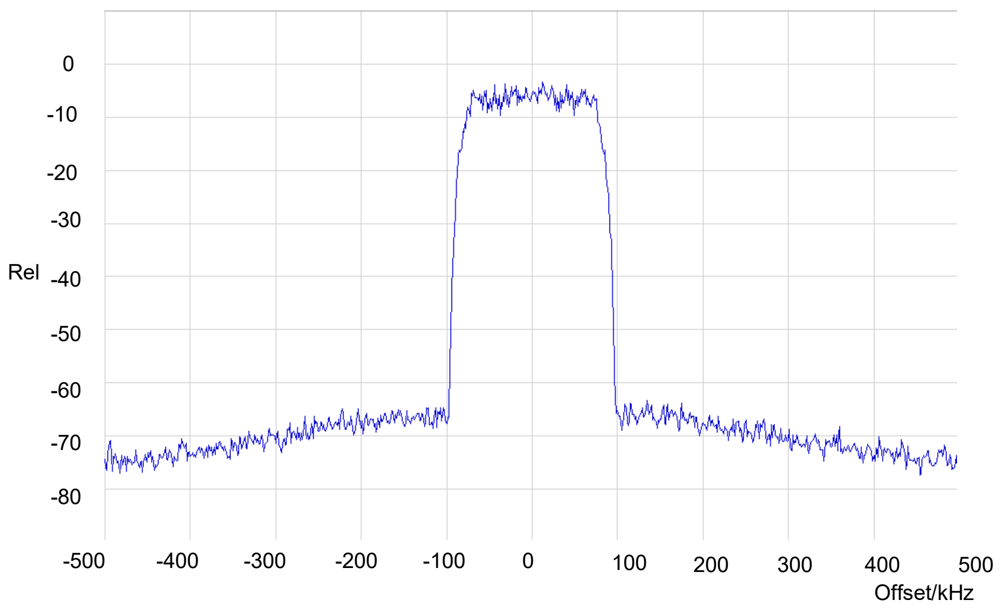


Figure 114: Interfering PSME signal generated with SMU200A signal generator

The interference potential of modulated continuous signals to DME/TACAN may be dependent on the PAPR which can range from 0 dB (for MSK/FSK modulation) up to about 13 dB if OFDM modulation is used. These other possible PMSE modulations were not tested due to time constraints.

All indicated PMSE levels are RMS values over the whole PMSE signal bandwidth.

A10.5 PERFORMANCE REQUIREMENTS

Operationally used DME- and TACAN. interrogator equipment are specified by one of the below listed FAA TSO C66(a to c) and may additionally be certified by MOPS listed below. The requirements vary as shown in the following table.

Table 127: TSO and MOPS requirement for the DME- and TACAN-interrogator under test(MOPS)

	TSO	MOPS		
Criteria	TSO-C66(a)	DO-141	DO-151(A)	DO-189 [51]
EUT	DME-40, KDM-706 KTU-709		KTU-709 (TACAN)	
Search speed	<35 s	Not defined	≥6 NM/s	
TTA	Not defined	Not defined	Not defined	Not defined
Ranging error	<100 NM: ±0.5 NM or 3% of distance, whichever is greater >100 NM: <3 NM		±0.4 NM or 1% of distance or <3 NM, whichever is greater	+/- 0.17 nautical miles (NM) or 0.25% of distance
Sens. DME source	Not defined	Not defined	Not defined	-83 dBm
Sens. TACAN source	-79 dBm	-78 dBm	-90dBm ≤-79 dBm search ≤-82 dBm track	Not defined

The criteria that were applied interrogator testing are mostly not identical to the mandatory requirements, for example, tests are to be conducted with TACAN-PAM or there are no requirements for the TTA at all.

A10.6 ON-BOARD INTERROGATOR AS EQUIPMENT UNDER TEST

A10.6.1 Failure criteria

Interference to the on-board interrogator equipment can have the following effects:

- the time to acquire (TTA) increases;
- the ranging error increases;
- for TACAN: the bearing distortion increases;
- the ID is not unambiguous or undetectable;
- the flag sign is raised, meaning no track occurs and memory flag is raised;
- loss of track occurs (lockout).

In this measurement campaign, not all interference criteria listed above have been investigated.

If the ID is distorted, interruptions of the audio signal occur. For example, depending on the position of these interruptions, they can cause a Morse code dash to be misinterpreted as a series of dots.

Except for the ID, which has to be evaluated separately, the most critical failure criterion measured in this series is a combination of multiple parameters that is called "acquire stable operation" (ASOP). For these measurements, the ASOP is "successful", if the following conditions are met:

- TTA is below a certain value;
- Ranging error is below a certain value;
- Absence of flag;

Assumptions made during TACAN- and therefore also today's DME/N System design (see EC-1956-xxx), result in the fact that not 100% of all interrogation pulse pairs will be decoded. These are especially:

- Interrogator pulses being transmitted at an arbitrary point in time from multiple aircraft may overlap at the ground transponder making it impossible to separate them in all cases;
- For transponder sites where due to multipath additional interrogations are received from the same interrogation signal;
- During the delay time for a pulse pair, and during the time of re-transmission, the ground station receiver is switched off and is therefore not able to receive pulses from other aircraft;
- During the time another on-board system such as secondary radar is transmitting, the DME receiver is switched off to avoid destruction.

The ASOP as defined for the evaluated failure criterion have been defined to be true for only 80% of the measurements. In this measurement campaign, the 80% requirement is also used (here: 8 out of 10 and 16 out of 20).

For TACAN systems, the required bearing accuracy of +/-3° has to be reached only in 95% of the cases.

A10.6.2 Measured receivers

The following on-board equipment was available for the measurements:

Table 128: Measured on-board interrogator equipment

No.	Type	Application	MOPS
Rx1	Rockwell Collins DME40	General aviation	TSO C66a
Rx2	Bendix King KDM-706	General aviation and business jets	TSO C66a
Rx3	Bendix King KTU-709 / TACAN	General aviation and military	TSO C66a, DO-151A

Measurement setup

For all measurements of the on-board interrogator, the following principle measurement setup was used:

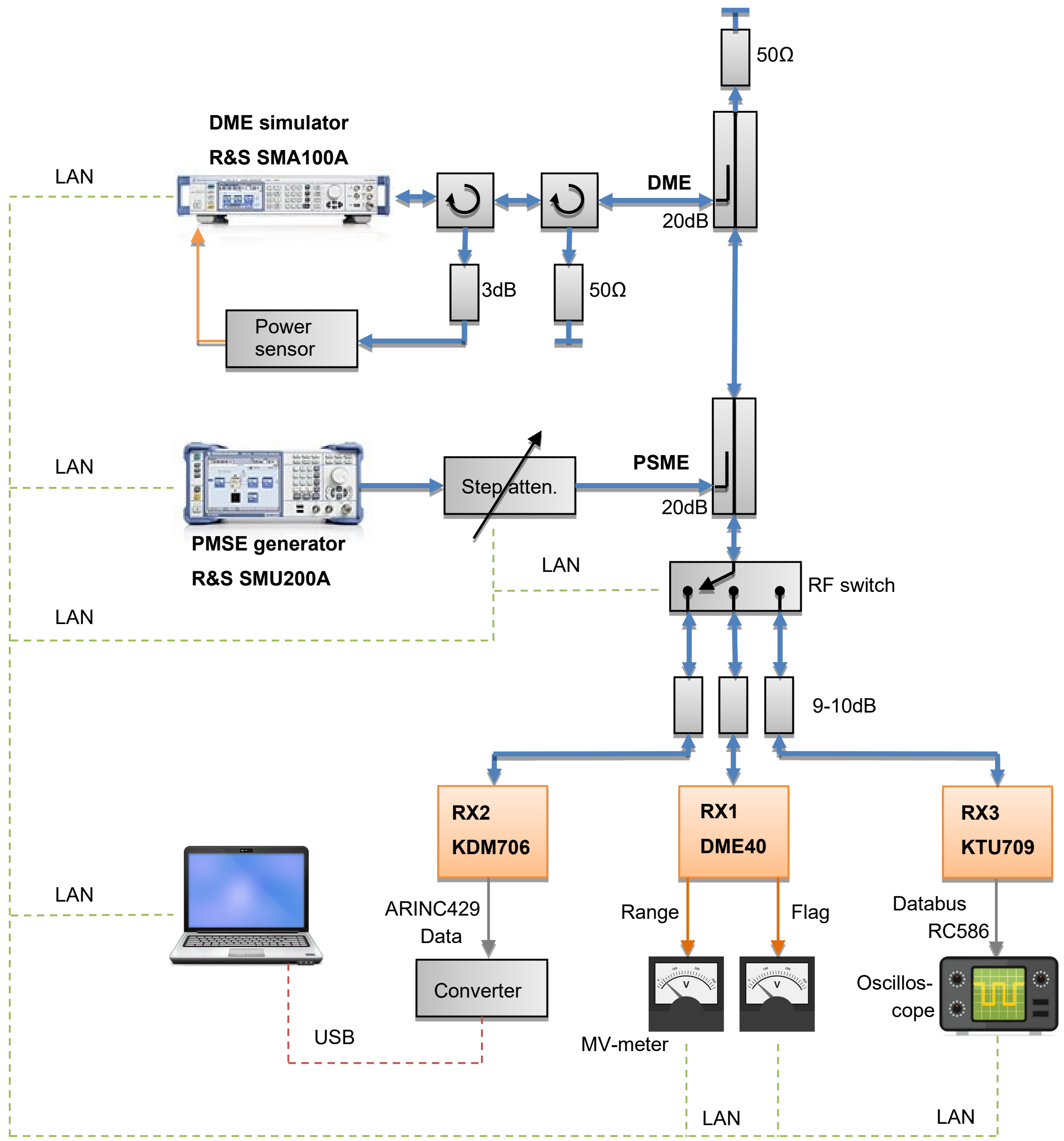


Figure 115: Measurement setup for on-board interrogators as EUT

A10.6.3 Measurement procedure

All measurements were performed automatically, controlled by a laptop computer with specially developed Python software. The results were stored in an SQL database. The principal measurement procedure was as follows:

- Set PMSE frequency (for interference measurements only, with PMSE generator);
- Adjust wanted and/or unwanted signal level(s) (DME generator and step attenuator after the PSME generator);
- De-select the desired EUT (RF switch off for EUT);
- Wait until EUT is locked out (typically 10 seconds);

- Select the desired EUT (RF switch);
- Select the desired EUT (RF switch on for EUT);
- Wait for the EUT to acquire signal (read out MV-meters/ARINC converter/oscilloscope;
- Measure the time to acquire signal (TTA) in case tracking was successful in less than predefined timeout;
- Wait for one second (if tracking was successful);
- Record indicated range in case tracking was successful;
- Switch to next EUT (RF switch);
- Repeat measurement from step 4;
- After predefined number of repetitions: continue with next signal combination at step 1.

To achieve results with some statistical relevance and to evaluate deviations in the performance of the same EUT when tested multiple times, each signal level/combination was measured between 10 and 20 times.

Measurements with additional background load simulating DME, TACAN, SSR and/or IFF signals were not done due to time constraints. Also the identification of the Morse code ID and bearing information were not evaluated in these measurements.

The onboard interrogator EUT measurements were done on the DME channel 17X (receive frequency: 978 MHz), whereas the ground station transponder EUT measurements were performed at 107Y (receive frequency: 1131 MHz).

A10.6.4 Measurements of sensitivity and non-interfered behaviour

In order to assess the general performance and behaviour of the EUT at low wanted signal levels, the different performance parameters were measured in a non-interfered situation.

The following graphs show the results of these measurements.

A10.6.4.1 Rx 1 (DME40)

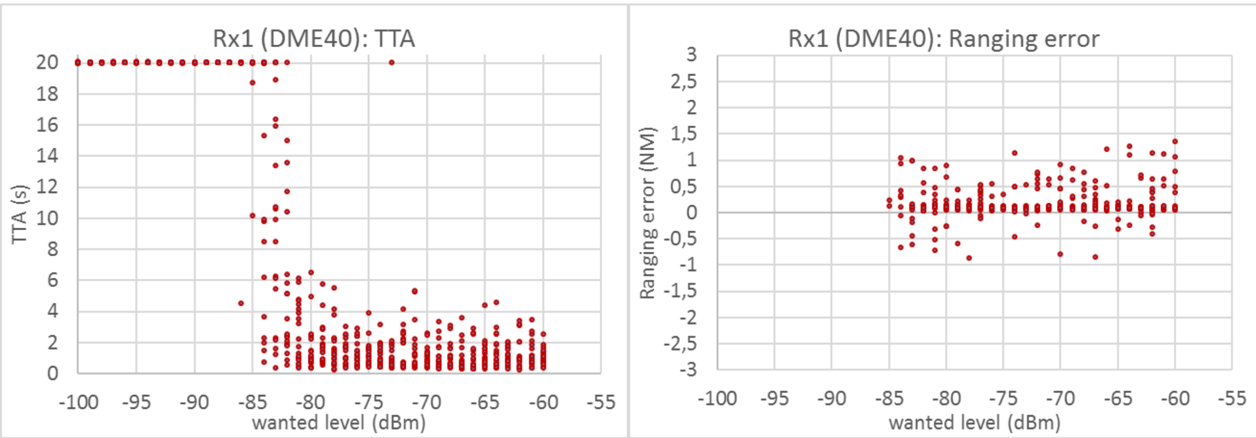


Figure 116: TTA (Time To Acquire) and ranging error for the non-distorted Rx1 (measurement timeout was 20 s)

Evaluation:

The equipment under test meets the requirements specified during time of certification

Following the above results, the threshold for an undistorted TTA was set to 5 seconds and the threshold for the ranging error was set to 1 NM which is 2 times the standard deviation of all measurements where the equipment was able to track the signal within 5 seconds. The resulting sensitivity of Rx 1 is -81 dBm.

A10.6.4.2Rx 2 (KDM-706)

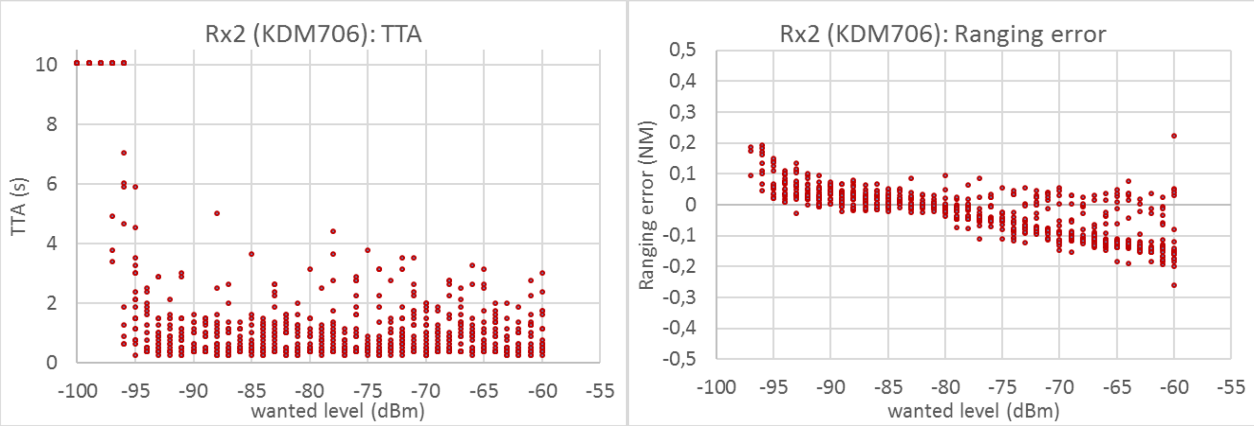


Figure 117: TTA and ranging error for the non-distorted Rx2 (measurement timeout was 10 s)

Evaluation:

- The equipment under test meets the requirements specified during time of certification;
- Following the above results, the threshold for an undistorted TTA was set to 4 seconds. The resulting sensitivity of Rx 2 is -95 dBm.

A10.6.4.3 Rx 3 (KTU709)

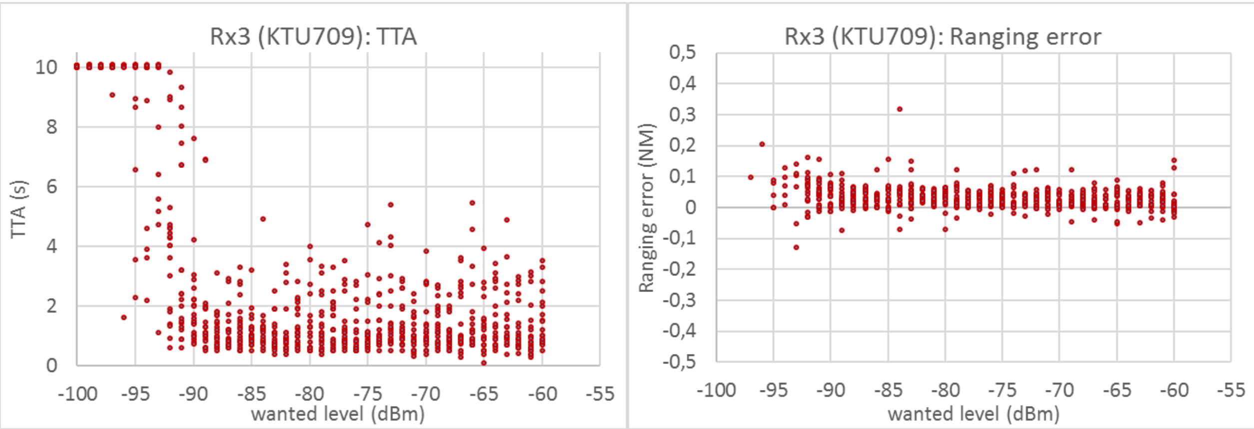


Figure 118: TTA and ranging error for the non-distorted Rx3 (measurement timeout was 10 s)

Evaluation:

- The equipment under test meets the requirements specified during time of certification;
- Following the above results, the threshold for an undistorted TTA was set to 5 seconds. The resulting sensitivity of Rx 3 is -90 dBm.

A10.6.4.4ASOP evaluation

Due to the observations above, the applicable threshold values for TTA and ranging error had to be adjusted individually for every tested receiver. The respective values that mark the point of failure were chosen as follows:

Table 129: Selected threshold values for the failure criterion of the tested on-board interrogators

Parameter	Rx1 (DME40)	Rx2 (KDM-706)	Rx3 (KTU709)
TTA	5 s	4 s	5 s
Ranging error	1 NM	0.17 NM	0.17 NM

The following figure shows the percentage of successful ASOP under the above criteria.

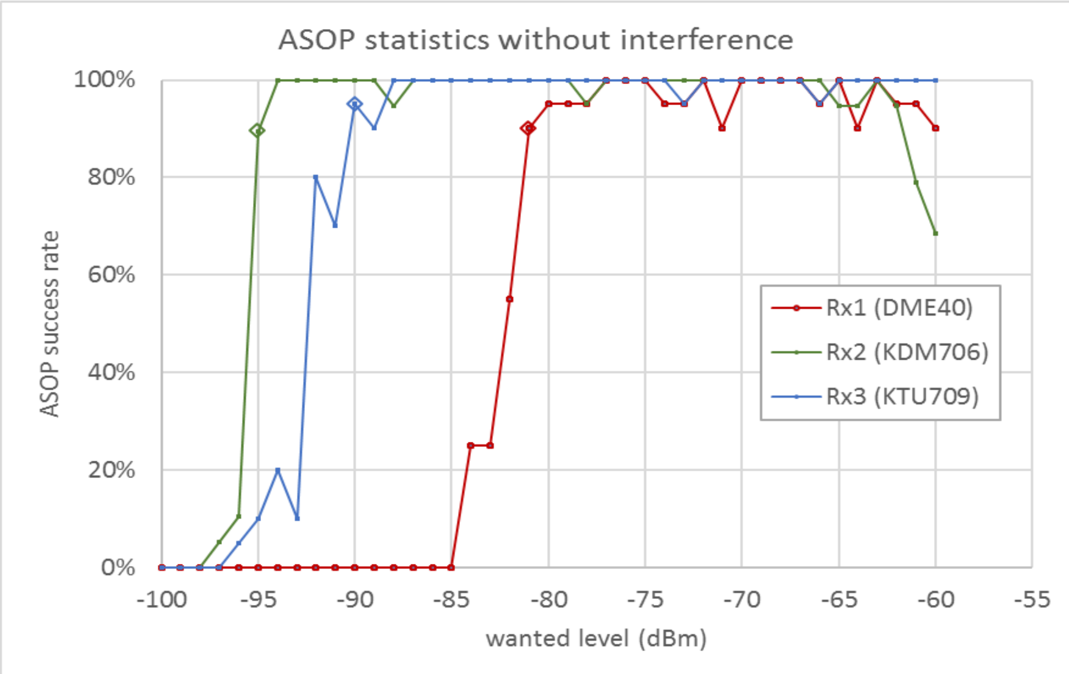


Figure 119: Non-interfered ASOP statistics for selected failure criterion

Evaluation:

- The sensitivity of the on-board interrogators ranges from - 95 dBm to -81 dBm;
- Whenever the system is operated at wanted levels above the sensitivity, the ASOP is always successful in more than the required 80%. An exception is Rx2 whose performance degrades with increasing wanted signal level owing to the raising ranging error. However, this behaviour was not considered in the following C/I measurements as it is not due to any interfering RF signal.

A10.6.5 Measurements with PMSE interferer

Using the failure criteria selected in the previous section, measurements with the interfering PMSE signal at different frequency offsets were conducted. The wanted signal levels for these measurements were set to 3 dB and 10 dB above the determined receiver sensitivity.

Only positive frequency offsets were measured, i.e. the interferer frequency was above the DME frequency.

The general behaviour at the interference threshold was equal to the behaviour near the sensitivity in the non-distorted case. As an example, the following graphs show the ASOP results for the co-channel case (offset wanted/unwanted signal = 0) at a wanted signal level that is 3 and 10 dB above the measured sensitivity.

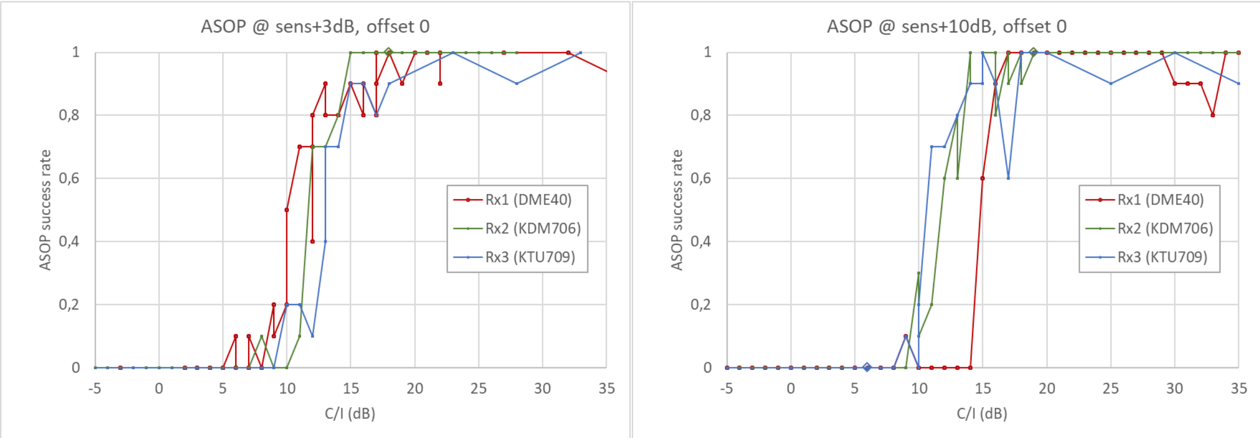


Figure 120: ASOP success rate at different wanted signal levels when interfered by a co-channel PMSE signal

The measurements showed a good reproducibility. This can be seen in the following graph that compares the same parameter combination (wanted signal level -79 dBm, offset = 0) in three different measurement series having been performed on different days.

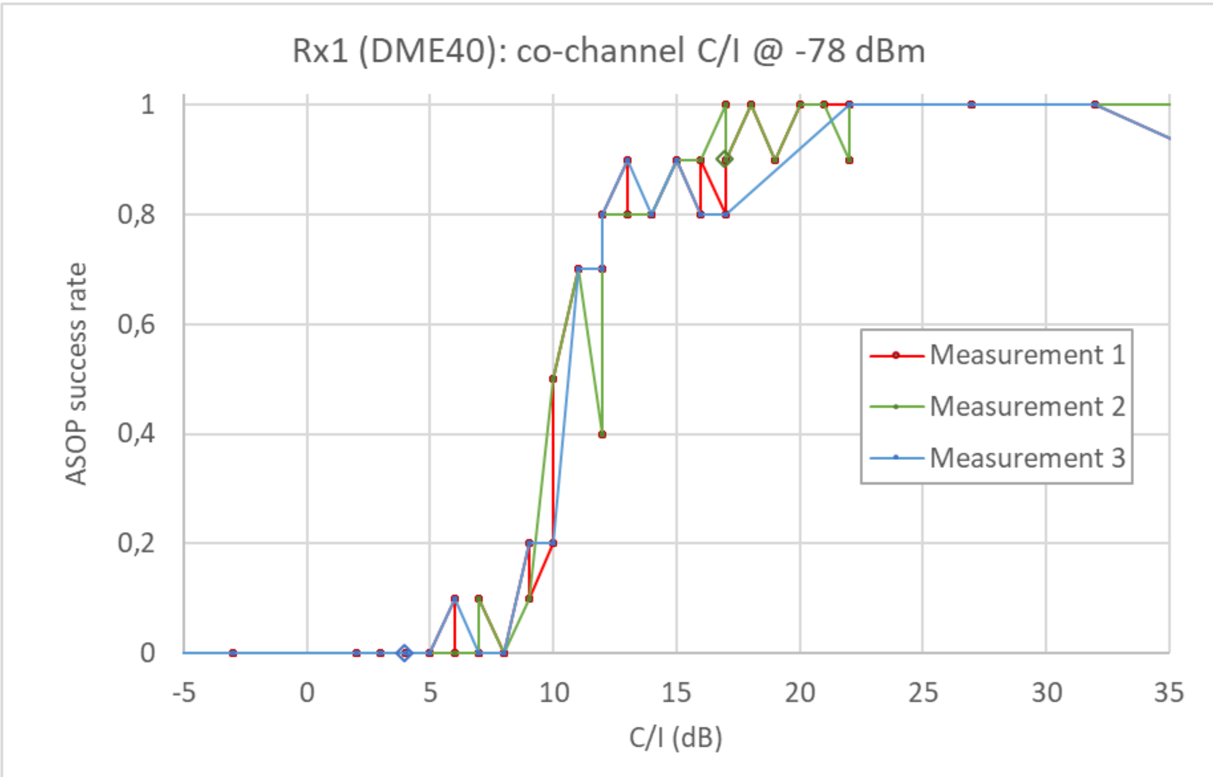


Figure 121: Co-channel C/I for the DME40 interrogator at three different measurement days

The following table and figures show the required C/I depending on the frequency offset and using the ASOP criterion described above.

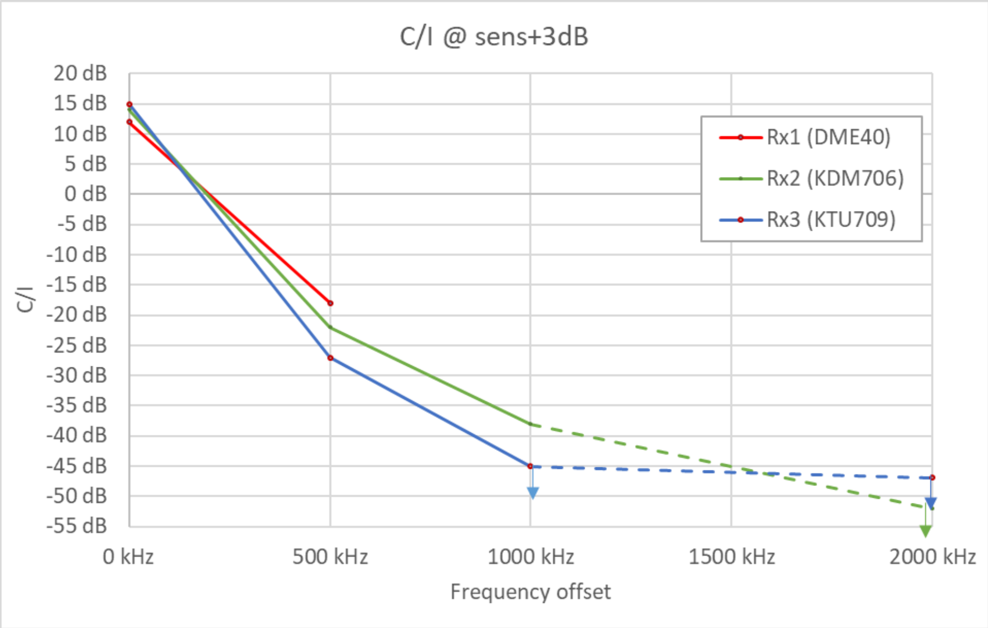


Figure 122: ASOP C/I for different offsets at wanted levels 3 dB above sensitivity

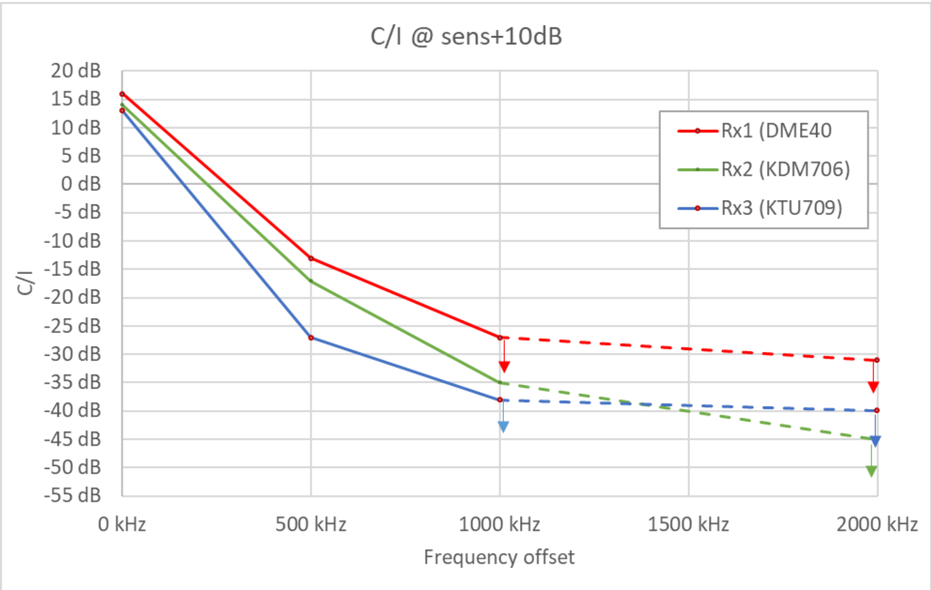


Figure 123: ASOP C/I for different offsets at wanted levels 10 dB above sensitivity

Table 130: Table A.5: ASOP C/I for different offsets

	Rx 1 (DME40)		Rx 2 (KDM-706)		Rx3 (KTU709)	
Offset	@sens+3dB	@sens+10dB	@sens+3dB	@sens+10dB	@sens+3dB	@sens+10dB
0 kHz	12 dB	16 dB	14 dB	14 dB	15 dB	13 dB
500 kHz	-18 dB	-13 dB	-22 dB	-17 dB	-27 dB	-27 dB
1000 kHz		< -27 dB	-38 dB	-35 dB	< -45 dB	< -38 dB
2000 kHz		< -31 dB	< -52 dB	< -45 dB	< -47 dB	< -40 dB

Evaluation:

- The co-channel C/I of the tested on-board receivers is around 15 dB with little variation;
- For offsets higher from 0.5 MHz on, the required C/I varies considerably. The receiver requiring the highest C/I is Rx 1 (DME40);
- When the frequency offset is 2 MHz or higher, none of the tested on-board receivers could be interfered with PMSE levels up to -40 dBm;
- The C/I measurement results were reproducible.

A10.7 GROUND TRANSPONDER AS EQUIPMENT UNDER TEST

A10.7.1 Failure criteria

The following interference effects to the ground transponder were investigated:

- The beacon reply efficiency drops;
- The ranging error increases;
- The monitor warning/alert is triggered.

The ground transponder receiver is internally tested by transmitting a series of test pulses from a short antenna located directly at the receiver antenna. The level of these pulses is near the expected receiver sensitivity. If these test pulses are not evaluated correctly by the system, the monitor alert is raised indicating that the system is malfunctioning. In such cases the system is switched off assuming that a stand-by system takes over. This is the most serious interference effect possible because if the effect is caused by external interference the standby system will also switch off and maintenance staff has to visit the site to switch the DME on again.

As mentioned before, several properties in the system design result in the fact that not 100% of all interrogator pulses will be evaluated correctly. These are for example:

- Interrogator pulses being transmitted at an arbitrary point in time from multiple aircraft may overlap at the ground transponder making it impossible to separate them in all cases;
- During the delay time for a pulse pair, and during the time of re-transmission, the ground station receiver is switched off and is therefore not able to receive pulses from other aircraft;
- During the time another on-board system such as secondary radar is transmitting, the DME receiver is switched off to avoid destruction;
- For transponder sites where due to multipath additional interrogations are received from the same interrogation signal.

For the above reasons, the beacon reply efficiency, which is the percentage of evaluated and re-transmitted interrogator pulses versus the total interrogator pulses being transmitted, is expected to be only 70%.

A10.8 MEASURED RECEIVERS

The following ground station equipment was available for the measurements:

Table 131: Measured ground transponder equipment

No.	Type	Tx power	Nominal sensitivity
Rx1	Selex SE 1119A	1 kW	-94 dBm
Rx2	Thales DME415	100 W	-81 dBm
Rx3	Alcatel/Thales FSD-45	1 KW	-91 dBm
Rx4	Alcatel/Thales DME40	100 W	-81 dBm

It should be noted that the receiver sensitivity is adjustable. The nominal sensitivity is adjustable between -81 and -97 dBm and depends on the transmitter e.i.r.p., typically -81 dBm or -91 dBm. It should be noted that the C/I measurements were done with wanted signal level that is 3 dB above the measured sensitivity, not the nominal sensitivity.

A10.8.1 Measurement setup

For all measurements of the ground transponder, the following principle measurement setup was used:

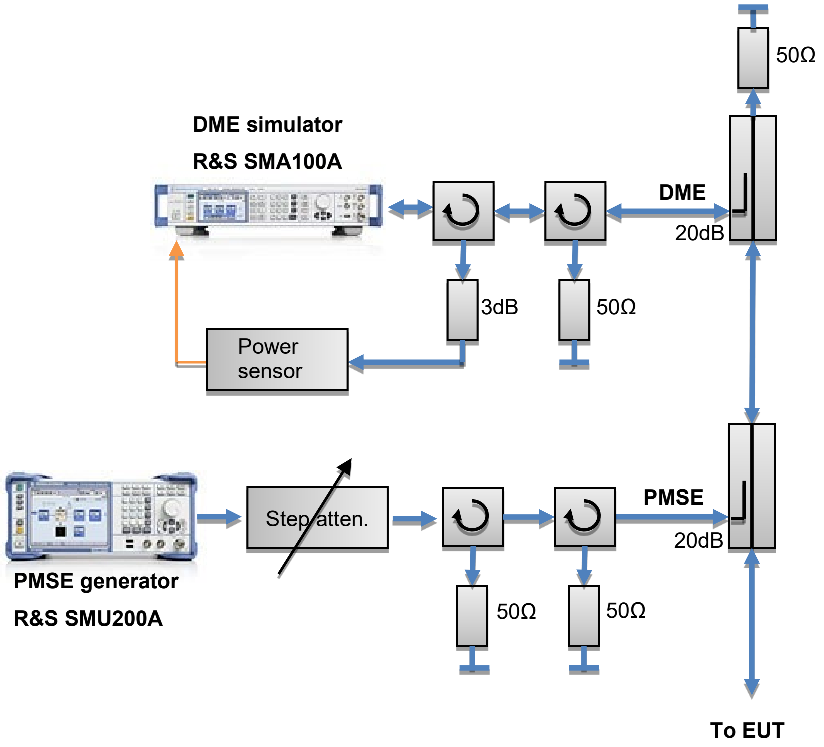


Figure 124 Measurement setup for ground transponders as EUT

In the laboratory environment, the DME transmitter is sent into a dummy load instead of the antenna. To simulate the nearfield monitor antenna directional couplers and attenuators were installed as shown in the following figure.

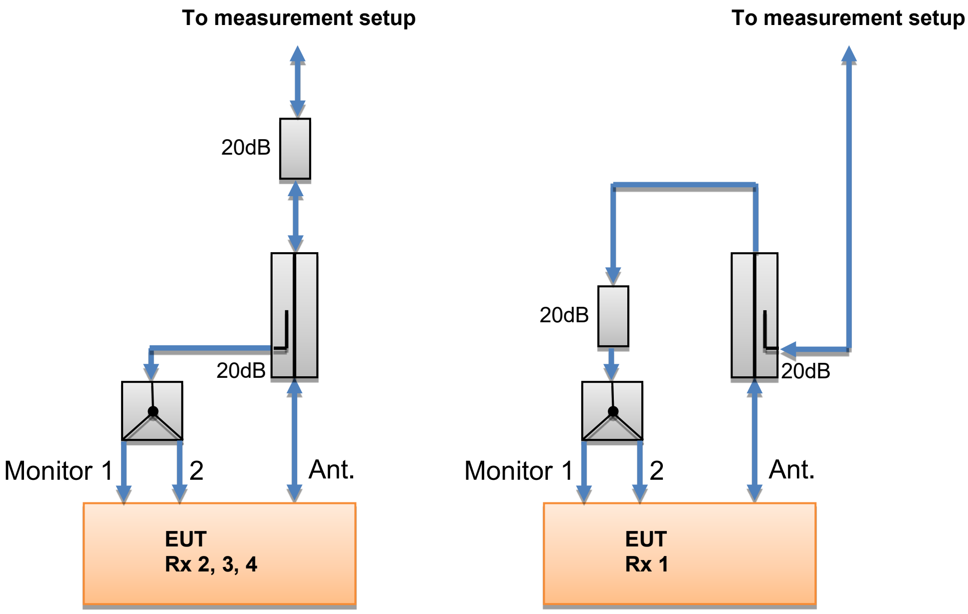


Figure 125: Setup for the monitor function of the EUTs

A10.8.2 Measurement procedure

All measurements were done manually. The DME level was adjusted directly at the DME generator, the PMSE level vas adjusted with the step attenuator. The DME generator was set to send 800 pp/s. Beacon reply efficiency (BRE) was evaluated and read from the DME generator SMA100. It should be noted that the DME stations also had an internal indication of the BRE. However, it was found that the values of this indicator were mostly higher than the actual BRE as evaluated by the SMA.

Note: Due to time constraints, the measurements were not conducted with activated SDES and/or LDES, which has been found during JTIDS/MIDS interference compatibility measurements to be more susceptible to pulsed interference.

A10.8.3 Measurements of sensitivity and non-interfered behaviour

In order to assess the general performance and behaviour of the EUT at low wanted signal levels, different performance parameters were measured in a non-interfered situation.

The following graphs show the results of these measurements.

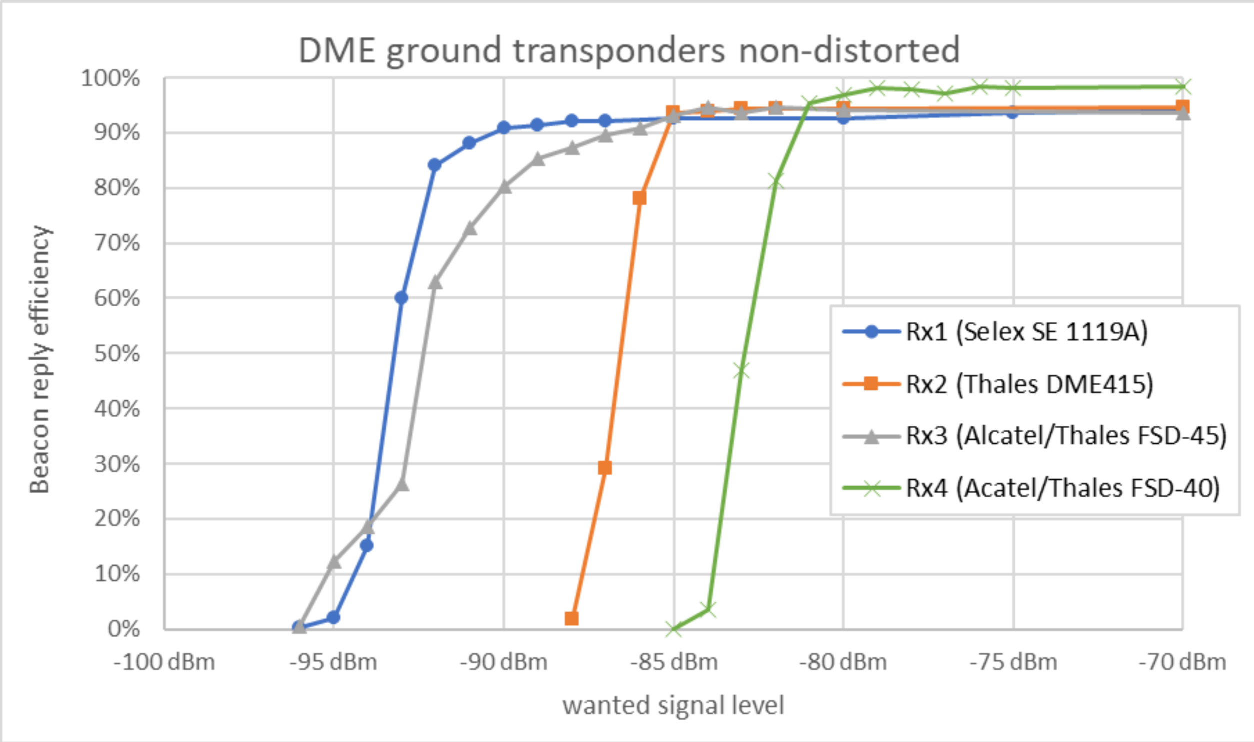


Figure 126: Beacon reply efficiency at low signal levels

Evaluation:

- The sensitivity varies considerably among the tested equipment.
- The following table lists the sensitivity for a BRE of at least 70%.

Table 132: Sensitivity of the DME ground transponders

Rx	Sensitivity for BRE > 70%
1	-92 dBm
2	-86 dBm
3	-91 dBm
4	-82 dBm

To determine the variation of the Reply efficiency versus number of interrogations, Rx 1 was tested at a wanted signal level of -87 dBm with different interrogation pulse pair rate.

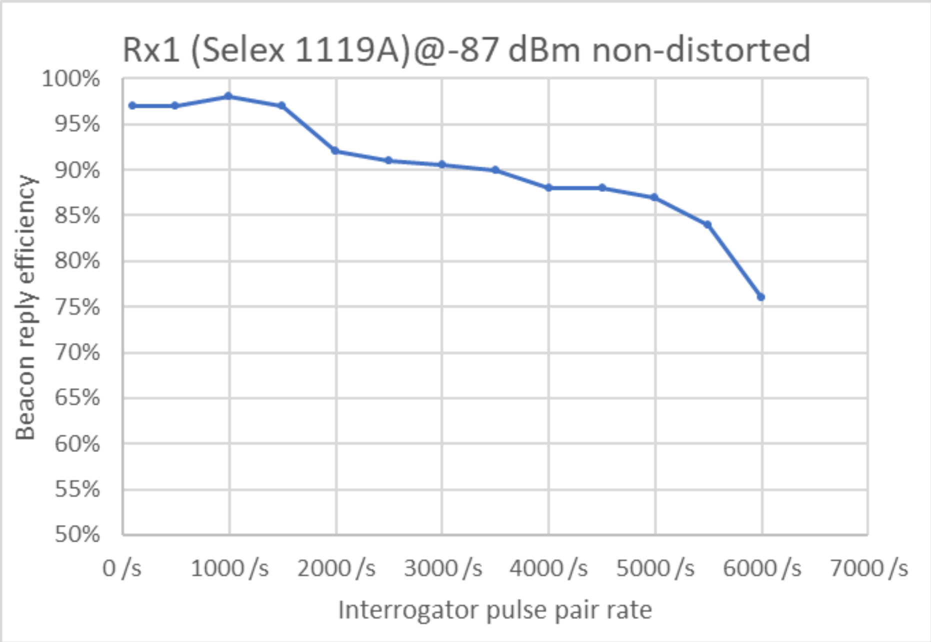


Figure 127: Ground transponder performance depending on the number of interrogator pulse pairs per second

The BRE decreases with an increase of interrogations. For the C/I measurements, the interrogator pulse pair rate (meaning interrogation pulse pairs) was set to 2000 Hz equalling to a of 2000 pp/s.

A10.8.4 Measurements with PMSE interferer

Using the BRE of 70% and the triggering of an alarm or warning as failure criteria, measurements with the interfering PMSE signal were conducted. To assess the behaviour around the failure points, a series of co-channel interference (offset = 0) at a wanted signal level that is 3 dB above the measured sensitivity for a BRE of 70% (see Table A.7). The following figure shows the result of these measurements:

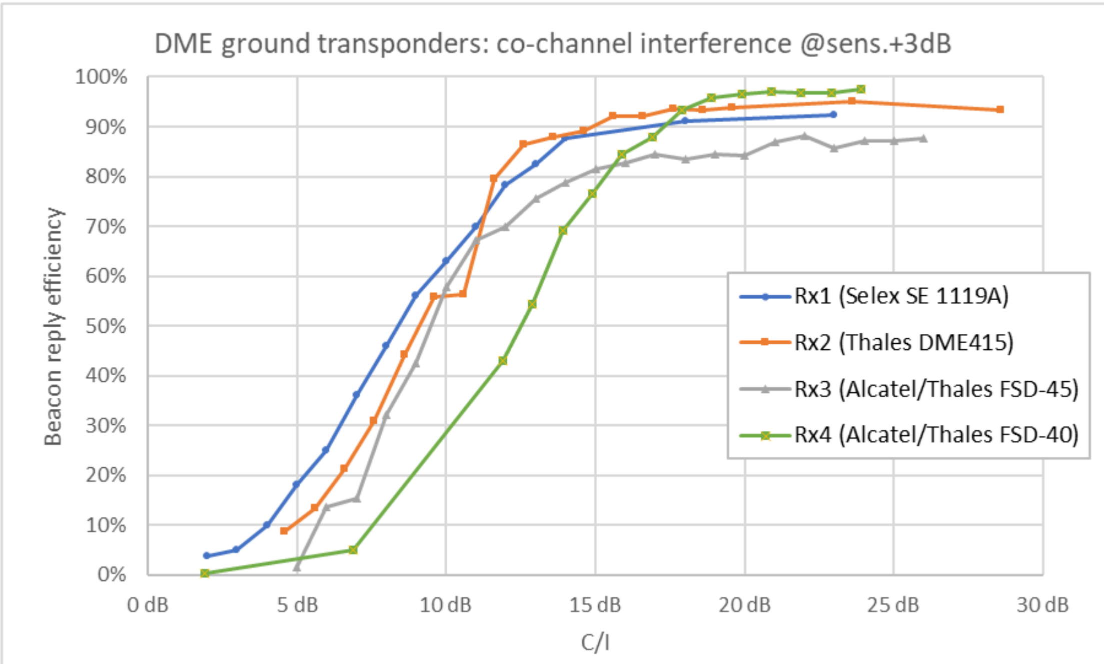


Figure 128: BRE at different co-channel C/I

Evaluation:

- When exposed to a co-channel PMSE interferer the BRE drops continuously. For C/I between 11 dB (Rx.1) to 14 dB (Rx.2) the BRE is below the required 70% BRE, until at a C/I of 2 dB the BRE is reduced close to at 0%;
- The following table denotes the resulting co-channel C/I for a BRE of 70%.

Table 133: Co-channel C/I for a BRE of 70%

Rx	C/I for BRE > 70%
1	11 dB
2	12 dB
3	12 dB
4	14 dB

The required C/I for both BRE ≥ 70%% and triggering of alarm or warnings was measured for different frequency offsets. The wanted signal levels for these measurements were set to 3 dB above the determined receiver sensitivity.

Only positive frequency offsets were measured, i.e. the interferer frequency was above the DME frequency.

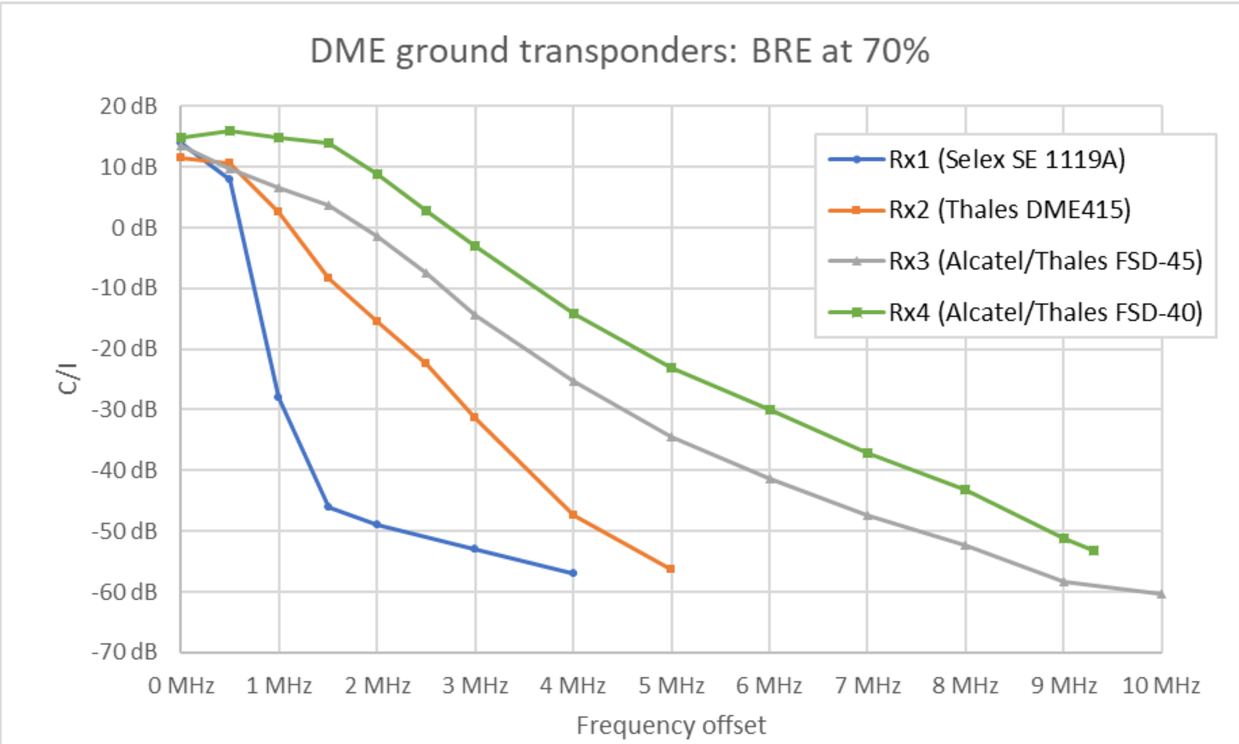


Figure 129: C/I for a minimum beacon reply efficiency of 70%

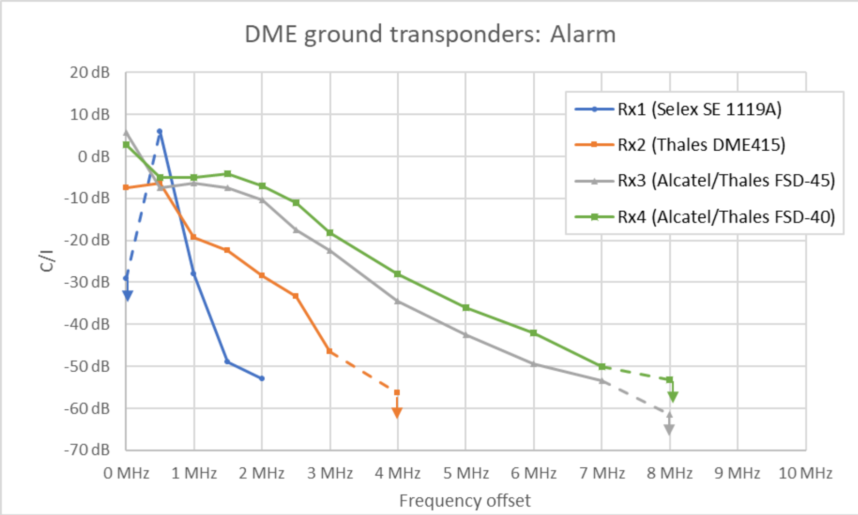


Figure 130: Required C/I to ensure no alarm or warning is triggered

In some cases the alarm/warning did not occur even at the highest possible interfering level. In these cases the arrows shown in Figure A.21 indicate that the C/I is higher (i.e. more negative) than shown in the graph.

Evaluation:

- The alarm criterion generally occurs at higher interference levels than the criterion to reach at least 70% BRE, even if the alarm interference level is sometimes very close to the interference level required to fulfil the BRE-requirement;
- The selectivity of the tested DME receivers varies considerably. For example Rx1 requires only -50 dB C/I at frequency offsets of 2 MHz. To accept the same interfering level, the PMSE frequency must be at least 9 MHz away from the receiving frequency of Rx4.

A10.9 CONCLUSION

The present test results indicate for the measured equipment that:

- The measured, non-distorted sensitivity of both on-board and ground DME receivers varies considerably by as much as 14 dB. More sensitive receiver than those tested exist, their behaviour during interference may be different;
- The C/I required by on-board interrogators for co-channel PMSE operation varies between 12 and 16 dB. If the frequency offset is at least 1 MHz, the C/I varies distinctly at values better than about -35 dB;
- The C/I required by ground transponders for co-channel PMSE operation varies between 11 and 14 dB and is typically 12 dB. Further increase of PMSE interference level reduces the beacon reply efficiency continuously down to approx. 0%. For frequency offsets of 1 MHz or more, the required C/I varies at maximum by 60 dB;
- The selectivity of on-board receivers varies less than that of ground receivers. At 1 MHz offset, for example, the spread among tested on-board receivers is about 10 dB while it is up to 45 dB for ground transponder receivers;
- The ground transponder alarm criterion generally occurs at higher interference levels than the criterion to reach at least 70% BRE, even if the alarm interference level is sometimes very close to the interference level required to fulfil the BRE-requirement. However, the alarm criterion is most critical and it must be ensured that the required C/I is not exceeded at any time;
- The selectivity for the alarm functions varied considerably for the tested DME receivers. One receiver tested required only -50 dB C/I at frequency offsets of 2 MHz, while another receiver tested required at least 9 MHz off set for the same rejection performance;
- It should be noted that due to time constraints the measurement campaign is incomplete up to now, and does not allow a conclusion in terms of compatibility. Particularly not all possible signal and interference combinations could be measured and therefore, the maximum C/I required in worst-case scenarios may be higher than these measurement results indicate.

ANNEX 11: DME AND TACAN TRANSPONDER IDENTIFICATION INTERFERENCE FROM DFS GERMANY

A11.1 SUMMARY

This Annex describes laboratory measurements of the susceptibility of the airborne DME and TACAN interrogator receiver to interference. In the case of TACAN as signal source, attention is given to the Pulse Amplitude Modulation of the signal. It is concluded that a TACAN signal as desired signal source needs an additional protection margin compared to DME as a desired signal source.

The results further demonstrate that a C/I protection of at least 20 dB is needed in order to avoid unacceptable interference to the TACAN transponder identification code.

A11.2 VARIATIONS OF THE NEEDED C/I FOR TACAN COMPARED TO DME

A11.2.1 Introduction

Today many European countries, e.g. Germany, operate TACAN at many locations instead of DME for civil and military users. TACAN transponders do not differ significantly from DME transponder, except TACAN provides bearing information, through 900 additional Reference Pulse Groups (RPG) and a negative 15 Hz and 135 Hz Pulse Amplitude Modulation (PAM) across all transmitted pulses. Consequently the peak pulse power can vary by over 10 dB.

A11.2.2 Difference in e.i.r.p. in reply pulses due to the PAM

The initial TACAN designs generated the PAM across all transmitted pulses in mechanically scanning antenna that consisted of two nonconductive cylinders, with embedded wires to provide the PAM a 15 Hz and 135 Hz modulation. In electronic scanning TACAN antenna, 16 or more vertical antenna arrays, aligned around the centre of the antenna base, are amplitude and phase shifted as necessary to generate the required PAM.

The depth of modulation for each of the two signals is defined as 21 ±9%, however some manufacturer define them as 20 ±10%, while the depth of modulation for the sum of the 15 Hz and 135 Hz is max. 55%. The depth of modulation varies with the elevation angle up to a max. of 55% between ±45° of the horizontal plane.

The peak pulse power can vary by over 10 dB and due to the PAM of the pulse pairs transmitted by TACAN transponder, only a few of the reply pulses will provide the same signal strength as a DME transponder having an identical, but continuous peak e.i.r.p.

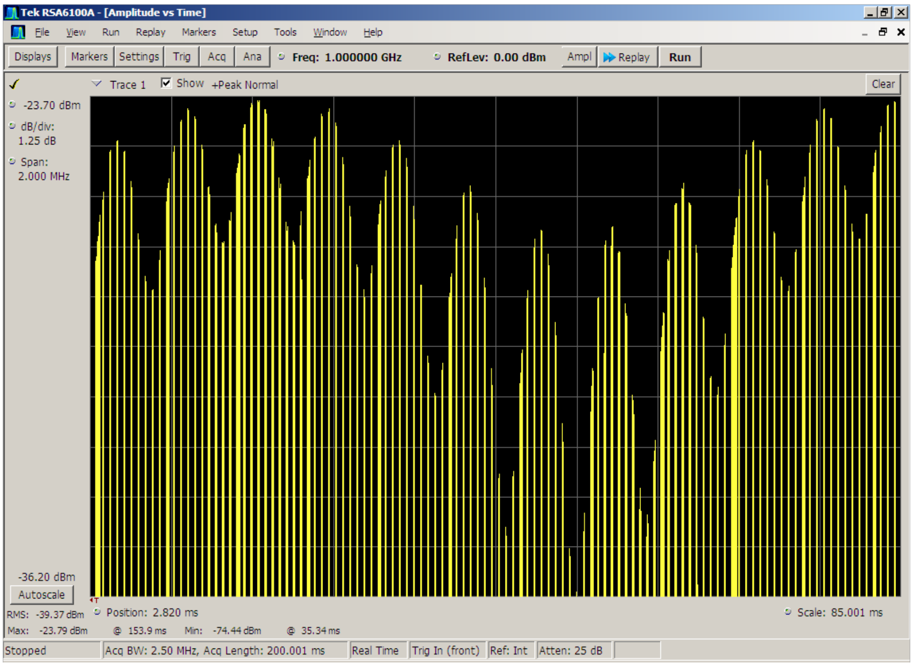


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Figure 131: Example of PAM during a morse code identification (SDX-2000).

A11.2.3 Conclusion

The peak pulse power can vary by over 10 dB. Therefore TACAN are more sensitive to PMSE interferences than DME. Hence when considering TACAN/PMSE compatibility, an additional protection ratio is required.

A11.3 MEASURED EFFECT OF PMSE INTERFERENCE ON TACAN IDENTIFICATION

A11.3.1 Introduction

As described in the section A11.2, TACAN and DME transponders are interchangeable in providing slant ranging distance and identification to the DME and TACAN interrogators. Therefore, any transponder used as source for distance ranging and the corresponding Identification of the transponder could be a TACAN. Ground DME and TACAN transmit up to 5400 pp/s and additional 900 pp/s during identification in Morse code. To enable identification of the specific ground station, an ID consisting of two to four characters is sent every 30 to 40 seconds as Morse Code, The Morse Code dots and dashes are generated by a series of pulses to sustain a 1350 Hz audio tone. The aircraft equipment decodes the ID into an audible tone or provides it as digital data word via the ARINC-429 aircraft bus.

A11.3.2 Test setup

The test setup is described in the figure below with SDX-2000 as TACAN transponder simulator source. The TACAN transponder signal was set to channel 17x (978MHz). Varying signal levels, each having a PAM with Depth of Modulation (DOM) of 50%, were used.

The PMSE Test signal was generated using a SMU-200A PMSE signal, with the following parameter, using QPSK modulation with a Bandwidth set to 180 kHz, having a PAPR (peak to average power ratio) of 3.5 dB.

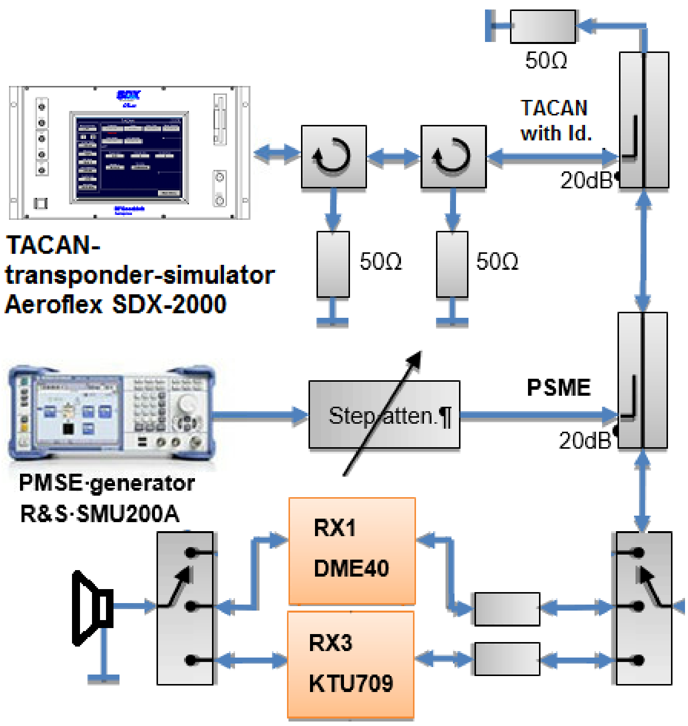

Figure 132: Test setup for PMSE on TACAN-Identification tests

The test Identification sent the Morse Code message "CQCQ". The TACAN transponder simulator signal level was varied between -85 dBm to -90 dBm, and recorded in an audio file.

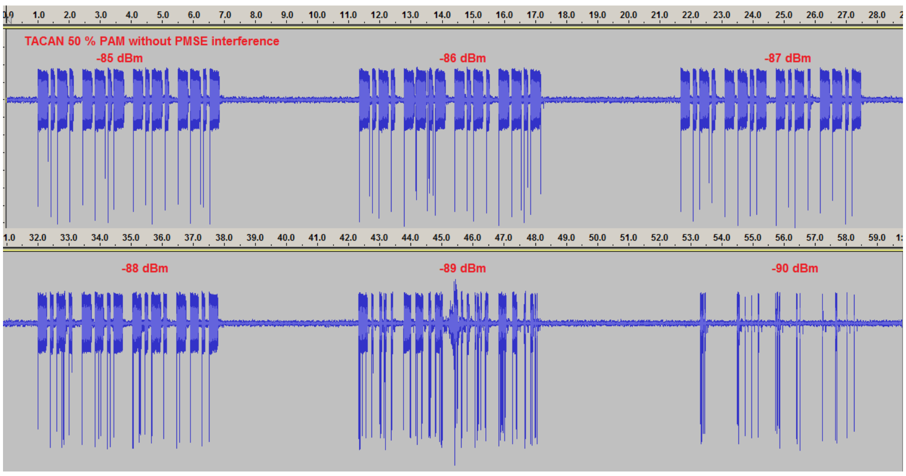

Figure 133: KTU-709 TACAN identification without PMSE interference

An Identification was considered to be clear and unambiguous, when dots, dashes and pauses of an Identification could be distinguished.

A signal level of -87 dBm was selected for tests when PMSE interference was added. To allow easier comparison between the Identification without interference and the interfered identification, the first CQ message was without PMSE interference, while before beginning of the second CQ message the PMSE interference was switched on. With increasing interference more of the audio sustaining the Morse code gets muted. At S/I of 20 dB detections of the identification became ambiguous, and with further increase of the PMSE signal level, more audio that sustains the identification in Morse code becomes muted.

Measurements on a Collins DME-40 interrogator identified that -82 dBm signal level and a S/I of 20 dB was required to detect Identification clear and unambiguous.

The receiver selectivity with offset to the DME/TACAN channel centre frequency for both receiver is asymmetrical, and therefore requires more detailed measurements, which were impossible due to time constraints.

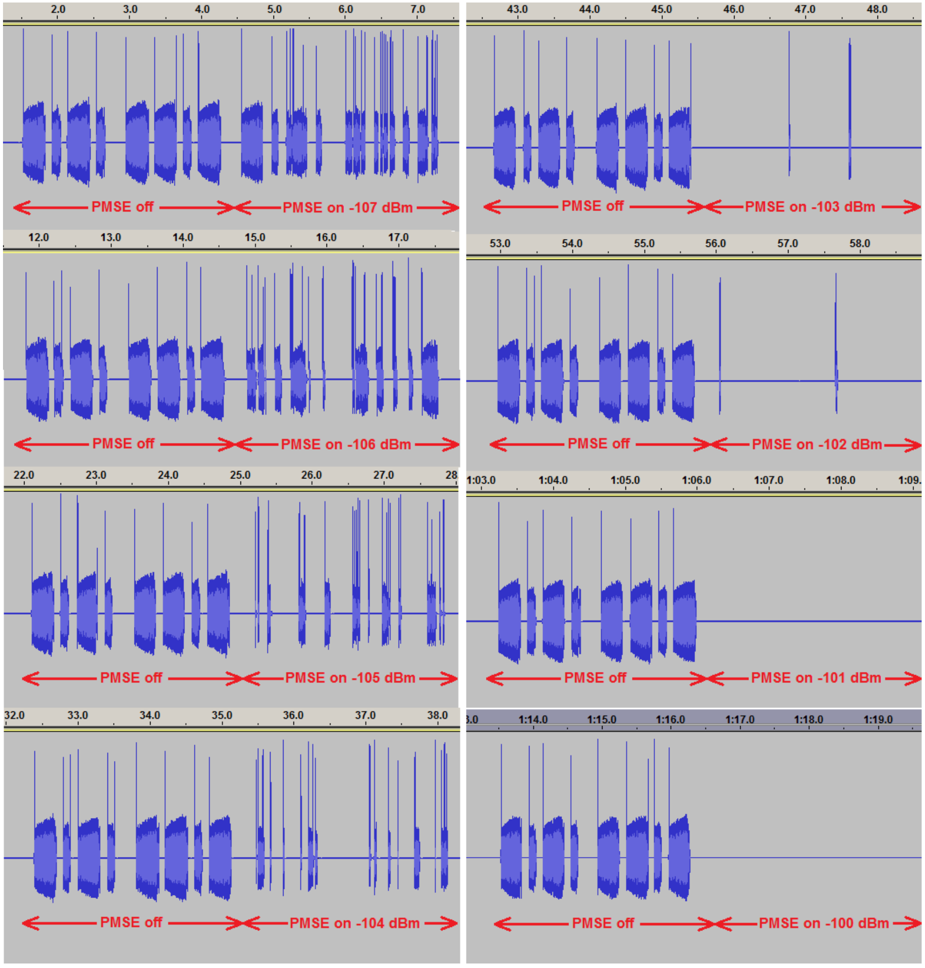

Figure 134: KTU-709 PMSE on DME interference requiring a S/I of 20 dB

A11.3.3 Conclusion

The measured, non-distorted sensitivity for identification varies by 7 dB. More sensitive receiver than those tested exist, their behaviour during interference may be different.

Due to the depth of the pulse amplitude modulation of TACAN signal during Morse Code identification, when there are co-channel PMSE signals, the S/I required by on-board interrogators is 20 dB for clear and unambiguous Identification from a TACAN source.

The receiver selectivity with offset to the DME/TACAN channel centre frequency for both receiver is asymmetrical, and therefore more detailed measurements may be required.

ANNEX 12: GUIDANCE BY ICAO RELATING TO THE PROTECTION OF AERONAUTICAL SYSTEMS

A12.1 SUMMARY

This Annex provides suggested guidelines, as developed by the International Civil Aviation Organization, for parameters to be used for the technical studies relevant to the safe operation of the aeronautical systems in the band 960-1164 MHz, referencing relevant ITU-R Recommendations; relevant ICAO Standards and Recommended Practices and guidance material; and other relevant industry standards.

A12.2 PARAMETERS TO BE USED IN SHARING STUDIES

Section A12.3 below discusses the appropriate I/N criteria to be used in a sharing studies based on the I/N methodology; section A12.4 discusses the application of aeronautical safety margins; and the remaining sections indicate the appropriate DME receiver parameters to be used in MCL studies based on the C/I methodology.

A12.3 TRADITIONAL PROTECTION OF THE RADIO BROADCAST SERVICES

Recommendations ITU-R BT.1895 [67] and ITU-R BS.1895 [68], "*Protection criteria for terrestrial broadcasting systems*", for Television and Sound respectively, *recommend:*

"1 that the values in recommends 2 and 3 be used as guidelines, above which compatibility studies on the effect of radiations and emissions from other applications and services into the broadcasting service should be undertaken;

2 that the total interference at the receiver from all radiations and emissions without a corresponding frequency allocation in the Radio Regulations should not exceed 1% of the total receiving system noise power;

3 that the total interference at the receiver arising from all sources of radio-frequency emissions from radiocommunication services with a corresponding co-primary frequency allocation should not exceed 10% of the total receiving system noise power."

The second recommends, which is equal to an I/N of -20 dB applies to interference sources such as PMSE when operating in the television broadcast bands, while the third recommends, which is equal to an I/N of -10 dB applies to interference between two equal co-primary services.

The 960-1164 MHz band is allocated to ARNS and AM(R)S and is heavily used by systems providing safety critical aeronautical radionavigation and radiocommunication. Any operation of PMSE in the band would be in accordance with ITU RR No. 4.4. In order to achieve sufficient protection of the incumbent aeronautical safety services, any sharing conditions provided to those incumbent services need to be, as a minimum, similar to those required by the Radio Broadcast services in the bands those services operate in. Hence, an I/N of no more than -20 dB is recommended.

A12.4 CONSIDERATION OF AERONAUTICAL SAFETY MARGINS IN SHARING STUDIES

The frequency band 960-1215 MHz is used by systems operating in the aeronautical radionavigation service (ARNS), the aeronautical mobile (R) service (AM(R)S) and the aeronautical mobile satellite (R) service (AMS(R)S), providing critical navigation, surveillance and collision avoidance functions on a global basis. Those systems operate in accordance with ICAO standards and recommended practices (SARPs). ITU RR No. 4.10 applies to the protection of aeronautical safety of life services.

Aeronautical radionavigation systems are characterised in ICAO SARPs and associated provisions as requiring exceptionally high Integrity and Continuity, typically measured as probabilities of $1 - 1*10^{-9}$ and $1 - 2*10^{-6}$ respectively.

While Recommendation ITU-R M.1903 [69] provides characteristics and protection criteria for receiving earth stations in the radionavigation-satellite service (s-E) and receivers in the aeronautical service operating in the band 1559-1610 MHz, its Annex 1 contains a generic and informative description of the term *aeronautical safety margin* and its purpose.

Following are a few quotes from Annex 1 of Recommendation ITU-R M.1903:

“1 Introduction

There is a long history within ITU and ICAO of reserving a portion of the interference link budget for a margin in order to ensure that the safety aspects of the radionavigation service are protected. These margin values typically lie in the range of 6 to 10 dB, or more. Furthermore, there is ample precedent for a safety margin for radionavigation safety applications in ITU-R

…

2 Purpose of a safety margin

A safety margin (which may also be called a public safety factor), is critical for safety-of-life applications in order to account for risk of loss of life due to radio-frequency interference that is real but not quantifiable. To support safety-of-life applications, all interference sources must be accounted for.

3 Aeronautical radionavigation applications of safety margin

3.1 Aeronautical radionavigation safety margin background

The utilization of safety margins in navigation systems is well established. ICAO specifies a safety margin for the microwave landing system (MLS) of 6 dB (Annex 10 to ICAO Convention **Error! Reference source not found.**: International Standards and Recommended practices Aeronautical Telecommunications, Vol. 1 – Radio Navigation Aids (Attachment G, Table G-2)). The instrument landing system (ILS) applies a safety margin of 8 dB (see Recommendation ITU-R SM.1009-1, Appendix 3 to Annex 2). In each case the margin is defined with respect to the navigation system carrier power.

That is, to test system performance for these systems, the desired signal power is reduced from the nominal level by the safety margin, and then tested to determine whether the system provides the required performance in the presence of interference. In other words, the manufacturer must design the equipment to handle the highest anticipated interference level while receiving a desired signal level lower (by the safety margin) than would be otherwise received.

…”

ICAO Doc 9718 [102], “*Handbook on Radio Frequency Spectrum Requirements for Civil Aviation*”, Volume I, has the following description of an aviation safety margin:

“9.2.23 Aeronautical safety applications are required to have continued operation through worst-case interference, so all factors which contribute to harmful interference should be considered in analyses involving those applications. An aviation safety margin is included in order to address the risk that some such factors cannot be foreseen (for example impacts of differing modulation schemes). This margin is applied to the system protection criteria to increase the operational assurances to the required level. Traditionally for aviation systems/scenarios an aviation safety margin of 6–10 dB is applied. Until established on the basis of further study on a case-by-case basis, an aviation safety margin of not less than 6 dB should be applied.”

Consideration of an aviation safety margin is included in a number of ITU-R Recommendations, including Recommendation ITU-R M.1639 [72] “*Protection criteria for the aeronautical radionavigation service with respect to aggregate emissions from space stations in the radionavigation-satellite service in the band 1164-1215 MHz*”, which applies a 6 dB aviation safety margin.

A12.5 DME RECEIVER SENSITIVITY AND SUSCEPTIBILITY TO INTERFERENCE FROM CONTINUOUS WAVE SOURCES

DME is an interrogator (airborne) / transponder (ground based) system which provides an aircraft with its slant range (distance) from the ground transponder. Transmitting a pair of 3.5 µs wide pulses on a frequency (up to a maximum of 40 times per second) the aircraft interrogates the ground transponder and the transponder replies on a separate frequency separated by 63 MHz. The turnaround time of this transaction is used for distance measurement.

Interrogations by the various aircraft are not synchronized in time, hence DME can be described as a self-interfering system. A ground transponder can serve multiple aircraft interrogators at a time, a DME transponder may handle traffic from more than 100 aircraft at the same time. During maximum loading conditions and with the minimum power flux densities prescribed in ICAO SARPs, the reply rate of the transponder shall never be less than 70% of the interrogation rate from the aircraft.

A12.5.1 Minimum received signal level by the ground based DME/N transponder

ICAO Annex 10 Volume I [44], para 3.5.4.2.3.1 **Error! Reference source not found.** defines the minimum sensitivity of the ground based DME transponder receiver as -103 dBW/m^2 (equating to -96 dBm) when the DME/N transponder is intended for a coverage range greater than 56 km (30 NM). This describes a typical En-route DME/DME navigation scenario, such as when used for Performance Based Navigation (PBN) RNAV 1 routes.

Since the issue is to compare the reception of both desired and undesired signals, a 0 dB gain antenna is assumed, with no dips or nulls. In the maximum lobe of a higher gain antenna, both the desired and undesired signals will be amplified equally. However in the worst case, as aircraft will be seen at an angle often substantially greater than 0 degrees, the antenna pattern of a higher gain antenna may often be more favourable towards the unwanted ground based signal which comes in at a lower angle.

While this does not accurately depict a worst-case scenario, the below conversion assumes 0 dB antenna gain and no cable loss.

A12.5.2 Minimum received signal level by the airborne DME/N interrogator

ICAO Annex 10 Volume I [44], para 3.5.4.1.5.2 **Error! Reference source not found.**specifies a means to determine the minimum specified transmitter power for a DME/N ground transponder used in association with an ILS or a VOR. In this case the minimum peak isotropically radiated power output of the DME transmitter needs to be sufficient to ensure a minimum received field strength of -89 dBW/m^2 within the intended coverage area of the DME/VOR or DME/ILS pair.

The conversion -89 dBW/m^2 equates to -82 dBm assumes 0 dB antenna gain and no cable loss.

In this context, note should also be taken of the DME/N monitoring function, for which ICAO Annex 10 Volume I [44], para 3.5.4.7.2.4 **Error! Reference source not found.** recommends that an alert should be asserted in the case of a fall of 3 dB or more in the transponder transmitted output power.

Hence, in order to ensure safe operation, a minimum level for the airborne interrogator receiver should be assumed to be -85 dBm. When applying SARPs, though not mandatory, the general rule is to apply Recommendations. However, since this is in the form of a *Recommendation*, these additional 3 dBs are not applied below.

In the above context, it needs also to be noted that DME/DME navigation (DME not used in association with ILS or VOR) as used for RNAV 1 may use DMEs at ranges outside of their designated DME/ILS or DME/VOR coverage areas. In this case the received signal levels will be even less.

The ICAO SARPs describe signal levels in an actual operational scenario, including interference from other DME as well as other pulse modulated aeronautical and governmental systems operating in the 960-1164 MHz band.

A12.6 PROTECTION AGAINST CONTINUOUS WAVE SIGNALS

A12.6.1 Definition of maximum Continuous Wave signals

EUROCAE ED-54 [49] “Minimum Operational Performance Requirements for Distance Measuring Equipment Interrogator (DME/N and DME/P) operating within the Radio Frequency Range 960-1215 MHz” provides parameters and test conditions to verify proper function of the airborne interrogator in a test bench scenario.

ED-54 [49] states that the sensitivity requirement shall be met when a Continuous Wave signal having a level of -99 dBm is applied on the assigned channel frequency. Assuming a zero gain antenna, this equates to -106 dBW/m^2.

EUROCAE ED-57 [50]"Minimum Performance Specification for Distance Measuring Equipment (DME/N and DME/P) (Ground Equipment)" provides parameters and test conditions to verify proper function of the ground based transponder.

ED-57 states that whenever an interrogation signal is within the dynamic range of the receiver, and is 10dB or more above the level of an interfering Continuous Wave signal, the reply efficiency shall remain greater than 70%. Note that this applies to a test bench scenario with no other interfering signals present.

This equates to -106 dBm, or -113 dBW/m^2 when assuming a zero gain antenna.

A12.6.2 Apportionment of interference levels

Recommendation ITU-R M.1639-1 [72] "*Protection criterion for the aeronautical radionavigation service with respect to aggregate emissions from space stations in the radionavigation-satellite service in the band 1164-1215 MHz*" describes a scenario where DME share frequencies with a "weak" Continuous Wave like signal from the RNSS. From a signal-in-space sharing point of view, this scenario is in fact similar to the one of DME sharing with PMSE.

As a point of verification, with the exception of the ground transponder receiver sensitivity level, Table 1 of Recommendation ITU-R M.1639-1 provides similar values to those displayed above. Since DME ground transponders do not receive in the band 1164-1215 MHz, only values for the aircraft interrogator receiver are provided in the material contained in that Recommendation.

Recognizing that DME is a pulse modulated (self-interfering) system, the Recommendation states the following:

- "2.3 Apportionment of the DME maximum allowable aggregate interference level to RNSS
  - The chosen factor of 6 dB for the apportionment of the maximum allowable aggregate interference level, from all other interference sources to the RNSS maximum allowable aggregate interference level, recognizes that there exists the possibility of interference from other DME in the same frequency band, from the spurious and out-of-band emissions of other airborne ARNS and aeronautical mobile-satellite service (AMSS) systems and also from the bands adjacent to the ARNS. The on-board ARNS systems include multiple secondary surveillance radar transponders, multiple airborne collision avoidance systems and other DME interrogators; on-board satellite terminals in the AMSS also operate. Adjacent band sources of interference are high-powered radiolocation service radar operating just above 1 215 MHz and broadcast service transmitters operating below 960 MHz."

25% apportionment or 6 dB is the factor Recommendation ITU-R M.1639-1 recommends in order to accommodate RNSS interference to DME in the 1164-1215 MHz, this band is not as heavily used for DME as the band 960-1164 MHz. Taking into account the much heavier loading of the band 960-1164 MHz, 10% or 10 dB is proposed as a more realistic apportionment factor for any Continuous Wave type of interference in that band.

A12.7 REQUIRED C/I BASED MCL STUDY LEVELS TO PROTECT DME AGAINST CONTINOUS WAVE INTERFERENCE

A12.7.1 Summary Tables

A12.7.1.1 DME Interrogator (airborne) receiver

Table 134: DME Interrogator (airborne) receiver

	Parameter	Unit	Value	Reference
1	Required minimum PFD of received signal	dBW/m²	-89	ICAO Annex 10 Volume I [44], para 3.5.4.1.5.2
2	Equivalent receiver input level	dBm	-82	See discussion above
3	Continuous Wave interference threshold at antenna	dBm	-99	EUROCAE ED-54, para 3.16.4 [49]
4	Equivalent PFD of interference threshold	dBW/m²	-106	See discussion above
5	Aeronautical Safety Margin	dB	6	Recommendation ITU-R M.1639-1 [72] Recommendation ITU-R M.1903 , Annex 1 [69] ICAO Doc 9718 [101]
6	Apportionment of Continuous Wave interference from PMSE to all the interference sources	dB	10	Apportion 10% of total permissible interference to PMSE
7	Maximum aggregate PFD of PMSE signal at receiver antenna	dBW/m²	-122	Combine 4, 5 and 6 (4 minus 5 minus 6)

A12.7.1.2DME Transponder (ground) receiver

Table 135: DME Transponder (ground) receiver

	Parameter	Unit	Value	Reference
1	Required minimum PFD of received signal	dBW/m²	-103	ICAO Annex 10 Volume I [44], para 3.5.4.2.3.1.
2	Equivalent receiver input level	dBm	-96	See discussion above
3	Continuous Wave interference threshold at antenna	dBm	-106	See discussion above and EUROCAE ED-57, para 3.3.8 [50]
4	Equivalent PFD of interference threshold	dBW/m²	-113	See discussion above
5	Aeronautical Safety Margin	dB	6	Recommendation ITU-R M.1639-1 [72] Recommendation ITU-R M.1903 [69], Annex 1 ICAO Doc 9718 [101]
6	Apportionment of Continuous Wave interference from PMSE to all the interference sources	dB	10	Apportion 10% of total permissible interference to PMSE

	Parameter	Unit	Value	Reference
7	Maximum aggregate PFD of PMSE signal at receiver antenna	dBW/m^2	-129	Combine 4, 5 and 6 (4 minus 5 minus 6)

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