Investigation of interference sources and mechanisms for Eurocontrol: Final Report

DA243D005-1.0

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List of abbreviations

ABD	Anti-Blocking Device
ACAS	Automatic Collission Avoidance System
ADF	Automatic Direction Finder
ADSP	Automated Dependent Surveillance Panel
AM	Amplitude Modulation
AMCP	Aeronautical Mobile Communications Panel
ANF	Agence Nationale de Frequence
ARINC	Aeronautical Radio INCorporated
ASDE	Airport Surface Detection Equipment
ATIS	Air Terminal Information Service
ATNP	Aeronautical Telecommunications Network Panel
AWOG	All Weather Operations Group
CAA	Civil Aviation Authority
CEPT	European Conference for Postal and Telecommunications Administrations
CNS	Communication Navigation and Surveillance
dB	deciBel
DFS	Deutsche FlugSicherung
DGAC	Direction General Aviation Civil
DME	Distance Measuring Equipment
ECM	Electronic Counter Measures
ELBA	Emergency Location BeAcon
ELT	Emergency Location Transmitter
EMC	Electro-Magnetic Compatibility
EPIRB	Emergency Position Indicating Radio Beacon

ERO	European Radiocommunications Organisation
ETSI	European Telecommunications Standards Institute
EUROCAE	EURopean Organisation for Civil Aviation Equipment
FMG	Frequency Management Group
GNSS	Global Navigation Satellite System
GLONASS	GLObal NAvigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile communications
HF	High Frequency
IATA	International Air Traffic Association
ICAO	International Civil Aviation Organisation
ILS	Instrument Landing System
IRFB	International Frequency Registration Board
ISM	Industrial, Scientific and Medical
ITU	International Telecommunications Union
ITU-RR	ITU-Radio Regulations
JTIDS	Joint Tactical Information Distribution System
LF	Low Frequency
MLS	Microwave Landing System
NATO	North Atlantic Treaty Organisation
NATS	National Air Traffic Services
NDB	Non-Directional Beacon
PED	Personal Electronic Devices
PSR	Primary Surveillance Radar
PTT	Press-To-Talk

RA	Radiocommunications Agency
RF	Radio Frequency
RTCA	Requirements and Technical Concepts for Aviation
SHF	Super High Frequency
SICASP	Secondary Surveillance Radar Improvements Collision Avoidance System Panel
SNG	Satellite News Gathering
S-PCS	Satellite – Personal Communications System
SSB	Single Side Band
SSR	Secondary Surveillance Radar
TACAN	Tactical Aircraft Control And Navigation
TCAS	Traffic alert and Collision Aviodance System
TDMA	Time Division Multiple Access
TFTS	Terrestrial Flight Telecommunication System
UHF	Ultra High Frequency
VHF	Very High Frequency
VLF	Very Low Frequency
VOR	VHF Omni-directional Range
VSB	Vestigial Side Band
WRC	World Radio Conference

1 Introduction

1.1 General

This document has been produced by Smith System Engineering Limited (Smith) for Eurocontrol DED/6. It consists of the final report written as part of a study to investigate interference problems associated with communication, navigation and surveillance systems.

1.2 Objectives

The objectives of the study are to present Eurocontrol with a comprehensive analysis of the interference problems that are currently occurring in aeronautical communication, navigation and surveillance (CNS) systems. The study provides Eurocontrol with the information necessary to define a future action plan to appropriately address interference problems.

The study consist of two main activities:

– gathering information on interference sources, effects and incidents;

– the categorisation and explanation of interference effects.

Descriptions of each type of interference identified are given, along with (where known) the mechanism that makes the interference sources a problem for aeronautical systems. In addition, following consultation with Eurocontrol, a basic categorisation scheme has been produced and this is used to judge the overall effect of each of the interference sources identified.

1.3 Study methodology

The information presented in this report has been gathered from two basic sources: documentation and interviews with appropriate personnel. Documentation includes:

– books on relevant subjects;

– articles in industry magazines;

– industry journals;

– reports and papers;

– specifications and user manuals/guides;

– the world wide web.

Discussions were held with a large number of personnel involved in the administration of aeronautical communication, navigation and surveillance systems. Not all organisations contacted kept records of interference problems and hence the information presented, particularly in section 7 which discusses interference problems, tends to concentrate on those countries that kept databases. In addition a number of bodies concerned with certain user or operational groups across all countries (such as the International Air Traffic Association, IATA) were contacted. There is therefore some interference details that are not specific to a certain country. Where an individual proved particularly helpful, face-to-face interviews have been held.

1.4 Structure of this document

Section 2 introduces the spectrum allocation process used by the International Telecommunications Union (ITU). Sections 3, 4 and 5 detail those systems found to be operating in aeronautical spectrum in the frequency ranges 0 to 30 MHz, 30 to 3300 MHz and above 3300 MHz respectively.

Section 6 looks at the treatment of interference and particularly at the roles of national administrations and aeronautical bodies. Section 7 contains details of all the interference sources identified during the course of the study. Section 8 summarises the interference sources.

Section 9 will presents the approach and strategies that Eurocontrol can put in place to assist with the resolution of interference problems in Europe.

There are four appendixes and these cover:

- Working Groups (Appendix A);
- a bibliography of the references read during the study (Appendix B);
- a list of people who were consulted as a part of the study (Appendix C);
- the detailed technical categorisation scheme developed during the study (Appendix D).

2 ITU spectrum allocation

2.1 Introduction

This section identifies the spectrum that is allocated to aeronautical communication, navigation and surveillance systems as well as the systems which operate in that spectrum. The identification of systems is key to ensuring that all aeronautical systems are covered when gathering information on interference incidents.

Additionally, this section identifies those services that are allowed to share spectrum with aeronautical systems. Where frequencies are shared between different services, there is an obvious potential for interference, hence the identification of shared spectrum provides the first indication of potential interference.

Section 2.2 explores the way in which spectrum is allocated to services and the difference between the designations given to services. Sections 2.3 to 2.5 identify the allocated spectrum and the systems that operate in that spectrum.

2.2 Spectrum allocation

This section identifies those parts of the radio spectrum allocated to aeronautical usage by the International Telecommunications Union (ITU) in Region 1. Region 1 encompasses Europe, Africa, the Middle East, the Former Soviet Union (FSU) and Mongolia. There are two other Regions, Region 2 which encompasses North and South America and Region 3 which encompasses South Asia, South East Asia, East Asia, and Oceania. As the majority of aviation takes place world-wide, many of the spectrum allocations to aeronautical services are common to all three regions, however minor differences do exist.

For the purpose of this study, we shall only be considering spectrum allocations in region 1. Other than for systems operating at frequencies below 30 MHz, this is a valid approach as radio waves at these frequencies do not propagate beyond the horizon. For frequencies below 30 MHz, where interference due to different allocations outside Region 1 is possible, an indication of this is given.

The ITU documentation lists the frequency allocations and designated users, however some countries use the frequencies for other purposes and these differences from the standard allocations are recorded in footnotes.

Where spectrum allocations in Region 1 are affected by footnotes to the ITU regulations but where those footnotes only affect spectrum outside western Europe, they have not been accounted for (there are, for example, a considerable number of footnotes affecting only the Middle East, the FSU, Africa and Mongolia).

Within each block of spectrum allocated by the ITU, the particular systems operating in that spectrum have been identified and are documented in this section. The frequency limits of these systems (which may vary from the ITU allocation) are also given. Also identified are those services that share spectrum with aeronautical systems either on a primary or secondary basis.

All services allocated to a particular block of spectrum on a primary basis have an equal status with each other. Whilst in theory this leads to an increased potential for interference, where more than one primary user has access to a piece of spectrum, attempts are usually made by national licensing administrations to minimise the amount of interference by separating users (geographically, by frequency, polarisation, etc).

Services allocated spectrum on a secondary basis are only allowed to operate within that spectrum on the basis of causing no interference to primary users; additionally they must accept interference from the primary user. It should be noted that certain national administrations occasionally allow services other than those allocated by the ITU to use certain sections of spectrum. These national variations have not been accounted for in this section (although in many cases it may be these variations which will lead to interference difficulties).

In blocks of spectrum where a number of different aeronautical systems operate or where the sharing between services is complex, a graphical representation of the way in which the spectrum is allocated is given.

In order to rationalise the way in which the data is presented, the spectrum allocations to aeronautical systems have been broken down into three distinct regions of spectrum:

- frequencies below 30 MHz (often known as Very Low, Low, Medium and High Frequencies ie VLF, LF, MF and HF);
- frequencies between 30 and 3300 MHz (Very High and Ultra High Frequencies ie VHF and UHF);
- frequencies above 3300 MHz (Super High Frequencies, SHF or microwaves).

The choice of a breakpoint at 3300 MHz (as opposed to 3000 MHz, which is more typical) is due to there being an aeronautical system which operates between 2700 and 3300 MHz which would otherwise have fallen uneasily across two categories.

2.3 Relationship between the ITU and CEPT

CEPT (European Conference of Postal and Telecommunications Administrations) is represented in all radio matters by the ERO (European Radiocommunications office). As of 1 January 1996, 43 European countries were members of CEPT[1]. The functions of the ERO include:

- long term planning of the radio spectrum;

1 The 43 CEPT members are Albania, Andorra, Austria, Belgium, Bulgaria, Bosnia and Herzegovina, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Macedonia, Moldova, Monaco, Netherlands, Norway, Poland, Portugal, Romania, Russian Federation, San Marino, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom and Vatican City.

– liaison with national frequency management authorities;

– co-ordination of research studies;

– consultation with interested parties on specific topics or parts of the frequency spectrum.

In addition, the ERO assists the ERC (European Radiocommunications Committee) in carrying out its numerous activities. The ERC is concerned with the development of policy on radiocommunications issues which includes the co-ordination of frequency, administrative and technical matters relating to the regulation of radio in Europe. The ERC is also responsible for preparing the European proposals and positions for conferences of the ITU dealing with radiocommunications (such as the WRC).

As such, in terms of spectrum allocation, CEPT (ERO) is responsible for making recommendations for the long term use of radio spectrum to its member countries. There recommendations are developed through a consultative process which results in the publication of documents detailing the recommendations for the use of a certain set of frequencies. The first phase was completed in March 1993 and addressed the band 3.4 – 105 GHz. The second phase was completed in March 1995 and addressed the band 29.7 – 960 MHz. This work has resulted in, amongst other things, a harmonised European common frequency allocation table which is to be phased in over the period to the year 2008.

Other input which the ERO has had to aeronautical communications was in the managing of plans for the introduction of the Terrestrial Flight Communications System (TFTS) and a wider study into Aeronautical Communications, Navigation and Surveillance Systems completed in 1996.

2.4 Designation of spectrum

The ITU applies a number of designations to the spectrum it allocates. These define the authorised use and users of the spectrum. Those designators which appear in the forthcoming sections are described below:

– **Aeronautical mobile:** A mobile service between aeronautical stations[2] and aircraft stations, or between aircraft stations, in which survival craft stations may participate. Emergency position-indicating radiobeacon stations may also participate in this service on designated distress and emergency frequencies.

– **Aeronautical radionavigation:** A radionavigation service intended for the benefit and for the safe operation of aircraft.

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2 A land station in the aeronautical service.

- **Amateur:** Telecommunication by means of radio for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorised persons interested in radio technique solely with a personal aim and without pecuniary interest.

- **Broadcasting:** Telecommunication by means of radio in which the transmissions are intended for reception by the general public. The service may include sound transmissions, television transmissions or other types of transmission.

- **Earth exploration:** Telecommunication between one or more space stations which may include links between space stations, in which:

  - information relating to the characteristics of the Earth and its natural phenomena is obtained from active sensors or passive sensors on earth satellites;

  - similar information is collected from airborne or Earth-based platforms;

  - such information may be distributed to earth stations within the system concerned;

  - platform interrogation may be included.

  This service may also include feeder links necessary for its operation.

- **Fixed:** Telecommunication by means of radio between specified fixed points.

- **Inter-satellite:** Telecommunication by means of radio providing links between artificial earth satellites.

- **Land mobile:** A mobile service between base stations and land mobile stations, or between land mobile stations.

- **Maritime mobile:** A mobile service between coast stations and ship stations, or between ship stations, or between associated on-board communication stations. Survival craft stations and emergency position-indication radiobeacon stations may also use this service.

- **Maritime radionavigation:** A radionavigation service intended for the benefit and for the safe operation of ships.

- **Meteorological aids:** Telecommunication by means of radio used for meteorological, including hydrological, observations and exploration.

- **Mobile:** Telecommunication by means of radio between mobile and land stations or between mobile stations.

- **Radio astronomy:** Astronomy based on the reception of radio waves of cosmic origin.

– **Radiolocation:** The determination of the position, velocity and/or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation of radio, used for purposes other than radionavigation.

– **Radionavigation:** The determination of the position, velocity and/or other characteristics of an object, or the obtaining of information relating to these parameters, by means of the propagation of radio, used for the purpose of navigation, including obstruction warning.

– **Space research:** Telecommunication by means of radio in which spacecraft or other objects in space are used for scientific or technological research purposes.

– **Space services:** Telecommunication by means of radio involving the use of one or more space stations or the use of one or more reflecting satellites or other objects in space.

In addition to the above designations, the suffix '-satellite'[3] may be added. When this is shown, communication is only allowed between earth stations and one or more space stations, or between space stations, or between one or more earth stations by means of one or more space stations. In some cases, feeder links to satellites may also occupy these frequencies.

3 This is shown as '-sat' in the tables to allow a tidier presentation.

3 Frequencies below 30 MHz

3.1 Introduction

This section identifies aeronautical systems that operate on frequencies below 30 MHz. For each system, the spectrum associated with (allocated to) that system is described along with any services that share that spectrum and the services that are adjacent to the spectrum. A brief description of each service is also given.

3.2 Characterisation

Frequencies below 30 MHz are characterised by:

– the ability to travel significantly beyond the recognised radio horizon (the radio horizon for a ground based station is typically of order 100km, the frequencies in question here are capable of travelling 3000km or more);

– daily/annual variations in propagation;

– heavy usage by those services to which spectrum is allocated;

– being suitable for narrowband applications only (due to the limitations of the amount of spectrum allocated to a particular service);

– being affected by both natural phenomena (lightning, ionospheric disturbances etc) and man-made sources (electrical equipment, electronic equipment).

3.3 Aeronautical use

Table 2-1 lists all the aeronautical systems found to be operating in frequencies below 30 MHz. For each system, the spectrum used by the system is indicated, as is the designation of this spectrum by the ITU. Additionally, services that share the spectrum are listed. Where the aeronautical system or shared service is only allocated the spectrum on a secondary basis, this is indicated by the use of *italics*.

The sharing arrangement between the various services between 0 and 550 kHz is relatively complex with small sections of spectrum allocated to a variety of different services at both primary and secondary levels. Figure 3-1 demonstrates these sharing arrangements graphically and also identifies other services sharing spectrum adjacent to the aeronautical services. Figure 3-1 represents graphically the current region 1 band plan for frequencies between 0 and 550 kHz. Only services which share or are adjacent to those used for aeronautical CNS systems are shown. Where a service is shown on a line, this identifies it as a primary user of the spectrum. Where a service is shown below a line this identifies it as a secondary user of the spectrum.

System	**Spectrum used (kHz)**	**ITU designation**	**Shared with**	**Adjacent service (lower)**	**Adjacent service (upper)**	**Footnotes**
Omega long range navigation system	9 - 14	radionavigation		not allocated	fixed, maritime mobile	none
Short range hyperbolic navigation systems	90 - 110	radionavigation	*fixed*	fixed maritime mobile radionavigation	fixed maritime mobile radionavigation	none
Non-directional beacons	255 - 283.5 283.5 - 315 315 - 325 325 - 405 415 - 435 435 - 495 505 - 526.5	aeronautical radionavigation aeronautical radionavigation aeronautical radionavigation aeronautical radionavigation aeronautical radionavigation *aeronautical radionavigation* aeronautical radionavigation	broadcasting maritime radionavigation *maritime* *radionavigation* maritime mobile maritime mobile maritime mobile	broadcasting	 broadcasting	490 and 518 kHz are to be used by coastal stations for navigational and meteorological warnings to ships

Table 0-1: Spectrum below 30 MHz allocated for use in region 1 by aeronautical services

System	Spectrum used (kHz)	ITU designation	Shared with	Adjacent service (lower)	Adjacent service (upper)	Footnotes
HF air-ground communications	2850 - 3155	aeronautical mobile		fixed, mobile	fixed mobile	3023 and 5680 kHz can be used for search and rescue operations
	3400 - 3500	aeronautical mobile		fixed, mobile	amateur, fixed, mobile	
	3800 - 3900	aeronautical mobile	fixed, land mobile	amateur, fixed, mobile		
	3900 - 3950	aeronautical mobile	fixed, land mobile		broadcasting, fixed	
	4650 - 4750	aeronautical mobile		fixed, mobile		
	4750 - 4850	aeronautical mobile			fixed, land mobile	
	5450 - 5480	aeronautical mobile	fixed, land mobile	fixed, mobile		
	5480 - 5730	aeronautical mobile			fixed, land mobile	
	6525 - 6765	aeronautical mobile		maritime mobile	fixed, *land mobile*	
	8815 - 9040	aeronautical mobile		maritime mobile	fixed	
	10005 - 10100	aeronautical mobile		space research	fixed, *amateur*	
	11175 - 11400	aeronautical mobile		fixed, *mobile*	fixed	
	13200 -13360	aeronautical mobile		maritime mobile	fixed, radio astronomy	
	15010 - 15100	aeronautical mobile		space research	broadcasting	
	17900 - 18030	aeronautical mobile		broadcasting	fixed	
	21870 - 21924	aeronautical fixed		fixed		
	21924 - 22000	aeronautical mobile			maritime mobile	
	23200 - 23350	aeronautical mobile, aeronautical fixed		fixed, *mobile*	fixed, *mobile*	

Table 3-1: Spectrum below 30 MHz allocated for use in region 1 by aeronautical services (continued)

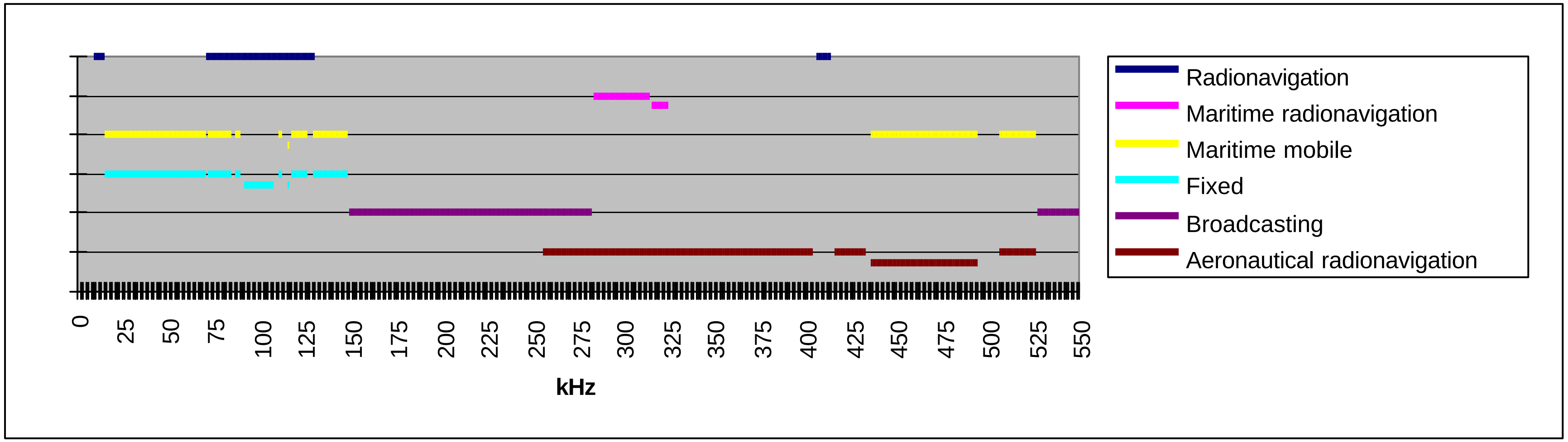

Figure 0-1: Region 1 frequency allocations 0 to 550 kHz

3.4 Other users

One of the major users of the frequencies up to 30 MHz are the broadcasters with approximately 5000 kHz total primary allocation. Despite this amount of spectrum, the broadcast bands are heavily congested and it is commonplace for broadcasters to operate outside the ITU allocated frequencies or 'out-of-band'. This makes sense for the broadcasters as the majority of receivers for services at these frequencies cover the frequencies between the allocated broadcast bands as well as those frequencies within the bands.

Use of out-of-band frequencies by broadcasters is even more common outside of region 1 and given the propensity for signals at these frequencies to propagate over large distances, this may cause significant problems (especially to those sections of aeronautical spectrum which are adjacent to broadcast frequencies).

Other large users of spectrum at these frequencies are:

– Amateur (3100 kHz total allocation);

– Maritime mobile (5030 kHz total allocation).

Both these services (as with most others operating in these frequencies) generally stay within their allocation. It is also unusual to find administrations allocating frequencies to services in contravention of the ITU band plan.

3.5 Description of systems

3.5.1 Omega long range navigation system (9 – 14 kHz)

The Omega long range navigation system is a system in which positional information is derived from the reception of radio signals from several ground stations. Further details, including technical specifications were not identified during the study, however the following references deal with communications codes and protocols:

– RTCA DO-164A;

– EUROCAE ED-29.

It is believed that the Omega system is used for location and time information for ground based stations and was a precursor to GNSS. The system is now old but is thought to be in use in many countries for receiving accurate time location where no national time standards are available.

3.5.2 Short range hyperbolic navigation systems (90 – 110 kHz)

The short range hyperbolic navigation system is a system in which positional information is derived from the reception of radio signals from several ground stations. It is known that the system is in use for land based services in the UK[4], but no information on its aeronautical use has been identified during the study.

3.5.3 Non-directional beacons (255 – 526.5 MHz)

Non-Directional Beacons (NDB) consist of low powered omni-directional transmitters located at strategic locations (such as airfields). Each one transmits a constant carrier signal, modulated with its call-sign in Morse code using Amplitude Modulation (AM).

Automatic Direction Finding (ADF) equipment on-board the aircraft uses rotatable directional receiving antennas to pinpoint the direction from which the NDB signal is emanating. The pilot then listens to the call-sign being transmitted and together with a map of the location of the NDBs can calculate the direction that the plane is travelling. NDBs are used internationally, both in Europe and elsewhere around the world.

The spectrum used by NDBs is shared with two other services, broadcasting and maritime mobile. The maritime mobile services operating in the spectrum tend to be similar to NDB's, ie low powered beacons for location identification purposes. Broadcasting services consist of high powered transmitters and cause significant interference to NDB operation. There are few NDBs (in Europe) operating in the spectrum shared with broadcasting as the level of interference is severe.

Relevant references include:

- ICAO Annex 10, Volume 1, Chapter 3, Section 3.9 and Volume 1, Chapter 2, Section 2.3;
- EUROCAE, ED-51;
- ARINC 712-7;
- ITU Res. No. 704.

3.5.4 HF air-ground communications (2850 – 23350 kHz)

HF air-ground communications supplement VHF communications in areas where VHF coverage does not exist (eg over the Atlantic Ocean or Africa). Due to the nature of HF, communication can take place beyond the line of sight. Operation is very similar to VHF communications and is speech based. Transmissions use Single Side Band (SSB). HF communication is used world-wide.

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4 The 'Datatrak' system operated by Securicor Ltd. uses transmitters at these frequencies.

Some sharing of spectrum with other services (fixed and land mobile) takes place and interference from these is usually small due to the use of low powers. Frequencies are also registered internationally (with the International Frequency Registration Board, IFRB) allowing co-ordination of frequencies and hence minimisation of interference. Of greater concern are out-of-band broadcast transmissions. Examples of frequencies in use by broadcasters that fall inside aeronautical HF spectrum include the BBC World Service who operate on 15.070 MHz.

Relevant standards include:

– ICAO Annex 10, Volume 2, Chapter 5, Section 5.2 and Volume 3, Part 3, Chapter 2, Section 2.4;

– ARINC 719-5 and 753;

– ITU Appendix 27 Aer 2 to radio refulations, Res. No. 207, 401, 402, 403, 405, 406 and 409;

– ITU radio regulations Chapter SVII and Appendix S13.

3.6 Summary of technical characteristics

Table 3-2 summarises the key technical characteristics of each of the systems described in this section. Transmitter powers refer to the effective radiated power of the system (erp) and therefore include the gain (or loss) of the antenna system. The bandwidth is that of the transmitted and received signal and does not refer to the channel spacing.

System	Frequencies used (kHz)	Transmitter powers	Bandwidth
Omega long range navigation system	9 – 14	Unknown	Unknown
Short range hyperbolic navigation systems	90 – 110	Unknown	Unknown
Non-directional beacons	255 – 525.6	3 Watts	typically 2 - 6 kHz
HF air-ground communications	various frequencies between 2850 and 23350	5000 Watts (ground) 400 Watts (aircraft)	3 kHz

Table 3-2: Summary of technical characteristics

4 Frequencies between 30 and 3300 MHz

4.1 Introduction

This section identifies aeronautical systems that operate on frequencies between 30 MHz and 3300 MHz. For each system, the spectrum associated with (allocated to) that system is described along with any services that share that spectrum and the services that are adjacent to the spectrum. A brief description of each service is also given.

4.2 Characterisation

Frequencies between 30 and 3300 MHz are characterised by:

– the ability under normal circumstances to travel to, but not beyond, the radio horizon (on rare occasions signals may propagate up to 3000 km);

– minimal daily or annual fluctuations in propagation;

– heavy usage by those services to which spectrum is allocated;

– being suitable for narrowband and wideband applications;

– being significantly affected by manmade sources but only slightly affected by natural phenomena.

4.3 Aeronautical usage

The following table lists all the aeronautical systems found to be operating in frequencies between 30 and 3300 MHz. For each system, the spectrum used by the system is indicated as is the designation of this spectrum by the ITU. Additionally, services which share the spectrum are listed. Where the aeronautical system or shared service is only allocated the spectrum on a secondary basis, this is indicated by the use of *italics*.

The sharing arrangements for the use of the blocks of spectrum between 105 and 140 MHz, 1210 and 1405 MHz and 1520 and 1665 MHz are relatively complex. Figures 4-1, 4-2 and 4-3 give graphical representations of this sharing and also indicate services which are adjacent to frequencies used by aeronautical CNS systems.

Figures 4-1, 4-2 and 4-3 represent graphically the current region 1 band plans for frequencies between 105 and 140, 1210 and 1405, and 1520 and 1665 MHz respectively. Only services which share or are adjacent to those used for aeronautical CNS systems are shown. Where a service is shown on a line, this identifies it as a primary user of the spectrum. Where a service is shown below a line this identifies it as a secondary user of the spectrum.

System	Spectrum used (MHz)	ITU designation	Shared with	Adjacent service (lower)	Adjacent service (upper)	Footnotes
ILS Marker Beacon	74.8 - 75.2	aeronautical radionavigation	*mobile*	fixed, mobile	fixed, mobile	
ILS localiser	108 - 111.975	aeronautical radionavigation	*mobile*	broadcasting		
VOR	108 - 117.975	aeronautical radionavigation	*mobile*	broadcasting, *mobile*		
VHF air-ground communications	117.975 - 136 136 - 137 138 - 143.6 143.6 - 143.65 143.65 - 144	aeronautical mobile aeronautical mobile aeronautical mobile aeronautical mobile aeronautical mobile	*aeronautical mobile - sat* space service *aeronautical mobile - sat* *fixed, mobile* maritime mobile, land mobile, *space research* maritime mobile, land mobile, *space research* maritime mobile, land mobile, *space research*	space services, *fixed, mobile*	space services, *fixed, mobile* amateur, amateur – sat	121.5 MHz is the aeronautical emergency frequency and, where required, 123.1 MHz is the auxiliary. Mobile stations of the maritime mobile service may communicate on these frequencies.
ILS Glide path	328.6 - 335.4	aeronautical radionavigation	*mobile*	fixed, mobile, radio astronomy	fixed, mobile, *mobile - sat*	
Low power EPIRB/ ELT/ELBA	406 - 406.1	mobile – sat		meteorological aids, *fixed, mobile*	fixed, mobile, radio astronomy	

Table 0-1: Spectrum between 30 and 3300 MHz allocated for use in region 1 by aeronautical services

System	Spectrum used (MHz)	ITU designation	Shared with	Adjacent service (lower)	Adjacent service (upper)	Footnotes
Primary surveillance radar	590 - 598	aeronautical radionavigation	broadcasting	broadcasting	broadcasting	Allocated in UK only
Distance measuring equipment	960 - 1018 1041 - 1080 1103 - 1215	aeronautical radionavigation aeronautical radionavigation aeronautical radionavigation		fixed, mobile	 radiolocation, radiolocation - sat	
Secondary surveillance radar	1018 - 1041 1080 - 1103	aeronautical radionavigation aeronautical radionavigation				
Airborne collision avoidance system	1018 - 1041 1080 - 1103	aeronautical radionavigation aeronautical radionavigation				
Ground based medium and long range primary surveillance radar	1215 - 1240 1240 - 1260 1260 - 1300 1300 - 1350 1350 - 1400	radionavigation – sat radionavigation – sat radiolocation aeronautical radionavigation radiolocation	radiolocation radiolocation *amateur* *amateur* *radiolocation* fixed mobile		 earth exploration – sat, radio astronomy, space research	In the band 1215 to 1300 MHz, radiolocation stations installed on satellites may be employed for earth exploration – satellite and space research on a secondary basis.
Distress and safety communications	1544 – 1545 1645.5-1646.5	mobile – sat mobile – sat		maritime mobile – sat, *land mobile – sat* maritime mobile – sat, *land mobile – sat*		

Table 4-1: Spectrum between 30 and 3300 MHz allocated for use in region 1 by aeronautical services (continued)

System	Spectrum used (MHz)	ITU designation	Shared with	Adjacent service (lower)	Adjacent service (upper)	Footnotes
Air-ground communications	1545 – 1555 1646.5 - 1656.5	aeronautical mobile – sat aeronautical mobile – sat			land mobile – sat land mobile - sat	
GPS	1559 - 1610	aeronautical radionavigation radionavigation – sat		land mobile - sat		
GLONASS	1559 - 1610 1610 - 1610.6 1610.6 - 1613.8 1613.8 - 1626.5	aeronautical radionavigation radionavigatoin – sat aeronautical radionavigation aeronautical radionavigation Aeronautical radionavigation	 aeronautical mobile – sat *radio astronomy* aeronautical mobile – sat aeronautical mobile - sat		maritime mobile – sat *land mobile - sat*	1593 – 1593 and 1625.5 – 1626.5 is also allocated to the aeronautical mobile service on a primary basis.
TFTS	1670 – 1675 1800 - 1805	mobile *mobile,* land mobile	meteorological aids, fixed, radio astronomy fixed	meteorological aids, fixed, mobile, radio astronomy fixed, *mobile*	meteorological aids, fixed, mobile, radio astronomy fixed, *mobile*	
Primary surveillance radar	2700 - 2900 2900 - 3100 3100 - 3300	aeronautical radionavigation radionavigation radiolocation	*radiolocation* *radiolocation*	earth exploration - sat, radio astronomy, space research	 radiolocation	3260 – 3267 MHz : administrations should take all practical steps to protect the radio astronomy service.

Table 4-1: Spectrum between 30 and 3300 MHz allocated for use in region 1 by aeronautical services (continued)

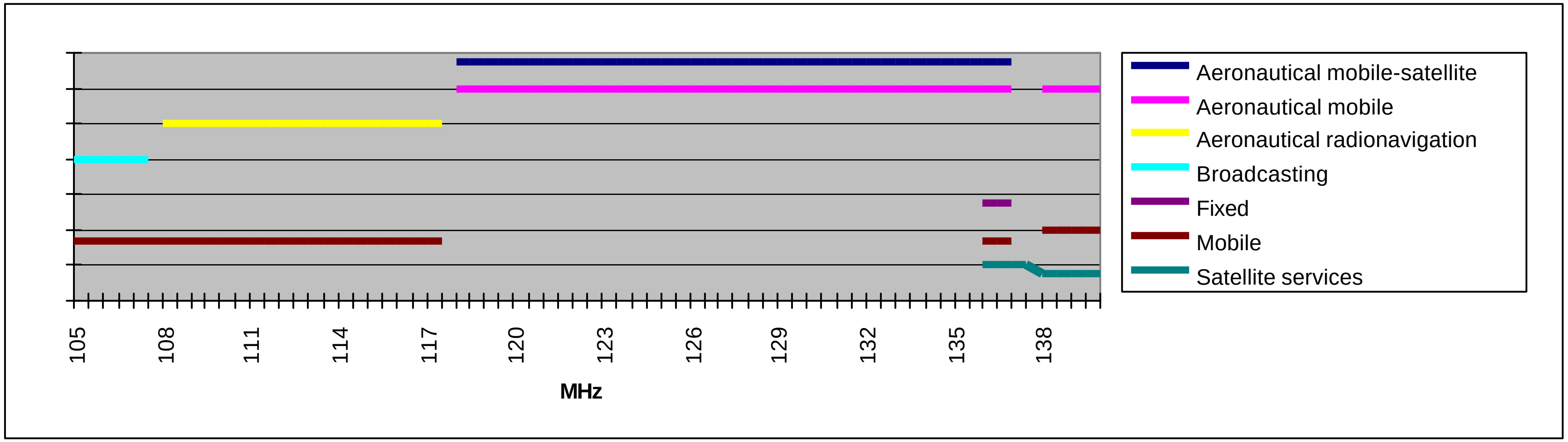


Figure 0-1: Region 1 frequency allocations 105 to 140 MHz

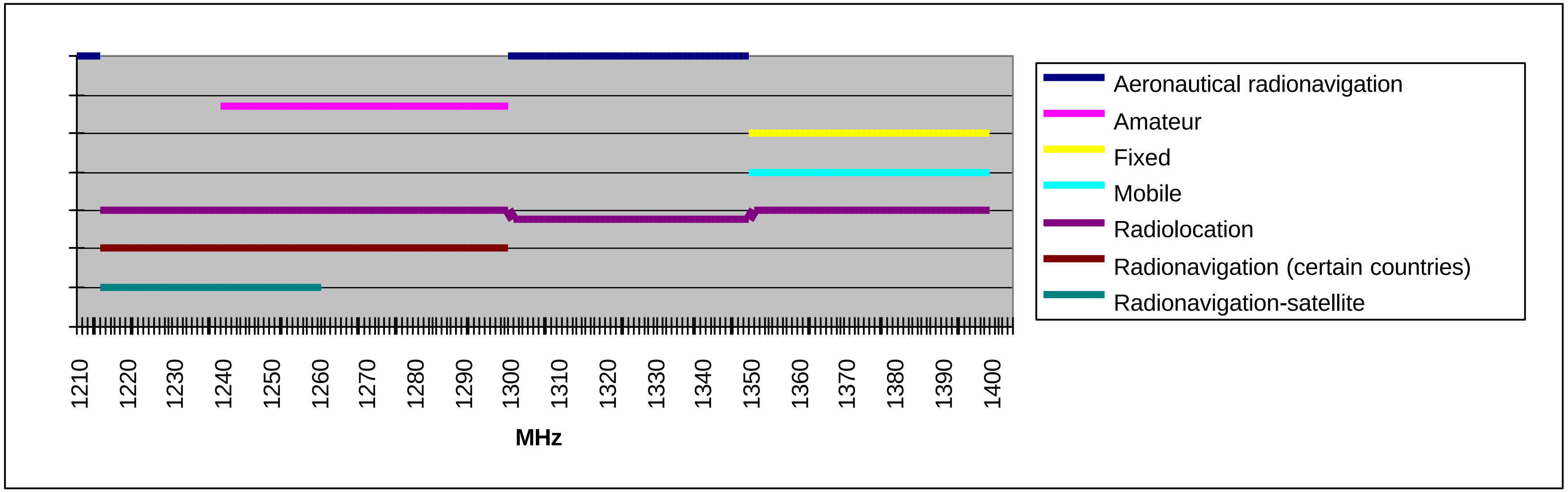


Figure 0-2: Region 1 frequency allocations 1210 – 1405 MHz

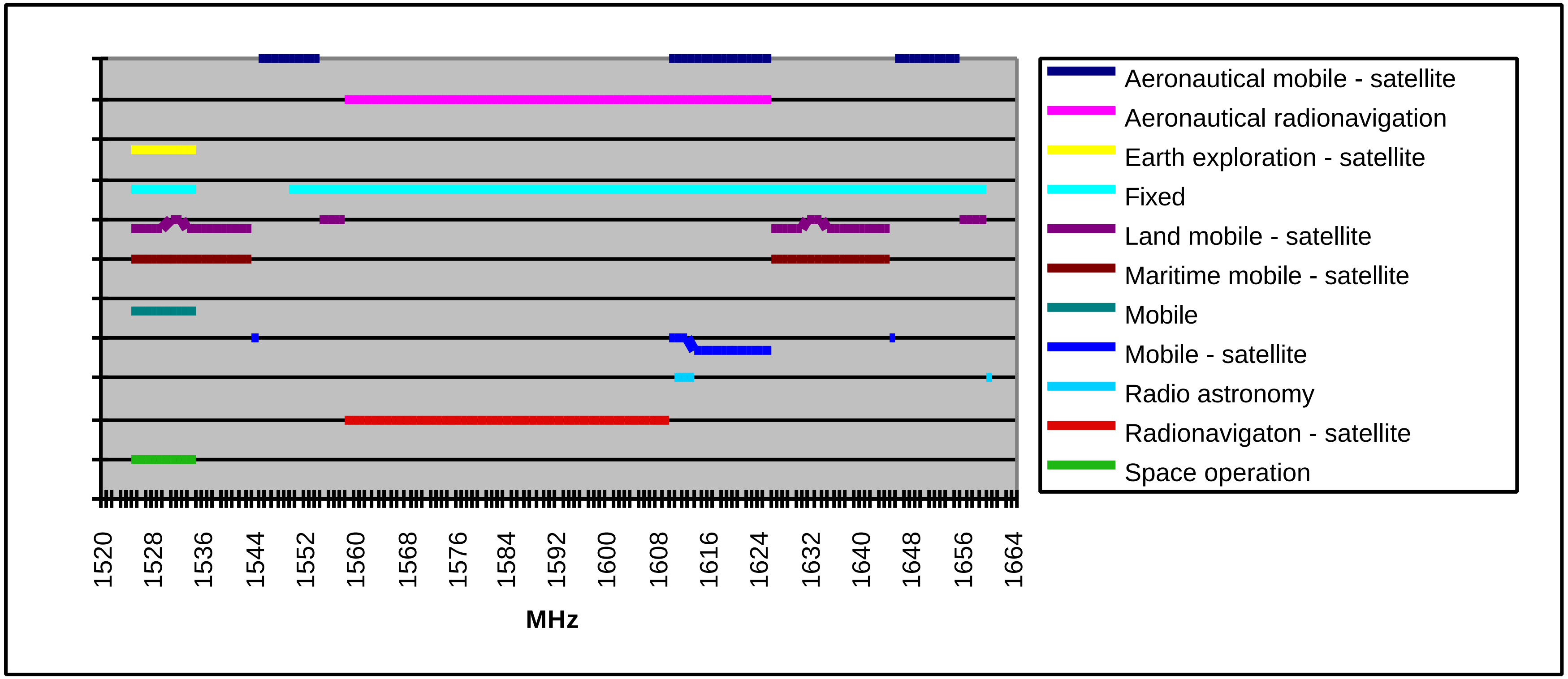


Figure 0-3: Region 1 frequency allocations 1520 – 1665 MHz

4.4 Other users

Again, one of the major users of this spectrum are broadcasters with a total allocation of 777.5 MHz. Compared to the use of broadcast spectrum below 30 MHz, however, licensed broadcasters rarely, if ever, operate outside those frequencies allocated to them. Broadcast receivers at these frequencies do not normally operate outside the allocated bands, hence there is no benefit to be gained by broadcasters in operating out-of-band in the same way as there is at HF.

Some national administrations do allow services to operate outside the spectrum allocated to them by the ITU, but such deviance from the regulations is rare, and administrations generally recognise and attempt to minimise the effect on the primary users of the band.

4.5 Description of systems

4.5.1 ILS Marker Beacon (74.8 – 75.2 MHz)

The Instrument Landing System (ILS) marker beacon is used in conjunction with ILS glide path and ILS localiser systems to give an indication of the position of an aircraft with respect to the runway for landing approaches. Each of the systems radiates a signal which varies with direction.

Three marker beacons are used at each runway, an inner marker (typically 200 metres from the runway), a middle marker (1,600 metres) and an outer marker (6,400 metres). Each of these transmits a signal vertically so that an aircraft flying above them will receive their signals. Each one is (AM) modulated with a different series of tones to make identification simple.

The frequencies used are shared in some parts of the world with Industrial, Scientific and Medical services (ISM) although no evidence of interference has been found by the study team. ILS marker beacons are used world-wide.

Relevant standards include:

- ICAO Annex 10, Volume 1, Chapter 2, Section 2.3; Chapter 3, Section 3.6; Attachment B and Attachment C, Section 5;
- EUROCAE 1/WG7/70.

4.5.2 ILS localiser (108 – 111.975 MHz)

The Instrument Landing System (ILS) localiser is used in conjunction with ILS glide path and ILS marker beacon systems to give an indication of the position of an aircraft with respect to the runway for landing approaches. Each of the systems radiates a signal which varies with direction.

Each ILS transmitter radiates two signals, one to either side of the axis of the runway. Each signal is modulated with a different tone. When the approaching aircraft is in line with the axis of the runway, the two tones are heard equally. If the aircraft is off-axis, one tone is heard more loudly than the other.

The proximity of the frequencies used by ILS localisers to the FM broadcast band have led to saturation and intermodulation effects. ILS localiser systems are employed world-wide.

Relevant standards include:

– ICAO Annex 10, Volume 1, Chapter 2, Section 2.1; Chapter 3, Section 3.1; Attachment B and Attachment C, Section 2;

– RTCA DO-177;

– EUROCAE ED-46B and ED-74;

– ARINC 710-10;

– ITU Rec. No. 704; ITU-R.M 44-1 and ITU-R.IS 1009

4.5.3 VOR (108 – 117.975 MHz)

The VHF omni-directional radio range (VOR) system is a ground based short-distance radio aid to navigation. The ground based VOR transmitter transmits two signals. One remains phase invariant with respect to the bearing from the VOR, the other changes phase. The airborne receiver compares the received phase of the two signals to give the pilot an indication of the bearing to the VOR.

VOR systems are operational world-wide.

Relevant standards include:

– ICAO Annex 10, Volume 1, Chapter 2, Section 2.2; Chapter 3, Section 3.3; Attachment C, Section 3 and Attachment E;

– EUROCAE ED-52 and ED-22B;

– ARINC 711-9;

– ITU Rec. No. 704; ITU R.M 44-1 and ITU-R.IS 1009.

4.5.4 VHF air-ground communications (117.975 – 144 MHz)

VHF air-ground communication is the mainstay of aeronautical voice communications between the ground and aircraft and between aircraft. Transmitters are typically 25 Watts and are amplitude modulated (AM). The range of a ground station varies between 50 and 300 kilometres depending upon the height of the aircraft (and hence line-of-sight). Several ground based transmitters can be operated on the same (or similar) frequencies to allow greater ranges than this to be achieved.

VHF communication is used world-wide.

Frequencies between 118 and 136 MHz are allocated world-wide. Frequencies between 136 and 137 MHz are becoming available world-wide as the band is cleared of other users. Frequencies above 138 MHz are not commonly used; in the UK for example, the only use of frequencies above 138 MHz is at US air-bases. Indeed, as part of the European Radiocommunications Committee’s review of spectrum, it has proposed that the allocation to aeronautical mobile services be removed from the band 142 to 144 MHz.

Relevant standards include:

- ICAO Annex 10, Volume 2, Chapter 5, Section 5.2; Volume 3; Part 1, Chapter 6; Volume 3, Part 2, Chapters 2.1, 2.2 & 2.3; Volume 3, Attachment A to Part 2, Section 1;
- EUROCAE ED-23A;
- ARINC 716-9 and 750-1;
- ITU Res. No. 408, 409, 714; ITU-R.IS 1009.

4.5.5 ILS glide path (328.6 – 335.4 MHz)

The ILS glide path is used in conjunction with ILS marker beacons and ILS localiser systems to give an indication of the angle of approach of an aircraft with respect to the runway for landing approaches. Each of the systems radiates a signal which varies with direction.

The ILS glade path system transmits two signals, one above and one below the correct glide path for a runway. Each signal is modulated with a different tones. If the incoming aircraft is on the correct glide path, the pilot hears the two tones equally. If the aircraft is above of below, one of the tones will be heard more loudly than the other.

Relevant standards include:

- ICAO Annex 10, Volume 1, Chapter 3, Section 3.1; Chapter 2, Section 2.1; Volume 1, Attachment B and Attachment C, Section 2;
- EUROCAE ED-47B;
- ARINC 551.

4.5.6 Low power EPIRB/ ELT/ELBA (406 – 406.1 MHz)

Low power Emergency Position Indication Radio Beacons (EPIRB), Emergency Locator Transmitters (ETL) and Emergency Low-power BeAcons (ELBA) are all variants of the same system. Low power transmitters radiate a signal that is detected by satellites which can identify the location of the transmitter site. Such transmitters are often fitted to aircraft, the transmission of the signal being triggered by crash sensors.

The system is in use world-wide.

Relevant standards include:

- ICAO Annex 10, Volume 2, Chapter 5, Section 5.3; Volume 3, Part 2, Chapter 5 and Appendix 1 to Chapter 5;
- EUROCAE ED-62;
- ITU Res. Nos. 601 and 604; ITU-RR Chapter SVII and S13; IUT-R.M 690.

4.5.7 Primary surveillance radar (590 – 598, 1215 – 1400 and 2700 – 3300 MHz)

Primary surveillance radar (PSR) is one of the radar systems used by aeronautical organisations to identify the location of aircraft. PSR typically has a range of 300 kilometres and a network of stations across a country will enable all the airspace to be monitored. PSR delivers only two dimensional positional information (ie no data on height) and hence is usually used as a back-up to SSR which provides both positional and height information.

The 600 MHz (50 cm) band is *only used in the UK* and most of the equipment in use is old (40 years). However, it continues to provide a useful service and, according to the UK's National Air Traffic Services (NATS), is likely to continue operation for some time to come.

The 1300 MHz (23 cm) band is commonly used across Europe and is the main PSR frequency band. The 3000 MHz (10 cm) band is also commonly used.

Relevant standards include:

- ITU-RR S.668;
- UK CAA CAP 581 RAD 01, 02, 04 (50 cm only).

4.5.8 Distance measuring equipment (960 – 1215 MHz)

Distance measuring equipment (DME) is used in association with VOR, ILS and MLS to provide pilots with location information.

Distance measuring equipment (DME) is a ground-based transponder that supplies distance information when interrogated by a suitably equipped aircraft. The reply is precisely timed so that the aircraft can calculate the distance (actually the slant range) to the DME by measuring the time delay between it and the interrogation. DMEs are often co-located with VORs. There are three types of DME: wide band (DME/W), narrow band (DME/N) and precision (DME/P). The latter is an integral part of the MLS system.

Each DME transmits a unique identifier in Morse code at regular intervals. Typical accuracies for the slant range measurement is 0.25 nautical miles. According to ICAO Annex 10, DME should be able to handle at least 100 aircraft. As loading (ie number of interrogations) increases the sensitivity of the receiver decreases to prevent over-loading.

DMEs are a standard navigation aid and as such are used world-wide.

Relevant standards include:

– ICAO Annex 10, Volume 1, Chapter 2, Section 2.2; Chapter 3, Section 3.5; Attachment C, Section 7;

– EUROCAE ED-57 and ED-54;

– ARINC 709-8 and 709A-1.

4.5.9 Secondary surveillance radar (1018 – 1103 MHz)

Secondary surveillance radar (SSR) was developed to overcome some of the problems with normal (primary) radar, namely range, target identification and the determination of target altitude. An SSR system consists of a ground based interrogator (similar to a primary radar) and an airborne transponder. As the radar antenna revolves it sends pulses to any transponder in range (at 1030 MHz). The transponder will reply on a different frequency (1090 MHz). The advantages of SSR are that: (1) range is increased (or alternatively, transmitter power may be reduced) because the returned signal has not been reflected off the target; (2) information can be sent to the interrogator in the reply pulse.

The most commonly used form of civilian SSR is termed ‘Mode A/C’, which indicates that the transponder replies with identity information (a 12-bit ‘squawk’ code) and altitude data. This allows the callsign and flight level of the aircraft to be displayed on an air traffic controllers screen next to the radar blip. A newer mode, Mode S (selective), has recently been endorsed by ICAO and is due to start pre-operational trials in Europe. This extends the number of possible identity codes (to over 16 million) and allows aircraft to be addressed individually. It extends the length of the uplink and downlink messages to provide a data link capability.

Airborne SSR transponders are also used by ACAS systems (eg TCAS) and it has been proposed to extended the transponder capabilities to provide ADS-B. This may have implications for the loading of the uplink and downlink frequencies. There is world-wide use of SSR.

Relevant standards include:

- ICAO Annex 10, Chapter 4;
- RTCA DO-181A;
- ITU Res. No. 18; ITU Res. No. 601.

4.5.10 Airborne collision avoidance system (1018 – 1103 MHz)

ICAO defined airborne collision avoidance systems (ACAS) use the Mode S (ACAS II and ACAS III) or Mode A/C (ACAS I) transponder fitted on an aircraft to provide surveillance and communications facilities. ACAS as such is not a separate system. An ACAS system (such as TCAS) will monitor the 1090 MHz band for “all call” replies (ie other aircraft replying to a ground interrogation). It can then either passively monitor replies containing altitude information or can interrogate airborne transponders on 1030 MHz. The system can communicate with other airborne transponders to provide co-ordinated traffic and resolution advisories to the pilot in the event of a possible conflict. The use of TCAS is mandated in the US but as yet, no ACAS system is mandated in Europe.

Relevant standards include:

- ICAO Annex 10, Volume 4, Chapter 4; Attachment A.

4.5.11 Distress and safety communications (1544 – 1545 and 1645.5 – 1646.5 MHz)

No information concerning this system has been identified during the course of the study. It is possible that the frequencies are allocated at the international (ITU) level but that no systems are yet operational.

4.5.12 Air-ground communications (1545 – 1555 and 1646.5 – 1656.5 MHz)

The air-ground communications systems operating in this frequency range rely on satellite communications. The lower frequency band used for air-ground communications (1545 – 1555 MHz) is used for Earth to space communications whilst the upper (1646.5 – 1656.5 MHz) is used for space to Earth. Much of the communication that takes place in these bands is data communications, however voice communication is also allowed.

Channels are shared with airline communications (for passengers and airline operations) with air traffic control having a pre-emptive priority.

It is not known how widespread the use of this form of air-ground communications is used. Relevant standards include:

- ICAO Annex 10, Volume 3, Part 1, Chapters 4 and 10.1; Volume 3, Attachment A to Part 1;
- RTCA DO-210;

- ARINC 741;
- ITU Res. No. 44, 208, 405, 828, 1037 and 1089.

4.5.13 GPS (1559 – 1610 MHz)

The Global Positioning System (GPS) is a satellite-based radio positioning, navigation and time transfer system. Signals from a minimum of four non-geostationary satellites are compared. By comparison of the phase and time delay received from each of the satellites, the location of the receiver can be calculated.

There is an additional GPS allocation at 1227.6 MHz, used for the precision positioning service (PPS). This service is currently for military use only and is not used for civil aviation.

Relevant standards include:

- ICAO Annex 10, Volume 1, Attachment B;
- RTCA DO-217;
- EUROCAE ED-72;
- ARINC 743 and 743A-2;
- ITU-R.M 823.

4.5.14 GLONASS (1559 – 1626.5 MHz)

The Global Navigation Satellite Service (GLONASS) is a satellite-based radio positioning, navigation and time transfer system. Signals from a minimum of three non-geostationary satellites are compared. By comparison of the phase and time delay received from each of the satellites, the location of the receiver can be calculated.

There is an additional GLONASS allocation at 1246 – 1256.5 MHz, used for the precise accuracy signal (PAS). This service is currently for military use only and is not used for civil aviation.

Relevant standards include:

- ICAO Annex 10, Volume 1, Attachment B;
- RTCA DO-217;
- ARINC 743A-2;
- ITU-R.M 823; ITU-R 83/8.

4.5.15 TFTS (1670 – 1675 and 1800 – 1805 MHz)

The terrestrial flight telecommunications system (TFTS) provides two way voice and data communication between aircraft and the ground. It is intended for use by passengers and the full introduction of ground stations is expected to be complete in 1998. Ground to air transmissions take place at 1670 – 1675 MHz with air-ground at 1800 – 1805 MHz.

A network of ground stations is being built in Europe by Jetphone, a joint venture between British Telecom and France Telecom. Air France, British Airways and Scandinavian Air Lines are equipped with TFTS. It is estimated that 250 aircraft will be fitted with the system by the end of 1997.

Relevant standards include:

– ETSI ETS 300 326 parts 1, 2 and 3;

– ARINC 746 and 752.

4.6 Summary of technical characteristics

The following table summarises the key technical characteristics of each of the systems described in this section. Transmitter powers refer to the effective radiated power of the system (erp) and therefore include the gain (or loss) of the antenna system. The bandwidth is that of the transmitted and received signal and does not refer to the channel spacing.

System	Frequencies used (MHz)	Transmitter powers	Bandwidth
ILS Marker Beacon	74.8 – 75.2	50 milliWatts	8 kHz
ILS localiser	108 – 112	100 milliWatts	18 kHz
VOR	108 – 117.975	200 Watts	25 kHz
VHF air-ground communications	118 – 144	100 Watts (maximum)	8.3 kHz
ILS Glide path	328.6 – 335.4	2 Watts	34 kHz
Low power EPIRB/ ELT/ELBA	406 – 406.1	4 Watts	4 kHz
Primary surveillance radar	590 – 598 1215 – 1400 2700 – 3300	100 MegaWatts (avrge) 30 GigaWatts (peak)	2 MHz 20 MHz 300 kHz
Distance measuring equipment	960 – 1215	1 kiloWatt (ground)	100 kHz
Secondary surveillance radar	1018 – 1103	2 MegaWatts (ground) 500 Watts (air)	9 MHz
Airborne collision avoidance system	1018 – 1103	Unknown	Unknown

Distress and safety communications	1544 – 1555 (s-E) 1645.5 – 1655.5 (E-s)	Unknown	Unknown
Air-ground communications	1545 – 1555 (s-E) 1646.5 – 1656.5 (E-s)	Unknown 3 kiloWatts	Unknown

Table 4-2: Summary of technical characteristics

System	Frequencies used (MHz)	Transmitter powers	Bandwidth
GPS	1559 – 1610	Unknown	2 MHz
GLONASS	1559 – 1626.5	400 Watts (satellite)	500 kHz
TFTS	1670 – 1675 1800 – 1805	48 Watts (ground) 10 Watts (airborne)	30 kHz

Table 4-2: Summary of technical characteristics (continued)

5 Frequencies above 3300 MHz

5.1 Characterisation

Frequencies above 3300 MHz are characterised by:

- being limited to line-of-site coverage, or less at some frequencies where absorption of the signal due to atmospheric constituents (ie water vapour) occurs;
- no daily or annual fluctuations in propagation;
- medium usage by those services to which spectrum is allocated;
- being suitable for mainly wideband applications;
- being generally unaffected by man-made sources and many natural phenomena (although those involving moisture: fog, rain, snow etc, can cause significant effects).

5.2 Aeronautical usage

Table 2-3 overleaf, lists all the aeronautical systems found to be operating in frequencies above 3300 MHz. For each system, the spectrum used by the system is indicated as is the designation of this spectrum by the ITU. Additionally, services which share the spectrum are listed. Where the aeronautical system or shared service is only allocated the spectrum on a secondary basis, this is indicated by *italics*. Footnotes are not shown as, where they are present, their sole purpose is to allow only those systems shown in the 'system' column to operate in the designated spectrum.

5.3 Other users

Much of the spectrum above 3300 MHz is used for satellite based communications, mostly for the fixed service. The most prevalent of these services are telecommunications satellites both for international telephony and broadcasting. There is little evidence to suggest that national administrations allow services to operate outside their allocations, although given the limited range of systems at these frequencies, even if they did so, as long as the rogue system was sufficiently distant from any aeronautical system, there is unlikely to be any interference caused.

0 5 Frequencies above 3300 MHz

System	Spectrum used (MHz)	ITU designation	Shared with	Adjacent service (lower)	Adjacent service (upper)
Radio altimeters	4200 – 4400	aeronautical radionavigation		fixed, fixed – sat, *mobile*	fixed, mobile
Microwave Landing System (MLS)	5000 – 5150 5150 - 5250	aeronautical radionavigation aeronautical radionavigation	aeronautical mobile - sat fixed – sat, mobile, aeronautical mobile - sat	fixed, mobile, radio astronomy, *space research*	radiolocation, *space research*
Airborne weather radar	5350 - 5460 5460 - 5470	aeronautical radionavigation radionavigation	*radiolocation* *radiolocation*	radiolocation	maritime radionavigation, *radiolocation*
Airborne Doppler navigation systems	8750 - 8850	aeronautical radionavigation	radiolocation	radiolocation	
Short range radar / Airfield surface detection equipment	8850 - 9000 9000 - 9200 9200 - 9300 9300 - 9500	radiolocation aeronautical radionavigation radiolocation radionavigation	maritime radionavigation *radiolocation* maritime radionavigation *radiolocation*		radiolocation, radionavigation
Airborne Doppler navigation systems	13250 - 13400	aeronautical radionavigation		fixed, fixed – sat, mobile, *space research*	radiolocation, *space research*
Short range radar / Airfield surface detection equipment	15400 - 15700 15700 - 16600	aeronautical radionavigation radiolocation	fixed – sat, aeronautical mobile - sat	earth exploration – sat, radio astronomy, space research	radiolocation, *space research*
Airfield surface detection equipment	31800 - 32000 32000 - 32300 32300 - 33000 33000 - 33400	radionavigation radionavigation radionavigation radionavigation	*space research* *space research* inter-satellite inter-satellite	earth exploration – sat, radio astronomy, space research, *fixed, mobile*	radiolocation

0 5 Frequencies above 3300 MHz

Table 0-1: Spectrum above 3300 MHz allocated for use in region 1 by aeronautical services

5.4 Description of systems

5.4.1 Radio altimeters

Radio altimeters are airborne downward looking radar systems that allow the height of the aircraft on which they are mounted to be calculated.

Relevant standards include:

– RTCA DO-155;

– EUROCAE ED-30;

– ARINC 707-5;

– ITU Rec. No. 606; ITU-R Report [BL/8], question 94/8.

5.4.2 Microwave Landing System (5000 – 5250 MHz)

The microwave landing system (MLS) was intended as an replacement for the ILS systems in common use today. However GNSS technology seems to have overtaken it - the FAA recently cancelled its MLS programmes and only Heathrow and Schipol airports are believed to have installed MLS systems to date. ILS has a narrow glideslope (4º by 0.3º) and is susceptible to multipath interference from ground and building reflections. MLS, on the other hand, broadcasts over an 80º wide/15º deep segment over a frequency range of 5,031 to 5,091 MHz (allowing 200 channels). The range (or 'radius' of the sector) is approximately 30 kilometres. The system operates in time reference scanning beam mode using electronic scanning over the sector and includes a data channel allowing various parameters (runway length, transmitter locations, local weather information etc) to uplinked to the aircraft.

A principle advantage of this system over ILS is the ability for the aircraft to conduct curved approaches. MLS also provides a smaller 40º wide 'sector' broadcast from the other end of the runway to provide precise navigation for take-offs and missed approaches.

Relevant standards include:

– ICAO Annex 10, Volume 1, Chapter 2, Section 2.1; Chapter 3, Section 3.11; Appendix A; Attachments B and G;

– RTCA DO-177;

– EUROCAE ED-53A;

– ARINC 727-1;

– ITU Rec. No. 607.

5.4.3 Airborne weather radar (5350 – 5470 MHz)

Airborne weather radar is a radar-based system for the detection of certain weather formations. At the frequencies on which the system operates (5350 – 5470 MHz), water particles can be detected by radio signals, hence cloud formations and certain other weather formations can be detected by the use of radar.

Despite its title, airborne weather radar systems can be installed on the ground as well as in aircraft.

Relevant standards include:

- RTCA DO-173;
- EUROCAE ED-38;
- ARINC 708-6 and 708A.

5.4.4 Airborne Doppler navigation systems (8750 – 8850 and 13250 – 13400 MHz)

Doppler navigation systems use airborne equipment to provide ground speed and drift angle information. The Doppler shift of signals reflected from the ground (or other objects such as clouds) can be used to calculate the speed at which an aircraft is travelling.

Relevant standards include:

- RTCA DO-220;
- EUROCAE WC7C/1-74.

5.4.5 Short range radar / Airfield surface detection equipment (8850 – 9500, 15400 – 15700 and 31800 – 33400 MHz)

Short range radar or airfield surface detection equipment (ASDE) is a ground-based radar system used for the observation of the positions of aircraft and other vehicles on the surface of an airport. At the frequencies used by these systems (9000 – 9500 MHz, 15400 – 16600 MHz and 31800 – 33400 MHz), absorption of the signal by the atmosphere (water vapour and oxygen) ensures that the range does not extend much beyond the airfield. It is not believed that the 15400 and 31800 MHz bands are currently in use.

Relevant standards include:

- EUROCAE ED-38;
- ITU-R.M 629.

5.5 Summary of technical characteristics

The following table summarises the key technical characteristics of each of the systems described in this section. Transmitter powers refer to the effective radiated power of the system (erp) and therefore include the gain (or loss) of the antenna system. The bandwidth is that of the transmitted and received signal and does not refer to the channel spacing.

System	Frequencies used (MHz)	Transmitter powers	Bandwidth
Radio altimeters	4200 – 4400	80 kiloWatts	Unknown
Microwave Landing System (MLS)	5000 – 5250	1 kiloWatt	26 kHz
Airborne weather radar	5350 – 5470	5 GigaWatts (ground) Unknown (airborne)	1 MHz
Airborne Doppler navigation systems	8750 – 8850 13250 – 13400	Unknown 70 Watts	Unknown Unknown
Short range radar / Airfield surface detection equipment	8850 – 9500 15400 – 15700 31800 – 33400	80 MegaWatts 400 MegaWatts Unknown	25 MHz 30 MHz Unknown

Table 5-2: Summary of technical characteristics

6 Treatment of interference

6.1 Introduction

This section explores the way in which interference complaints are dealt with by national administrations and aeronautical bodies. This is important for understanding the mechanisms which allow interference to be identified and in solving interference problems.

Section 6.2 looks at the way frequencies are assigned to individual users whilst section 6.3 examines the resolution of interference problems.

6.2 Frequency assignment

6.2.1 Source of information

From conversations held with the frequency managers of the National Air Traffic Services Limited (NATS) and the Civil Aviation Authority (CAA) in the UK and Direction Generale Aviation Civil (DGAC) in France, it is clear that the way in which interference complaints are dealt with is generally similar. The similarity stems from the framework established in the ITU Radio Regulations and the implementation of these regulations by member administrations.

6.2.2 ITU framework

The use of frequencies or groups of frequencies (bands) is determined at international conferences such as the World Radio Conference (WRC). Agreements on frequency use are detailed in the ITU regulations and such agreements on frequency use are deemed *allocations*. Examples of allocations include the frequencies listed for the services shown in section 2.

Where a number of national administrations can agree on the common use of a certain frequency in all relevant countries, this frequency is *allotted* (as an example, the frequencies assigned to the GSM phone system are allotted by various countries). Where a single national administration allocates a particular frequency to a certain use or user, this frequency is *assigned* (frequencies in use for airfields, broadcasting etc are assigned by an administration).

6.2.3 The role of the World Radio Conference

The ITU Radio Regulations (ITU-RR) can only be modified by obtaining agreement from all countries within a region. Such an agreement may not affect all the countries but, even for national changes, their permission must be sought. The only exception to this is where a national administration operates services in derogation of the ITU-RR and can prove that the services operating in derogation will not cause interference outside the country for which they are responsible.

Agreements such as are required to modify the ITU-RR can only be made at World Radio Conferences (WRC). At these conferences, held biennially (on average), representatives from each countries administrations (and, for larger countries, often a representative for each service) meet to agree changes to the ITU-RR.

The process is as follows:

- the change to the ITU-RR must first be proposed (and accepted) as an agenda item for the next WRC;
- at the following WRC, the administration (or administrations) requesting the change make their case. If there are no objections, a decision can be taken at this time to allow the change. If there are objections, usually a study is proposed to ascertain the feasibility of the change (this is particularly the case where an additional service wishes to share spectrum with existing services). Alternatively, the administration(s) may be asked to modify their proposal and present it at the next WRC;
- the results of the study or the revised proposals are then discussed at the next WRC and it is usual for a decision to be taken at this point as to whether to allow the change. If there are no further objections, the change may go ahead. If objections still remain, the proposal will be rejected.

It can therefore take between 2 and 6 years for any changes to the ITU-RR to be accepted by the WRC.

6.2.4 Allocation of spectrum

Spectrum is allocated by the ITU and assigned by national administrations which are usually government bodies, for example the Agence Nationale de Frequence (ANF) in France and the Radiocommunications Agency (RA) in the UK. These assignments are, in the main, based on the allocations established in the ITU radio regulations, including, where appropriate, relevant footnotes (hence aeronautical systems are allocated appropriate spectrum along the lines of the assignments highlighted in sections 3 through 5).

Within individual segments of spectrum, the assignment of individual channels or frequencies is handled either by the national administration or by a body representing the interests of the aeronautical users (eg DGAC or CAA). The responsibility for ensuring that the user assigned to a particular channel operate on that channel can be split, but the ultimate responsibility usually rests with the national administration.

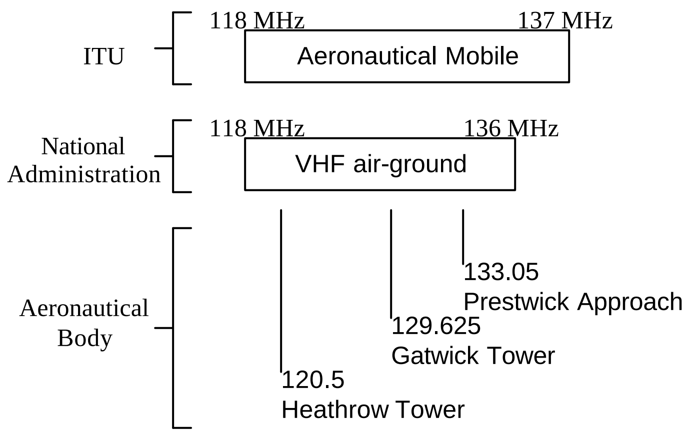


Figure 0-1: Allocation and assignment of frequencies

Figure 6-1 demonstrates an example of the way in which the ITU regulations are implemented through national administrations and then by the appropriate aeronautical body. In the example, the ITU has allocated 118 to 137 MHz for Aeronautical Mobile systems. The national administration has then assigned 118 to 136 MHz for use by VHF air-ground communications. The decision not to allocate 136 to 137 MHz could be made by the administration if the use of such spectrum is likely to cause interference to other users (in practise this is only likely if the spectrum is allocated on a secondary basis). The national aeronautical body has then allocated specific frequencies within the band to specific users.

6.3 Identification of interference sources

Interference complaints usually arise when a problem persists on a particular system. Such complaints are usually passed from air traffic controllers or pilots directly to an air traffic control manager within major control centres. The appropriate department within the aeronautical body is then informed of the problem.

In most instances, the expertise to deal with interference complaints, at least on a first line basis, lies within the aeronautical body. Such expertise will usually allow the possible source (both in terms of the type of transmission and its likely location) to be estimated. Where the source is thought to be one controlled by the aeronautical body, the body itself will investigate the problem to such an extent that it can be determined whether or not the source is, indeed, aeronautical. Where a source can be identified as being from a non-aeronautical source (such as an illegal broadcaster) the national body is normally contacted immediately.

The determination of the source of interference can be carried out in a number of methods. There are, however, common threads in the methods used by those organisations that have been contacted:

– where the source can only be heard from the air, any search begins from a location beneath where the source was reported (given that reports may only be possible or feasible after the interference has subsided, this may not necessarily be the most appropriate start location);

- where the source can be heard from the ground, the location of the receiver where the interference was reported is used as the start a search;
- the aeronautical body possesses basic interference searching equipment.

If the interference source proves to be from an aeronautical system, typically the aeronautical body will make whatever changes are required to that system in order to cease the interference. This may include:

- reducing the transmitter power of the system;
- modifying the characteristics of the system (antenna bearing, transmit frequency, etc);
- in extreme cases, switching the system off until the fault can be rectified.

In instances where the interference source is not an aeronautical system, the complaint along with all associated information will be passed to the national administration for resolution.

6.4 Resolution of interference

6.4.1 Resolution by national administration

National administrations (such as the Agence Nationale de Frequence, ANF in France and the Radiocommunications Agency, RA in the UK) have extensive facilities for the location and identification of interference sources. These consist of both simple, local, facilities available at a number of offices across a country and also more comprehensive facilities located centrally (or at a smaller number of offices). Such equipment would normally comprise:

- directional antennas and direction finding equipment;
- receivers capable of operating on almost all frequencies and modulation modes;
- calibrated signal strength measuring devices;
- spectrum analysers.

Other tools or information sources are also available to national administrations which assist in the identification of interference sources including:

- a list of all national frequency assignments (and the parameters associated with those assignments);
- extensive historical experience of identifying interference problems;
- local knowledge of persistent problems.

Generally, a national administration will use direction finding search mechanisms to locate a source. The search will typically start at either the location reported by the aeronautical body or near to a suspect source. Once the location of the source has been identified, the options open to the administration are basically the same as for the aeronautical body. It is, however, more common for an administration to force the closure of the interfering station until the problem is resolved, especially if interference is being caused to safety-critical services.

6.4.2 Cross-border interference difficulties

Where a source of interference is traced as being in another country (ie not the one in which the problem is being caused), the problem can be raised with the country in one of two ways:

- the national administration of the country in which the interference problem is occurring can contact the administration in the country from which the interference is emanating;
- an official complaint can be raised via the ITU from the country in which the problem is occurring.

In the first of these instances, if the two administrations have a good working relationship, the problem can often be resolved quickly with the two organisations working together co-operatively. Many European countries that share borders already have such good working relationships as the planning and assignment of frequencies along borders is best organised co-operatively. Those countries that do not share borders often do not have such a good relationship. Problems can easily occur between two such countries especially given the potential range of systems as received by aircraft flying at high altitudes, and worse, for transmissions below 30 MHz.

Where a complaint has to be raised via the ITU, procedures are set out in article 21 of the radio regulations. A form is printed in the radio regulations which must be used for each such complaint. The form ensures that all relevant data is recorded. A complainant must include information on:

- the frequency on which the interference is occurring;
- dates and times when the interference has occurred;
- details of transmission that is being affected;
- proof that the interference is emanating from the country against which the complaint is being raised.

This latter requirement can be difficult to meet. Proving that a source is from a certain country requires either detailed direction finding evidence or other indisputable evidence (such as a recording containing pertinent speech or something similar).

When the ITU are convinced that the interference is from the offending country, it will apply pressure on the national administration to clear up the problem. It should be noted however, that this route is often unsuccessful as many countries refuse to admit that they are to fault, or worse, do not care. In general, problems which require resorting to this approach are better dealt with by changing the frequency of the service that is being interfered with.

7 Interference incidents

7.1 Introduction

This section documents all the interference sources and problems identified during the study. This information comes from a number of sources, mainly from frequency managers and other technical staff from national aeronautical administrations. For each interference source, a description of the source and its effect on the affected system is given. The mechanism that causes the interference source to affect the system is then described (where known). Finally, the source is categorised so that comparisons can be made between the different sources and a structured and directed approach taken to their resolution.

It should be noted that although discussions have been held with personnel of almost all the aeronautical administrations in Europe, those countries that keep records of interference problems have had more to contribute to the study than those who do not. As such, many of the problems originate in the same countries – this does not mean that the particular interference source does not occur in another country, only that that country had no records of it.

Section 7.2 explains the basic mechanisms that cause interference. Section 7.3 describes a scheme for categorising the interference sources. Each of the remaining sections examines the interference sources known to have caused problems to a specific system.

7.2 Interference mechanisms

There are three basic mechanisms by which the performance of systems can be reduced by radio frequency interference:

– **direct radiation:** where a piece of equipment or a system radiates energy at a frequency being used by an aeronautical system, the aeronautical system will directly receive the interfering signal.

– **third order products:** one or more strong interfering signals on certain frequencies related to the one to which an aeronautical system is operating can cause interference effects.

– **induction:** where systems are placed in particularly strong RF fields, RF currents can be induced into lengths of metal (which effectively act as small antennas) causing malfunction of the system.

Each interference source will typically affect the performance of a system by only one of the mechanisms identified above. Whilst a more detailed description of the mechanism by which any particular system is interfered with will be given, it is first worth understanding the nature of each of the mechanisms described above.

7.2.1 Direct radiation

There are three basic mechanisms which will cause a system to radiate energy on the same frequency as an aeronautical system:

- it is licensed to operate on the same frequency as the aeronautical system;
- it is malfunctioning and producing spurious transmissions (eg harmonics);
- it is unlicensed and operating on the frequency illegally.

In all these instances, given the high sensitivity of the majority of aeronautical systems, only a small amount of interfering signal is required to cause a problem. Additionally, all systems which are within range of the interfering source and are tuned to the frequency on which it is radiating, will suffer from interference.

7.2.2 Third order products

There are a large number of mechanisms that will produce third order effects, however typical ones include:

- intermodulation products caused in the output stages of a transmitter or at the input to a receiver as a result of non-linearities. In these instances, two frequencies, f_1 and f_2 interact to cause resultants, the strongest of which are typically at $2f_1$-f_2 and $2f_2$-f_1. Where three or more frequencies interact the resultants can become many and complex;
- digital modulation schemes typically produce wide bandwidth transmissions (with modified sinc[5] function spectra). Such transmissions, although nominally on a central frequency can spread into frequencies allocated to other services;
- a super-heterodyne receiver (which make up almost all modern receiver designs) has an image frequency upon which it will also receive signals. Although every effort is usually made by manufacturers to include filters which prevent transmissions on the image frequency from reaching the receiver, which typically offer up to 80dB of rejection, a strong signal at the image frequency will still be received. This is also true of transmissions on the receiver's intermediate frequency (IF) although rejection tends to be better;
- transmissions on channels adjacent to that on which an aeronautical system is operating, whilst being within their specifications, may be so strong as to overcome the filtering included in the aeronautical system designed to reject such signals.

In each case, relatively strong interfering signals are required to cause problems. Also, each individual piece of equipment, even from the same manufacturer, may react differently to the interference. Given also that the majority of cases arise from interactions between two or more signals, the incidences of such interference can be fleeting and irregular.

5 sinc(x) represents sin(x)/x.

7.2.3 Induction

For any system to be affected by induced interference, the electromagnetic field causing the problem must be very strong (of order many Volts/metre). Much has been done within the EU to reduce the effects of induced interference through Electro-Magnetic Compatibility (EMC) legislation, but there may still be instances where such problems occur. Fields strong enough to cause problems can arise in the neighbourhood of:

– high power transmitters (broadcast transmitters, satellite uplinks and radars in particular can have radiated powers in the order of several MegaWatts);

– industrial RF heating equipment (dryers, microwave ovens etc);

– loading inductors for low frequency transmitters (it is not unusual for several kiloVolts of RF to be present even at relatively low powers).

It should be noted that this type of interference can affect any system which is susceptible to radio frequencies, ie those which are electronic in nature (as opposed to simple electrical or mechanical systems). Such systems which include computers, navigation systems, electronic 'fly-by-wire' systems and so forth will all be susceptible to problems caused by strong RF fields. The level of susceptibility which each system will suffer is a function of several factors including shielding, filtering and other protective measures.

Extremely strong RF fields are required to cause such interference problems and, as with third order products, individual items of equipment may react differently.

7.2.4 Summary

Table 7-1 overleaf summarises the characteristics of the types of interference discussed above.

Characteristic	Direct radiation	Third order products	Induction
Signal strength required to cause interference	Small	Large	Very large
Which systems affected	All tuned to frequency of interference	Only those susceptible	Only those susceptible
Number of systems affected	All tuned to frequency of interference	Unpredictable	Unpredictable
Likely duration of affectation	Continuous until the source is identified	Brief, sporadic	Constant, in affected area
Area affected	Dependent on power of interfering source	Only in close proximity (<1 km) to source(s)	Only in immediate proximity (<200 m) of source
Predictability	Relatively simple	Complex	Complex

Table 0-1: Summary of interference mechanisms

From the descriptions given in this section, we can draw some general characteristics which will enable us to distinguish between the interference mechanisms. Table 7-1 above highlights these characteristics and how they manifest in the case of each of the types of interference.

7.3 Categorisation scheme

7.3.1 Introduction

In order to assist in determining which of the interference sources identified poses more severe problems than others to systems, a categorisation scheme has been developed. The scheme is to help determine at which of the interference sources Eurocontrol should target its effort. The scheme used is based on simple-to-apply measures and can be used on any type of interference source and any system.

It is important to consider when comparing results for an interference source affecting one system to a different source affecting a different system that it is not necessarily valid to directly compare the results as the mechanism of the effect can be significantly different and the categorisation scheme can not account for this. For example, an interference source that affects Airport Surface Detection Equipment, even if extremely severe, would only slow down the operation of an airport. However, a source affecting air-ground communications could endanger life if instructions are unable to be given to an aircraft. Care should be taken, therefore, in interpreting the results of the scheme.

The scheme is designed to allow comparison of interference sources based on their operational effect, not on their technical effect, and is therefore based on the perception of the user to the interference.

The categorisation scheme used is simple and easy to apply and has been developed in consultation with Eurocontrol over the duration of the project. A more detailed scheme, developed earlier in the project has been included in Appendix D and may be used where a detailed technical comparison between sources affecting different systems needd to be categorised. It has not been used to categorise the interference sources identified during the study as there is a lack of detailed technical information on the interference sources (it would, however, be possible to estimate the technical parameters of an interference source based on knowledge of the mechanism whereby it affects the system).

7.3.2 Scheme

For each of the interference descriptions given later in this section, the criteria shown below will be evaluated. For each criterion, there are three possible outcomes and these are described. The choice of three represents a simple choice but gives sufficient resolution to discriminate between similar sources.

For each of the criteria described, the description outlines the basis for the scoring system. In addition to this simple basis, the perception and expertise of the project team has been used to augment and build upon the raw data. For example, some interference sources, whilst not having been reported by many sources, are taken by many organisations to have been addressed to often as to be of little interest. A good example of this are the problems associated with FM transmitters – these have been known to cause interference for 15 years or more and still cause problems today. As such many organisations regard them as of little interest and hence do not report them as the problems are so well understood. Whilst the number of actual reports may therefore be small, the real picture is different and it is in instances like this that the scoring may not reflect the actual data presented in the report.

In addition, where different countries reported an interference problem in a different light (eg one said that the problem was common whilst another said that is was occasional) the aggregate of the information gathered has been used to produce the final score.

The criteria used to assess each interference source are:

- **sources of reports:** This criterion is used to assess the number of sources that have reported the interference problem. Sources include aeronautical bodies, national administrations and documentation. Possible outcomes are:
  - **few:** mentioned by one or two sources;
  - **several:** mentioned in around 50% of cases;
  - **many:** mentioned by most sources.
- **frequency of reports:** This criterion is used to assess how often the cases which had been reported arose and is based on the frequency that the problem was addressed by an aeronautical body (or other source) as opposed to the number of reports from pilots or air traffic controllers. Possible outcomes are:

  - **rare:** the problem has only occurred once or twice;
  - **occasional:** the problem occurs several times within a year;
  - **common:** the problem is regularly occurring.
- **severity:** This criterion is used to assess the degree to which the interference complaint affected the operation of the system it interfered with. It is based on the perception of the person reporting the problem. Possible outcomes are:
  - **noticeable:** the interference was evident but did not affect the operation of the system;
  - **problematic:** the interference caused the system to malfunction but did not render it inoperable;
  - **severe:** the interference forced the system to become inoperable.
- **area affected:** This criterion is used to assess the geographical spread of the interference, ie how much of the area over which the system operates is affected by the interference. Possible outcomes are:
  - **localised:** the effect only occurred in the direct vicinity of the interference source or affects a small percentage of the total area over which the system operated;
  - **regionalised:** the effect is experienced over a reasonable proportion of the area over which the system operates;
  - **widespread:** most or all of the area in which the system operates is affected.
- **duration:** This criterion is used to assess the proportion of time for which the interference is active compared to the duration of operation of the system. The measure is a aggregation of the short (ie seconds), medium (ie minutes or hours) and long (ie days) term effects and is based upon the perception of the party reporting the problem. Possible outcomes are:
  - **short:** the effect is short-lived or occurs at such times as to minimise the impact on the system affected;
  - **medium:** the effect is experienced over a sufficiently long time to cause operational difficulties;
  - **long:** the effect is felt over a long time.

In the detailed assessment described in Appendix D, there are additional categories for the ‘strength’ or ‘sensitivity’ of the interference effect on the system. However, the result for this Criterion will be similar (or the same) as the assessment for severity, hence it is not proposed to add another criterion to this simple scheme.

In the detailed scheme, there is also an assessment of the spectrum occupied by an interferer. It is highly unlikely, however, that this could be determined by the type of observations that have been used in this simplified scheme. As an example, were an interference source to affect 5 adjacent VHF communications channels, the effect would still only appear on a single channel, unless the alternative channel used was also within the block of 5 channels interfered with. For this reason, no measure of the likely spectrum occupancy of an interferer can be derived from subjective observation and the criterion has not been replicated in the simple scheme.

In order to compare the results of the categorisation for the different interference source, a simple scoring scheme will be used. For each criterion a score of 1 to 3 will be allocated with 1 representing the least serious effect (eg rare, localised or short) and 3 representing the most serious effect (eg common, widespread or long). The scores for each criterion will then be summed to produce an overall score for the interference source. Using this system, the minimum score is 5 and the maximum 15. The final scores will be given in the summary section (section 8). Table 7-2 below demonstrates a typical application and the scores attributed to the criteria.

Criterion	Outcome	Score
Number of reports	Several	3
Frequency of reports	Occasional	2
Severity	Noticeable	1
Area affected	Widespread	3
Duration	Medium	2
	TOTAL:	11

Table 0-2: Example criteria application

The following sections categorise all interference sources identified in the work according to the above scheme.

7.4 Non-directional beacon

7.4.1 Interference from high powered short wave broadcast transmitter

Description

Two high powered transmissions (approximately 10 GigaWatts effective radiated power), from the British Broadcasting Corporation (BBC)'s transmitter site in Rampisham, Dorset, were being made on frequencies of approximately 15 MHz. These frequencies were spaced by 350 kHz (eg one was 15.000 MHz whilst the other was 15.350 MHz). The NDB at the local airfield transmitted on a frequency of 350 kHz. A number of aircraft attempting to use the airfield's beacon were receiving a spurious reading in the direction of the BBC's transmitter site. Also, instead of receiving the NDB callsign, the BBC programmes were being received.

Mechanism

Third order product: The problem was traced to the BBC's transmissions being received with such a large signal strength by the ADF receiver on-board the aircraft that the receiver was overloading and distorting. The problem was caused by the third-order intermodulation product from the two transmitted signals at 350 kHz and the strength of this was greater than the signal received from the NDB.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Problematic
Area affected	Localised
Duration	Medium
TOTAL SCORE:	7

This problem is only known to have occurred in the UK.

Resolution of problem

By changing the frequencies on which the BBC operated, such that the difference was no longer 350 kHz, the problem was eliminated.

7.4.2 Interference from LF broadcast stations

Description

Part of the band used for NDBs is shared with broadcast stations (255 – 283.5 kHz). There are a number of very high powered broadcast transmitters operating in this band which cause severe interference to NDB operation. Because signals at these frequencies carry over long distances (upwards of 3000 kilometres), transmitters in operation across Europe cause interference in many countries. Because of this problem it has become impossible to operate NDBs in this frequency range (indeed there is a note in the ITU-RR to this effect).

Mechanism

Direct radiation: Signals transmitted by the broadcast stations are on the same frequencies as are used for NDBs. As the powers used by the broadcast stations are hundreds of kiloWatts as opposed to a few Watts for NDBs severe interference is caused.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Severe
Area affected	Widespread
Duration	Long
TOTAL SCORE:	11

Whilst there is great potential for interference to be caused, there are not thought to be any NDBs operating in frequency range affected, hence no reports have been received.

Resolution

The only way in which such problems could be stopped would be to cease the operation of broadcast stations in this frequency range. As these transmitters are still commonly in use to provide national service, it is unlikely that this operation will cease in the near future. It is possible, with the development of digital radio and satellite delivered radio that alternative delivery mechanisms for the radio programmes could be developed. Until this time, the use of these frequencies for NDBs will continue to prove extremely difficult.

7.5 VHF air-ground voice communications

7.5.1 General

The VHF communication band is one of the most heavily used aeronautical bands. Several types of interference have been detected in Europe from a large range of sources. 90% of these reports are made by pilots whilst only 10% are observed by the ATC on the ground. Pilots usually notice interference by a background noise being present on the channel making it difficult to understanding the wanted transmission.

In many cases, reports of interference have been unable to be elaborated upon as the source of the interference has not been able to be identified by the relevant authoritied. For instance in Ireland, a buzzing noise has been heard by pilots in the South of Dublin on 124.650 MHz. After investigation by the Office of the Director of Telecommunications Regulation, and regular monitoring of the frequency, the interference source has still not been identified.

7.5.2 Interference from cable TV networks

Description

In the Northern part of Germany, pilots reported interference to VHF communications whereby communication with the ground became difficult. After a detailed investigation by Deutsche Flugsicherung (DFS), it was discovered that the source of this interference was cable TV networks. Around 3 or 4 VHF channels are affected, dependent upon the strength of the interfering signal.

Interference mechanism

Direct Radiation: The offending cable television networks use frequencies which lie within the VHF communications band to transmit pictures to their subscribers. Each cable in the network leaks a small amount of signal but this is generally below the level that would cause interference. At junctions between cables, however, larger amounts of signal can leak out from the cable. Whilst at ground level, such leakage does not produce interference, at high altitudes, the effects of the leaks combine to produce a more significant interference problem.

Categorisation

Criterion	Rating
Number of reports	Several
Frequency of reports	Occasional
Severity	Problematic
Area affected	Regionalised
Duration	Long
TOTAL SCORE:	11

This problem has been noticed in the Northern part of Germany and has also been detected in Belgium.

Resolution

In Germany, it has been proposed that the cable TV operator changes frequency in order to avoid the interference occurring. The process of changing the frequency requires re-working of the cable head-end installation and of the cable network itself and can take a long time. For the moment, therefore, the problem has not been resolved. Authorities are still investigating the problem and seeking alternative solutions.

In Belgium, the cable TV operators have agreed to change their frequency. The interference problem has therefore stopped. However, due to pressure to increase the number of channels available on the cable network there is discussion on the reallocation of the offending frequencies to cable TV operators. The Belgium Aviation Authority is concerned about this move and is keeping abreast of developments.

It is worth noting that were such effects occurring in the VHF navigation bands (ie ILS or VOR) there is less likelihood that they would be detected. Both Germany and Belgium suspect that this interference may also be occurring in ILS or VOR bands without being noticed.

7.5.3 Interference due to illegal or misaligned radio transmitters

Description

Due to the large line-of-sight range of aircraft flying at high altitudes and the fact that the path is effectively free-space and hence lower loss than a ground based path, any transmitter operating within the VHF communications band has the potential to cause interference to airborne receivers. Powers of less than 1 Watt can effectively render a channel unusable over a 200 kilometre radius. Frequencies above 136 MHz are particularly affected as this band was allocated to other services up until recently and some of these services have not yet left the band.

Interference mechanism

Direct Radiation: Transmissions from ground based transmitters will be heard in both ground based and airborne receivers. Even low powered transmitters will cause interference to be heard over large areas.

Badly aligned transmitters have a tendency to produce oscillations at frequencies other than that on which it is operating. These are known as spurious emissions. Such emissions often go unnoticed by the operator of the system but can cause serious interference problems to other radio users.

Categorisation

Criterion	Rating
Number of reports	Several
Frequency of reports	Occasional
Severity	Severe
Area affected	Widespread
Duration	Medium
TOTAL SCORE:	12

Cases have been reported in the Netherlands, France and the UK. In France, the problem was traced to illegal mobile phones. In the UK, studio to transmitter links for ‘pirate’ radio stations have caused problems, as have people using hand-held aeronautical radios as ‘walkie-talkies’. In the UK, a number of instances of badly aligned transmitters producing spurious signals in the VHF communication band have also been reported.

Resolution

The only way in which such interference can be rectified is to identify the source of the interference and close it down. As the transmitter is illegal, such a closure has the backing of the national administration who are also usually keen to identify and possibly prosecute the interferer themselves.

It should be noted that the sale of equipment capable of transmitting in the VHF band is permitted in some countries, even though its use is forbidden. Although frequencies between 136 and 137 MHz are now available to aeronautical services on a primary basis, many national civil aviation authorities have found unacceptable levels of interference in this band and have not, as yet, allocated it for aeronautical use.

7.5.4 Interference due to Band II FM radio transmitters

Description

High powered transmitters operating on frequencies adjacent to sensitive receivers are problems in many situations and cause a problem known as ‘blocking’ whereby the receiver is blocked from receiving the wanted signal by the strong unwanted signal. In this instance, as the high powered transmitter is close in frequency (up to 108 MHz) to that on which the receiver is operating (118 MHz upwards), the receivers input circuits (and the antenna) are unable to discriminate between the wanted, weak signal and the unwanted strong signal.

Interference mechanism

Third order products: Typically the input circuits to the receiver will become overloaded by the high powered transmitter as the receiver is unable to discriminate against the unwanted signal. The effect of such an overload is varied but typically manifests in one of two ways:

– the receiver becomes insensitive and is unable to receive weak signals (known as blocking);

– the unwanted signal is modulated onto the wanted signal such that it can be heard in addition to the wanted signal (known as cross-modulation).

It should be noted that these effects occur when a single signal overloads the input circuits but is caused by third order effects in the receiver. Where two (or more) high powered transmitters are located on frequencies adjacent to the receive frequency, the overload can cause intermodulation. Intermodulation effects are described in another section.

Categorisation

Criterion	Rating
Number of reports	Many
Frequency of reports	Common
Severity	Problematic
Area affected	Localised
Duration	Long
TOTAL SCORE:	12

Problems of this type have been reported in Belgium, Austria, the Netherlands, Sweden, Macedonia, Greece and Turkey. It should be noted that in many countries, frequencies at the top of Band II (ie above 105 MHz) are assigned only to low powered stations in an attempt to ensure that this problem does not occur.

One case of particular note occurred in Austria. Interference occurred at Salzburg airport due to the proximity of an aeronautical VHF ground station and commercial FM transmitters. This occurrence would rate as problematic rather than severe as communication could still take place, however, the complete system (10 channels) was affected.

Resolution

This type of interference problem could be resolved by the aeronautical organisation in one of two ways:

– the location of the VHF ground station could be moved such that it no longer received the strong unwanted signals. Many VHF ground stations are already located remotely from the airport and often in places distant from Band II FM transmitters to reduce the likelihood of such interference occurring. This was the solution employed in Austria;

– an alternative solution is to fit sharp rejection filters at the input at the receiver to reject the unwanted strong signal. Such filters are relatively inexpensive (circa 500 ECU), however, they can often be quite large and are generally unsuitable for fitment to aircraft.

If the commercial broadcaster is operating with excessive power (ie above that assigned to them), action could be taken via the national administration to resolve the problem. If the station is acting legitimately, it is possible that the broadcaster could modify their antenna configuration such that there is a notch in the radiated power towards the aeronautical receiver. Such a solution may be costly and may also reduce the coverage of the radio station (and hence lose them listeners). It is apparent that any such change may involve incentives from the aeronautical body itself.

7.5.5 Interference due to broadcast FM receivers

Description

All broadcast FM receivers operate by mixing the incoming received signal with an oscillator to convert the incoming signal to a fixed frequency. The actual demodulation then takes place at this fixed frequency, usually 10.7 MHz. By varying the frequency of the oscillator, the receiver can be tuned. Such a receiver in known as a ‘super-heterodyne’. As an example, a receiver tuned to 107 MHz would mix the incoming signal with an oscillator at 117.7 MHz (ie 107 + 10.7) to produce a resultant at 10.7 MHz. Equally, the oscillator could be tuned to 96.3 MHz (ie 107 – 10.7). In this example, if the receiver is badly aligned or poorly manufactured the signal could leak from the receiver causing interference to nearby receivers tuned to 117.7 MHz.

Mechanism

Direct radiation: For FM broadcast transmitters with frequencies above 107.3 MHz, the oscillator in the receiver falls in the frequency range used by VHF communications (ie above 118 MHz). Whilst one receiver is unlikely to cause a significant problem, the combination of the leakage of signal from a large number of receivers can produce a significant problem. The problem is more marked when received from the air where the receiver is line-of-sight to the large number of receivers.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Problematic
Area affected	Regionalised
Duration	Long
TOTAL SCORE:	9

This problem has been noted in Austria and the UK. In Austria, the problem occurred in the popular tourist area on the border with Italy, and was at its worst during summer time when a lot of tourists were listening to their radios. Only one channel was affected but note that the affected channel was not always the same and that it could have been worst if more channels were affected. Pilots noticed, and aided the identification of the problem as they were able to hear music on their communications.

Resolution

The problem is particularly difficult to resolve as it is the result of a large number of receivers that have been purchased by the public. One solution would be to insist that FM receivers used oscillator frequencies that were lower than the receive frequency (ie 10.7 MHz lower), but such a solution would require the agreement of all national and international standardisation bodies. Another solution is to change the frequency of the FM transmitter such that the emissions from the receivers were no longer on the aeronautical frequency (this was the solution employed in Austria). The simplest, but least satisfactory solution is to change the frequency being used for aeronautical communications.

7.5.6 Interference due to ISM harmonics

Description

Industrial , Scientific and Medical (ISM) transmitters typically operate at 13 or 27 MHz and comprise very high powered transmitters (100 kW or more). Such transmitters, unless extremely carefully installed, produce harmonic radiation and only a small amount of such harmonic radiation is required to cause interference. The interference typically takes the form of a carrier which can be silent, noisy, steady or can drift in frequency. The variety of effects that can be heard often make it difficult to identify the source of the interference.

Mechanism

Direct radiation: The ISM bands that have the potential to interfere with the VHF communications band are the lower frequency bands since the harmonics of signals produced in these bands lie within the range 118 MHz - 137 MHz. In particular, table 7-3 shows the bands of frequencies that are most likely to be affected by such interference. In addition to these, it should be noted that the 8th harmonic of ISM sources operating between 13.553 and 13.567 MHz falls just above 108 MHz and could therefore cause interference to ILS and VOR equipment.

ISM frequency	3rd Harmonic	5th Harmonic	9th Harmonic	10th Harmonic
13.553 – 13.567	Out of band	Out of band	121.977 – 122.103	135.533 – 135.670
26.957 – 28.283	Out of band	134.785 – 136.415	Out of band	Out of band
40.660 – 40.700	121.980 – 122.100	Out of band	Out of band	Out of band

Table 0-3: Harmonic relation of ISM bands
All frequencies are in MHz

It is known that some ISM equipment operates outside these bands, in particular on frequencies around 30 MHz, offering the potential for harmonics from such equipment to cause interference across a wider range of frequencies within the VHF channel than those identified above.

ISM sources include:

– *Surgical heat treatment:* These machines are used to carry out heat treatment on patients limbs. They typically operate at 27.12 MHz and may be pulsed or continuous

– *Surgical diathermy:* These machines operate in the vicinity of 27 MHz and are used for cleaning and sterilising surgical instruments

– *Industrial drying and cooking:* Machines operating at about 27 MHz are used in, for example, the nylon industry for drying, the biscuit industry for removing moisture from biscuits after they have been baked, and the furniture industry for curing resins.

– *Scientific use:* RF etching and deposition machines operate around 13.5 MHz and are operated by many universities and companies in the semiconductor industry. Of particular concern is that equipment operated in universities tends to be old and is often modified or customised to perform a specific function or experiment. The result is that RF shielding is often poor.

Ideally an ISM source should have sufficient shielding such that it does not radiate any power outside its immediate environment. However, most practical designs cannot be perfectly shielded, and the high powers used in some ISM processes (up to several MW in some industrial heating applications) mean that even a small shielding inefficiency can result in the radiation of strong unwanted signals.

Categorisation

Criterion	Rating
Number of reports	Many
Frequency of reports	Common
Severity	Problematic
Area affected	Widespread
Duration	Medium
TOTAL SCORE:	13

Cases of ISM interference have been reported in Ireland, the Netherlands, France, UK, Italy and Switzerland. However, many unidentified interference incidents are often blamed on ISM transmitters and caution must be taken in precisely identifying this source of interference.

The interference problems observed in the Netherlands happen on a random basis, making investigation more difficult. In average on a year, around 3 to 5 occurrences are reported per month. However there have been periods of two months where no occurrences have been reported. Around 5 or 6 channels are perturbed and can be rendered unusable, however it is more common for the channel just to become ‘annoyingly noisy’.

In Switzerland, interference is often heard in the upper airspace of Geneva Area Control Centre at the frequencies 136.575 MHz and 136.150 MHz. When it occurs, the interference renders 2 VHF channels inoperable (although usually at different times). It is assumed that the interference comes from local industry.

Resolution

In order to avoid interference due to ISM sources in Switzerland, the frequencies on which offending ISM machines were operating were changed such that the harmonics either no longer fell within the VHF communications band, or were not on frequencies being used in that country. This solution is not ideal as the sources are still radiating and future changes to the frequency used for aeronautical purposes may cause the problem to re-occur. This method has also been used in the UK.

Another method, as used in the UK, is to fit filters or shielding to the ISM equipment to reduce the amount of harmonic radiation. Such modifications can be costly (typically UK£20,000) but eliminate the problem both in the short and long terms.

7.5.7 Interference due to intermodulation products

Description

When two signals interact in a non-linear fashion, intermodulation products are generated (see section 7.2.2). Such problems can occur at transmitter sites by loose or corroded connections or can be caused when two (or more) strong signals combine to overload a receiver. For VHF communications the most common source of strong signals is the FM broadcast band although other sources have been noted. The problem is relatively easy to identify as the resulting signal is modulated by both the originating sources, ie the intermodulation product of two broadcast FM transmitters will contain the audio of both the original stations.

Mechanism

Direct radiation or Third order product: Where the intermodulation occurs at the transmitter site, an actual signal is radiated at the unwanted frequency; interference is therefore caused by direct radiation. Where the intermodulation occurs in the receiver, the interference is caused by the receiver overloading and is therefore a third order product (this is more common). The most common cause is the mixing of two FM broadcast signals as these are often very powerful (250 kiloWatts is not unusual) and they are close in frequency to the VHF communications band. As an example, one station transmitting on 107 MHz and another transmitting on 95 MHz, interacting to produce intermodulation will cause signals to be heard on 119 MHz (and 83 MHz). The problem becomes worse when three (or more) frequencies interact. Figure 7-1 illustrates the intermodulation products caused by three broadcast transmitters on 90 (*f*1), 105 (*f*2) and 108 (*f*3) MHz.

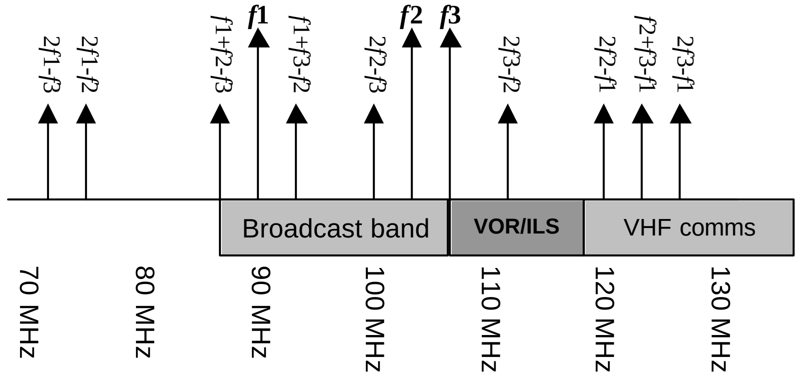


Figure 0-1: Intermodulation products

It can be seen that the interaction between three signals produces a large number of products. Not all of these are within the VHF communications band hence it is possible that other services will notice the problem as well as aeronautical users.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Occasional
Severity	Problematic
Area affected	Localised
Duration	Long
TOTAL SCORE:	9

Cases of interference resulting from intermodulation products between FM broadcast stations have been reported in Austria and Greece. Interference resulting from intermodulation products caused by paging transmitters operating at 137/138 MHz has been reported in the UK.

Resolution

In the case where the intermodulation products are being caused at the transmitter site, the problem can be rectified by identifying and correcting the source of the non-linearity in the transmission path. This is usually a loose, dirty or corroded connection, cable or antenna. An antenna connected to a spectrum analyser close to the offending transmitter site can be used to identify the problem.

In the case where the intermodulation products are being generated in the receiver, there are two basic solutions. The first is to improve the filtering at the input of the receiver to try and reject signals on unwanted frequencies. The specification of VHF receivers for aeronautical communications already include such filters, however the filter specification is not particularly stringent, hence problems still occur. The second method is to improve the design of the receiver. Receivers that can continue to receive weak signals in the presence of strong signals can be designed, however, at some point as the unwanted signal gets stronger, all receivers eventually overload.

7.5.8 Interference due to Personal Electronic Devices

Description

Personal Electronic Devices (PED) taken onto aircraft by passengers can cause interference to VHF communications. PEDs include:

- portable computers (laptops);
- compact disc players;
- personal stereos and radios;

– mobile phones.

Electronic circuitry (especially digital electronics) generate large amounts of spurious radio signals over a wide range of frequencies (typically 0 – 1000 MHz) and these can be picked up by the sensitive receivers on-board the aircraft. As an example, it has been reported that in one instance, the pilot was able to hear one of the passengers compact disc players on his VHF receiver.

Note that some interference has occurred that has been caused by the electronic equipment installed within the cabin by the airline company itself, such as TVs and video games.

Mechanism

Direct radiation: The circuitry within the PED's generates radio signals. These are radiated throughout the cabin and can either be picked up by antennas outside the aircraft or can be induced into the cabling running through the cabin into the aircraft's wiring. The problem is made worse at VHF frequencies as most cabins are around 3 metres in diameter; as this is the wavelength of the VHF frequencies in question, the cabin acts as a resonator and can amplify the signal.

Categorisation

Criterion	Rating
Number of reports	Several
Frequency of reports	Common
Severity	Problematic
Area affected	Localised
Duration	Short
TOTAL SCORE:	9

This problem is well known by airline companies and manufacturers and occurs in all countries.

Resolution

Several solutions exist that can ameliorate the problems presented by PEDs, however many of these are either impractical or would be prohibitive to implement. Potential solutions include:

– design cabins such that radio signals were unable to affect the communication equipment (ie effectively make the cabin into a Faraday cage). This solution is difficult as radiation will always escape from the windows unless metallised windows could be installed;

– ban the used of PEDs during a flight. This would prove extremely unpopular with passengers;

– install sensors on-board aircraft to detect the use of PEDs. This may be possible, but the sensor would prove equally sensitive to the transmissions from the pilot and may be triggered by the standard operation of the aircraft;

– insist that all PEDs brought onto an aircraft meet certain emission standards. Either equipment could be checked prior to the flight or it could be designed to ensure that radiation does not occur. In either instance the cost of doing so is likely to be prohibitive.

Most airline companies now ban the use of PEDs during landing and take-off which are the most critical times in the flight. However, problems can still occur if, for example, a passenger forgets to turn off their PED.

7.5.9 Interference due to ‘stuck’ transmitters

Description

Interference occurs when pilots do not turn off their transmitter once they have finished the communication. This can occur for s number of reasons for example:

– the transmit switch can become damaged such that although the pilot operates the switch correctly, the transmitter is not turned off;

– the pilot may forget to operate the transmit switch;

– the transmitter may develop a fault such that it does not switch correctly between transmit and receive.

It should be noted, that it is equally likely in most instances that the pilot becomes unable to transmit rather than having the transmitter stuck on. This represents an equally severe problem but will not be dealt with here as it is not strictly an interference problem.

Mechanism

Direct radiation: If the transmitter fails to cease transmitting, all the other receivers on the frequency will hear the transmission from the offending aircraft and will be unable to communicate effectively with the ground. This also renders it difficult for air traffic control to inform aircraft to change frequency (to a clear channel) as communication is so badly impaired.

Categorisation

Criterion	Rating
Number of reports	Several
Frequency of reports	Occasional
Severity	Severe
Area affected	Widespread

Duration	Short
TOTAL SCORE:	11

This problem happens quite frequently (for example, about 10 reports per year are received in Switzerland). Fortunately, it takes usually around 30 seconds for the pilot to notice and rectify the problem. Any VHF frequency could be affected by the problem.

Resolution

This type of interference is well recognised by the aeronautical industry and represents another example of interference due to the potential misuse (or failure) of the system. Again, education can be (and has been) used to instruct pilots on radio operating procedures.

However, as the problem is so severe, attempts have been made to offer a technical solution to the problem. A device, known as an Anti-Blocking Device (ABD) has been trialled by a number of organisations in the United States. ABD's form part of the radio installation on an aircraft and principally consist of a timer. The timer is activated once the Press-To-Talk (PTT) switch on the microphone is activated by the pilot. After a certain time (typically 30 seconds), if the transmission is still active and there is no speech being transmitted, the ABD automatically turns the transmitter off. The US trials have been successful and a number of organisations are attempting to mandate the inclusion of ABDs in all future radio installations on aircraft.

7.5.10 Use of the radio system outside of its intended coverage area

Description

This is not fundamentally an interference related problem, but has been reported as such by a number of pilots. Pilots occasionally change frequency to a radio service, particularly Air Traffic Information Services (ATIS) whilst they are still out of the area that the particular service is intended to serve. The reception they therefore obtain is poor as the signal is weak.

Alternatively the frequency to which they are tuned may be used in the vicinity of the aircraft by a local station. As such it appears that the service that they are trying to receive is being interfered with by the local station.

Mechanism

There is no physical mechanism, just misuse of the radio system.

Categorisation

Criterion	**Rating**
Number of reports	Many
Frequency of reports	Rare

Severity	Noticeable
Area affected	Localised
Duration	Short
TOTAL SCORE:	N/A

This problem has been reported in Switzerland, Ireland, Denmark, Austria and the Netherlands. It should be noted that this type of interference could occur anywhere as it does not depend on a specific interference source but on the correct use of the system.

Resolution of the problem

The only real solution to this problem is to educate pilots to better understand the correct operation of their radios. Such an exercise was undertaken in Switzerland as the air traffic control body posted a notice explaining the area over which its ATIS transmissions should be able to be received and added that reception outside this area should not be expected.

7.6 VOR and ILS

7.6.1 General

Interference to systems operating in the VHF frequencies between 108 and 118 MHz (which include VOR and ILS) are often noted but are difficult to locate. The way in which the problem manifests itself does not help with the diagnosis as most problems cause the direction that is being communicated by the radio signal to appear incorrect (eg bearings are skewed). In addition, VOR and ILS equipment must be carefully aligned to operate correctly and often cases of interference prove to be due to misaligned equipment.

Both VOR and ILS systems use similar mechanisms to deliver their positional interference, that is that two transmissions each of which are slightly different, are used and are compared by receivers in the aircraft to display positional information. As such, it is valid to consider interference sources to both systems together as most (in fact all identified as a result of this study) interference sources are likely to affect both systems equally.

7.6.2 Interference due to Band II FM radio transmitters

Description

The main interference problems associated with ILS and VOR systems are caused by broadcast FM transmitters operating in Band II (88 – 108 MHz). The types of interference caused are similar to those described in section 7.5.4 for VHF air-ground communication. As the VOR/ILS band is nearer in frequency to the broadcast band interference problems are more common and also more difficult to rectify.

Mechanism

Third order products: The mechanisms described in sections 7.5.4 and 7.5.7 apply equally to ILS/VOR systems.

Categorisation

Criterion	Rating
Number of reports	Many
Frequency of reports	Common
Severity	Problematic
Area affected	Localised
Duration	Long
TOTAL SCORE:	12

Problems of interference between FM broadcast transmitters and VOR/ILS have been noted in most countries.

Resolution

The frequencies affected by intermodulation products are predictable and hence the transmitted frequencies or the frequency on which the aeronautical system is operating can be changed to avoid such clashes (this solution was used for a particular problem in Denmark). In the event of the strong signals desensitising the receivers, the same solutions as described in section 7.5.4 can be applied. It should be noted, however, that it is not possible to move the ground station as its purpose is to indicate its location.

7.6.3 Interference due to large vehicle moving on the ground

Description

Following complaints from a large number of pilots that ILS localiser indications had indicated a position up to 6 metres from the correct runway location, investigations into the problem were instigated. The investigations showed that the problem was caused by signals being reflected from large moving metal objects in the vicinity of the airfield such as cranes on a nearby building site, heavy goods vehicles, airport vehicles and aircraft themselves.

This is not strictly an interference problem as it does not involve third party systems but has been included in this report for completeness.

Mechanism

Obtaining position information from an ILS localiser relies on comparing the two radio signals transmitted by the localiser. If one of the signals is received via another path (eg reflected from a vehicle), the position indicated by the receiver can be skewed to a different angle. The precision involved in ensuring an accurate localiser reading means that even if the reflected signal is significantly weaker than the main transmission, errors in position can become evident.

Whilst the problems identified by the study for this particular problem have centred around ILS localisers, as VOR operates using similar mechanisms, it is likely that this problem could affect their operation as well.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Severe
Area affected	Localised
Duration	Short
TOTAL SCORE:	7

This type of interference has only been reported in Switzerland and in Denmark, however it is possible that the problem could re-occur at any location if the same circumstances were repeated.

Resolution

The simplest way to resolve the problem (and the method use in the reported cases) is to ensure that no objects that could cause radio reflections are allowed in the vicinity of the ILS transmitters or the approach path to the runway. This may not be possible in some circumstances and other methods may need to be employed. The coating of objects in some kind of non-reflective compound could be one alternative method of ameliorating the problem.

7.6.4 Interference due to Personal Electronic Devices

Description

As described in section 7.5.8, PEDs can radiate signals at the frequencies on which ILS and VOR systems operate. The cabin also acts as a resonator to make the problem worse at VHF frequencies. The effect of the interference from the PED is to give anomalous and incorrect ILS readings. Normally the effect is random, making the reading ‘wander’ and is hence easy for the pilot to detect. It can be more difficult to identify which of the PEDs being used on the aircraft is causing the problem.

Mechanism

Direct radiation: The mechanism is identical to that described in section 7.5.8 and is caused by emissions from the PED being received by the ILS or VOR receivers.

Categorisation

Criterion	Rating
Number of reports	Several
Frequency of reports	Common
Severity	Severe
Area affected	Localised
Duration	Short
TOTAL SCORE:	10

The problem has been categorised as being severe opposed to problematic as for the case of interference to VHF communications as the operational ramifications of the effect are much more serious.

Resolution

The reader is referred to section 7.5.8 where a full description of the possible mechanisms to resolve interference problems caused by PEDs is given.

7.6.5 Other problems

The aeronautical navigation aids frequency band (ILS-VOR) is also affected by meteorological problems such as static electricity and lightning. These problems were recognised and understood by aeronautical bodies and manufacturers who took action to protect on-board systems The actions taken by manufacturers of aeronautical equipment (both aircraft and on-board systems) have been successful such that no further problems with such meteorological sources exist.

7.7

GNSS

7.7.1 General

Most of the systems identified and discussed in this report operate in spectrum that is allocated for aeronautical use only. GNSS is one of the exceptions to this and shares its spectrum with commercial and military systems.

Currently, GNSS is not heavily used for positioning information for civil aviation, hence interference problems to GNSS are unlikely to form a short term priority for Eurocontrol. However, given the potential use of GNSS in the future as a key element of navigation systems, any interference problems should be monitored, lest they become more severe.

7.7.2 Interference due to intentional jammers

Description

As the two systems that make up GNSS (GPS and GLONASS) are used by the military for obtaining location information in battle situations, they are an obvious target for attack by electromagnetic countermeasures (ECM). In particular, a ground based radio transmitter operating on the frequencies used by GNSS can cause interference over a relatively wide area. In such an instance, the signal from the GNSS satellites is said to be 'jammed' by the ground based transmitter.

This type of interference is not currently critical as other navigation systems are available such as ILS and VOR. However, if GNSS becomes the only navigational equipment in the future, interference of this type could have a very large impact on flight safety.

Mechanism

Direct Radiation: Creating intentional interference to a system is generally easy. All that is required is to transmit a jamming signal on the same frequency as the system is operating. At the frequencies used by GNSS (around 1600 MHz) transmission is mainly line-of-sight, hence a high powered transmitter located high up (eg on top of a hill or tall building) could cause interference over a wide area. For aircraft, the problem is greater as the line-of-sight from an aircraft is around 300 kilometres.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Problematic
Area affected	Localised
Duration	Medium
TOTAL SCORE:	7

This problem has only been reported by Switzerland and seemed to have been caused by military activity taking place on the Italian border. Following complaints to the Italian authorities, the problem ceased but appears to have restarted.

Resolution

In peacetime, the problem should not exist, except for military exercises. Should the use of GNSS jammers become commonplace, due to heightened military activity, there is probably very little that could be done.

7.7.3 Interference due to commercial satellite telephones

Description

The implementation of new satellite telephone services such as those provided by Iridium or Globalstar is planned to be in a frequency band adjacent and in some areas sharing with GNSS (GPS and GLONASS). As GNSS is foreseen as the sole means of future airborne navigation, it is necessary to take particular notice of the implications of this problem.

Mechanism

Direct radiation: The transmission power of the commercial satellite station is large (-112 dBW/m^2/MHz), and is certainly larger than for the GNSS system. The impact on the GNSS service is expected to be severe, making reception of the position signal significantly more difficult than at present.

Categorisation

Criterion	Rating
Number of reports	N/A[6]
Frequency of reports	N/A
Severity	Severe
Area affected	Widespread
Duration	Medium
TOTAL SCORE:	N/A

This type of interference has not been noted to date, as the satellite telephone systems are not in use yet. However, the mechanism is well understood and therefore, the impact on the GNSS system can be anticipated (see below).

Resolution

Standardisation organisations are currently acting on behalf of the aeronautical industry in order to protect the GNSS bands and are trying to solve the problem prior to the introduction of the commercial services. Most aeronautical bodies are concerned with the problem, including IATA, ARINC, national CAAs and Eurocontrol.

It is planned in the near future to use GNSS as the main positioning system for aircraft in the three different flight phases, ie take off, en-route and landing. Therefore, it is fundamental to protect this band for security reasons. One solution would be to reduce the transmission power of the satellite stations below a fixed level under which the risk of interference to GNSS would be limited. At these reduced levels, however, the satellites may no longer be able to provide a commercially viable service so there is a trade-off between viability and interference to be had. Stances against the problem differ from organisation to organisation.

7.7.4 Interference due to television stations

Description

An interference problem affecting GNSS has been detected during a research study in the USA. Television transmitters are amongst the most powerful radiating sources in the UHF and VHF spectrum, with continuous transmitter powers ranging from 0.3 to 5 Megawatts. Harmonics of these transmitters, either locally generated within the receiver or externally radiated, have the potential to interfere with the weak signals from GNSS satellites, creating areas where GNSS can not be received.

6 Not applicable as no reports have been received.

Harmonic emissions of television transmitters operating on the frequencies identified in the table overleaf could cause interference to the GNSS band (1559 – 1610 MHz). It should be noted that high order harmonics are much less likely to cause interference problems than low order harmonics. This is because the amount of harmonic radiation generally decreases with rising frequency.

Frequencies (MHz)	Television channels	Order of harmonic in GNSS band[7]
779.500 – 805.000	59 – 62 (Band V)	2nd
519.666 – 536.666	27 – 29 (Band IV)	3rd
222.715 – 230.000	IK (Band III)[8]	7th
194.875 – 201.250	IF – IG (Band III)	8th
173.222 – 178.888	ID (Band III)	9th

This problem does not affect only the aeronautical industry but all users of the GNSS system. As the problem is localised near the TV transmission (at a distance up to 30 km), particular caution must be taken not to locate such transmitters near airports.

Mechanism

Third order product/Direct radiation: In the instances where the sheer strength of the signal overloads the GNSS receiver such that the receiver distorts and produces harmonics of its own, the problem can be attributed to third order products in the receiver. In instances where the harmonics are radiated from the transmitter itself, the mechanism is direct radiation.

7 Harmonics caused by band I (47 – 68 MHz) television transmissions would have to radiate harmonics of order 23 to 34 to cause interference. At these high orders it is unlikely that any interference will be caused, hence these have not been included in the table.

8 Allocated to digital audio broadcasting (DAB) in Europe. DAB uses much lower power transmitters than television hence interference is much less likely to be caused.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Problematic
Area affected	Localised
Duration	Medium
TOTAL SCORE:	7

The number of actual reports of this type of interference is currently low. This is potentially due to the low use made of GNSS for civil aviation. Were GNSS in more common use, the problem may be more prevalent.

The problem was identified by an American student studying electronic countermeasure resistant communications. No report concerning this particular type of interference has been received from any of the European aeronautical bodies contacted as part of the study. Television transmitter powers in Europe are typically less than in America hence the affected area will be smaller, nevertheless, the problem is considered as potentially serious as the areas of interference could exceed 300 square kilometres and easily include airports.

Resolution

The FAA is concerned by the existing problem and how this may change following the introduction of digital TV. They are concentrating their efforts on ensuring that out-of-band emission standards for television emissions are revised such that sufficient harmonic emission limits are imposed on transmitters. Current limits are based on an allowed level of spurious (including harmonic) emissions related to the power of the carrier. Hence, the more powerful the carrier, the greater the level of spurii allowed.

It is also interesting to note that different types of GNSS receivers tend to be more or less susceptible to television interference. Therefore, a solution to this problem may be to revise the specification of GNSS receivers to be installed on board of aircraft.

7.7.5 Due to amateur digital (and analogue) relay stations

Description

Amateur radio organisations operate high speed digital relay stations. These stations, known as ‘Digipeaters’, as well as traditional analogue FM relays operating in the same frequency range, cause interference to GPS. This is because the amateur systems transmit in band 1240-1243.25 MHz, disrupting the reception of GPS L2 (Precision Positioning System) and in the process causing interference to L1 (GPS Standard Positioning System) due to the poor interchannel isolation within many receivers. The problem is considered as potentially severe as the amateur stations transmit permanently.

It should be noted that the L2 signal is not normally used by civil GPS users as its content is scrambled by the military bodies that operate the GPS satellites. The problem of interference to the L2 signal is therefore not as severe as interference to the L1 signal.

Mechanism

Third order product: The L2 channel of GPS uses a frequency of 1227.6 MHz and is therefore adjacent to the amateur transmissions. GPS frequencies are particularly sensitive to interference due to their weak power received on Earth. In order to make the receivers sensitive, high gain amplifiers are used and these become overloaded in the presence of strong signals. Due to the need to receive signals at 1227.6 MHz for L2 and at 1559 – 1610 MHz for L1, GPS receivers usually have a wide-bandwidth front end and are therefore susceptible to overload by strong signals operating anywhere between 1227 and 1610 MHz (and probably above and below this range too).

Categorisation

Criterion	Rating
Number of reports	Several
Frequency of reports	Rare
Severity	Problematic
Area affected	Localised
Duration	Medium
TOTAL SCORE:	8

The problem has been noticed in Germany, the Netherlands and Switzerland where amateur activity is at high levels. In other European countries, the frequency range above 1240 MHz is also used by amateur radio, hence as activity in other countries increases, more problems are likely to occur.

Problems on the L1 frequency, have also been noticed due to bad interchannel isolation within the receiver of the L2 frequency. This is considered as more problematic as it is planned to base the aircraft navigation system on the GPS Standard Positioning System which uses the L1 system. These problems are, however, caused by poorly designed receivers and it is to be hoped that receivers installed in aircraft for navigation purposes are designed so as not to suffer from this problem.

Resolution

The problem could be avoided with more robust GNSS receivers, ie with a greater selectivity, thereby rejecting unwanted signals outside the actual GNSS band. One solution would therefore consist of actions within standardisation organisations in order to make sure that the GNSS receivers to be installed on board of aircraft have an acceptable immunity to out-of-band interference.

It is also important to specify the design of the GNSS receivers in order to avoid bad interchannel isolation causing interference on the L1 frequency to be used by airborne GNSS equipment. Note that it is not planned to use the GNSS Precision Positioning System (PPS, L2 frequency) for aeronautical navigation.

7.8

HF communications

7.8.1 General

By their nature, transmissions from any transmitter site on HF can be heard across the world. For this reason, attempts are made by all administrations to register and co-ordinate the use of frequencies to minimise the potential for interference. However, even if one country allows operation in derogation of the internationally agreed regulations, the effect of that derogation will be experienced over an extremely wide area.

7.8.2 Interference due to illegal transmission

Description

Aeronautical HF communication frequencies are close to other HF communication services such as maritime and fixed services. Where a frequency is likely to be set manually, there is potential for an incorrect frequency to be set. When this occurs, it is possible for other users to intrude upon the spectrum allocated for HF communications and cause interference. Such intrusions into aeronautical HF spectrum is not uncommon and can be caused accidentally or purposefully either due to a lack of regard for the regulations or by illegal operators.

Mechanism

Direct radiation: The interfering signal is transmitted on the same frequency as the wanted signal and can therefore be received by the aeronautical signal. It should be noted that the use of Single Side Band (SSB) causes transmissions that are not correctly tuned-in to become garbled hence it is not always easy to understand (and hence identify) the source of the interference.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Occasional
Severity	Noticeable
Area affected	Widespread
Duration	Short
TOTAL SCORE:	8

Interference due to illegal use of aeronautical HF frequencies is known to have caused problems in the UK, France and Portugal. It is worth noting that there are a large number of illegal citizens band type operators that use frequencies around 6.6 MHz. Such operators usually try to choose frequencies on which they can hear no transmissions, and hence are unlikely to cause interference, however they do occasionally cause problems.

Resolution

If the illegal operators are based in the country where the problem is evident, the problem can be resolved by contacting the national administration. However, as HF transmissions can be received over such large areas, this is unlikely to be the case therefore the ITU procedures for making complaints about interference sources (as described in section 6.3.3) should be used.

7.8.3 Loss of HF communications due to solar flare

Description

Problems are regularly noted by operators of HF ground stations and by pilots whereby communication becomes extremely difficult. Signals become weak or totally unreadable. These problems have been traced to the occurrence of solar flares (storms on the Sun).

Whilst not strictly an interference problem, this problem has been included in this report for completeness.

Mechanism

HF communications rely on reflection of the transmitted signal on a layer of ionised gasses above the earth known as the ionosphere. There are a number of different layers of gas each with different properties and different ones are used during the day and during the night. This is because the reflective properties of the gasses are affected by ionising radiation from the Sun.

When the Sun emits a solar flare, many times the normal amount of ionising radiation is emitted. These high levels of radiation effectively burn up the gasses in the ionosphere. This makes communication by HF radio infeasible as it is no longer possible to reflect signals from the ionosphere. The effect is variable such that small solar flares may only serve to decrease the reflectiveness of the ionosphere whereas large flares will render communication impossible.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Problematic
Area affected	Widespread
Duration	Medium
TOTAL SCORE:	9

The problem tends to affect HF communications over the hemisphere of the Earth that is being illuminated by the Sun. It has been reported by Portugal but is probably not regarded as a problem by other administrations as it is a ‘fact of life’ for HF operators. All frequencies are affected when large flares occur. When smaller flares occur only some frequencies, usually the lower frequencies are affected. The problem occurs rarely, typically once a year and during daylight hours.

Resolution

Obviously, no action towards the interference source can be taken and as the problem is difficult to predict, the only action to avoid the problem is to switch to higher frequencies which may be less affected.

7.9

Radar

7.9.1 General

Whilst there are a large number of frequency bands in which different types of radar system operate, there were very few cases of interference reported. This is possibly due to the fact that radar system generally operate at microwave frequencies where the range of transmitters is severely limited. As such, even if other stations were transmitting in the bands used by radar systems, it is unlikely that problems would be caused. Those cases of interference affecting radar systems have been collated in this section.

7.9.2 Interference due to satellite ground stations

Description

Commercial satellite ground stations transmit at microwave frequencies but at very high powers. There is therefore currently a concern about the impact they could have on nearby radar installations. Currently with Satellite News Gathering (SNG) and potentially in the future with the emergence of new satellite communication systems, such as Iridium or Globalstar, the number of such ground stations is increasing rapidly. Aeronautical organisations take this problem seriously and have already taken some preventive actions.

Mechanism

Third order product: Satellite ground stations represent very high powered microwave transmitters with effective radiated powers often in excess of 1 MegaWatt. These power levels are required to ensure that the signal can be clearly received by the satellite even in the event of rain and other moisture based meteorological effects which cause severe attenuation of microwave signals.

Categorisation

Criterion	Rating (predicted)
Number of reports	N/A
Frequency of reports	N/A
Severity	Severe
Area affected	Localised
Duration	Medium
TOTAL SCORE:	N/A

Radar receivers incorporate very sensitive receivers and radiation from the ground stations could easily overload the receiver and cause it to become insensitive (in much the same way as broadcast FM transmitters affect VHF communications).

No score has been attributed to this interference problem as no cases have yet been reported. All activity to date has been preventative to ensure that such problems do not occur in the future. The problem is, however, of great concern to aeronautical bodies.

Resolution

As no cases have yet been recorded, it is difficult to determine what counteractive measures could be taken. However, it is known that a number of airports have placed an exclusion zone around their radar installations such that no satellite uplinks may be operated within 500 metres of the radar station. Generally, this is of little concern for the satellite operators as alternative locations can be found. The possible exception are news teams who would like to set up their cameras within the airport, especially on occasions where a major event is taking place at the airport.

7.9.3 Interference from amateur television transmitters

Description

On a number of occasions, transmission from the amateur television services have caused interference problems with primary surveillance radar systems (PSR) operating in the 23 cm band. The interference causes spurious readings to be taken and show up as dots or lines on the radar screen. The interference only affects the radar in the direction of the amateur station.

Mechanism

Direct radiation: The 23 cm primary surveillance radar band (1215 – 1400 MHz) is shared by amateur stations on a secondary basis. Amateur operations take place in a number of modes, most of which use narrowband emissions which are unlikely to affect the operation of radar stations. There are however, a number of amateur television stations operating at these frequencies with bandwidths up to 36 MHz, which is similar to the bandwidth used by radar systems and hence have the potential to cause large amounts of interference.

The amateur television transmitters are often located on top of large hills or masts and as such have a large range. It is easy, therefore, for stray transmissions to be received by nearby radar installations.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Problematic
Area affected	Regionalised
Duration	Medium
TOTAL SCORE:	8

The problem has been reported in the UK and in France. Given the relative bandwidths of the two systems, it is unlikely that more than one channel would be affected at any one time, however there is only usually one channel in use from each radar site.

Resolution

As the amateur service has only a secondary allocation at these frequencies, it must not cause interference to primary users. In addition, amateur licensees must transmit their callsign at regular intervals, hence identification of the offending station is simple (assuming that a suitable television receiver is available).

Two ways to solve the problem exist. The first is to force the amateur station to stop transmitting. This should be done in the first instance any way to ensure that no further problems occur. The second is to get the amateur station to change frequency. This should be relatively simple for the station as equipment is usually home made and the operator will understand how to make such a change simply and quickly and will generally be willing to help solve the problem.

7.10

Other types of interference

7.10.1 Introduction

This section contains details of those interference incidents either for systems which have only had one interferer or that have been identified as part of this study but for which insufficient information is available to perform a more detailed analysis. They are included in the report for completeness.

As the information available on these incidents is sometimes limited, it has not always been possible to use the categorisation scheme to develop a score for all interference problems.

7.10.2 DME interfering with TACAN systems

Description

Problems have been known to occur between Tactical Aircraft Control and Navigation Systems (TACAN) and DME systems such that is has become impossible to install a DME in a TACAN area as it would cause interference. This presents a problem as the navigation information provided by TACANs must be augmented by that of DMEs to be precise.

Mechanism

Direct radiation: The DME and TACAN systems both operate in the same frequency band. In areas with a high density of air traffic, it sometimes becomes impossible to select frequencies for TACAN and DME within the agreed planning parameters. In particular, the frequency separation between the two systems becomes smaller than is nominally acceptable. In these instances, the two systems operate on frequencies which are too close and interference is caused.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Problematic
Area affected	Localised
Duration	Long
TOTAL SCORE:	8

The problem has been reported in Belgium and France.

Resolution

The solution adopted by the countries concerned consists of not installing both systems in the same area. The consequence of this incompatibility is that Belgium and France cannot provide navigation aid to other countries as their TACAN information is not sufficiently accurate.

Another potential solution would be to make sure that the national radio agencies do not allocate frequencies too close for the DME and TACAN systems to operate, in order to avoid the interference between them.

7.10.3 JTIDS interfering on DME bands

Description

Joint Tactical Information Distribution System (JTIDS) is a decentralised position location and navigation system wherein each user independently determines its position, velocity and altitude from data received from other users. JTIDS system is of military use principally in USA and throughout NATO. It appears that this inter-operable system throughout all army forces in the world causes interference problems to the civil DME system.

Mechanism

Direct radiation: This system operates in the 960-1215 MHz band and therefore shares spectrum with DME, creating interference on the civil navigation system.

Categorisation

Criterion	Rating
Number of reports	Few
Frequency of reports	Rare
Severity	Noticeable
Area affected	Localised
Duration	Short
TOTAL SCORE:	5

Being a fast hoping frequency system, JTIDS transmits only during a short of time. Therefore, its effect on the DME system is not considered severe for the moment.

Currently, the JTIDS system is not widely used, hence only a small number of incidents have been noticed. However, it is planned that all the NATO aircraft will be equipped with that system in the few next years therefore the potential of this type of interference to increase is large.

Resolution

The JTIDS interference issue is handled in a civil and military forum within NATO Committee for European Airspace Coordination (CEAC). It is necessary that civil and military authorities agree on a minimum distance between areas where the two systems are operational in order to avoid any interference problem.

7.10.4 Satellite phones interfering with MLS

It has been reported by EUROCAE that the new satellite telephony provider Iridium may cause interference on MLS. No more details have been identified during the course of this study.

7.10.5 High powered HF transmissions

International broadcasters such as Radio France International, Deutsche Welle and BBC World Service operate a number of high powered HF transmitter sites. The radiated power from these sites can easily reach 50 MegaWatts. The field strength produced by such high powered transmissions is very large and can induce current into any piece of wire that is unshielded. Aircraft flying in front of antennas radiating these power levels have been known to suffer systems failures due to the voltages induced onto control cables. This is the only known instance of interference due to **induction**, and to avoid it, ‘no-fly-zones’ are usually established around high powered transmitter sites.

7.10.6 Interference to GNSS from ATC radars

Problems in reception of the GNSS signal have been noticed in Germany due to medium range air traffic control radars operating in the 1250-1259 MHz band. As the radars’ carrier frequency is adjacent to the L2 frequency of GNSS, interference occurs easily. No further information has been given on this type of interference. However, as 12 radars of this type are implemented in Germany, the problem is considered as very localised and minor.

8 Summary of interference sources

8.1 Summary of scores

Table 8-1 below summarises the scores obtained for each interference source identified as produce by applying the categorisation scheme of section 7.

System	Interferer	Score
Non-directional beacon	High powered short wave transmitter	7
	Low frequency broadcast transmitter	11
VHF air ground communications	Cable television	11
	Illegal transmitters	12
	Band II FM transmitters	12
	Broadcast receivers	9
	ISM harmonics	13
	Intermodulation products between transmitters	9
	Personal Electronic Devices	9
	Stuck VHF aeronautical transmitters	11
	Use outside intended coverage area	N/A
VOR and ILS	Band II FM transmitters	12
	Vehicles / Large metal objects	7
	Personal Electronic Devices	10
GNSS	Intentional jammers	7
	Commercial satellite phones	N/A
	High powered television transmitters	7
	Amateur relay stations	8
	ATC radars	N/A
HF voice communications	Illegal transmitters	8
	Solar flares	9
Radar systems	Satellite ground stations	N/A
	Amateur television transmitters	8
Distance Measuring Equipment	TACAN	8
	JTIDS	5
Microwave Landing System	Commercial satellite phones	N/A
All aeronautical systems	High powered short wave transmitter	N/A

Table 0-1: Summary of interference categorisation scores

Table 8-1 aids in the classification and prioritisation of actions to be taken against the interference sources identified by this study. It is not within the scope of this study to suggest solutions to these problems however the table does offer an indication of which problems should be tackled first.

8.2 Interference classified by country

Certain countries keep records of occurrences of interference whereas others do not. It is likely that reports from those countries that do keep records will be more prevalent than reports from countries who do not. This should be borne in mind when interpreting the data given in table 8-2. The following countries keep records of interference incidents:

- the Netherlands;
- Austria;
- Ireland;
- Greece;
- Macedonia;
- Turkey;
- Portugal;
- France;
- the United Kingdom.

Table 8-3 at the end of this section, shows which of the interference sources described in section 7 were reported by the various countries administrations with whom we spoke. Note that interferers for which little or no information is available are not included in this table. It is possible that interference of the types identified is occurring in other countries but that the expertise to assess and identify such interference problems is not available. It should not therefore be taken to mean that if a cross does not appear next to a country that that country is not experiencing that particular interference problem, rather that it has not been identified.

Where interference reports are said to be from an 'other source' this indicates that the particular source of interference has been reported by another organisation or has been related in reports, articles or other documentation that has been examined as part of the study.

8.3 Analysis and validity of interference categorisation results

The application of the basic interference categorisation scheme has produced the results detailed in table 8-1. The scores that could have been produced ranged from 5 (the least severe) to 15 (the most severe) but the actual scores ranged from 5 to 13. Those interference sources that scored 12 or more were:

- Illegal transmitters (VHF comms) 12
- Band II FM transmitters (VHF comms) 12
- ISM harmonics (VHF comms) 13
- Band II FM transmitters (VOR/ILS) 12

Those interference sources which scored 7 or less were:

- High powered short wave transmitter (NDB) 7
- Use outside intended coverage area (VHF comms) 7
- Vehicles/Metal objects (VOR/ILS) 7
- Intentional jammers (GNSS) 7
- High powered television transmitters (GNSS) 7
- JTIDS (DME) 5

In general, this split is fair. Those interference sources that have scored highly are the most persistent. Those interference sources that have a low score are the least troublesome. Note that interference to GNSS is not currently of significant concern to Eurocontrol, but is likely to become so as the use of GNSS becomes the norm for aeronautical navigation.

These results do not, however, necessarily suggest which of the interference sources should be addressed by Eurocontrol. This is because there are a number of other factors which have not been included in the categorisation scheme that relate to the need for further investigation; issues such as:

- what effort has already been expended in resolving the interference problems;
- to what degree can Eurocontrol actually affect the interference;
- are the interference sources likely to become greater problems in the future;
- are the problems interference related (certainly use outside the intended coverage area is not an interference issue).

For example, the interference caused by high powered television transmitters to GNSS has a low score as it is relatively infrequent in Europe. With the increased number of transmitters and the move to digital transmission, this is likely to change, hence further investigation is warranted. Conversely, the interference caused by FM transmitters is well understood and documented and mechanisms have been developed to try and minimise the effects – hence further study is unlikely to produce additional reductions in the levels of interference caused.

Despite the drawbacks highlighted above, the categorisation scheme has been able to determine which of the interference sources identified cause the greatest problem and which cause the smallest. To some extent, it has allowed comparisons to be made to interference sources affecting different systems, although it should be emphasised that as the scheme is based on the perceptions of those who reported the interference, the results will also be coloured by the priority they attach to the system affected.

8.4 Description of interference sources and characteristics

8.4.1 Introduction

This section provides a brief description of each of the interference sources identified as part of the study. Where known, it also gives brief technical characteristics such as bandwidth and transmitter powers. Where an interference source affects more than one system (such as for Personal Electronic Devices), its description has only been included once. Additionally, the following ‘interference sources’ have not been described as they are not physical sources of interference:

- use outside of intended coverage area;
- vehicles/large metal objects;
- solar flares.

Descriptions of these items can be found in the description of the interference mechanisms in section 7.

8.4.2 High powered short wave transmitter

Short wave broadcasting is still used by most (if not all) European countries as well as countries outside Europe as a means to reach listeners overseas. To do this, high powered transmitters are used, typically operating into high gain directional antennas. Transmitter powers are typically 100 to 500 kiloWatts with the effective radiated power being 0.5 to 50 MegaWatts. The bandwidth of the transmissions is usually 10 kHz. The frequencies on which these transmitters operate are split into a number of bands. These bands, identified by their wavelength in metres, are detailed in the table overleaf:

Band	Frequency allocation (kHz)
75 metre	3950 – 4000

49 metre	5950 – 6200
41 metre	7100 – 7300
25 metre	9500 – 9900
19 metre	11650 – 12050
17 metre	13600 – 13800
15 metre	15100 – 15600
13 metre	17550 – 17900
12 metre	21450 – 21850
11 metre	25670 – 26100

8.4.3 Low frequency broadcast transmitter

Low frequency (LF) or long wave broadcasting is utilised by countries across Europe (including the Former Soviet Union, Russia and Mongolia) for national broadcasting. A single high powered long wave transmitter is capable of covering a large area to provide a national radio service. Occasionally, several high powered transmitters are operated on the same frequency with the same service to extend coverage yet further.

Transmitter powers are typically 50 to 2000 kiloWatts with effective radiated powers being similar. Bandwidths are typically 10 kHz and frequencies of operation are 148.5 to 283.5 kHz.

8.4.4 Cable television

Much of the distribution of television signals to houses in the Benelux countries, Ireland and Germany has traditionally been via cables laid beneath street level. Cable systems are also becoming more popular in many other parts of Europe as the demand for multi-channel television increases.

Television programmes are received in a single location (known as the cable head-end) and distributed to homes in a city by a number of different methods. For each method, however, the drop between the main cable infrastructure and the house is via coaxial cable. This cable carries television signals in standard format and interference is caused when these signals lie within the frequencies used for aeronautical systems and the cables are old or connections are poor and the signal is allowed to leak out of the cable.

Television transmissions occupy a bandwidth of between 7 and 8 MHz depending on the format. As far as cable networks are concerned the signals are typically distributed on frequencies between 47 and 750 MHz. Cable systems are nominally closed, hence power should not leak, but where poor or ageing infrastructure allows signal to leak out the power is likely to be less than 1 milliWatt.

8.4.5 Illegal transmitters

This category encompasses a large number of potential systems. As such it is difficult to describe the exact technical characteristics of the interferer. Illegal transmitters could come from a number of different systems, but the most likely are ‘pirate radio’ systems, private mobile radio systems and through the misuse of aeronautical radio systems (both HF and VHF) themselves. The table below represents typical characteristics for these systems.

System	Frequency of operation (MHz)	Bandwidth	Transmitter power
‘Pirate’ radio	88 – 108 (for transmitters) 47 – 1000 (for programme feeds)	180 – 256 kHz 180 – 256 kHz	10 to 1000 Watts Typically 1 Watt
Private mobile radio	68 – 470	12.5 – 25 kHz	Typically 25 Watts
HF aeronautical systems	2 – 30	3 kHz	Typically 100 Watts
VHF aeronautical systems	118 – 137	8 kHz	1 to 25 Watts

8.4.6 Band II FM transmitters

Broadcasting in Band II (87.5 – 108 MHz) has been established for over 30 years, yet the number of transmitters is still increasing. This is especially the case in Eastern Europe where systems previously operated in a different band at 68 – 74 MHz, known as the OIRT band. In order to bring the frequency allocations in these countries in line with services in Western Europe, most stations are transferring from the OIRT band to Band II.

Transmitters in this band either operate in mono or stereo. Mono transmissions have a bandwidth of 180 kHz whilst stereo transmissions have a bandwidth of 256 kHz. Transmitter powers vary from a few watts up to around 100 kiloWatts, with effective radiated powers going up to 500 kiloWatts.

8.4.7 Broadcast receivers

Receivers for Band II FM transmissions come in many shapes and sizes from ‘Walkman’ style portable units through to home hi-fi systems. In terms of their interference potential, they are much the same. It is the local oscillator in the receiver that leaks through the receiver to the antenna which causes the problems. These oscillators either operate 10.7 MHz below or above the wanted frequency. The possible range of frequencies is therefore 76.8 to 118.7 MHz.

The oscillators are usually relatively stable and are not modulated, hence transmitted bandwidths are small (certainly less than 100 Hz). It is difficult to determine transmitter powers but it is likely that they range from a few nanoWatts up to around 1 milliWatt.

8.4.8 ISM harmonics

ISM sources include:

- *Surgical heat treatment:* These machines are used to carry out heat treatment on patients limbs. They typically operate at 27.12 MHz and may be pulsed or continuous

- *Surgical diathermy:* These machines operate in the vicinity of 27 MHz and are used for cleaning and sterilising surgical instruments

- *Industrial drying and cooking:* Machines operating at about 27 MHz are used in, for example, the nylon industry for drying, the biscuit industry for removing moisture from biscuits after they have been baked, and the furniture industry for curing resins.

- *Scientific use:* RF etching and deposition machines operate around 13.5 MHz and are operated by many universities and companies in the semiconductor industry. Of particular concern is that equipment operated in universities tends to be old and is often modified or customised to perform a specific function or experiment. The result is that RF shielding is often poor.

Ideally an ISM source should have sufficient shielding such that it does not radiate any power outside its immediate environment. However, most practical designs cannot be perfectly shielded, and the high powers used in some ISM processes mean that even a small shielding inefficiency can result in the radiation of strong unwanted signals.

The bandwidth of ISM emissions can vary depending upon the stability of the source, however typically they are of order 100 Hz to 100 kHz. Transmitter powers are actually high (up to several MW in some industrial heating applications), however the harmonic radiation which causes the problems for aeronautical communications is typically a few milliWatts.

8.4.9 Intermodulation products

Intermodulation products caused in a receiver that is being overloaded are not physical signals hence their characteristics can not be described. Those caused at transmitter sites are simpler to detail although, as they are caused by combinations between more than one signal, the characteristics can vary significantly. Typically an intermodulation product occupies two or three times the bandwidth of the signal that is causing it, hence for a private mobile radio system this could be as little as 25 kHz, whereas for FM transmitters this could be 768 kHz. For intermodulation products caused between television transmissions, it is possible that the resultant signal could be 24 MHz or more in bandwidth.

Transmitter powers are equally difficult to determine but a good guide would be a few microWatts to a few milliWatts. The frequency of the resultant product could be anywhere but is typically near the frequency of the transmitters that are interacting to cause the problem. Figure 7-1 gives an example of the type of resultants that occur.

8.4.10 Personal Electronic Devices

Personal Electronic Devices (PED) are those items of electronic equipment that are likely to be taken onto an aircraft by a passenger. In particular, any such item that is likely to cause interference to the aircraft's systems. Typical items include:

– portable computers (laptops);

– compact disc players;

– personal stereos and radios;

– mobile phones.

Each of these has characteristics all of their own, however, in terms of their potential to cause interference the key is that they radiate radio waves at the frequencies that are used by aeronautical systems. The transmitted power is usually very small (or order a few microWatts), however they are in extremely close proximity to the aircraft systems.

8.4.11 Stuck VHF R/T transmitters

In the context of this study, stuck transmitters refers to the problems that occur when an aeronautical transmitter is keeps transmitting when it should have ceased. As such the characteristics are simple to determine. The bandwidth of emissions is around 8 kHz and the transmitter power between around 10 and 100 Watts. Frequencies of operation are 118 to 137 MHz.

8.4.12 Intentional GNSS jammers

As GNSS is used by the military for determining position, it is open to attack from electronic counter measures (ECM). A simple ECM technique that can be used against any radio system is that of 'jamming' the receiver. This consist of transmitting a radio signal on the same frequency as the wanted signal but with sufficient strength to overcome the wanted signal.

GNSS signals are relatively weak and hence a low powered transmitter mounted in a high location (the fact that GNSS is a satellite system requires that the receive antennas are better vertically than along a horizontal plane) will be sufficient to knock out GNSS reception over a relatively wide area. The exact power of the jammers is not known but a 10 Watt transmitter would probably be sufficient to cause problems. So far as the bandwidth of the transmission goes, it would be better for the jammer to cover a significant proportion of the 1559 – 1610 MHz frequency band.

8.4.13 Commercial satellite phones

A commercial satellite phone service has been available for many years, in the form of the Inmarsat service. The concept is simple – radio signals from a number of satellites provide coverage of the whole globe, hence a satellite based phone system allows communication from anywhere in the world (assuming that there is a line of sight to the appropriate satellite).

A number of new operators (such as Iridium, Globalstar and ICO) have recently announced plans to commission their own satellite based phone services and these will provide phone communications to small, easily portable handsets (as opposed to the suitcase style equipment required for use with Inmarsat). In order to reach these smaller handsets, the signal produced on the ground from the satellites is significantly stronger than for existing services.

Operator	Uplink frequency (MHz)	Downlink frequency (MHz)
Iridium	1610 – 1626.5	2483.5 – 2500
Globalstar	1610 – 1626.5	2483.5 – 2500
ICO	1980 – 2010	2170 – 2200

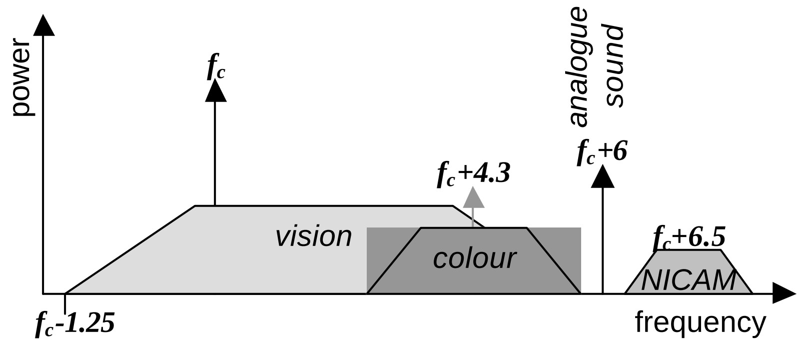
The table above details the frequencies intended to be used by some of the satellite phone operators. As these frequencies are a similar frequency band to aeronautical services, there is a potential for interference to be caused. In addition spectrum at 2500 – 2520 and 2760 – 2790 MHz is allocated to mobile satellite services for use after the year 2005.

8.4.14 High powered television transmitters

High powered television transmitters are used by most countries to provide terrestrial television signals to wide areas. Transmitter powers can be up to 100 kiloWatts, although high gain antennas are used making effective radiated powers up to 1 MegaWatt or more in some cases. Television operates (in Europe) in four distinct frequency bands which are shown in the table below.

Television band	Frequency range (MHz)
Band I	47 – 68
Band III	174 – 230
Band IV	470 – 614
Band V	614 – 862

The bandwidth of signals varies but is normally either 7 or 8 MHz. Amplitude modulation is used with one of the sidebands produced by this modulation scheme mostly filtered out. This gives rise to the term ‘Vestigial Side Band’ or VSB. The figure below illustrates the spectral content of a typical television transmission with f_c being the nominal carrier frequency.



8.4.15 Amateur relay stations

Many amateur radio operators operate from their home or mobile in their car. As such, the coverage achievable for an individual operator can be severely limited if they are in an unfavourable location for radio propagation. In order to increase the range of a station, relay stations are used.

Relay stations receive incoming signals on one frequency and relay them on another. They are usually on the top of hills, tall masts or tall buildings so that they have the maximum possible range. Both digital and analogue transmission is used with bandwidths ranging from 12.5 kHz for some analogue relays to up to 1.2 MHz for high speed digital relays. Television relays also operate using Frequency Modulation (FM) with bandwidths of around 30 MHz.

Transmitter powers are usually around 10 to 25 Watts. Amateur bands in which amateur relay stations operate are shown in the table below. It should be noted that not every country allows amateurs to use these frequency bands and of those that do, not all countries allow relay operation in these bands.

Frequency band	**Frequency range MHz**
10 metres	28 – 29.7
6 metres	50 – 52
2 metres	144 – 146
70 centimetres	433 – 440
23 centimetres	1240 – 1300
3 centimetres	10000 – 10500

8.4.16 Satellite ground stations

Broadcast and telecommunication satellites are effectively relays in much the same sense as the amateur relays described previously. They receive signals on one frequency and relay them on another. The feeds to satellites are known as uplinks and require high power, ground based transmitters. High powers are required as, to minimise size, small receive antennas are used on the satellites hence their sensitivity is poor.

Transmitter powers are typically 1 kiloWatt, however antenna gains are very large and effective radiated powers can be 50 MegaWatts or more. The majority of the power generated by a ground stations is directed at the satellite, however radiation patterns from dish antennas include a number of other lobes, each of which could contain significant amounts of radiated power. It is these lobes that are likely to cause problems to other systems operating nearby. Bandwidths (for television links) are typically 27 – 36 MHz and use frequency modulation.

In Europe, for most broadcast satellites, the uplinks are on frequencies between 12.5 and 13.25 GHz. Other frequencies (such as 14.4 – 14.8 and 17.3 to 17.7 GHz) are much less frequently used.

8.4.17 JTIDS

The Joint Tactical Information Distribution System JTIDS provides jam-resistant digital communications of data and voice form command, control, navigation, relative positioning and identification. JTIDS, used by US and NATO forces, is a Time-Division Multiple-Access (TDMA) digital communication system operating in the 960-1215 MHz band. It operates over line-of-sight ranges up to 500 miles with automatic relay extension beyond.

The primary function of JTIDS is to distribute tactical information in digital form. JTIDS technology also located and identifies subscribers with respect to other users. Data rates are between 28,800 and 238,000 bits per second.

Transmission powers are between 200 and 1,000 Watts. The bandwidth of transmissions is approximately 3 MHz.

8.4.18 Amateur television transmitters

Amateur radio operators are licensed to transmit television pictures in addition to voice and data. Television relay stations can also be licensed in some countries. Some television transmission in the 70 centimetre band (430 – 440 MHz) takes place using Vestigial Side Band Amplitude Modulation, however this is being phased out in favour of Frequency Modulated transmissions at higher frequencies. The most popular bands for FM television are 1240 – 1300 MHz, 2300 – 2450 MHz and 10000 – 10500 MHz.

Bandwidths are typically 30 MHz and transmitter powers between 100 milliWatts and 100 Watts. High gain antennas can be used to make the effective radiated power in excess of 5 kiloWatts (where licensing permits the use of such powers).

8.5 Summary of interferers

Table 8-2 overleaf summarises the key technical characteristics of the various interference sources described in this section.

Interferer	Frequency range	Bandwidth	Transmitter power
High powered short wave transmitter	3.95 – 26.1 MHz	10 kHz	100 – 50,000 kW
Low frequency broadcast transmitter	148.5 – 283.5 kHz	10 kHz	50 – 2,000 KW
Cable television	47 – 750 MHz	7 – 8 MHz	<1 mW
Illegal transmitters	2 – 1000 MHz	3 – 256 kHz	1 – 1000 W
Band II FM transmitters	87.5 – 108 MHz	180 or 256 kHz	1 – 500,000 W
Broadcast receivers	76.8 – 118.7 MHz	<100 Hz	<1 mW
ISM harmonics	Various including 108 – 137 MHz	100 Hz – 100 kHz	1 mW
Intermodulation products (direct radiation only)	Any	25 kHz – 24 MHz	<1 mW
Personal Electronic Devices	Typically 0 – 1000 MHz	Unknown	1 – 10 µW
Stuck transmitters	118 – 137 MHz	8 kHz	10 – 100 Watts
Intentional GNSS jammers	1559 – 1610 MHz	Unknown	Unknown
Commercial satellite phones	1610 – 2500 MHz	Unknown	1 Watt
High powered television transmitters	47 – 862 MHz	7 – 8 MHz	up to 100 kW
Amateur relay stations	28 – 10500 MHz	12.5 kHz – 30 MHz	10 – 25 W
Satellite ground stations	12.5 – 17.7 GHz	27 – 36 MHz	up to 1 kW
JTIDS	969 – 1206 MHz	3 MHz	200 to 1,000 Watts
Amateur television transmitters	1240 – 10500 MHz	30 MHz	100 mW – 100 W

Table 0-2: Summary of interference sources

System	Interferer	Germany	Netherlands	Belguim	Norway	Switzerland	Austria	Ireland	Greece	Sweden	Macedonia	Denmark	Turkey	Portugal	France	United Kingdor	Other source
Non-directional beacon	High powered SW transmitter															X	
	LF broadcast transmitter																X
VHF air-ground comms	Cable television	X		X													
	Illegal transmitters		X			X									X	X	
	Band II FM transmitters			X	X		X		X	X	X		X				
	Broadcast receivers						X									X	
	ISM harmonics		X									X			X	X	
	Intermodulation products						X									X	
	Personal Electronic Devices																X
	Stuck transmitters					X											X
	Use outside coverage area		X			X	X	X				X					
VOR and ILS	Band II FM transmitters						X		X		X	X	X				
	Vehicles / Large metal objects					X						X					
	Personal Electronic Devices																X
GPS	Intentional jammers						X										
	Commercial satellite phones																X
	High powered TV transmitters																X
	Amateur relay stations	X	X														
	ATC radars																X
HF voice comms	Illegal transmitters													X	X	X	
	Solar flares													X			
Radar systems	Satellite ground stations																
	Amateur TV transmitters														X	X	
Distance Measuring Equipment	TACAN			X											X		
	JTIDS																X
Microwave Landing System	Commercial satellite phones																X
All systems	High powered SW transmitter																X

Table 8-2: Summary of interference sources by country

9 Conclusions and way forward

9.1 Introduction

There are two main elements to the elimination of interference problems in air transport:

– the identification of the source of interference;

– the development of a solution to solve the interference problem.

This section looks at both of these issues and identifies how Eurocontrol could best apply its resources to assist in the elimination of air transport-related interference problems across Europe.

9.1.1 Determination of interference source

Not all sources of interference are identified. As an example, in France of the 460 cases of interference reported in 1996, it is estimated that the sources of up to 70% were not identified. The position is similar in the UK, although the percentage of interference sources unidentified in the UK is estimated to be less than 50%. Of persistent problems (ie those which become a significant nuisance), the UK Radiocommunications Agency estimates that up to 95% are identified and resolved.

The large number of interference problems that go unidentified have led some aeronautical organisations to instigate systems to try and improve the rate of success in identifying sources. Such systems include:

– aircraft with on-board receivers and direction finding equipment (operated or being planned by STNA, France and NATS, UK);

– a network of monitoring stations at strategic locations (implemented in France, Switzerland and Austria).

Even with such systems in place, however, the proportion of interference complaints for which the source is not identified remains high. Many of these reports are one-offs and the interference complaint is never repeated. In these instances, it is questionable whether expending resource to identify the source would be cost-beneficial. Where additional resource could prove useful is in the identification and resolution of persistent interference problems and it is these that are concentrated on further in this section.

9.1.2 Resolution of problems

Many of the interference sources discovered as a result of the study have existed for many years and have had significant resource applied to them in an attempt to identify a solution. Problems such as those caused by VHF FM broadcast stations are well known and well understood but continue to cause problems, whilst others such as interference to radar from amateur television transmitters, once identified, have been resolved quickly and permanently.

What makes the persistent, long term problems so difficult to resolve are the numbers of potential interference sources. For instance there are significantly more ISM sources and VHF FM transmitters than there are amateur television transmitters, and the number of ISM/FM sources is still increasing.

It is also worth noting that the systems causing the interference may be operating quite legally, ie within the appropriate regulatory standards. As such, the resolution of these problems can only come from either a tightening of the regulations or a change of specification for the aeronautical system affected, both of which are likely to result in significant cost increases for end users.

An example of such a resolution at European level is the joint action between Eurocontrol and IATA to publicise to airlines the importance of equipping airborne radios with anti-blocking devices. Most airlines agreed to plan their 8.33 kHz retrofit with radios including this device. As a consequence, it is expected that most of the 8.33 kHz retrofitted fleet will be protected against this kind of transmission problem.

An additional difficulty is that of negotiating with operators of equipment that is interfering with aeronautical systems but is operating legally as no radio protection requirements between aeronautical and non-aeronautical systems exist. As such protection measures need to be applied world-wide, they will have to be defined at an international level.

It is unlikely that a European or International body could provide additional assistance in identifying or resolving those interference problems that are identified and resolved quickly by national administrations. For these sources, the systems already in place are working. It is possible, however, that identifying what it is about these systems that make them so effective and making this information available to a wider audience would increase the incidences of interference being identified.

The level of resource available to identify or resolve interference problems varies from country to country, dependent upon:

- the budget, equipment and staff resource available;
- the spectrum available (in countries with low radio or air traffic there is a tendency to plan a new frequency instead of trying to identify interferers).

The whole civil aviation community would benefit were the identification and resolution of interference difficulties harmonised taking into account the level of air and radio traffic and the number of installations.

Where there is significant benefit to be gained from a European or International body becoming involved is in assistance with the changes to equipment (aeronautical or otherwise) that would need to be made to resolve longer standing interference problems.

9.2 Co-ordination activities related to interference problems

9.2.1 Introduction

A large proportion of interference sources are not identified. This can be for a number of reasons:

- insufficient information is given in the report (from the pilot/air traffic controller) to enable identification to take place;
- a search is begun but the interference source can not be found (ie it does not reappear);
- the interference source is found but its nature can not be determined (ie the type of source can not be established);
- the interference source and its nature can be found but the exact location of the source can not be established.

For each of these problems, a different solution presents itself. These solutions are highlighted in detail in the remainder of this section.

9.2.2 Insufficient detail in the report

When an interference source has been regarded as sufficiently severe for action to be taken against it, the information contained in the reports relating to that interference source will be collated to give an indication of where to begin looking for the source. A good report will contain:

- the system that was affected by the interference;
- the settings of the system when the interference occurred (eg the frequency or channel tuned to);
- the location of the aircraft when the interference occurred;
- meteorological conditions;
- the effect of the interference on the affected system (including the ‘sound’ of the interference if heard in headphones).

The lack of any one of these elements, in particular the first three, leads to a situation where those conducting the investigation have nowhere to begin looking.

Reports generally come from pilots or air traffic controllers. Not being experts in radio interference problems, many of these reports often omit key information that would assist bodies in identifying interference problems. By providing additional education to them as to the benefits of accurately reporting interference sources (through training or even by having a simple-to-complete form available), cases of this type should be reduced.

9.2.3 The interference source can not be found

In many instances, an interference source, despite being accurately reported, may not be able to be identified. There are a number of reasons why this could occur:

– the source was sporadic and did not reoccur during the search;

– the source is no longer active;

– the source only affected the particular type of equipment being used when the interference was reported (this is common in cases of third order problems);

– the source can not be received by the detection equipment (this is especially the case where interference is reported from the air, and ground based equipment is used for a search);

– the range of the interference source is very limited (hence unless the detector is in *exactly* the same location as the reporter, the source can not be found).

In the first two instances, the only solution is to have the detection equipment ready to take measurements at the same time that the interference is reported. If this is tied in with the latter two instances, there is a very small likelihood that the source will be located at all.

Some organisations rely on fixed ground based detection equipment for interference detection. Such equipment is only of use where the interference source has a sufficient ground range to reach the detection equipment and this is rarely the case. Mobile ground based detection equipment is used by some organisations and this offers some advantages.

Airborne detection equipment is by far the most preferable but this is costly and few aeronautical bodies could afford to have such equipment available. It is possible that some form of portable equipment could be used and taken onto an aircraft when required (or used as a ground based mobile). This is not ideal but may help poorer organisations. Co-ordination at an international level should assist in a number of ways:

– by determining the optimum solution for ground based detection equipment;

– by providing guidance on the instigation of detection systems;

– by identifying and recommending suitable detection equipment;

– with funding of the purchase of detection equipment;

– by providing a forum for countries with existing systems or who are planning systems to discuss their approaches.

9.2.4 The nature of the source can not be identified

If the source can be detected but the nature of the source can not be identified (for example, it can be heard on a radio but it is not evident what the source is) it can prove difficult to take any action against the source. Obviously, if the location of the source can be accurately pinpointed then this is less of a problem, but unless portable direction finding equipment is used, the likelihood of the interference being traced to a particular building or even area is small. In these instances, it would be useful to be able to compare the characteristics of the interference with other, previously identified sources.

Interference from similar types of source usually have similar characteristics. By determining which characteristics to measure and by having a database of previously identified sources available, there would be a much greater chance of the type of interference source being identified. By identifying the type of source, the search for the actual location of the source is narrowed. For example, if the source was identified as being from a surgical diathermy ISM source, one would immediately know to look towards hospitals and clinics for the offending interferer.

At the moment, most of the knowledge concerning the characteristics of the various kinds of interference is held by a very small number of experts, who are either part of the aeronautical body or the national administrations. These individuals have built up experience of a large number of interference sources and are often able to identify a new interferer quickly. Making their knowledge available to the wider audience and combining the knowledge of several such persons would enable many more interference sources to be identified. Co-ordination at an international level should assist by:

– identifying which characteristics are key in determining the source of interferers;

– developing a working group of the experienced individuals to allow their ideas to be combined;

– preparing, administering and disseminating a database of the characteristics of interference sources.

9.2.5 The exact location of the source can not be identified

Even though the nature of the source may be known, it may still not be possible to pinpoint the exact location of the source. If, for example, the source has been identified as a cable television network, unless the exact location of the source can be identified, thereby pinpointing a single cable network, no resolution of the problem is possible.

In many instances it is the *exact* location which is critical. As an example, ISM sources will be located in areas with a high density of industry (such as an industrial park). In these areas there may be any number of ISM sources, only one of which is causing the actual problem. The same could apply for FM broadcast station, however it is more likely that any interference caused by an FM station would contain the modulation of the station, hence identification becomes simpler. There are other sources where the exact location is essential including:

– illegal transmitters;

– cable systems (the leak from the system causing the problem may be at a single junction);

– intentional jammers.

Fixed monitoring equipment would not provide sufficient positional accuracy to allow sources such as these to be identified (and hence resolved). A mobile or portable system offers the greatest benefit in these instances and may comprise one of the following:

– A hand-held detection unit with direction finding capabilities. This is the lowest cost option as a simple directional antenna connected to a receiver could be used;

– A vehicle mounted with automatic or manual direction finding equipment;

– A series of linked vehicles with automatic direction finding equipment;

– An aircraft with automatic direction finding equipment.

Each of these systems is used in one or more countries, and it should be possible, within an international forum, to identify and evaluate the performance of each. From the results of such a study, an international organisation could make specifications available to those countries interested in developing their interference identification network.

9.3 Resolution of interference problems

9.3.1 Introduction

Despite being identified and located, there remain a significant number of interference sources that cause problems to aeronautical systems time and time again. Sources such as:

– Industrial, Scientific and Medical (ISM) sources;

– VHF FM broadcast transmitters; and

– illegal transmitters.

continue to cause problems despite their nature as an interferer having been identified, studied and documented. There are obviously a larger number of these sources and hence a larger potential for interference from them than for certain other sources, but there are other reasons why they continue to cause problems. These reasons include:

– interference can still be caused by the sources whilst operating within their specification;

– modifications to equipment required to mitigate the effects are costly to implement;

– whether or not a particular incidence of their occurrence will cause interference is unpredictable.

Much effort has already been expended by aeronautical bodies around the world in minimising interference from in these instances, however there remain a number of areas where international co-ordination could assist in ensuring that potential future interference problems are minimised before they occur.

9.3.2 Well documented problems

Many of the interference problems identified in this study have existed for a number of years and are well understood and documented. Much effort has been expended by aeronautical bodies in minimising interference from these sources. The number of interference problems caused by broadcast FM transmitters are an example of where the aeronautical community as a whole has banded together to produce operating procedures, equipment specifications and other solutions.

These problems still, however, persist. This is due to a number of factors, and given the level of effort that has already been expended by the aeronautical community in finding solutions to these problems, it is unlikely that further effort co-ordinated at an international level would make a significant impact on further reducing these problems.

There are a number of problems, that whilst documented and understood, still persist. These have not yet been fully addressed by the aeronautical community. This is mainly due to the localised nature of the problem. Where interference problems have occurred only in a limited area (or a limited number of countries), less effort has been spent in identifying solutions. An example of this type of interference is that from ISM equipment. This type of interference is well understood and documented, yet little action has been taken by the aeronautical community as a whole to combat the problem. As this seems to occur more readily in Europe than elsewhere, it is an obvious contender for co-ordinated action at a European level.

Interference sources which come into the category of ‘understood but require further action’ include:

– ISM equipment;

– Cable television systems;

- Amateur radio systems (operating around 1240 MHz).

International groups could be set up to investigate these problems further and identify what might be done to ameliorate their effects. Such action could include:

- tightening specifications of equipment (whether aeronautical, consumer or industrial) via the appropriate standardisation organisation;
- working with the affected community to revise frequency allocations;
- developing technical solutions or employing new technology to overcome the problems;
- producing procedures for the installation, commissioning and operation of equipment, highlighting methods for minimising interference.

9.3.3 Future problems

In addition to those problems that have existed for a length of time, there are other, new problems which are just being identified. These interference problems are the ones which offer the most potential for the involvement of international co-ordinators as, making moves to minimise the effects at an early stage has a greater chance of producing benefit.

Interference sources that have been identified as part of this study that would benefit from further investigation include:

- Personal Electronic Devices;
- Commercial Satellite Phones;
- Television transmitters (especially digital transmitters);
- Satellite ground stations.

Each of these interference sources is known to have caused a problem or is expected to cause a problem (but with careful planning this has so far been avoided). In addition, each of the sources listed above belongs to an area of technology that is growing such that the potential for interference, whilst currently small, is likely to grow rapidly over the coming years.

Investigations into the above problems should start by identifying relevant specifications for the equipment and for the system that is likely to be affected. The detailed categorisation scheme found in Appendix D could be used to identify the element of the system that was most likely to cause interference and the results of this could then be used to determine an appropriate course of action. The investigation should aim to identify:

- the technical specification of the system causing interference;
- the technical specification of the system that will be caused interference;

- the mechanism or mechanisms that cause the interference to occur (this could be carried out on paper, or a series of laboratory or field tests could be used);
- the elements of the technical specification that should be changed in order to minimise interference;
- changes in operating parameters that could minimise interference (such as using different antenna patterns, transmitter powers or modulation schemes);
- any operational procedures that could be adopted to minimise interference;
- alternative frequency allocations for either the interferer or the aeronautical system (these may be already available or may require actual changes in the frequencies allocated).

By identifying such resolutions before interference occurs widely, any potential incidents or accidents could be avoided.

9.4 Summary of potential co-ordinated actions related to interference problems

This section has looked at the potential actions that international bodies such as Eurocontrol, ICAO and IATA working together with national civil aviation bodies could take in order to reduce interference problems occurring in Europe. Two main areas that should be addressed have been identified. These are:

- assistance in identifying interference problems;
- assistance in resolving interference problems.

Within each of these areas, there are a number of ways forward. There are three types of interference source and three associated activities. These are:

- **interference sources that are never identified:** the identification of these sources can be improved by better co-ordination of effort and resources and information distribution between states;
- **interference sources that are identified and resolved:** although resolution of these sources takes place satisfactorily at a national level, it is expected that improved co-ordination between states could reduce the resolution workload of each state and that action on a long term (such as ensuring that regulation and technical requirements for radio transmitters take full account of aeronautical requirements) will reduce the number of interference reports;
- **interference sources that are identified but not satisfactorily resolved:** Co-ordination between states will improve resolution. In the short term co-ordination of resource, information distribution, improvements in interference identification and resolution procedures would provide benefit. In the long term modifications to regulation and technical requirements for radio transmitters will provide further benefit.

The exact route to take will be determined by the effort available, however the key elements of future work are:

- producing briefing packs for pilots and air traffic controllers detailing the information required in interference reports to ensure that essential information is logged;
- determining the optimum specification and system design for ground based interference detection systems;
- providing guidance on the instigation of detection systems;
- producing recommendations as to the most suitable and appropriate interference detection equipment for use against aeronautical interferers;
- harmonising interference detection and resolution procedures, taking into account the level of air traffic and number of installations;
- providing a forum for countries with existing interference detection systems to discuss and refine their approach;
- identifying which characteristics of an interferer are key in determining the type or nature of the source;
- instigating a working group of knowledgeable individuals to allow ideas to be exchanged;
- producing and providing a database of the key characteristics of interference sources;
- perform a study to identify the most appropriate equipment to be used on various vehicles/mobile platforms;
- review and revise specifications of equipment that causes or suffers from interference;
- work with users affected or causing interference to identify revised frequency allocation plans;
- develop technical solutions to interference problems;
- produce procedures for minimising interference when installing, commissioning or maintaining equipment;
- instigate a number of studies to identify the most appropriate mechanism for minimising potential interference problems.

A Working groups

A.1 Introduction

This appendix presents information on working groups whose remit includes radio systems and particularly those related to aeronautical communications.

A.2 National working groups

Where an interference problem occurs frequently from a particular source, and when both the source of the interference and the system affected are in the same country, working groups consisting of representatives from the national administration, the aeronautical body and the organisation representing the users of the interfering system are instigated. The purpose of these working groups is to ascertain methods of resolving the problem. Such groups are then disbanded once a resolution has been reached. In some instances, the working group may only exist for a single meeting. As such, it is difficult to identify such national working groups.

The involvement of Eurocontrol in such groups could be pivotal in ensuring the optimum solution for the aeronautical body, especially if the body could be backed up by European policy or experiences. It is suggested, therefore, that Eurocontrol make it known to the national aeronautical bodies that such support is available. In this way, the decision as to the correct level of national and international involvement can be gauged by those parties involved in resolving the interference problem.

A.3 ITU study working groups

ITU working groups usually fall under the remit of the frequency management group (FMG). At present within the ITU, there are 8 study groups. These together with all relevant task groups working to those study groups are shown below.

- SG 1: Spectrum management:
  - Task Group 1/3 Modification of Recommendation ITU-R SM.329-6 on spurious emissions;
  - Working Party 1A Engineering principles and techniques, including computer-aided analysis for effective spectrum management;
  - Working Party 1B Principles and techniques for spectrum planning and sharing;
  - Working Party 1C Techniques for spectrum monitoring.
- SG 3: Radio propagation;
- SG 4: Fixed-satellite service;
- SG 7: Science services;

- Joint Working Party 7-8R Compatibility between active spaceborne sensors and systems in the radionavigation and radioloccation services.

- SG 8: Mobile, radiodetermination, amateur and related satellite services;

See below for more details.

- SG 9: Fixed service;

  - Working Party 9D Frequency sharing with other services (except for the fixed-satellite service).

- SG 10: Broadcasting service (sound);

- SG 11: Broadcasting service (television).

Each study group is assigned a number of topics to address, each of which is in response to a question. Most, if not all, of the questions arising from aeronautical radio matters are dealt with by study group 8. The following list contains all those questions assigned to study group 8 that directly concern aeronautical communications. Those of most relevance are shown in bold.

- ITU-R No. 35-1/8 Efficient use of the radio spectrum by radar stations in the radiodeterminaton service;

- ITU-R No. 45-4/8 Technical and operating considerations for a global land and maritime distress and safety system;

- **ITU-R No. 62-2/8 Interference to the aeronautical mobile and aeronautical radionavigation services;**

- ITU-R No. 83-3/8 Efficient user of the radio spectrum and frequency sharing within the mobile-satellite service;

- ITU-R No. 90/8 Technical and operating characteristics of systems providing radiocommunication using satellite techniques for distress and safety operations;

- ITU-R No. 91-1/8 Technical and operating characteristics of the radiodetermination-satellite service;

- ITU-R No. 94/8 Necessary bandwidth required for radio altimeters operating in the band 4200 – 4400 MHz;

- **ITU-R No. 95/8 Sharing between the aeronautical radionavigation service and the mobile service in the band 5000 – 5250 MHz;**

- **ITU-R No. 105/8 Criteria for sharing between the fixed service, and the mobile, radiodetermination, amateur and related services within the range 1 – 3 GHz;**

- **ITU-R No. 110/8 Interference to the aeronautical mobile-satellite (R) service;**
- **ITU-R No. 111/8 Coordination of frequency assignments in bands allocated to the aeronautical mobile-satellite (R) service;**
- ITU-R No. 202/8 Spurious emissions of radar systems operating in the 3 GHz and 5 GHz bands;
- ITU-R No. 203/8 Use of the maritime radionavigation band 283.5 – 315 kHz in Region 1;
- **ITU-R No. 207/8 Procedures for determining the interference coupling mechanisms and mitigation options for systems operating in bands adjacent to and in harmonic relationship with radar stations in the radiodetermination service;**

A.4 CEPT working groups

Matters relating to the use of radio systems and radio spectrum are dealt with within the CEPT by the European Radiocommunications Office (ERO). ERO has five working groups which report to the European Radiocommunications Committee (ERC):

- CPG: ITU WRC and Radiocommunications Assembly preparation;
- ERC-FM: Frequency Management;
- ERC-SE: Spectrum Engineering;
- ERC-RR: Radio Regulations;
- Joint ERC/ECTRA ITU group: ITU Council and Plenipotentiary Conference Preparation.

Each of the working groups report to the ERC at regular meetings. At the ERC meeting held on 17 to 21 March 1997, the following topics relating to spectrum used by aeronautical systems were addressed:

- Draft ERC Decision (ERC/DEC/(97)FF) on management of the Schiever Plan for the Terrestrial Flight Telecommunications System;
- Draft ERC Decision (ERC/DEC/(97)GG) on the harmonised use of spectrum for satellite personal communications services (S-PCS) operating within the bands 1610 – 1626.5 MHz, 2483.5 – 2500 MHz, 1980 – 2010 MHz and 2170 – 2200 MHz.

The next meeting of the ERC is in Copenhagen on 5 – 7 May 1998. Up to date information on the activities of the ERO can be found on the Internet at http://www.ero.dk/.

A.5 Other working groups

RTCA

The Requirements and Technical Concepts for Aviation group (RTCA) is a US based organisation comprising 16 individual working groups, each studying a particular topic. The ones relevant to this study (ie those examining issues associated with radio systems) include:

- SC-142 SSR Mode S;
- SC-159 Global Positioning System;
- SC-165 Aeronautical Mobile Satellite Service;
- SC-169 Datalink Communications;
- SC-172 VHF Air-Ground Communication.

More information on relevant RTCA activities can be found on the Internet at http://www.rtca.org/.

ICAO

The International Civil Aviation Organisation (ICAO) is an agency of the United Nations. It carries out its work on telecommunications matters via a number of panels. These panels are:

- Aeronautical Telecommunications Network Panel (ATNP);
- Automatic Dependent Surveillance Panel (ADSP);
- Secondary Surveillance Radar Improvements Collision Avoidance System Panel (SICASP);
- All Weather Operations Group (AWOG);
- Aeronautical Mobile Communications Panel (AMCP).

The latter of these, the AMCP, has a number of sub-groups, some of which research certain interference and other radio related matters. More details of ICAO activities can be found on the Internet at http://www.cam.org/~icao/.

EUROCAE

EUROCAE is the European Organisation for Civil Aviation Equipment. It is an international non-profit making organisation in Europe. Members include in Europe users and manufacturers of equipment for aeronautics and trade association. Its work programme is directed to the study of technical problems facing users and manufacturers of equipment for aeronautics and all related questions. EUROCAE works in collaboration with RTCA.

There are 17 EUROCAE Working Groups, including the following (the most relevant to the study):

- WG 28, GNSS in co-operation with RTCS CS-159;
- WG 33, High Intensity Radiated Field (protection of aircraft systems against the effects of the external RF environment);
- WG 47, VHF Data Link, in co-operation with RTCA SC-172;
- WG 51, ADS Broadcast.

More information concerning Eurocae could be obtained contacting Mr Grimal (see Appendix C).

ARINC

ARINC provides communications services, systems development and integration, system engineering and management service to the aviation community. ARINC also provides guidance for establishing avionics and other technical standards. Part of their business consists of representing the aviation industry in international forum.

The Airlines Electronic Engineering Committee (AEEC) is part of the ARINC. AEEC sets the standards for avionics equipment which are co-ordinated with other airline organisations, including ICAO. Activities are numerous and include:

- Global Navigation Satellite System (GNSS);
- Date Link Users Forum;
- Flight Managemnt Systems (FMS);
- High Frequency Data Link (HFDL);
- Navigation Data Bases;
- TCAS/Transponder (XPDR);
- VHF Data Radio (VDR);
- Weather Radar (WXR).

More information on relevant ARINC activities can be found on the Internet at http://www.arinc.com.

ETSI

The European Telecommunications Standard Institute (ETSI) has three main technical committees. Between them, these committees investigate all matters relating to radio systems. No direct mention of aeronautical interference resolution was identified, however ETSI does produce some technical standards for certain aeronautical systems (TFTS in particular). The three committees are:

- Technical Committee SES : Satellite Earth Stations and Systems;
- Technical Committee RES : Radio Equipment and Systems;
- Special Group RPM : Radio Policy Matters.

More information on ETSI activities can be found on the Internet at http://www.etsi.fr/.

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D Detailed categorisation scheme

D.1 Introduction

This appendix contains a description of a detailed categorisation scheme that can be used to give a thorough technical comparison of two or more interferers affecting a particular system.

Section D.2 examines the basic technical characteristics that define systems and interference sources. Section D.3 develops a set of more detailed characteristics which are then summarised in section D.4, which also develops a potential scoring scheme.

D.2 Basic interference characteristics

Whether or not a particular interference source will affect a particular system will depend upon the interaction between the interferer and the affected system. For some systems the interaction can be easily explained, defined and therefore categorised (such as for rogue transmitters operating on the same frequency as an aeronautical receiver). For other interferers, especially where problems may be sporadic (such as intermodulation products caused by a number of transmitters) the interaction is less able to be defined and hence categorisation becomes more difficult. Due to this inability to accurately identify the interaction between any particular interferer and the system it is affecting there are no internationally agreed methods for measuring interference or for assessing the impact, either real or potential of interferers.

What is therefore needed from an interference categorisation scheme is a way in which any particular interferer can be 'measured' such that the severity of its effect on a particular system can be compared with other potential interferers that could cause problems to the same system. The severity of any particular source will, as stated above, depend upon the characteristics of the system that is being affected, hence it is important that any categorisation scheme takes account of the characteristics of the affected system.

Characteristics that can be associated with any system and also with interference sources include:

- time signature;
- spectrum;
- sensitivity;
- geographical spread.

These characteristics are expanded in section D.3. In addition to those characteristics which can be associated with interference and systems, there is also one further which can not be associated with systems but which has relevance when categorising interference sources. This is the identifiability of a source and will likewise be expanded in section D.3.

D.3 Detailed characteristics

This section expands upon the interference characteristics developed in section D.2 to give specific criteria against which interference sources can be categorised.

D.3.1 Time signature

The time signature of a system or interference source details the period for which the given system is active. Within this definition there are a number of levels of granularity or resolution and it is important to capture each of these. Typically, the duration of activity of a system can be captured by answering the following questions:

- what is the duration of each individual burst of activity;
- what is the interval between typical bursts of activity;
- during which hours of the day is activity present;
- which days of the week is activity present;
- are there changes in the above parameters during the course of a year and if so, what effect do these changes have?

The last question in particular is an important one as it can be applied to almost all of the potential characteristics. Taking account of the variations of each characteristic with time would significantly complicate the categorisation of interference sources but it seems unlikely that this would add anything to the overall assessment of severity.

D.3.2 Spectrum

Both the system being affected and the interference itself will use or occupy a certain amount of spectrum. In cases where the interference occupies more spectrum than the affected system it is likely that more than one channel of the system or more than one system will be affected. In extreme cases it is possible the interference may be sufficiently wide-band to cause apparent effects on all frequencies to which the system is capable of tuning. Included in the characteristics associated with frequency is stability, which is generally relevant to interference sources only as systems tend to operate on a fixed frequency (or frequencies) and remain stable on those frequencies until they are re-tuned.

Typical questions that need to be asked in order to capture the spectrum related attributes of a system include:

- over what range of frequencies is the system/source active;
- what is the received/transmitted bandwidth of the system/source;

– does the interference source change frequency significantly between occurrences?

D.3.3 Sensitivity

The sensitivity of the affected system is important in determining the extent to which any interference source will impede the use of the system. If a system is more sensitive then less received interference power is required in order to cause problems, however it may also cause the wanted signal to be received more effectively. The sensitivity of a system therefore needs to take account of the typical received powers from the wanted sources, which need comparing to the received power of the interfering source.

In addition to pure wanted to unwanted signal ratios, the modulation scheme used by the affected system may also change the way in which the interference impedes the use of the system. As an example, amplitude modulation (AM) as used by VHF air-ground communications delivers received audio powers with ratios equal to the difference between wanted and unwanted signals (ie an interferer giving 10dB less received power than a wanted signal will deliver audio that is 10dB quieter). For a frequency modulated (FM) system, there is a capture effect whereby as little as 3dB difference between wanted and unwanted signals can be sufficient to ensure adequate reception of the wanted signal and exclude reception of the interferer.

Questions which need to be addressed to ensure that sensitivity characteristics are captured include:

– what is the minimum detectable signal that a system can adequately receive;

– what is the minimum required wanted to unwanted signal ratio to ensure adequate reception

– what modulation scheme is used;

– what is the minimum signal strength produced by the wanted signal;

– what is the signal strength produced at the affected system by the interferer?

The last question can be answered in two ways, either by measurement of actual received signal or by calculation of received signal based on transmitted power, distance from source etc. It is unlikely that in the majority of cases the received power will have been measured, or that the transmitted power will be known so other methods (such as judging the degree of degradation to service) may need to be used to ascertain the result.

D.3.4 Geographic spread

Both systems and interferers will operate over a given area. Where the area over which an interfering source includes receivers of the affected system, interference will be caused. Given the large radio horizon of aircraft flying at high altitudes (circa 300 km at a height of 10 km) the potential for even a low power interferer to cause problems is large. It is important to recognise the radio horizon of aircraft as being the extent of coverage for systems that incorporate airborne receivers. Even though the actual system may not normally be used except in the neighbourhood of the ground transmitters, such systems are still capable of being affected by interferers beyond the actual range of the ground system.

In theory the range of any particular system could be calculated from its sensitivity and the power of the transmitter, and hence the received wanted or unwanted signal. However, as a standalone measure it benefits from the ability to be readily understood and a lack of reliance on wanted to unwanted signal rations and often inaccurate (especially for frequencies below 30 MHz) signal strength prediction.

Location is also an important characteristic as although an interferer may cover a large area, it may be sufficiently removed from any system to cause any problems.

Questions to be asked to ascertain geographic characteristics include:

– what is the maximum range of the system or interference source;

– how far is the interferer from the system (alternatively where is the system located, where is the interferer)?

D.3.5 Identifiability

Although not strictly a characteristic relating to interference severity, any interference source which can easily be identified when active can be corrected much more rapidly thereby minimising its impact. Being able to identify a source of interference depends upon building a database of attributes against which any particular incidence can be measured. Currently such information typically resides within the aviation and radio administration bodies of various countries. Pooling of this information would enable more sources to be identified and also improve inter-country interference resolution.

The types of attributes that need to be gathered when attempting to identify a source include those examined in sections D.3.1 to D.3.4 but also include:

– the 'sound' of the interference as heard a receiver;

– the 'look' of the interference when viewed on a spectrum analyser.

D.4 Summary of characteristics

The characteristics therefore requiring measurement or determination in order to assess the severity of an interference source are shown in table D-1. Also shown is the unit by which the characteristic can be measured (where appropriate) and an indication of whether the particular characteristic can be measured for the system and/or the interferer.

In the following table, a tick (✓) represents a measurement which can be taken, whereas a cross (✕) represents a parameter that can not be measured.

Characteristic	Unit	System	Interferer
Time signature			
- burst duration	seconds	✓	✓
- interval between bursts	seconds	✓	✓
- daily hours of activity	hours	✓	✓
- weekly days of activity	days	✓	✓
- Annual variations in activity	none	✓	✓
Spectrum			
- frequency range	MHz	✓	✓
- bandwidth	kHz	✓	✓
- total channels available	None	✓	✕
- frequency drift	kHz / second	✕	✓
Sensitivity			
- minimum receivable signal	dBm	✓	✕
- minimum wanted to unwanted signal ratio	dB	✓	✕
- modulation scheme	none	✓	✓
- minimum signal strength produced by wanted signal	dBm	✓	✕
- typical signal strength produced by interferer	dBm	✕	✓
Geographic spread			
- maximum range	km	✓	✓
- distance between interferer and system	km	✓	✓
Identifiability			
- 'sound' of interferer	none	✕	✓
- 'look' of interferer	none	✕	✓

Table D-1: Summary of characteristics

From table D-1 it can be seen that for certain characteristics, a direct comparison between the value given for the system and the value given for the interferer will enable a sensible comparison to be made. In other cases (especially those where a measurement can not be taken for both interferer and system) the comparison will need to incorporate a number of different parameters.

Take as an example, the burst duration. Comparing the duration of bursts produced by the system with those produced by the interferer gives a direct comparison of the amount of an individual burst that is likely to be affected. To use, however, the typical signal strength produced by the interferer, it needs to be compared with another characteristic such as the minimum receivable signal strength (giving the level of the interferer above the receiver threshold).

Tables D-2 and D-3 below list the comparisons that can be made using the characteristics given in table D-1. Table D-2 considers those comparisons which can be made directly between two like characteristics whereas table D-3 considers those which require more than one different characteristic to be used.

Characteristic	**Result**	**Comparison**[9]
Burst duration	Amount of burst likely to be affected	Int / Sys
Interval between bursts	Likelihood of bursts coinciding	Sys / Int
Daily hours of activity	Amount of time for which the system is affected	Int / Sys
Weekly days of activity	Amount of days per week for which the system is affected	Int / Sys
Frequency range	Amount of wanted spectrum affected	Int / Sys
Maximum range	Amount of total range of system affected	Int / Sys

Table D-2: Direct comparison of two similar characteristics

To be able to compare different types of characteristics against each other it is essential that the results of the comparison have no unit. It is also sensible that the greater the potential for interference to be caused, the larger the result from the comparison.

In the comparisons of table D-2, a result of 1 represents a situation where an event will occur (ie the system will be affected by the interferer). Results greater than 1, in theory, represent situations where the interferer will be causing problems beyond those experienced by the system (eg a situation where the interferer causes interference over 5 times the spectrum occupied by the system). What is important is that the spectrum occupied by the system is affected; spectrum outside or beyond this is not important. As such, when actually calculating the results, any answer greater than 1 will be treated as being equal to 1. In this way, all results, for all comparisons, will vary between 0 and 1.

Characteristic comparison	**Result**

9 Int represents the measurement for the interferer, Sys represents the measurement for the system.

Burst duration of system * Frequency drift of interferer / Frequency range of system	*For a drifting source only*, the likelihood of an individual burst being affected
(Bandwidth of system + Bandwidth of interferer) / (Frequency drift of interferer * Burst duration of system)	*For a drifting source only*, the amount of an individual burst that will be affected
Bandwidth of interferer / (Bandwidth of system * Number of channels of system)	Amount of channels affected by interference
Typical signal strength produced by interferer – Minimum receivable signal	Level of interferer above system noise (in dB)
Minimum signal strength produced by wanted signal – Typical signal strength produced by interferer	Level of interferer above wanted signal (in dB)
Minimum signal strength produced by wanted signal - Minimum wanted to unwanted signal ratio - Typical signal strength produced by interferer	Level of interferer above wanted to unwanted signal ratio (in dB)
(Minimum receivable signal[10] + Typical signal strength produced by interferer) / Minimum receivable signal	Increase in system noise levels
Maximum range of system – Distance between interferer and system	Interferer in range of system (if answer > 0)
(Maximum range of system + Maximum range of interferer - Distance between interferer and system) / 2*whichever range is smallest[11]	Amount of overlap between area covered by interferer and area covered by system

Table D-3: Comparisons between different characteristics

D.5 Application of interaction model

Whilst the characteristic comparisons made in section D.4 may seem complex, they are in fact, based upon simple to apply formulae, easily dealt with using simple spreadsheets. In order to demonstrate the application of the interaction model, such a spreadsheet has been developed and this section demonstrates its application.

Figure D-1 gives an example of the above categorisation scheme as applied to the interference caused to a VHF air-ground communications system by an ISM source. No account is taken of annual variations or the modulation scheme of either the system or interferer or the identifyability of the interferer as these do not produce calculable results and therefore must be considered separately following an assessment based on those parameters that do.

10 Note that the minimum receivable signal and the signal produced by the interferer need to be converted from dB to Volts in order to make this comparison.

11 This is a linear approximation to a complex trigonometric function. The maximum error (≈20%) occurs when the range of the system and interferer are similar and the amount of overlap is small.

For each comparison a weighting has been applied. The weightings used in the examples given are arbitrary and are for the purpose of demonstrating the application of the model. In the example given, weightings have been set at either 4, 2 or 1. Were all the weightings identical, the overall score given for a category would be the arithmetic mean of the individual scores. If one of the weights was double the others (eg weights of 2, 1 and 1 were applied to a set of three individual scores), the score with the higher weighting would have twice the influence on the overall score compared to the other results. The overall scores have been calculated such that the answer lies between 0 and 1. Table D-4 below demonstrates the results that would be obtained for sets of example weightings applied to an arbitrary set of individual scores.

Individual Scores	Weightings (1)	Weightings (2)	Weightings (3)	Weightings (4)
1	1	2	1	4
0.6	1	1	1	1
0.2	1	1	2	4
Overall Score:	0.6	0.7	0.5	0.6

Table D-4: Examples of application of weightings

When the model is actually used, it will be important to determine the relative importance of the individual results produces. For instance, it has been assumed for the examples that the amount of time for which spectrum is affected and the number of days per week that the system is affected are twice as important in determining the overall time signature effect of the interferer than the amount of a burst affected or the likelihood of bursts coinciding.

A score has been produced for each area of the comparison. These scores take into account the weightings applied such that the overall score for an area of comparison can vary between 0 and 1.

Characteristic	System	Interferer	Unit
Time signature	VHF air-ground	ISM harmonics	
burst duration	15	60	seconds
interval between bursts	120	300	seconds
daily hours of activity (start to finish)	0 24	8 18	hours
weekly days of activity (1=Mon, 7=Sun)	1234567	12345	days
annual variations in activity	none	none	-
Spectrum			
frequency range (start and finish)	117.975 137	130 131	MHz
bandwidth	25	100	kHz
number of channels supported by system	760		
frequency drift		0.1	kHz/s
Sensitivity			
minimum receivable signal	-120		dBm
minimum wanted to unwanted signal ratio	14		dB
minimum signal strength produced by wanted signal	-93		dBm
typical signal strength produced by interferer		-120	dBm
Geographic spread			
maximum range	300	80	km
minimum distance between interferer and system	50		km

Resultant	Result	Modified result	Weight	Total score
Time signature				
Amount of burst likely to be affected	4.000	1.000	2	
Likelihood of bursts coinciding	0.400	0.400	2	
Amount of time for which the system is affected	0.417	0.417	4	
Number of days per week that both systems operate	0.714	0.714	4	0.610
Spectrum				
Amount of wanted spectrum affected by interferer	0.053	0.053	4	
Amount of channels affected by interference	0.005	0.005	4	
For a drifting source - Likelihood of individual burst being affected	0.000	0.000	1	
For a drifting source - Amount of burst affected	83.333	1.000	1	0.123
Sensitivity	dB			
Level of interferer above system noise	0	1.000	2	
Decrease in system sensitivity	3	1.000	2	
Level of interferer above wanted signal	-27	0.002	2	
Level of interferer above wanted to unwanted signal ratio	-13	0.050	2	0.513
Geographic spread				
Amount of total range of system affected	0.267	0.267	2	
Is the interferer in range of the system	1.000	1.000	2	
Amount of overlap between interferer area and system area	2.063	1.000	2	0.756

Figure D-1: Example application of interaction model

In the ‘Characteristic’ box, boxes shaded in grey represent measurements that can not be made (see table D-1). In the ‘Resultant’ box, results that are given in dBs are shaded in grey.

For the example comparison shown in figure D-1, the scores for the individual comparison areas are:

– **Time Signature: 0.610**

– **Spectrum: 0.123**

– **Sensitivity: 0.513**

– **Geographical spread: 0.756**

By comparison of these results against each other we can ascertain certain simple facts about the interference source:

– the most significant effect of the interferer is in its geographic spread;

– the least significant effect of the interferer is in the amount of spectrum it affects.

These simple facts can form the basis of a method for tackling the interference source. As the largest problem is the geographic spread of the source, methods to reduce this should be the target for any improvement (examples of such measures include re-focussing the radiation from the source or limiting the beamwidth of the source). In doing so, other factors may be affected such that the overall effect is significantly reduced, however, even simply reducing the geographic effect would offer benefits.

In the second example (shown in figure D-2), the results for an illegal broadcast transmitter affecting the same system are calculated. In this instance, the results show:

– **Time signature: 0.762;**

– **Spectrum: 0.048;**

– **Sensitivity: 0.800;**

– **Geographical spread: 0.997.**

Again, it is clear that geographical spread is a key factor in the way the interference source affects the system and that spectrum is a smaller issue. However, the major benefit from the application of the model comes in making a comparison between this interferer and the previous one.

The illegal broadcaster scored higher on time signature than the ISM source, hence the effect caused by it is likely to be more prevalent than the ISM source. The score for spectrum for the illegal broadcaster was particularly small, and in comparison to the ISM source is therefore likely to affect many fewer channels.

The sensitivity score was higher for the illegal broadcaster meaning that it is likely to cause more of a problem, when it does occur, than the ISM source. Finally, the illegal broadcaster scores nearly 1 for geographic spread, as opposed to only 0.756 for the ISM source, hence the area affected by the illegal broadcaster will be much greater than the ISM source and indeed, the illegal broadcaster may affect all of the area covered by the system it is affecting.

Characteristic	System		Interferer		Unit
Time signature	VHF air-ground		'Pirate' transmitter		
burst duration	15		86400		seconds
interval between bursts	120		0		seconds
daily hours of activity (start to finish)	0	24	0	24	hours
weekly days of activity (1=Mon, 7=Sun)	1234567		67		days
annual variations in activity	none		none		-
Spectrum					
frequency range (start and finish)	117.975	137	108	120	MHz
bandwidth	25		250		kHz
number of channels supported by system	760				
frequency drift			0		kHz/s
Sensitivity					
minimum receivable signal	-120				dBm
minimum wanted to unwanted signal ratio	14				dB
minimum signal strength produced by wanted signal	-93				dBm
typical signal strength produced by interferer			-100		dBm
Geographic spread					
maximum range	300		300		km
minimum distance between interferer and system	5				km

Resultant	Result	Modified result	Weight	Total score
Time signature				
Amount of burst likely to be affected	5760.000	1.000	2	
Likelihood of bursts coinciding	########	1.000	2	
Amount of time for which the system is affected	1.000	1.000	4	
Number of days per week that both systems operate	0.286	0.286	4	0.762
Spectrum				
Amount of wanted spectrum affected by interferer	0.106	0.106	4	
Amount of channels affected by interference	0.013	0.013	4	
For a drifting source - Likelihood of individual burst being affected	0.000	0.000	1	
For a drifting source - Amount of burst affected	0.000	0.000	1	0.048
Sensitivity	dB			
Level of interferer above system noise	20	1.000	2	
Decrease in system sensitivity	20	1.000	2	
Level of interferer above wanted signal	-7	0.200	2	
Level of interferer above wanted to unwanted signal ratio	7	1.000	2	0.800
Geographic spread				
Amount of total range of system affected	1.000	1.000	2	
Is the interferer in range of the system	1.000	1.000	2	
Amount of overlap between interferer area and system area	0.992	0.992	2	0.997

Figure D-2: Second categorisation example

D.6 Conclusions

The above comparisons demonstrate the application of the categorisation scheme and show how the results can usefully be interpreted. It has been shown that the scheme can:

– be applied to a number of different sources affecting the same system;

– produce results that are meaningful with respect to the nature of the interference;

– allow comparison between interference sources and hence determine the relative severity of each.