NTIA Report 05-432

INTERFERENCE PROTECTION CRITERIA
Phase 1 - Compilation from Existing Sources

technical report

U.S. DEPARTMENT OF COMMERCE ● National Telecommunications and Information Administration

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EXECUTIVE SUMMARY

The National Telecommunications and Information Administration (NTIA) launched this two-phase study of interference protection criteria (IPC) in order to compile, explain and validate, modify or supplement the levels of protection from interference that are generally expected and provided for various radiocommunication systems. The study is an integral part of President Bush's Spectrum Policy Initiative that was established in May 2003 to promote the development and implementation of a United States spectrum policy for the 21st century. The Secretary of Commerce then established a Federal Government Spectrum Task Force and initiated a series of public meetings to address improvements in policies affecting spectrum use by the Federal Government, State, and local governments, and the private sector. The recommendations resulting from these activities were included in a two-part series of reports released by the Secretary of Commerce in June 2004, under the title *Spectrum Policy for the 21st Century - The Presidents Spectrum Policy Initiative*. Based on the recommendations contained in these Reports, the President directed the federal agencies on November 30, 2004, to plan the implementation of the 24 recommendations contained in the Reports. There were several recommendations that will consider the interference protection criteria contained in this study including:

- assessment of new technologies and their impact on incumbent radiocommunications;
- managing interference;
- development of a "Best Practices Handbook" for spectrum engineering;
- establishment a pilot program and long-range plan for improved sharing of spectrum between federal and non-federal entities; and
- creation of new analytical computer models that will facilitate spectrum engineering.

The U.S. spectrum management process has evolved to meet the rapidly changing spectrum requirements of both the private sector and the federal government. Within this spectrum management process, the Federal Communications Commission (FCC), acting on behalf of the private sector, and the NTIA, acting on behalf of the federal agencies, provide spectrum planning, allocation and assignment in a manner that prevents interference. In the last five to ten years, spectrum usage and demand have increased significantly. Associated with the increased spectrum usage demand, came the increased geographic densities of transmitters and receivers, that means increased interference risks. One of the key elements in preventing interference is identification of the appropriate IPC. Implementation of a new technology often requires a significant amount of time to define and obtain agreement on an appropriate IPC. For example, it took several years to obtain sufficient measurement and analytical information on potential interference from ultrawideband (UWB) devices in order to define and apply the necessary IPC. To speed up the introduction of a new technology associated with the addition of licensed or unlicensed operations, means that advocates, incumbents and regulators will have to find more effective ways for analyzing the potential interference in a more timely manner. To this end, it is appropriate to predict and define the interfering signal levels at which radio systems may experience unacceptable degradation in performance, and to establish methods for protection of radio communications from interference.

One of the key steps in any interference, electromagnetic compatibility, or spectrum sharing study is identifying IPC, to determine the necessary distance or frequency separations, or other frequency sharing constraints. The identification of IPC is often a confusing, time-consuming step with no single reference source from which to draw. The complexity of this process is exacerbated by the numerous terms used to define interference. For example, the NTIA, FCC, and International Telecommunication Union, Radiocommunication Sector or (ITU-R), define various terms relative to interference, including: *Interference, Permissible Interference, Accepted Interference,* and *Harmful Interference.* The diverse concepts behind these terms can lead to confusion when addressing potential interference between systems. Furthermore, since IPC normally depend upon details of the interfering and interfered-with systems as well as their operating environments, a very large number of combinations of frequency sharing situations must be considered with regard to a proposed new service or technology.

NTIA reviewed publications of national, international, public and private organizations to compile established IPC for various radio services operating between 30 MHz and 30 GHz. The results are presented in this Phase 1 report. One common feature was that for continuous, long-term interfering signal levels, nearly all established IPC were based on an interference-to-noise power ratio of –6 to –10 dB. Short-term IPC that accommodate relatively high interfering signal levels for small percentages of time or locations were not found for many services. For pulsed or intermittent interfering signals, the IPC for many of the radio services were not specified or the available IPC varied due to the specific types of desired and interfering signals being received.

In the second phase of this study, NTIA will review the relevant federal government policies and practices regarding IPC and recommend regulatory and technical refinements that may improve IPC application's scope, utility, clarity, or effectiveness.

ACRONYMS AND ABBREVIATIONS

AFTRCC	Aerospace and Flight Test Radio Coordinating Council
AI	Articulation Index
AMSS	Aeronautical Mobile-Satellite Service
AMS(OR)S	Aeronautical Mobile-Satellite Service (Off-route)
AMS(R)S	Aeronautical Mobile-Satellite Service (Route)
ANSI	American National Standards Institute
AP30	Appendix 30 of the ITU Radio Regulations
APCO	Association of Public-Safety Communications Officials
APT	Automatic Picture Transmission
ARINC	Aeronautical Radio Incorporated
ATCRBS	Air Traffic Control Radar Beacon System
ATM	Air Traffic Management
ATPC	Automatic Transmitter Power Control
ATSC	Advanced Television Systems Committee
BBER	Background Block Error Ratio
BEP	Bit Error Probability
BER	Bit Error Ratio
BS	Broadcasting Service
BSS	Broadcasting-Satellite Service
BW	Bandwidth
C/A	Coarse Acquisition
CATV	Community Antenna Television
CCIR	International Radio Consultative Committee (now called "ITU-R")
CDA	Command and Data Acquisition System
CD	Color Decoding
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administrations
CFR	Code of Federal Regulations
C/I	Carrier-to-Interfering Signal Power Ratio
C/(I+N)	Carrier-to-Interference-plus-Noise Power Ratio
C/N	Carrier-to-Noise Power Ratio
CW	Continuous Wave
DAQ	Delivered Audio Quality
dB	Decibel
dBi	Antenna gain in dB over isotropic
dBic	Antenna gain in dB over isotropic (circular polarized)
dBm	Power in dB referred to 1 milliwatt
dBµ	Field strengths in dB above one microvolt per meter
DBS	Direct Broadcast Satellite
dBW	Power in dB referred to 1 watt
dBZ	Radar reflectivity factor in dB

DME	Distance Measuring Equipment
DMS	Digital Microwave System
DNR	Draft New Recommendation
DOD	Department of Defense
DRS	Data Relay Satellite
DTV	Digital Television
D/U	Desired-To-Undesired Signal Power Ratio
DVB-T	Digital Video Broadcasting-Terrestrial
ECC	Electronic Communications Committee
EES	Earth Exploration-Satellite
EIA	Electronics Industry Alliance
EMC	Electromagnetic Compatibility
ERO	European Radiocommunications Organization
ESR	Errored Second Ratio
ETSI	European Telecommunications Standards Institute
EVA	Extra-Vehicular Activity
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FDP	Fractional Degradation of Performance
FEC	Forward Error Correction
FH	Frequency Hopping
FM	Frequency Modulation
FS	Fixed Service
FSS	Fixed-Satellite Service
GHz	Gigahertz (10^9 Hertz)
GLONASS	Global Navigation Satellite System (Russian)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRD	Global Recorded Data
GSO	Geostationary Satellite Orbit
HDTV	High Definition Television
HRDP	Hypothetical Reference Digital Path
HRPT	High Resolution Picture Transmission
Hz	Hertz
IBOC	In-band on-channel
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ILS	Instrument Landing System
IMO	International Maritime Organization
IMT-2000	International Mobile Telecommunications-2000
I/N	Interfering-to-Noise Power Ratio
IP	Internet Protocol
IPC	Interference Protection Criteria
ISDB-T	Integrated Service Digital Broadcasting-Terrestrial

ISDN	Integrated Services Digital Network
ISM	Industrial, Scientific, and Medical
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication Sector
ITU-T	ITU Telecommunications Standardization Sector
JSC	Joint Spectrum Center
JTF	Joint Task Force
K	Kelvin
Kbps	Kilobits per second
kHz	Kilohertz (10^3 Hertz)
LMSS	Land Mobile-Satellite Service
LEO	Low Earth Orbit
LRPT	Low Resolution Picture Transmission
m	Meter
Mb/s	Megabits per second
MEA	Multiple Exposure Allowance
METSAT	Meteorological-Satellite
MHz	Megahertz (10^6 Hertz)
MIL-STD	Military Standard
MLS	Microwave Landing System
MMSS	Maritime Mobile-Satellite Service
MS	Mobile Service
MSS	Mobile-Satellite Service
MVDDS	Multi-Channel Video Distribution and Data Service
N/C	Noise-to-Carrier Ratio
NGSO	Non-Geostationary Satellite Orbit
NIB	Non-Interference-Basis
NPRM	Notice of Proposed Rulemaking
N/S	Not Specified
NTIA	National Telecommunications and Information Administration
NTSC	National Television Standards Committee
NWS	National Weather Service
NWP	Numerical Weather Prediction
OSM	Office of Spectrum Management
OSS	One-Stop-Shopping Procedure
PCM	Pulse Code Modulation
pfd	Power Flux Density
PLMR	Private Land Mobile Radio
QPSK	Quadrature Phase Shift Keying
RA	United Kingdom Radiocommunications Agency
RAS	Radio Astronomy Service
Rec	Recommendation
RF	Radio Frequency
RMS	Root Mean Square
RNSS	Radionavigation-Satellite Service

RR	Radio Regulations
RTCA	Radio Technical Commission on Aeronautics
RTCM	Radio Technical Commission on Maritime
SAR	Synthetic Aperture Radars
SCPC	Single Channel Per Carrier
SESR	Severely Errored Second Ratio
SG	Study Group
S/I	Signal-to-Interference Power Ratio
SINAD	Signal to Interference, Noise, and Distortion Power Ratio
SPTF	Spectrum Policy Task Force
TACAN	Tactical Air Navigation
TBD	To Be Determined
TDMA	Time Division Multiple Access
TIA	Telecommunications Industry Association
TSB	Telecommunications Systems Bulletin
UHF	Ultra High Frequency – 300 to 3000 MHz
USCG	United States Coast Guard
UWB	Ultrawideband
VHF	Very High Frequency – 30 to 300 MHz
VLBI	Very Long Baseline Interferometry
VOR	Very-High-Frequency Omnidirectional Range
VSAT	Very Small Aperture Terminal
WAAS	Wide Area Augmentation System
WEFAX	Weather Facsimile
WMO	World Meteorological Organization
WP8B	ITU-R Working Party 8B
WRC	World Radiocommunication Conference

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

The National Telecommunications and Information Administration (NTIA) is the Executive Branch agency responsible for developing and articulating domestic and international telecommunications policy. NTIA acts as the principal advisor to the President on telecommunications policies pertaining to the nation's economic and technological advancement and regulation of the telecommunications industry. NTIA is also responsible for managing the federal government's use of the radio spectrum. Federal agencies are highly dependent on interference-free spectrum access to support a wide variety of critical missions including weather forecasting and homeland security.

The spectrum management process, originally established under the Communications Act of 1934,has been frequently faced with rapidly changing perceived spectrum requirements of both the private sector and the federal government. The Federal Communications Commission (FCC), and NTIA have coordinated their spectrum management efforts to ensure that policies, rules, and practices for spectrum usage adequately prevent interference.

One of the primary goals in spectrum management is to plan, allocate and assign spectrum in a way that prevents interference. This goal was discussed at NTIA's April 2002 Spectrum Summit of the federal and private sector spectrum management community as well as the radio service users and providers. In parallel, the FCC created a Spectrum Policy Task Force (SPTF) that focused on a number of issues, including interference, and formed an Interference Protection Working Group (IPWG). This forum posed several relevant questions. For example, how does one determine whether interference is harmful? What are the property rights of the licensed or assigned user? What are the property rights relative to freedom from interference? Many participants indicated that answers need to be developed with a clear view of the necessary spectrum management policies and conditions under which interference will be prevented.

On June 6, 2002, the FCC SPTF issued a public notice seeking comment on issues related to the FCC's spectrum policies.[1] The IPWG held several public workshops where the public was invited to present input. Over forty-eight companies provided comments on interference protection, suggesting that both licensed and unlicensed spectrum users should have clearly defined rights and obligations relating to interference. Participants also suggested that the United States integrates its domestic and international spectrum policy efforts on interference and concluded that interference protection was at the heart of many contentious debates before the FCC and NTIA. Furthermore, commenters suggested that both agencies should recognize and address several key interference principles:[2]

- some level of interference can be tolerated, which varies depending on the nature of the service involved and the nature of the interference;
- due to advances in digital signal processing and antenna technology, communications systems and devices are becoming more tolerant of interfering signals through their ability to sense and adapt to the RF environment;
- all systems require some degree of margin to ensure reliable communications; the regulators should not assume that eliminating that margin is acceptable;
- the regulations and practices of interference protection differ between different radio services, with the rules of some services prescribing detailed criteria for predicting interference;
- the regulators should consider interfering signal aggregation of multiple sources;
- harmful interference is an extreme level and that just because interference does not rise to that level, it cannot be concluded that the interference is acceptable to the victim; and
- the FCC should make clear that its spectrum policies are based on an "interference-limited" rather than "ambient noise-limited" environment.

The SPTF provided a report of its findings and recommendations to the FCC in November 2002.[3]

In the last five to ten years, spectrum usage and demand have increased significantly. The major interference issues have required a substantial time to define and resolve. For example, in adopting rules for implementing the new technology referred to as ultrawideband (UWB), it took several years to obtain measurement and analytical information on interference susceptibility, sufficient to define the necessary Interference Protection Criteria (IPC). In order to accommodate new technologies and additional licensed and/or unlicensed operations more quickly, advocates, incumbents and regulators will have to find better ways to analyze the interference potential. Moreover, system designers need guidance on the levels of interfering signals that should be tolerated. To this end, it is appropriate to further define IPC.

The identification of the appropriate IPC is often a confusing, time-consuming process that is not supported by a single reference source. This process is further complicated by numerous relevant regulatory and technical terms. For example, the NTIA, FCC, and the International Telecommunication Union, Radiocommunication Sector, (ITU-R) define several terms relative to interference, including: *Interference, Permissible Interference, Accepted Interference, Harmful Interference,* and *Protection Ratios.* Other terms that are commonly used, but not specifically defined are: *Allowable Performance*

Degradation, Interference Protection Criteria, and *Spectrum Sharing Criteria*. Furthermore, since spectrum-sharing criteria normally depend upon parameters of both the interfering and interfered-with systems and their operating environments, a very large number of combinations is possible. Consideration of interference is "at least a six dimensional problem, meaning spatial, x-y-z, frequency, time, and waveform, and of course since the waveform can be infinitely complicated, you can make it an n-fold problem, which basically has more variables than you have numbers."[4]

In 1990, International Telecommunication Union, Radiocommunication sector, Study Group 1 attempted to reduce this complexity by adopting Rec. ITU-R SM.669 that includes a matrix of protection ratios for various combinations of interfering and desired-signal modulation types.[5] An earlier, but more comprehensive approach was undertaken jointly by NTIA and the Department of Defense (DOD) Joint Spectrum Center (JSC), resulting in the publication of the Communications Receiver Performance Degradation Handbook.[6] However, the IPC presented in Rec. ITU-R SM.669 as well as the Degradation Handbook have become largely obsolete for several reasons, including:

1)The Degradation Handbook and Rec. ITU-R SM.669 focus on analog and early digital modulations, which are in many cases being supplanted by more complex, digital modulations.

2) Both efforts focused primarily on modulation with little regard to radio service requirements or factors stemming from the operating frequency, whereas most spectrum sharing studies today focus primarily on radio services and specific frequency bands.

3) The IPC in these texts do not include temporal or spatial statistical allowances that should be considered in detailed analyses.

Since the adoption of Rec. ITU-R SM.669 and completion of the Degradation Handbook, extensive spectrum sharing studies have been completed and documented within the International Telecommunication Union, Radiocommunication sector, and elsewhere. As part of on-going spectrum sharing studies within the International Telecommunication Union, Radiocommunication sector, the various service study groups have refined and documented IPC for their respective radio services within numerous International Telecommunication Union, Radiocommunication sector Recommendations. In light of these developments, NTIA launched a study of IPC. This Phase 1 report compiles available IPC. In the second phase of this study, NTIA will review the relevant federal government policy and practices regarding derivation of IPC, and recommend regulatory and technical refinements that may improve IPC application's scope, utility, clarity, or effectiveness.

1.2 OBJECTIVE

The National Telecommunications and Information Administration (NTIA) launched a two-phase study of interference protection criteria (IPC) to compile, explain and validate, modify or supplement the levels of protection from interference that are generally expected and provided for various radiocommunication systems.

The study is an integral part of President Bush's Spectrum Policy Initiative that was established in May 2003 to promote the development and implementation of a United States spectrum policy for the 21st century. The Secretary of Commerce then established a Federal Government Spectrum Task Force and initiated a series of public meetings to address improvements in policies affecting spectrum use by the Federal Government, State, and local governments, and the private sector. The recommendations resulting from these activities were included in a two-part series of reports released by the Secretary of Commerce in June 2004, under the title *Spectrum Policy for the 21st Century - The Presidents Spectrum Policy Initiative*. Based on the recommendations contained in these Reports, the President directed the federal agencies on November 30, 2004, to plan the implementation of the 24 recommendations contained in the Reports. There were several recommendations that will consider the interference protection criteria contained in this study including:

- assessment of new technologies and their impact on incumbent radiocommunications;
- managing interference;
- development of a "Best Practices Handbook" for spectrum engineering;
- establishment a pilot program and long-range plan for improved sharing of spectrum between federal and non-federal entities; and
- creation of new analytical computer models that will facilitate spectrum engineering.

Based on the above, the objectives of this study are as follows:

<u>Phase 1:</u>

- Review publicly available texts to identify and document IPC for radio services that accommodate federal government radiocommunications and apply this information as applicable to the completion of the appropriate recommendations approved by President Bush.

<u>Phase 2:</u>

- Review federal government policy and practices regarding IPC and recommend regulatory refinements that may improve the scope, clarity or effectiveness of interference-protection provisions, as appropriate;

- Review applications for IPC;

- Develop a methodology for determining appropriate IPC that can be used to supplement, validate or refine existing IPC;

Additional objectives will be determined during Phase 2 of this study. These may include:

- Apply the methodology for determining appropriate IPC to supplement or refine, as appropriate, IPC identified in Phase 1 to establish validated IPC for each radio service;

- Incorporate findings in NTIA's planned best practices handbook;

- On a case-by-case basis, promote IPC and associated regulatory provisions for the private sector through rulemakings at the FCC;

- Provide the results to ITU-R Study Group 1 for possible replacement of Rec. ITU-R SM.669.

1.3 PHASE 1 APPROACH

- Define IPC.

- Compile IPC in five broad areas covering fixed and fixed-satellite services, radiodetermination and radiodetermination-satellite services, broadcasting and broadcasting–satellite services, mobile and mobile-satellite services, and science services.

- Categorize IPC according to the type of interfering signal (continuous wave (CW), noise-like, pulse, and other) and, where available, associated statistical allowances (long-term or short-term).

- Document results in an NTIA Phase 1 report.

1.4 SCOPE

This report includes IPC covering the frequency range 30 MHz to 30 GHz. Numerous sources of IPC are available from international agencies, government agencies, trade associations, academic institutions, and others. This report compiles IPC from generally accepted sources. The sources considered were as follows:

- ITU-R. A role of the ITU-R is to provide guidance for the rational, equitable, efficient, and economical use of the radio-frequency spectrum by all radiocommunication services. The ITU-R carries out studies culminating in Recommendations, which serve as a repository of technical and procedural guidelines for the design, implementation and operation of radiocommunications systems. The ITU-R Study Groups (SG) listed below focus on particular radiocommunications services, as do the subsequent sections of this report. Working parties are established within each Study Group to address service issues such as performance objectives.

    - SG 1 - Spectrum management
    - SG 3 - Radiowave propagation
    - SG 4 - Fixed-satellite service
    - SG 6 - Broadcasting service
    - SG 7 - Science services
    - SG 8 - Mobile, radiodetermination, amateur and related satellite services
    - SG 9 - Fixed service

- International Civil Aviation Organization (ICAO). One of the chief activities of the ICAO is the establishment of International Standards, Recommended Practices and Procedures covering the technical fields of aviation including aeronautical telecommunications, air traffic services, search and rescue, navigation, surveillance, and aeronautical information services. The principle document considered herein is the ICAO International Standards and Recommended Practices.

- International Maritime Organization (IMO). The IMO was established with the chief task of developing a comprehensive body of the international conventions, codes and recommendations to be implemented by all member governments. The Maritime Safety Committee has sub-committees dealing with relevant subjects, including safety of navigation, radiocommunications and search and rescue.

- International Electrotechnical Commission (IEC). The IEC is a global organization that prepares and publishes international standards for all electrical, electronic and related technologies. These serve as a basis for national standardization and as references when drafting international tenders and contracts.

- World Meteorological Organization (WMO). The WMO coordinates global scientific activity to allow increasingly prompt and accurate weather information services for public, private and commercial use, including international airline and shipping industries. WMO's major scientific and technical programs include the World Weather Watch, which offers up-to-the-minute world-wide weather information through member-operated observation systems and telecommunication links (presently using four polar-orbiting and five geostationary satellites, about 10,000 land observation stations, 7,000 ship stations and 300 moored and drifting buoys carrying automatic weather stations).

- European Radiocommunications Organization (ERO). ERO is the permanent office supporting the Electronic Communications Committee (ECC) of the European Conference of Postal and Telecommunications Administrations (CEPT). ECC is the Committee that brings together the radio and telecommunications regulatory authorities of the 45 CEPT member countries.

- National Telecommunications and Information Administration (NTIA). NTIA is the Executive Branch agency principally responsible for developing and articulating domestic and international telecommunications policy as well as managing and regulating federal government use of the spectrum. Accordingly, NTIA conducts studies and makes recommendations regarding telecommunications matters to Congress, the FCC, and the public. NTIA rules and publications include the NTIA Manual and the library of reports produced by the Office of Spectrum Management (OSM) and the Institute for Telecommunication Sciences (ITS).[7]

- Federal Communications Commission (FCC). The FCC manages and regulates use of the spectrum by non-federal entities. The FCC rules and regulations are codified in Title 47 of the Code of Federal Regulations (CFR).

- Joint Spectrum Center (JSC). JSC conducts various frequency sharing studies for the Department of Defense (DOD). The Joint Staff J-6 of DoD directed the JSC to develop Spectrum XXI as a Windows-NT based application to address the spectrum management requirements of the Force Commanders, the Joint Task Force (JTF) commanders, the Military Departments, and the sustaining base elements. Spectrum XXI uses a table containing IPC for many services that is based on NTIA reports, FCC Rules and Regulations, ITU-R Recommendations and Reports, the DOD/JSC Degradation Handbook, and industry standards.
- Military Standards (MIL-STDs). MIL-STDs generally impose requirements and instructions on the military. They are written primarily for the benefit of program offices and product centers. Compliance may not be mandatory. MIL-STDs were found through searching the DOD Index of Specifications and Standards (DODISS).

- RTCA Inc. (formallyTechnical Commission on Aeronautics). The RTCA Inc., is an association of aeronautical organizations from the United States and other countries that seeks sound technical solutions to problems involving the application of electronics and telecommunications to aeronautical operations.

- Radio Technical Commission on Maritime (RTCM). The RTCM is chartered in the District of Columbia, as a non-profit scientific and educational organization, focusing on all aspects of maritime radiocommunications, radionavigation, and related technologies. Participants are from government and private sectors. Since its establishment in 1946, the RTCM has been supported by its member organizations to serve as a focal point to collect and distribute information, and to serve as a catalyst in developing solutions to both national and international maritime radiocommunications and radionavigation issues.

- Telecommunications Industry Association (TIA). TIA, in conjunction with the Electronics Industry Alliance (EIA), sponsors committees of experts to prepare standards dealing with performance testing and compatibility. TIA is accredited by the American National Standards Institute (ANSI) to develop voluntary industry standards for a wide variety of telecommunications products.

- Aerospace and Flight Test Radio Coordinating Council (AFTRCC). AFTRCC provides recommendations to the FCC for non-government use of flight test voice and telemetry frequencies. Its role is strictly advisory.

- Association of Public-Safety Communications Officials (APCO). APCO is an international non-profit professional organization dedicated to the enhancement of public safety communications. It serves the people who manage, operate, maintain, and supply public safety communications systems mainly at the state level.

- Institute of Electrical and Electronics Engineers (IEEE). IEEE is a non-profit, technical professional association in 150 countries. The IEEE is a leading authority in technical areas such as computer engineering and telecommunications. Through its technical publishing, conferences and consensus-based standards activities, IEEE produces 30 percent of the world's published literature in electrical engineering, computers and control technology, holds annually more than 300 major conferences and has nearly 900 active standards with 700 under development.

- The European Telecommunications Standards Institute (ETSI). ETSI is the technical standards body under the European Conference of Postal and Telecommunications Administrations (CEPT). It publishes European technical standards that are adopted by most regulatory authorities in Europe as well as in some non-European countries. Having common standards facilitates equipment testing and type acceptance in these countries.

- United Kingdom Radiocommunications Agency (RA). RA was an executive agency of the Department of Trade and Industry, United Kingdom. It was responsible for the management of the non-military radio spectrum in the United Kingdom, which involves international representation, commissioning research, allocating spectrum and licensing its use. Recently, office of communicatons (OFCOM), has taken over these responsibilities and assumed the powers of the five former regulators it has replaced - the Broadcasting Standards Commission, the Independent Television Commission, OFTEL, the Radio Authority and the Radiocommunications Agency. OFCOM is the regulator for the United Kingdom communications industries, with responsibilities across television, radio, telecommunications and wireless communications services.

- Eurocontrol. Eurocontrol is an organization consisting of 41 European states whose mission is to co-ordinate the development of a uniform system of air traffic management throughout Europe. Eurocontrol works with its members in the air transport industry to provide a range of services, including air traffic controller training; managing air traffic flow; regional control of airspace to development of innovative technologies and procedures; and collection of air navigation charges, civil/military among other things.

REFERENCES

[1] *Spectrum Policy Task Force Seeks Public Comment on Issues Related to Commission's Spectrum Policies,* Public Notice, ET Docket No. 02-135, DA-02-1311, 17 F.C.C. Rca. 10560, Federal Communications Commission (2002).

[2] *Spectrum Policy Task Force, Interference Protection Working Group Report* (Working Group Report), ET Docket No. 02-135, at www.fcc.gov/sptf/, Federal Communications Commission (2002).

[3] *Spectrum Policy Task Force Report,* ET Docket No. 02-135, DOC-228542, Federal Communications Commission (2002).

[4] Working Group Report, at 5 (Remarks by Dr. Paul Steffes).

[5] *Protection Ratios for Spectrum Sharing Investigations,* Rec. ITU-R SM. 669-1, (1994).

[6] *Communications Receiver Performance Degradation Handbook*, Electromagnetic Compatibility Analysis Center, Annapolis, Maryland (1987).

[7] *Manual of Regulations & Procedures for Federal Radio Frequency Management* (Manual), National Telecommunications and Information Administration, at Chapter 6 (September 2003).

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SECTION 2
TECHNICAL PERSPECTIVES

2.1 INTRODUCTION

This section provides an overview definitions and relevant terms related to interference and IPC.

2.2 RELEVANT DEFINITIONS

The ITU Radio Regulations (Article 1), NTIA Manual (Chapter 6), and FCC Rules and Regulations (Part 2), define several terms related to interference, including:[1]

1.166
Interference*:* The effect of unwanted energy due to one or a combination of *emissions*, *radiations*, or inductions upon reception in a *radiocommunication* system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy.

1.167
Permissible Interference*:* Observed or predicted *interference* which complies with quantitative *interference* and sharing criteria contained in these Regulations or in ITU-R Recommendations or in special agreements as provided for in these Regulations.

1.168
Accepted Interference*: Interference* at a higher level than that defined as *permissible interference* and which has been agreed upon between two or more administrations without prejudice to other administrations.

1.169
Harmful Interference*: Interference* which endangers the functioning of a *radionavigation service* or of other *safety services* or seriously degrades, obstructs, or repeatedly interrupts a *radiocommunication service* operating in accordance with these Regulations (CS).

1.170
Protection Ratios (R.F.)*:* The minimum value of the wanted-to-unwanted signal ratio, usually expressed in decibels, at the receiver input determined under specified conditions such that a specified reception quality of the wanted signal is achieved at the receiver output.

The following terms are not formally defined in any regulatory documents. These terms have been in common use, in NTIA.

- ***Allowable Performance Degradation***: Agreed upon degradation in the performance of a radiocommunication system due to interference that is at a sufficiently low level such that the performance capabilities are not significantly compromised. This is often defined in terms of a percentage change in a key performance measure such as voice circuit noise, outage time, or target detection probability.

- ***Interference Protection Criteria (IPC)***: A relative or absolute interfering signal level defined at the receiver input, under specified conditions, such that the allowable performance degradation is not exceeded. This is usually defined as an absolute interference power level I, interference-to-noise power ratio I/N, or carrier-to-interfering signal power ratio C/I.

- ***Sharing Criteria***: Broadly defined criteria that ensure compliance with IPC by specifying technical and operational constraints that permit sharing of a given portion of the spectrum between two or more radio systems or services.

2.3 ELEMENTS OF INTERFERENCE PROTECTION CRITERIA

All of the IPC compiled herein specify permissible interference. IPC are specified for aggregate interfering signals (i.e., total from all interferers) or single-entry interfering signals (i.e., from one interfering system). Aggregate IPC are generally derived from performance objectives and may be used to define the potential interfering signal environment in system design or performance analyses. Single-entry IPC, in turn, are derived from aggregate IPC and are used as “spectrum sharing criteria” directly or as the basis for other forms of sharing criteria (e.g., transmitter power and antenna pointing limits).

IPC for many services are quite dependent upon the specific type of interfering signal received. Nevertheless, a relatively small number of generic classes of interfering signal modulation can define bounding situations. These bounding cases include continuous wave (CW), noise-like, and pulse. For some services, interfering signals characterized as “impulse” and “same as desired signal” are included. Additionally, for some radio services, “short-term” and “long-term” IPC are specified. Table 2-1 summarizes these categories.

IPC are generally given in terms of (C/I) ratios or power (I/N) ratios. The former defines the interfering signal level relative to a known carrier level, whereas the latter defines the level of interfering signal level relative to the system noise level. Some IPC directly specify interfering signal power levels.

Table 2-1

Interfering Signal Types Typically Specified With IPC

Type of Interfering Signal	Definition
Continuous Wave (CW)	A continuous signal with a bandwidth much smaller than the receiver baseband (output) bandwidth.
Noise-Like	A continuous signal that resembles Gaussian white noise over the RF bandwidth of the receiver (uniform power spectral density) or produces the same effect as such a signal.
Pulse	A signal that is turned on and off over time and can be described in terms of a pulse width and pulse repetition rate. The pulses may occur with a constant or changing repetition rate.
Impulse	A pulsed signal having a very short pulse width (often much less than a microsecond). In general, any pulsed signal having a pulse width much smaller than the impulse response of the receiver bandpass under consideration can be considered as an impulse signal.
Same as Desired Signal	All signal modulation parameters are the same as the desired signal except baseband information content (carrier frequencies may differ).
Long-Term	Interfering signal levels that are present most of the time, e.g., levels not exceeded for more than 80% of the time.
Short-Term	Interfering signal levels that are rarely exceeded, e.g., levels not exceeded for more than 99.9% of the time.

For a given service and type of system, IPC must include the parameters listed in Table 2-2 in order to rigorously define the intended degree of protection from interference and enable application of the IPC with detailed, statistical analysis models. Omission of any of the parameters comprising complete IPC may prevent proper analysis of potential interference or performance and could yield less or more than the intended degree of protection.

Table 2-2

Parameters Needed to Fully Specify Aggregate and Single-Entry IPC

IPC Parameter	Typical Units	Description
Power Threshold	dBm, dBW, dB	One or more levels of interfering signal power I, I/N, or C/I.
Reference Bandwidth	Hz, kHz, MHz	Bandwidth in which interfering signal power should be calculated or measured.
Percentage of Time	%	For each threshold, the percentage of time during which the threshold should (C/I) or should not (I or I/N) be exceeded.
Percentage of Locations	%	For each threshold, the percentage of locations at which the threshold should (C/I) or should not (I or I/N) be exceeded. Used in some services to protect operations within a service area.
Special Conditions	various	Information needed for interpretation or application of the thresholds, including as a minimum: whether the IPC are for aggregate or single-entry interference; the type of interfering signal (e.g., noise-like) for which the IPC apply; and for I/N and C/I thresholds the definition of the N or C reference levels. May include duration of permissible threshold exceedance (e.g, # seconds); specific category of victim or interfering stations; and frequency off-tuning associated with the thresholds.

REFERENCES

[1] ITU, Radio Radio Regulations, Geneva, Volume I, Article 1 (2001); Manual, at Chapter 6; 47 C.F.R. § 2.1.

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SECTION 3
OVERVIEW

3.1 INTRODUCTION

This section contains an overview of the detailed findings presented in Sections 4 through 8. At the end of each of these sections, a table presents a summary of the IPC values.

3.2 FIXED AND FIXED-SATELLITE SERVICES

Section 4 presents the IPCs for fixed services (FS) and fixed-satellite services (FSS) with a focus on digital modulation. For the FS, the discussion includes system characteristics and performance objectives of point-to-point, line-of-sight, digital microwave systems (DMS) and IPC values that have been adopted nationally or internationally. The technical parameters of DMS vary over a wide range and cannot be simply characterized. The performance of DMS is generally defined in terms of error performance and availability objectives. DMS are designed to achieve very low bit error ratios with typical per hop availability of 99.999% and higher. As a general rule, IPC values have been developed based on limiting performance degradation due to interference to a small percentage of the design objective values. IPC values for DMS are generally defined in ITU-R Recommendations in terms of I/N, whereas TIA Bulletins and FCC Regulations define the IPC in terms of C/I. For DMS, IPC values are presented in three categories: long-term CW and noise-like interfering signals, short-term CW and noise-like interfering signals, and pulse interfering signals.

For FSS, the discussion first presents representative FSS system characteristics and IPC defined in ITU-R texts for purposes of triggering frequency coordination. Then the desired signal qualities, specified in the form of error performance requirements, are discussed. The IPC are specified as an apportionment of the total noise allowance, while the total noise allowance is indirectly specified as the error performance requirement. Aggregate and single-entry IPC for both long-term and short-term interfering signal levels are given.

3.3 RADIODETERMINATION AND RADIODETERMINATION-SATELLITE SERVICES

Section 5 specifies IPC for systems operating in the radiodetermination and radionavigation satellite services in terms of an I/N, S/I, or interfering signal power level (I). The ITU has developed Part 4 of the M series of ITU-R Recommendations that contain the IPC for radars that rely on reflections or scattering from targets to perform their mission. These IPC are based on CW-like and noise-like interfering signals.

IPC do not consider the statistical nature of the interfering signal power levels and they do not differentiate between long and short-term interfering signal levels. Systems that employ a data link or a transponder have IPC based on an S/I or I forms of IPC. These IPC come from national and international aviation advisory committees. The IPC for these systems tends to be more conservative because they are intended to protect aircraft flight and landing operations under unfavorable circumstances. Depending on the system, the IPC can be for CW, noise, or pulse-like interfering signals.

IPC for radionavigation satellite service (RNSS) were developed to protect receivers that are designed to use the Global Positioning System (GPS) and the Global Navigation Satellite System (GLONASS) operated by the United States, DOD and the Russian Federation to obtain position fixes and timing information. The ITU has developed IPC in the form of I levels for both GPS and GLONASS receivers that are contained in Part 5 of the M series of ITU-R Recommendations. The RTCA has developed IPC for aviation GPS receivers that are also based on I criteria.

3.4 BROADCASTING AND BROADCASTING-SATELLITE SERVICES

Section 6 discusses IPC for broadcasting services (BS) and the broadcasting-satellite services (BSS). The BS involves radio or television transmissions from terrestrial stations for direct reception by the general public. IPC for television are contained primarily in ITU-R Recommendations and FCC Rules. IPC for digital television apply to continuous and/or tropospheric interfering signals. These continuous interfering signals are long-term interfering signals at levels that are not exceeded for a large percentage of the time (e.g., 50%) and generally serve as the baseline for establishing protection criteria. Tropospheric interfering signals are short-term interfering signals at levels exceeded for no more than 1% to 10% of the time.

FCC Rules addressing Frequency Modulation (FM) radio broadcasting define sharing criteria between FM radio stations in terms of minimum distance separations and do not specify general IPC values. IPC are given for interference between Very High Frequency (VHF) television channel 6 and FM radio broadcasting as well as between public safety (land mobile service) and television broadcasting.

IPC for BSS systems are in the forms of C/I, I/N, or power flux density (pfd). They are found primarily in international texts. IPC are listed for both co-channel and adjacent channel interfering signal sources. In some cases, the adjacent channel IPC are a linear function of carrier frequency offset. IPC are specified for BSS service links (space-to-Earth) and their associated feeder links (Earth-to-space). The majority of IPC are for long-term interference protection although statistical approaches are being developed to provide short-term IPC.

3.5 MOBILE AND MOBILE-SATELLITE SERVICES

Section 7 discusses the IPC for mobile service (MS) and mobile-satellite service (MSS). The MS includes land mobile, maritime mobile, and aeronautical mobile services. IPC values provided for the MS in this document have been adopted nationally or internationally. They cannot be characterized simply since the majority of these IPC vary depending on the reference and do not contain all of the parameters required to fully define IPC (e.g., the percentage of time that an interfering signal level can be exceeded, type of interfering signal, single-entry versus aggregate). Most of the IPC are for co-channel operations.

For land mobile applications, TIA Telecommunications Systems Bulletin (TSB) 88-A provides a methodology to determine IPC in terms of the carrier-to-interference-plus-noise power ratio (C/(I+N)) needed for satisfactory voice applications. Specifically, IPC for different desired signal modulation types may be calculated based on the power spectrum of the given signal modulations and Intermediate Frequency (IF) filter selectivity as well as the C/N required to fulfill the specific Channel Protection Criterion (CPC). TIA is currently developing IPC that could be applicable to data applications. A limited number of IPC values are available for the maritime and aeronautical services.

For the MSS, the only source found for IPC is the ITU-R M series of Recommendations. ITU-R does not have MSS IPC specifications for analog desired signals. For MSS systems using the geostationary orbit, IPC are specified as an apportionment of the total noise, while the total noise is indirectly specified as the error performance requirement. For digital signals of MSS systems using non-geostationary orbits, IPC are specified in terms of the maximum aggregate interfering signal level at the input of the receive antenna, and the IPC values depend on the type of service, earth station antenna size, modulation, reference bandwidth, and access method.

3.6 SCIENCE SERVICES

Section 8 discusses IPC for science services. Science services include the space research service, inter-satellite service, space operations, meteorological aids service, Earth exploration-satellite (EES) service, meteorological-satellite (METSAT) service, and radio astronomy. These services support various missions including manned space flights and routine data collection. IPC for science services vary widely and are specified in ITU-R Recommendations.

IPC for science services are generally given as the power spectral density for noise-like interfering signals or the total power of CW interfering signals at the receiver terminals in a specified frequency band. In some cases, both long-term and short-term IPC values are specified. In the case of radio astronomy, IPC are given in the form of power flux density.

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SECTION 4
FIXED AND FIXED-SATELLITE SERVICES

4.1 INTRODUCTION

The IPC for fixed services (FS) and fixed-satellites service (FSS) have been extensively studied and are well documented in the ITU-R Recommendations (S, F and SF Series) and publications issued by the TIA and others. As previously discussed, key factors that influence the establishment of IPC values include: emission type, allocation status of the interferer, and the duration of the interfering signal. This section discusses IPC for the FS and FSS with a focus on digital modulation.

4.2 FIXED SERVICE

4.2.1 General

This sub-section addresses systems in the FS, specifically point-to-point DMS. The following paragraphs discuss source documents defining FS characteristics and performance objectives that are associated with IPC values that have been adopted nationally or internationally. Within this sub-section, all interfering signal power levels are based on the average power unless explicitly stated as peak power.

4.2.2 System Characteristics and Performance Objectives

The technical parameters of DMS vary over a wide range and cannot be simply characterized even within a given frequency band. Typical parameters and characteristics for DMS operating in bands from 800 MHz to 52 GHz are described in Appendix 7 of the ITU-R Radio Regulations Rec. ITU-R/ F.758, F.1101, F.1102 and TIA-TSB 10-F.[1] Appendix 7 of the ITU-R Radio Regulations applies the values shown in Table 4-1 for certain DMS receiver parameters that are used in determination of coordination distances between transmitting earth stations and DMS.

Table 4-1

FS DMS Default Values in Appendix 7 of ITU-R Radio Regulations

Band (GHz)	Receive Antenna Gain (dBi)	Noise Temperature[i] (K)	Fade Margin (dB)	Interference Criteria[ii]	
				I [iii] (dBW/MHz)	Percent of Time (%)
1.4	33	750	33	–107	0.01
1.6-2.7	35	750	33	–107	0.01
5.7-8.4	46	750	37	–103	0.005
10.7-11.5	50	1100	40	–98	0.005
12.5-14.8	52	1100	40	–98	0.005
17.7-19.7	48	1100	25 [iv]	–113	0.005
24.7-29.5	50	2000	25 [iv]	–111	0.005
40-51.4	42	2600	25 [iv]	–110	0.005
47.2-50.2	46	2000	25 [iv]	–111	0.001
71-95	45	2000	25 [iv]	–111	0.002

i. System noise temperature defined at the input to the antenna terminal.
ii. These criteria are applicable to only short-term interfering signals. The interfering signal power I is to be exceeded for no more than the specified percentage of time.
iii. I: level of permissible short-term interfering signal power per MHz from all sources that may be exceeded for no more than the indicated percentage of time. Levels are defined at the input to the antenna terminals. This is based on the methodology defined for short-term interfering signals in RR Appendix 7 for DMS as follows: I = receiver noise + fade margin (all values in dB).
iv. These values are net fade margin assuming the use of automatic transmitter power control (ATPC).

TIA TSB 10-F defines default values for several key parameters that may be used for frequency coordination purposes when more specific information is not available; these parameters and their default values are listed in Table 4-2.

Table 4-2

FS DMS Default Values in TIA TSB 10-F

Parameter		Default Value
Per Hop Annual Path Availability Objective		99.999%
Fade Margin at 10^{-6} BER	2 GHz band	35 dB
	6 GHz band	40 dB
	11 & 13 GHz bands	45 dB
	18 GHz band	40 dB
Receiver Noise Figure		5 dB

The performance of DMS is generally defined in terms of error performance and availability objectives. The performance objectives defined in the ITU-R for the DMS systems implemented at the national level are defined by a series of recommendations, with the most important one from the standpoint of interference considerations being Rec. ITU-R F.1189.[2] In this Recommendation, each direction of a multi-hop DMS system should meet the performance objectives listed in Table 4-3.

Table 4-3

Error Performance Objectives of National FS DMS Systems

Bit Rate (Mb/s)	1.5 to 5	>5 to 15	>15 to 55	>55 to 160	>160 to 3500
Errored Second Ratio (ESR)	0.04A	0.05A	0.075A	0.16A	Under study
Severely Errored Second Ratio (SESR)	0.002A	0.002A	0.002A	0.002A	0.002A
Background Block Error Ratio (BBER)	$2A \times 10^{-4}$	$2A \times 10^{-4}$	$2A \times 10^{-4}$	$2A \times 10^{-4}$	$A \times 10^{-4}$

A = 0.015 + 0.01L/500 for long haul systems
= 0.08 for short haul and local access systems
L = total length of DMS network, rounded up to the next multiple of 500 km
For definition of ESR, SESR, and BBER, see Rec. ITU-R F.1189.

4.2.3 Interference Protection Criteria

As described above, DMS are designed to achieve very low bit error ratios with typical per hop availability of 99.999% or higher. Equivalent outage times are measured in seconds per month. As a rule, IPC values have been developed based on limiting degradation of performance due to interfering signals to a designated percentage of the overall degradation allowance. IPC values for DMS are generally defined in ITU-R documentation in terms of I/N, whereas TIA TSB 10-F and FCC Rules define the criteria in terms of C/I.[3] For DMS, IPC values have been discussed in three areas, namely, long-term interfering signal levels, short-term interfering signal levels, and pulse interfering signals; no information was identified regarding impulse forms of interfering signals.

4.2.3.1 Long-Term Interfering Signals

Virtually all available studies addressing interference to DMS consider low levels of CW, noise-like, and modulated interfering signals as all having the same impact on system performance. For DMS, long-term interfering signals refers to signal levels that are exceeded for 20% or more of the time. One common misconception is that typical DMS design features including high fade margins, forward error correction (FEC), and ATPC circuitry impart a degree of immunity to interfering signals. Both theory and practice show that this is not the case for continuous long-term interfering signals. Both the large fade margins and FEC circuitry (when employed) are key elements in achieving the high reliability objectives; continuous interfering signals simply add to system noise resulting in a reduction in link fade margin.

Regardless of the amount of fade margin or type of FEC designed into the link, any reduction in fade margin due to interfering signals will lead to a reduction in performance. As discussed later, large fade margins and FEC may under certain conditions improve immunity to short-term and pulse interfering signals, respectively. ATPC can actually increase the vulnerability of a DMS receiver to short-term interfering signals. It should be recognized that operationally measuring long-term performance degradation due to interfering signals in FS systems is often difficult, or impractical, because of the very long measurement time period required.

Permissible levels of interference in FS receivers are commonly defined differently depending on the source of the interference. A key ITU-R document that defines performance degradation is Rec. ITU-R F.1094, which describes three categories of interference sources to DMS, namely,[4]

- sources within the FS,
- other services sharing the same band on a primary basis, and
- other emissions and radiations from sources having lesser rights then FS.

The latter includes sources such as secondary allocations, adjacent band emissions, unlicensed systems, and industrial, scientific, and medical (ISM) operations.

The different IPC levels for these three interference categories are derived in that Recommendation by allocating 89%, 10%, and 1% of total allowable degradation to interfering signals from these three categories, respectively. These three categories of interference are discussed below.

- **Interference from Other FS Systems:**

  In this category, I/N should not exceed –6 dB for more than 20% of any month.

The methodology defined in Rec. ITU-R F.1094 allocates the largest amount of performance loss, 89%, to factors within the FS, including outage due to propagation fades, equipment breakdown, as well as interfering signals, but provides no further allocation among these factors. Therefore, this Recommendation does not provide specific guidance for FS interferers.

TIA TSB 10-F is widely recognized domestically and is explicitly accepted by both FCC and NTIA for FS sharing. The IPC specified in TSB 10-F are based on an increase in total noise of 1 dB or, equivalently, a reduction in fade margin of 1 dB. In most FS bands, simultaneous interfering signals from multiple FS transmitters is considered rare and therefore, this criterion is commonly used as a single-entry interference criterion. An exception is the non-government bands at 6 and 11 GHz where high equipment densities occur resulting in possible multiple interfering signal exposures. A multiple exposure allowance (MEA) for these two bands is defined in TIA TSB 10-F as follows:

$$(I/N)_{se} = -6 - MEA \quad \text{(dB)} \qquad (4\text{-}1)$$

where $(I/N)_{se}$ = single-entry long-term interference criteria,
MEA = greater of $\{5, 10\mathrm{Log}(BW_C/BW_I)\}$,
BW_C = receive bandwidth of victim carrier,
BW_I = transmit bandwidth of interferer.

- **Interference from Other Primary Allocated Services:**

  In this category, I/N should not exceed –10 dB for more than 20% of any month.

This level corresponds to a reduction in overall fade margin of about 0.4 dB. It can be shown that, under certain conditions, an I/N of –10 dB corresponds to the 10% performance degradation defined in Rec. ITU-R F.1094 for sharing with other primary services.

- **Interference from Non-Primary Allocated Services:**

  In this category, I/N should not exceed –20 dB for more than 20% of any month.

Rec. ITU-R F.1094 allocates 1% of the total performance degradation to non-primary interfering signal sources. It can be shown that under certain conditions this corresponds to an I/N ratio of –20 dB.

4.2.3.2 Short-Term Interfering Signals

The effects of short-term interfering signal levels have been shown to differ depending on whether the DMS performance in the absence of interfering signals is limited mainly by multipath fading or rain fading. The former occurs in frequency bands below about 13 GHz and the latter above about 17 GHz, with a transition zone between these frequencies.

- **Below 13 GHz**

The generally accepted procedure for assessing the effects of short-term or time varying interfering signal levels on DMS performance in bands below 13 GHz is found in Rec. ITUR F.1108.[5] This methodology, called fractional degradation of performance (FDP), results in very simple equations for non-diversity DMS links as follows:

$$FDP = 10^{[(I/N)_{ave}(dB)]/10} \quad (4\text{-}2)$$

$$(I/N)_{max} \leq 20 \text{ dB}$$

where FDP = Fractional degradation of performance (corresponds to the percentages defined in Rec. ITU-R F.1094),

$(I/N)_{ave}$ = I/N from all sources, averaged over a sufficiently long period of time to account for any periodicity in the interfering signal,

$(I/N)_{max}$ = Maximum instantaneous value of I/N.

In this application, the average I/N does not refer to an average as may result from pulsed type interfering signals, but rather to a CW or noise-like interfering signals that are time varying or intermittent, such as a mobile transmitter or low orbiting satellite. Evaluated in this manner, the FDP methodology accounts for magnitudes of both long-term and short-term interfering signals in any combination.

- **Above 17 GHz**

Rec. ITU-R F.1495 describes IPC to protect the DMS from time varying aggregate interfering signal from other primary services in the 18 GHz band.[6] These IPC include the following two constraints:

$I/N \leq NFM - 5$ (dB) not exceeded more than 0.01% of the time,

$\leq NFM - 1$ (dB) not exceeded more than 0.0003% of the time,

where NFM is the net fade margin taking into account any use of ATPC.

No standardized methodology was identified for the transition region between the above short percentages of time and long-term values.

4.2.3.3 Pulse Interfering Signals

The following discusses interference to DMS systems from pulse interfering signals.

- **DMS Not Employing Forward Error Correction**

As a rule, pulse interfering signal power should be evaluated in terms of peak envelope power over the entire necessary bandwidth of a radio channel of the interfered-with system.[7] Pulse interfering signals in DMS not employing FEC can often be just as damaging to performance, or nearly so, as a continuous noise-like interferer. However, except for the special case described below, few measurements or studies were identified that address pulse interfering signals to DMS not employing FEC. As default criteria, the criteria identified for noise-like interfering signals may be used for pulse interfering signals, but using the peak interfering signal power within the receiver passband.

Rec. ITU-R F.1190 identifies IPC for DMS operated below 7 GHz from fixed and mobile radar systems. It did not take into account the possible use of FEC. Based on the fact that radar antenna mainbeams either rotate or continuously vary, the worst-case, peak interfering signal values only occur intermittently. Consequently, short-term interference criteria may be applied. For mobile radars, the fraction of time that the peak interfering signal levels would occur is further reduced as a result of the radar mobility. The following criteria were established:

Fixed or transportable radar interfering signals : $I_{pk}/N = 0$ dB,

Maritime or land mobile radar interfering signals: $I_{pk}/N = 10$ dB.

- **DMS Employing Forward Error Correction**

Several studies have documented measurements demonstrating that under certain conditions, a receiver employing FEC will be more immune to pulse interfering signals than simple CW or noise-like interfering signals. NTIA completed measurements on a digital satellite receiver that would be similar in functionality to a DMS.[8] For the single case studied, the digital receiver was quite robust in the presence of low duty cycle pulse interfering signals when the duty cycle is less than 0.5%. The NTIA report gives guidance as to the degree of immunity for various pulse widths and duty cycles but additional study would be useful.

The NTIA study shows that for continuous pulse interfering signals having a high duty cycle and/or long pulse characteristic, defined in terms of peak power, resulted in the same degree of degradation as a CW signal.

4.2.4 Possible Mitigating Factors

The technical literature describes a number of situations where the criteria discussed above may be relaxed as follows:

- **Excess Link Margin**

While designers and operators of FS equipment, as is the case of all radio services, aim to achieve the highest possible reliability, in practice each link and the overall network as a whole are normally designed to meet specified error performance and availability objectives. From a practical standpoint, some links in the network may be implemented with excess link margin, higher than necessary to achieve these design objectives. For example:

  - A multi-hop microwave network may be designed around the single worst link in the network using common equipment (transmitters and antennas) for all links. The result is that all but one link in the network may have excess link margin.

  - FS transmitters are generally available in only one or two transmitter power options. The link designer must, in some cases, use the next higher power available, again resulting in possible excess link margin.

As described in TIA TSB 10-F, if excess fade margin is available, the IPC may be relaxed dB for dB.[9]

Using the C/I methodology and default values for fade margin described in TIA TSB 10-F may also allow for relaxed IPC when excess fade margin is present.[10]

- **Relaxed Degradation Criteria**

As described above, the baseline ITU-R degradation allowance for co-primary sharing with DMS FS systems is 10%, or the equivalent I/N of –10 dB. This criterion has been relaxed to 25%, or the equivalent I/N of –6 dB, under certain situations to facilitate sharing, especially in the 1-3 GHz region.

- **Time Sharing**

Most FS systems are operated 100% of the time. Therefore time-sharing in the conventional sense is generally not possible. However, microwave fading due to multipath (i.e., in bands below about 13 GHz) generally occurs during the period midnight to 8:00 am. If a potential interfering system only operates during the 8:00 am to midnight time period, some relaxation of the long-term IPC may be possible for DMS operations below 13 GHz.[11]

- **Short-haul Paths**

The established IPC for the DMS are generally based on long-haul performance requirements with many links connected in tandem. However, interfering signal levels 1-10 dB or more above these IPC values are usually acceptable on shorter or other minimally fading digital paths since long-term performance is not adversely affected.[12]

4.3 FIXED-SATELLITE SERVICE

4.3.1 General

This subsection presents IPC for the FSS. The satellite can be in either the geostationary orbit (GSO) or non-GSO (NGSO). Because of the advantages of digital signal processing, most FSS traffic is digital, or is expected to be digital after earth station receiver upgrades. Therefore, only IPC of digital applications are presented.

A telecommunication satellite channel includes an uplink, the satellite, and a downlink; noise is included in each portion. The signal quality, in terms of error performance requirement, is discussed. The IPC are specified as an apportionment of the total noise allowance, while the total noise allowance is indirectly specified as the error performance requirement.

4.3.2 System Characteristics and Performance Objectives

4.3.2.1 System Characteristics

As in the case of the FS, FSS system characteristics vary over a wide range and cannot be easily characterized. However, Appendix 7 of the ITU-R Radio Regulations defines certain receiver technical parameters for use in determination of coordination distances between receiving FSS earth stations and FS systems. These values, summarized in Table 4-4, may be useful in other spectrum sharing studies.

Table 4-4

FSS Default Values in Appendix 7 of ITU-R Radio Regulations

Band (GHz)[i]	Main-beam Antenna Gain (dBi)	Minimal Elevation Angle (Deg)	Equivalent Uplink Noise, N_{up} (dB)[ii]	Noise Temperature[iii] (K)	Fade Margin, FM (dB)	Interference Criteria[iv]	
						I [v] (dBW/MHz)	Duration (%)
2.5-2.69	N/S	3	1	75	2	–151	0.003
3.4-4.2	N/S	3	1	75	2	–151	0.005
4.5-4.8	N/S	3	1	75	2	–151	0.005
5.15-5.216 N	48.5	3	1	75	2	–151	N/S
6.7-7.075	50.7	3	1	75	2	–151	0.005
7.25-7.75	N/S	N/S	1	75	2	–151	0.005
10.7-12.75	N/S	5	1	150	4	–144	0.003
10.7-11.7 N	51.9	6	1	150	4	–144	0.003
12.5-12.75 N	31.2	10	1	150	4	–144	0.003
15.4-15.7 N	48.4	5	1	150	4	–141	0.003
17.7-18.8	58.6	5	1	300	6	–138	0.003
18.8-19.3	N/S	N/S	0	300	5	–141	0.003
19.3-19.7 N	53.2	5	0	300	5	–141	0.01
19.3-19.7	49.5	10	1	300	6	–138	0.003

i. Bands indicated with an "N" refer to FSS systems using non-geostationary orbits.
ii. N_{up} is an approximation for the portion of the noise in an earth station receiver due to the uplink and satellite intermodulation noise.
iii. Noise temperature defined at the input to the receiving antenna terminals.
iv. These criteria are applicable to only short-term interfering signals.
v. I : level of permissible short-term interfering signal power per MHz from all sources that may be exceeded for no more than the indicated percentage of time ("Duration"). The levels are defined at the input to the antenna terminals. This is based on the methodology defined for short-term interfering signals in Appendix 7 for Digital FSS as follows: I = receiver noise power density + N_{up} + 10 Log($10^{FM/10}$ – 1) .

4.3.2.2 Performance Objectives

In satellite communications, interference regulation is typically an international issue. Thus, FSS frequency coordination procedures, sharing criteria, and IPC have been established by the ITU-R in its "S series" of Recommendations. A satellite operator, an administration, or an entire ITU-R Region may impose more stringent IPC to meet their interference suppression or frequency reuse requirements.

The signal quality of a digital channel is the bit error ratio (BER) after decoding. Different coding schemes yield different BER for the same C/N at the input of the demodulator. Since coding schemes are implemented by system designers, and can vary even during operation, the total noise allowance can be specified only indirectly by the BER requirement. Therefore, in ITU-R Recommendations, the digital channel performance requirement is specified in terms of an array of BER and availabilities. Each transmission link has its own C/N requirement that will enable compliance with the required BER. The IPC are determined by budgeting total system noise allowance to the interfering signal power, where the total system noise is defined as the noise level giving rise to certain BER under clear sky conditions. A summary of these Recommendations are listed in Table 4-5 for various digital channels.

Table 4-5

List of ITU-R Recommendations Related to IPC

	ITU-R Recommendations	
Signal	**Error Performance Objective**	**Interfering Signal Power Apportionment**
Digital connection as part of international network at or above T1 rate	S.1062 [13, i]	S.1323 [14] S.1429 [15, ii]
Digital connection as part of international Integrated Service Digital Network (ISDN)	S.614 [16]	S.735 [17]
Digital Pulse Code Modulation (PCM) telephony, non-ISDN	S.522 [18]	S.523 [19]
Digital Single Channel per Carrier (SCPC) interfered with by TV/FM	N/S	S.671 [20]

i. Performance objectives specific to Asynchronous Transfer Mode (ATM) transmission are in S.1420.[21]
ii. For short-term interfering signals occurring between GSO/FSS and NGSO/FSS systems.

4.3.3 Error Performance Objective

4.3.3.1 Long-term Interfering Signals

FSS digital signal transmission is generally classified as broadband or narrowband. Broadband transmission is defined as data rate of 1.5 Mb/s or above (1.5 Mb/s is called T1 rate in the U.S. and primary rate in ITU-R documents.) Narrowband transmission can be either ISDN at data rate of 64 kb/s, or multiples thereof.

The end-to-end error performance objective of a broadband international connection and the error performance apportionment to a satellite hypothetical reference digital path (HRDP) are given in Rec. ITU Telecommunications Sector (ITU-T) G.826.[22] Based on the G.826 requirements, Rec. ITU-R S.1062 specifies the allowable error performance of a FSS satellite HRDP as follows: the allowable BER at the output of a HRDP should not exceed the mask given in Table 4-6.

Table 4-6

FSS Error Performance Objectives

Bit Rate (Mb/s)	% Total Time, Worst Month	BER/α [i]
1.5	0.2	$7x10^{-7}$
	2	$3x10^{-8}$
	10	$5x10^{-9}$
2	0.2	$7x10^{-6}$
	2	$2x10^{-8}$
	10	$2x10^{-9}$
6	0.2	$8x10^{-7}$
	2	$1x10^{-8}$
	10	$1x10^{-9}$
51	0.2	$4x10^{-7}$
	2	$2x10^{-9}$
	10	$2x10^{-10}$
155	0.2	$1x10^{-7}$
	2	$1x10^{-9}$
	10	$1x10^{-10}$

i. α: average number of errored bits in a burst of errors.
The specification applies to systems operating below 30 GHz.
Rec. ITU-T G.826 uses bit-error-probability (BEP) instead of BER.

The end-to-end error performance objective of a 64 kb/s ISDN international connection and the error performance apportionment to a satellite HRDP are given in Rec. ITU-T G.821.[23] Based on the G.821 requirements, Rec. ITU-R S.614 specifies the error performance of a 64 kb/s satellite HRDP as follows: the BER at the output of a satellite HRDP operating below 15 GHz should not exceed:

- 10^{-7} for more than 10% of any month,
- 10^{-6} for more than 2% of any month,

- 10^{-3} for more than 0.03% of any month.

The performance requirement for PCM telephony is given in Rec. ITU-R S.522 as follows: the allowable BER at the output of the HRDP should not exceed:

- 10^{-6}, 10-minute mean value for more than 20% of any month,
- 10^{-4}, 1-minute mean value for more than 0.3% of any month,
- 10^{-3}, 1-second mean value for more than 0.05% of any month.

4.3.3.2 Short-term Interfering Signals

Rec. ITU-R S.1323 specifies that interfering signals between FSS networks (GSO/FSS, NGSO/FSS, NGSO/MSS feeder link) which are considered short-term and time-variant should:

- be responsible for at most 10% of the time allowance for the BER (or C/N) specified in the short-term performance objectives and corresponding to the shortest percentage of time (or lowest C/N value),
- not lead to loss of synchronization for more than once per x days, with the value of x for further study.

Since ITU-R documents consider the interfering signals between GSO/FSS and NGSO/FSS systems to be short-term, it is specified in Rec. ITU-R S.1429 that 10% of the error performance objective should be allotted to the short-term interfering signals between GSO/FSS and NGSO/FSS systems. Specifically, the allotment is listed in Table 4-7.

Table 4-7

FSS Error Performance Objectives for Short-term Interfering Signals

Bit Rate (Mb/s)	% Total Time, Worst Month	BER/α
1.5	0.02	$7x10^{-7}$
	0.2	$3x10^{-8}$
	1	$5x10^{-9}$
2	0.02	$7x10^{-6}$
	0.2	$2x10^{-8}$
	1	$2x10^{-9}$
6	0.02	$8x10^{-7}$
	0.2	$1x10^{-8}$
	1	$1x10^{-9}$
51	0.02	$4x10^{-7}$
	0.2	$2x10^{-9}$
	1	$2x10^{-10}$
155	0.02	$1x10^{-7}$
	0.2	$1x10^{-9}$
	1	$1x10^{-10}$
Applicable to transmissions below 15 GHz.		

4.3.4 Interference Protection Criteria Summary

ITU-R documents describe a unified interfering signal noise apportionment for all digital FSS channels. Rec. ITU-R S.1432 summarizes the IPC from Recs. ITU-R S.523, S.671, S.735 and S.1323 as follows:[24]

For FSS systems operating below 15 GHz, the apportionment of the allowable aggregate interfering signal is limited to:

- 32% of the clear sky satellite system noise for systems not practicing frequency reuse;
- 27% of the clear sky satellite system noise for systems practicing frequency reuse.

The aggregate interfering signal is further partitioned as follows:

- 25% for other FSS systems for victim system not practicing frequency reuse;
- 20% for other FSS systems for victim system practicing frequency reuse;
- 6% for other systems having co-primary status;
- 1% for all other sources.

Frequency reuse is a technique to utilize either electromagnetic wave polarization isolation or antenna direction isolation (sometimes called coverage area spatial isolation) characteristics to reuse the same frequency band multiple times on the same satellite network. Almost all FSS systems use polarization isolation to use the frequency band twice, and some use direction isolation to further reuse the frequency band multiple times. For example, most of the INTELSAT satellites utilize both isolation characteristics to use the same frequency band 6 times. Frequency reuse generates additional intra-system noise.

Recs. ITU-R S.523, S.671, S.735 and S.1323 specify that the single-entry interfering signal power apportionment is 6%.

Rec. ITU-R S.1323 also specifies that short-term interfering signals between the FSS systems should account for only 10% of the error performance allotment. Rec. ITU-R S.1429 provides more specific information.

4.3.4.1 Coordination Trigger

For a proposed FSS system sharing the same frequency bands with existing or other proposed FSS systems, there is a need to determine if coordination is required to prevent unacceptable mutual interference. The ITU-R provides two methodologies to calculate trigger levels for determining if coordination action is required.

From Rec. ITU-R S.738, the trigger level to determine if coordination action is required between two GSO/FSS systems is:[25]

$$\Delta T/T \geq 6\%, \qquad (4\text{-}3)$$

Where:
- ΔT = Increase in system noise temperature due to interfering signals,
- T = receiver noise temperature,
- $k(\Delta T)B = I$,
- $kTB = N$,
- k = Boltzmann's constant,
- B = carrier bandwidth.

From Rec. ITU-R S.739, a less conservative trigger level to determine if coordination action is required between two GSO/FSS systems is the normalized ΔT/T value, which modifies the ΔT/T value by taking into account the interfered-with and the interfering carriers.[26]

4.3.4.2 IPC for Fixed Satellite Service Broadband Digital Signals

The IPC for broadband digital signal transmission are given in Rec. ITU-R S.1323. The maximum permissible level of interference between GSO/FSS satellite networks is considered time-invariant and should not exceed, under clear-sky conditions,

- for aggregate interfering signal power:

  - 25% of total system noise power level for systems not practicing frequency reuse;
  - 20% of total system noise power level for systems practicing frequency reuse;

- for single-entry interfering signal power: 6% of total system noise power level.

Here the total system noise power level is defined as the noise power at the input of the demodulator, which gives rise to BER of 10^{-6}. The criteria apply to transmissions below 30 GHz.

4.3.4.3 IPC for Fixed Satellite Service Narrowband Digital Signals

The IPC for ISDN transmission are given in Rec. ITU-R S.735. The maximum permissible level of interference from other FSS systems to a 64 kb/s GSO/FSS satellite ISDN link should not exceed, under clear-sky conditions,

- for aggregate interfering signal power:

  - 25% of total noise power level for systems not practicing frequency reuse;
  - 20% of total noise power level for systems practicing frequency reuse;

- for single-entry interfering signal power: 6% of total noise power level.

Here the total noise power level is defined as the noise power at the input of the demodulator which gives rise to BER of 10^{-6}. The criteria apply to systems operating below 15 GHz.

4.4 SUMMARY

Tables 4-7 and 4-8 present summaries of IPC for the FS and FSS.

Table 4-7

Summary of IPC for FS Digital Channels

Systems/ Services	Frequency Bands	Interference Protection Criteria		Reference Bandwidth	% Time	Source Document(s)	Comments
		CW/Noise	Pulse/Other				
FS (DMS)	All FS bands	I/N ≤ –6 dB (Other FS systems)	see rows below	1 MHz	20 (of any month)	TIA TSB 10-F, ITU-R F.1094, NTIA Report 02-393	Long-term interfering Signals
		I/N ≤ –10 dB (Other primary services)					
		I/N ≤ –20 dB (Non-primary sources)					
	All FS bands below 13 GHz	$(I/N)_{av}$ ≤ –10 dB (Other Primary Services)	see rows below	1 MHz	Any	Rec. ITU-R F.1108	Short-term Multipath fading dominates; $(I/N)_{max}$ not to exceed 20 dB
		$(I/N)_{av}$ ≤ –20 dB (Non-primary sources)					
	All FS bands above 17 GHz	I/N ≤ NFM[i] – 5 dB	see rows below	1 MHz	0.01	Rec. ITU-R F.1495	Short-term Rain fading dominates
		I/N ≤ NFM – 1 dB			0.003		

Table 4-7

Summary of IPC for FS Digital Channels (cont)

Systems/ Services	Frequenc y Bands	Interference Protection Criteria		Reference Bandwidth	% Time	Source Document(s)	Comments
		CW/Noise	Pulse/Other				
FS (DMS without FEC)	All FS bands	see rows above	Same criteria as noise using peak interfering signal power	IF Passband	N/S	Rec. ITU-R F.1190	Continuous pulse interfering signal
	Below 6 GHz	see rows above	I/N ≤ 0 dB (Fixed radar source) I/N ≤ 10 dB (Mobile radar source)	IF Passband	N/S	Rec. ITU-R F.1190	Radars with rotating antennas
FS (DMS with FEC)	All FS bands	see rows above	See text	IF Passband	Long-term	NTIA Report 02-393	Continuous or pulse interfering signals
[i.] NFM = Net fade margin taking into account the use of ATPC							

Table 4-8

Summary of IPC for FSS Digital Channels

Systems/ Services	Frequency Bands	Interference Protection Criteria		Reference Bandwidth	% Time	Source Document(s)	Comments
		CW/Noise	Pulse/Other				
FSS	All FSS bands below 15 GHz	$I_{total}/N_{BER} \leq -5.7$ dB $I_{agg, FSS}/N_{BER} \leq -7$ dB $I_{se, FSS}/N_{BER} \leq -12$ dB $I_{co\text{-}prim}/N_{BER} \leq -12$ dB $I_{others}/N_{BER} \leq -20$ dB	N/S	IF Passband	20 (of any month)	ITU-R S.523 ITU-R S.671 ITU-R S.735 ITU-R S.1323 ITU-R S.1432	For FSS system practicing frequency reuse.
	All FSS bands	10% of error performance objective	N/S	IF Passband	Short-term	ITU-R S.1429	Aggregate interfering signals between GSO/FSS and NGSO/FSS

Frequency reuse: a satellite reuses the same frequency band multiple times,
I_{total} total interfering signal power,
$I_{agg, FSS}$ total interfering signal power from other FSS systems,
$I_{se, FSS}$ interfering signal power from another FSS system,
$I_{co\text{-}prim}$ total interfering signal power from services of co-primary status,
I_{others} total interfering signal power from all other sources,
N_{BER} total clear sky noise power giving rise to the BER objective.

REFERENCES

[1] Radio Regulations, Appendix 7; Rec. ITU-R F.758, *Consideration in the development of criteria for sharing between the terrestrial fixed services and other services* (2003); Rec ITU-R F.1101, *Characteristics of digital fixed wireless systems below about 17 GHz* (1994); Rec ITU-R F.1102-1, *Characteristics of fixed wireless systems operating in frequency bands above about 17 GHz* (2002); TIA TSB 10-F, *Interference Criteria for Microwave Systems* (TIA TSB 10-F), Telecommunications Industry Association, Arlington, Virginia (1994).

[2] Rec. ITU-R F.1189-1, *Error performance objectives for constant bit rate digital paths at or above the primary rate carried by digital radio-relay systems which may form part or all of the national portion of a 27 500 km hypothetical reference path* (1997).

[3] 47 CFR §101.105.

[4] Rec. ITU-R F.1094, *Maximum allowable error performance and availability degradations to digital radio-relay systems arising from interference from emissions and radiations from other sources* (1995).

[5] Rec. ITU-R F.1108, *Determination of the criteria to protect fixed service receivers from the emissions of space stations operating in non-geostationary orbits in shared frequency bands* (2000).

[6] Rec. ITU-R F.1495, *Interference criteria to protect the fixed service from time varying aggregate interference from other services sharing the 17.7-19.3 GHz band on a co-primary basis* (2000).

[7] Rec. ITU-R F.1190, *Protection criteria for digital radio-relay systems to ensure compatibility with radar systems in the radiodetermination service* (1995).

[8] NTIA, Report 02-393, *Measurements of Pulsed Co-Channel Interference in a 4-GHz Digital Earth Station Receiver* (2002).

[9] TIA TSB 10-F, at Sec. 4.2.3.

[10] TIA TSB 10-F, at Sec. 2.5.5 & Appendix B.

[11] TIA TSB 10-F, at Annex F-3.5.

[12] TIA TSB 10-F, at Sec. 2.5.6.

[13] Rec. ITU-R S.1062-2, *Allowable error performance for a hypothetical reference digital path operating at or above the primary rate* (1999).

[14] Rec. ITU-R S.1323-1, *Maximum permissible levels of interference in a satellite network (GSO/FSS; non-GSO/FSS; non-GSO/MSS feeder links) in the fixed-satellite service caused by other codirectional networks below 30 GHz* (2003).

[15] Rec. ITU-R S.1429, *Error performance objectives due to internetwork interference between GSO and non-GSO FSS systems for hypothetical reference digital paths operating at or above the primary rate carried by systems using frequencies below 15 GHz* (2000).

[16] Rec. ITU-R S.614-3, *Allowable error performance for a hypothetical reference digital path in the fixed-satellite service operating below 15 GHz when forming part of an international connection in an integrated services digital network* (1994).

[17] Rec. ITU-R S.735-1, *Maximum permissible levels of interference in a geostationary-satellite network for an HRDP when forming part of the ISDN in the fixed-satellite service caused by other networks of this service below 15 GHz* (1995).

[18] Rec. ITU-R S.522-5, *Allowable bit error ratios at the output of the hypothetical reference digital path for systems in the fixed-satellite service using pulse-code modulation for telephony* (1994).

[19] Rec. ITU-R S.523-4, *Maximum permissible levels of interference in a geostationary-satellite network in the fixed-satellite service using 8-bit PCM encoded telephony, caused by other networks of this service,* (1992).

[20] Rec. ITU-R S.671-3, *Necessary protection ratios for narrow-band single channel-per-carrier transmissions interfered with by analogue television carriers* (1994).

[21] Rec. ITU-R S.1420, *Performance for broadband integrated services digital network asynchronous transfer mode via satellite* (1999).

[22] Rec. ITU-T G.826, (*End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections* (2002).

[23] Rec. ITU-T G.821, *Error performance of an international digital connection operating at a bit rate below the primary rate and forming part of an Integrated Services Digital Network* (2002).

[24] Rec. ITU-R S.1432, *Apportionment of the allowable error performance degradations to fixed satellite service (FSS) hypothetical reference digital paths arising from time invariant interference for systems operating below 15 GHz* (2000).

[25] Rec. ITU-R S.738, *Procedure for determining if coordination is required between geostationary-satellite networks sharing the same frequency bands* (1992).

[26] Rec. ITU-R SF.739, *Additional methods for determining if detailed coordination is necessary between geostationary-satellite networks in the fixed-satellite service sharing the same frequency bands,* (1992).

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SECTION 5
RADIODETERMINATION AND RADIODETERMINATION-SATELLITE SERVICES

5.1 INTRODUCTION

Various types of systems operate in the radiodetermination and radiodetermination-satellite services from 30 MHz to 30 GHz. These systems perform a variety of functions in the United States, including monitoring weather phenomena, surveillance of the national airspace and waterways, and providing navigation safety-of-life services.

The radiodetermination service includes radiolocation, aeronautical radionavigation and maritime radionavigation services. With the exception of aeronautical and maritime radionavigation systems that use transponders or transmit information to and from ground stations, these systems rely on passively reflected or scattered radar signal returns to detect and/or track point targets (e.g., planes, ships,). Meteorological aids (weather radars) are also included here because of certain commonalties they have with radars that are operated in the radiodetermination service (i.e., pulse width, pulse rate, and type of transmitter output device). However, weather radars are designed to detect/monitor distributed targets such as clouds, rain, hail, and other weather phenomena. Radar altimeters are unique in that they radiate towards the earth so that aircraft can determine their height above ground.

The form of the IPC for radiodetermination systems that rely on reflected returns is I/N. For aeronautical radionavigation systems that employ a data-link between ground stations and aircraft, the IPC are in the form of S/I, an absolute interfering signal power limit, or other form.

5.2 RADIODETERMINATION SERVICE

5.2.1 Radars operated in the Radiolocation, Aeronautical Radionavigation, Meteorological Aids, and Maritime Radionavigation Services

The technical characteristics and IPC for systems operating in the radiolocation and radionavigation services are contained in Part 4 of the M series of the ITU-R Recommendations. Rec. ITU-R. M.1461 contains the general IPC for these systems if no other IPC are identified in a Recommendation that addresses a particular frequency band.[1] Rec. ITU-R M.1461 also contains guidance on the methodology for analysis of potential interfering signals between radars and systems operating in other services. Table 5-1 lists the relevant ITU-R Recommendations that are in effect and the preliminary and draft new Recommendations (DNR).

Table 5-1

List of Relevant ITU-R Recommendations for Radiodetermination Service

Frequency Band And Service	IPC for CW and Noise-like Interfering Signals	ITU-R Recommendation
420-450 MHz Radiolocation	I/N ≤ –6 dB	M. 1462[2]
1215-1400 MHz Radiodetermination	I/N ≤ –6 dB	M. 1463[3]
2700-2900 MHz Radionavigation and Meteorological Aids	I/N ≤ –10 dB	M. 1464[4]
2900-3100 MHz Maritime Radionavigation	I/N ≤ –6 dB	M. 1313[5]
2900-3100 MHz Radiodetermination and Meteorological Aids	I/N ≤ –6 dB	M. 1460[6]
3100-3700 MHz Radiodetermination	I/N ≤ –6 dB	M. 1465[7]
5250-5850 MHz Radiolocation, Aeronautical Radionavigation, and Meteorological Aids	I/N ≤ –6 dB	M. 1638[8]
8500-10500 MHz Radiodetermination	I/N ≤ –6 dB	Preliminary DNR (Doc.# 8B/282)
13.75-14 GHz Radiolocation and Radionavigation	I/N ≤ –6dB	M. 1644[9]
31.8-33.4 GHz Radionavigation	I/N ≤ –6 dB	M. 1466[10]
33.4-36 GHz Radiodetermination	I/N ≤ –6 dB	M. 1640[11]
All except as noted	I/N ≤ –6 dB	M. 1461

5.2.2 CW and Noise-like Interfering Signals

The baseline ITU-R IPC for interfering signals that appear CW or noise-like in the radar receiver are an I/N of –6 dB for single entry and aggregate interfering signals if multiple interferers are present. The I/N is calculated within the 3 dB IF bandwidth of the victim receiver. The IPC represents a 1 dB increase in the effective noise power of the radar receiver. These IPC do not apply to interfering signals that appear pulse-like in the radar receiver. The I/N of -6 dB applies 100% of the time, and so, it is applied for both long-term and short-term interfering signals. In the ITU, Work Party 8B has developed a work program to address the feasibility of determining IPC based on statistical methods.

The IPC in the ITU-R Recommendations are not referenced to particular radar performance standards such as a decrease in the target probability of detection or an increase in the number of false targets. However, the performance degradation can be determined once the specific system characteristics are known along with the IPC. For maritime radars, the International Maritime Organization (IMO) specifies that radars operating on a vessel must be able to detect a target of 10 square meters at a distance of 2 nautical miles.[12] A European standard exists for the performance of aeronautical surveillance radars that specifies the minimum probability of target detection is 0.90.[13]

NTIA, with assistance from the Federal Aviation Administration (FAA), National Weather Service (NWS) and the United States Coast Guard (USCG), performed tests with maritime radars in the 2900-3100 MHz band and with aeronautical radionavigation radars and meteorological aids in the 2700-2900 MHz band to determine if the current ITU-R I/N IPC are stringent enough to protect their operations. The results of these tests were submitted to the ITU as contributions to Working Party 8B (WP8B) as United States contributions (WP8B Documents 8B/275 and 8B/272 (available from NTIA)). Eurocontrol also submitted a similar contribution to WP8B concerning the aeronautical radionavigation radars (WP8 B Documents 8B/137, 8B/137, 8B/139 (available from NTIA)). Generally, the results of the tests show that the current I/N IPC of –6 dB is not sufficient to protect radar operations in those bands and that the IPC should be no higher than an I/N of –10 dB. The ITU Radiocommunication Assembly has reviewed the contributions and the protection criteria in Rec. ITU-R M.1464 has been changed to an I/N of –10 dB.

5.2.3 Pulse-Like Interfering Signals

IPC for radiolocation and radionavigation receivers for pulse-like interfering signals have not been specifically addressed by the ITU in the M series of Recommendations. However, test results submitted to the ITU by NTIA have shown that radars that contain Interference Rejection (IR) circuitry and/or software can operate in the presence of other similar low duty cycle (< 2%) radars with I/N up to 60 dB without detrimental effect (WP8B documents 8B/207 and 8B/124 (available from NTIA)). These results have been published by the ITU as a Report.[14] Rec. ITU-R M.1372 contains methods for radars to operate in a more efficient manner with other radars.[15] This includes descriptions of typical interference rejection mechanisms that are capable of limiting the effects of pulsed interfering signals in radars.

5.2.4 Impulse-Like Interfering Signals

Neither the ITU, ICAO, RTCA, RTCM, nor the IEC have published any recommendations concerning IPC for impulse-like, ultrawideband (UWB) interfering signals. However, ITU Task Group 1/8 has been formed by the ITU to address the issue of UWB signal characteristics and protection criteria. The ITU has directed that any compatibility studies between UWB devices and systems in other services must be submitted through Task Group 1/8.

In NTIA Special Publication 01-43, NTIA performed compatibility analyses between federal government systems and UWB devices for the FCC UWB rule-making.[16] NTIA chose to use the existing and proposed ITU thresholds for the radiodetermination receiver protection criteria which was an I/N of –6 dB or –10 dB, as per Table 5-6.[17]

The I/N values were based on the average interfering signal power within the IF passband calculated with the RMS voltage. After the UWB Rulemaking was completed, NTIA, USCG, and the British Coast Guard performed interference susceptibility tests on maritime radionavigation radars that operate in the 2900-3100 and 9200-9500 MHz bands with UWB devices. The full results of those tests have been submitted to the ITU and were used for modifying the Recommendations. Generally, the test results show that marine radars in these bands require an I/N of –10 to –6 dB based on average power of the UWB transmitter.

5.2.5 Aeronautical Radionavigation Systems (other than radars using passive reflections)

The IPCs for aeronautical radionavigation systems using transponders or beacons are in the form of S/I, S/(N+I), an absolute interfering signal power limit in dBm, or I/N. The IPCs for some of these systems are published by the ITU, FAA, RTCA, and ICAO. These systems include the Instrument Landing System (ILS) localizer and VOR, Distance Measuring Equipment (DME), Air Traffic Control Radio Beacon (ATCRBS), and the Microwave Landing System (MLS). IPCs for these systems are shown in Table 5-2.

The FAA has developed procedures for coordinating the use and positioning of VOR, DME, TACAN, and ILS localizer systems in FAA publication 6050.32.[18] The material contained in the document is intended to be used by FAA personnel for determining frequency and/or distance separations for these types of systems. The IPCs for these systems, when considering interfering signals from another system of the same type, are in the form of a desired-to-understand signal power ratio (D/U). These D/U-s are based on an availability of 95 percent. The D/U-s are specified for different frequency separations. The D/U is the greatest when the systems are co-channel and is lessened as the frequency separation increases.

Table 5-2

Aeronautical Radionavigation Protection Criteria

System	Frequency Band	IPC
ILS Localizer	108-112 MHz	Signal Dependent, see ITU-R SM.1009-1,[19] ITU-R SM.1140[20]
ILS VOR	108-117.95 MHz	Signal Dependent, see ITU-R SM.1009-1, ITU-R SM.1140
ILS Marker Beacon	74.8-75.2 MHz	I/N ≤ 0 dB[21]
ILS Glide Slope	328.6-335.4 MHz	N/S
DME	962-1213 MHz	I ≤ –99 dBm[22]
MLS	5030-5091 MHz	I ≤ –134 dBm[23]
Radar Altimeters	4200-4400 MHz	S/(N+I) ≥12 dB for FM-CW type altimeters, S/(N+I) ≥ 6 dB for Pulsed type altimeters
ATCRBS	1030 and 1090 MHz	S/I ≥ 12 dB for Interrogator[24] S/I ≥12 dB for Transponder[25]

The IPC in Table 5-2 are for a continuous type of signal and are not apportioned for interference allotment to other services. They are not defined in terms of short- and long-term criteria. The references for each system in Table 5-2 further define the exact nature of the interfering signals.

5.3 RADIONAVIGATION-SATELLITE SERVICE

The primary systems operating in the radionavigation satellite service (RNSS) are GPS, launched and maintained by the United States, and GLONASS, launched and maintained by the Russian Federation. In addition there are space-based augmentation systems (SBAS) and ground-based augmentation systems (GBAS) operating in the RNSS frequency bands.[a] These augmentation systems provide additional information that enhances the integrity, accuracy, continuity, and reliability

[a] In the United States the SBAS is the Wide Area Augmentation System (WAAS) and the GBAS is the Local Area Augmentation System (LAAS). These augmentation systems are capable of supporting both GPS and GLONASS signal formats.

of the RNSS systems. The GPS and GLONASS RNSS systems allow users equipped with appropriate receivers to determine position, velocity, and time (PVT) information free of charge.

GPS is a Code Division Multiple Access (CDMA) based system. That is, each satellite broadcasts ranging signals with different coding sequences to allow the receiver to access the individual satellite signals. GLONASS is a Frequency Division Multiple Access (FDMA) based system. That is, each satellite that is visible to a user receiver broadcasts ranging signals on different frequencies to allow access to individual satellite signals. The various ranging signals are coded at clock rates from 1.023 MHz up to 10.23 MHz.

The frequency bands allocated internationally to the RNSS are 1164-1215 MHz, 1215-1350 MHz, 1559-1610 MHz, and 5000-5030 MHz. GPS provides a ranging signal centered at 1227.6 MHz (L2) and two ranging signals centered at 1575.42 MHz (L1). In the future, GPS is to add ranging signals at 1176.45 MHz (L5) and 1227.6 MHz for civil use. Additional ranging signals will also be added at L1 for military use. GLONASS provides ranging signals in the 1559-1610 MHz and 1215-1350 MHz RNSS bands.

The European Union is also developing a RNSS system referred to as Galileo that will provide ranging signals in the three frequency bands allocated for RNSS. Galileo will use CDMA and will provide ranging signals for both public and restricted use. The operators of this system will charge some kind of user fee or excise tax for the service.

5.3.1 IPC Values for GPS Receivers

GPS receivers are used in a myriad of applications including navigation (aviation, space, maritime, rail, and vehicular), position determination (surveying, asset tracking, enhanced-911), and timing (banking, power distribution, Internet synchronization). The IPC values for GPS receivers will depend on: 1) the receiver application; 2) the category of interfering signal (noise-like, CW, or pulse-like); 3) receiver architecture (coarse/acquisition (C/A), semi-codeless, narrow correlator C/A code); and 4) performance criteria (break-lock, reacquisition, pseudorange error).

Since the IPC for GPS receivers are better organized by the type of application rather than the type of interfering signal, the IPC are presented below for Aviation, Maritime, Land-based, and Space-based uses of RNSS.

5.3.1.1 Aviation Applications

The ITU-R and the RTCA are the primary sources of published IPC values for GPS receivers used in aeronautical applications. General receiver characteristics and IPC values are contained in Rec. ITU-R M.1477 for aeronautical and ground-based receivers.[26] The RTCA has also published IPC values for GPS receivers that are used for aviation applications in RTCA DO-229B.[27]

The GPS IPC in Rec. ITU-R M.1477 are based on a minimum desired signal and are specified for the signal tracking and signal acquisition modes of a GPS receiver. The IPC are applicable to GPS receivers used for airborne navigation (en-route and Category I precision approach)[b] and GPS receivers used in a ground-based network (WAAS reference stations). The airborne receivers are intended for use with the C/A code signal at 1575.42 MHz. The ground-based network receiver employs the semi-codeless architecture that processes both the C/A code and Precision code (P-code) signals at 1575.42 MHz and the P-code signal at 1227.6 MHz. The P-code signals are cross-correlated (does not require knowledge of the coding sequence) to provide a measure of the ionospheric delay to improve the accuracy of the range determination. The cross-correlation is made possible by the fact that the two P-code signals from a given satellite have identical, synchronized code sequences. For each of the receivers addressed in Rec. ITU-R M.1477, IPC are specified for narrowband (CW) and wideband (noise-like) interfering signals. In this context, narrowband is defined as a bandwidth of less than 700 Hz, and wideband is defined as a bandwidth of between 100 kHz to 1 MHz.

The GPS IPC presented in Rec. ITU-R M.1477 are specified in terms of interfering signal power threshold and are summarized in Table 5-3. These IPC are referenced to the input of the GPS receiver and are based on a minimum available GPS C/A code signal level of –134.5 dBm (–130 dBm minimum guaranteed signal level into a –4.5 dBic antenna). The associated performance criteria for GPS aeronautical receivers are in the form of pseudorange error.

The ITU-R is the primary source of published IPC values for GLONASS receivers used in aeronautical applications. General receiver characteristics and IPC are contained in Rec. ITU-R M.1477 for aeronautical receivers. Rec. ITU-R M.1477 specifies IPC applicable to four types of GLONASS aeronautical receivers. These receivers are used for en-route navigation and Category I approaches, SBAS, and Category I/II/III approaches. The GLONASS IPC values in Rec. ITU-R M.1477 are contained in Table 5-4.

[b] Category I, II, and III approaches are required for different landing visibility conditions in terms of vertical visibility ceiling and runway visual ranges; the visibility decreasing with increasing category numbers.

Table 5-3

ITU-R Aeronautical GPS Receiver IPC Values for Wideband and Narrowband Interfering Signals

Receiver Application and Mode	Interfering Signal Power Threshold	
	Narrowband Signal	Wideband Signal
Airborne Navigation		
Tracking Mode	–150.5 dBW	–140.5 dBW/MHz
Acquisition Mode	–156.5 dBW	–146.5 dBW/MHz
Ground-Based Network		
Tracking Mode	–154.5 dBW	–146.5 dBW/MHz
Acquisition Mode	–156.5 dBW	–146.5 dBW/MHz
Note: The IPC values in this table are in terms of the highest aggregate interfering signal power at the receiver input at which the receiver is to operate without unacceptable performance degradation.		

Table 5-4

ITU-R Aeronautical GLONASS Receiver IPC Values for Wideband and Narrowband Interfering Signals

Receiver Mode	Interfering Signal Power Threshold	
	Narrowband Signal	Wideband Signal
Tracking Mode	–149 dBW	–146 dBW/MHz
Acquisition Mode	–155 dBW	–152 dBW/MHz
Note: The IPC values in this table already take into account the effects of GLONASS intra-system interference based on analysis of random codes. The IPC values must account for the aggregate of all other interfering signals.		

The RTCA IPC thresholds are meant to be applied to only aviation GPS receivers. RTCA has developed IPC for initial satellite acquisition, satellite reacquisition, and steady state conditions. They are shown below in Table 5-5, and apply to broadband noise-like interfering signal sources centered at the L1 frequency of 1575.42 MHz. The test procedures for the RTCA IPC are quite extensive and detailed. RTCA DO-229B should be thoroughly reviewed before application of these IPC. The IPC values specified by RTCA are referenced to the input of the GPS receiver and are based on a minimum available GPS C/A code signal level of –134.5 dBm (–130 dBm minimum guaranteed signal level into a –4.5 dBic antenna).

RTCA has published IPC for CW-like signals for aviation GPS receivers in DO-229B that are shown below in Table 5-6. They only apply to receiver steady state conditions.

Table 5-5

Noise-like IPC values for Aviation GPS Receivers

Initial Satellite Acquisition [i]	
Noise Bandwidth	**Total Power Threshold**
100 kHz 20 MHz	$I \le -116.5$ dBm $I \le -103.5$ dBm
[i] Single Trial Pass criteria: The sensor provides a valid position fix within 5 minutes and maintains an accuracy of 15 meters for 95 percent of the time for the next 60 seconds.	
Satellite Reacquisition [ii]	
Noise Bandwidth	**Total Power Threshold**
100 kHz 20 MHz	$I \le -110.5$ dBm $I \le -97.5$ dBm
[ii] Single Trial Pass criteria: The sensor includes the reacquired satellite into the position solution within 10 seconds and maintains an accuracy of 15 meters for 95 percent of the time for the next 60 seconds.	
Steady State Accuracy IPC [iii]	
Noise Bandwidth	**Total Power Threshold**
100 kHz 20 MHz	$I \le -110.5$ dBm $I \le -97.5$ dBm
[iii] The pass/fail criteria are based on the normalized RMS range error statistic of the satellite pseudorange.	

Table 5-6

CW IPC Values for Aviation GPS Receivers

Frequency (MHz)	**Interfering Signal Power Threshold (dBm)**	**Corresponding I/S (dB)**
1525.0	–12.0	122.5
1555.42	–89.5	45.0
1575.42	–120.5	14.0
1595.42	–89.5	45.0
1610.0	–30.0	104.5
1618.0	–12.0	122.5
1626.0	+8.0	142.5
The pass/fail criteria are based on the normalized RMS range error statistic of the satellite pseudorange.		

RTCA has published IPC in DO-229B for pulse-like signals for aviation GPS receivers that are summarized in Table 5-7. These IPC apply only to steady state conditions. These IPC are specified as a function of interfering pulse width, duty cycle, and carrier power.

Table 5-7

Pulsed Interfering Signal IPC for Aviation GPS Receivers

Frequency (MHz)	**GPS only Interfering Signal Pulse Width**			**GPS and WAAS Interfering Signal Pulse**		
1575.42	Pulse width 1 millisecond	I ≤ 20 dBm	Duty Cycle 10 %	Pulse Width 125 μS	I ≤ 20 dBm	Duty Cycle 10 %
The pass/fail criteria are based on the normalized RMS range error statistic of the satellite pseudorange.						

5.3.1.2 Maritime Applications

Maritime GPS receivers are used for navigation in constricted waterways, harbor navigation, docking operations, navigation around bridges, lock operations. IEC has adopted a maximum permissible interference level based on the levels developed by RTCA for aviation receivers.[28] The IPC are specified for a GPS L1 narrow correlator C/A code receiver. For in-band broadband noise-like interfering signals, the IEC has specified that the interfering signal power density should not exceed –140 dBW/MHz in a GPS maritime receiver operating in the tracking mode.

5.3.1.3 Space Based Applications

GPS and GLONASS receivers are used for navigation of spacecraft (real-time and post-processed), spacecraft attitude determination, orbit determination, time synchronization, launch vehicle range safety, and launch vehicle guidance. GPS receivers for space-based applications use the C/A code signal at 1575.42 MHz and the P-code at 1227.6 MHz. IPC for space-based GPS and GLONASS receivers are provided in Rec. ITU-R M.1479.[29]

The GPS IPC for aggregate interfering signal power spectral density at the antenna output from Rec. ITU-R M.1479 are: –135 dBW/MHz for wideband interfering signals and –135 dBW/100 kHz for narrowband interfering signals. These IPC were derived from the 34 dB(Hz) carrier-to-noise density threshold for L1 C/A code acquisition and assume certain desired GPS signal power levels and GPS co-channel interfering signal levels experienced by receivers in low-earth orbit (receiver < 2000 km altitude).

The front-end of a GPS receiver is affected by interfering signals in two ways. The first mechanism affects the high-level limiter diode in the RF front-end. The diode will saturate and prevent burnout of the following receiver stages. Rec. ITU-R M.1479 specifies a preamplifier limiting level of –70 dBW, which causes a temporary loss of signal. If the average RF power at the receiver input exceeds 0 dBW or peak RF power exceeds 10 dBW, the high-level limiter diode may fail because of burnout.

In Rec. ITU-R M.1479, the in-band wideband interfering signal power density at the receiving antenna output of a GLONASS space-based receiver should not exceed –140 dBW/MHz.

5.4 Summary

Table 5-10 presents a summary of IPC for the radiodetermination services.

Table 5-10
Summary of IPC for Radiodetermination Services

Systems Services	Frequency Bands	Interference Protection		Reference bandwidth	% Time	Source Documents	Comments
		CW/Noise	Pulse Other				
Aeronautical Radionavigation (ILS Beacon)	74.8-75.2 MHz	I/N ≤ 0 dB	N/S	System IF Bandwidth	N/S	RTCA DO-143, NTIA Tech Report	None
Radiolocation	420-450 MHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1462	None
Aeronautical Radionavigation (DME)	962-1213 MHz	I ≤ –99 dBm	N/S	System IF Bandwidth	N/S	RTCA DO-189, NTIA RPT 01-143	none
Aeronautical radionavigation (ATCRBS)	1030 and 1090 MHz	S/I ≤ 12 dB	N/S	System IF Bandwidth	N/S	RTCA DO-181A, FAA-E-2716	IPC same for transponder and interrogator
Radiodetermina-tion	All unless otherwise noted	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1461	General ITU-R Recommendation for radars
Radiodetermina-tion	1215-1400 MHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1463	None
Radionavigation and Meteorological	2700-2900 MHz	I/N ≤ –10 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1464	None
Maritime Radionavigation	2900-3100 MHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1313, NTIA RPT 01-143	Revision underway in ITU-R WP8B
Radiodetermina-tion and Meteorological	2900-3100 MHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1460	Revision underway in ITU-R WP8B
Radiodetermina-tion	3100-3700 MHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1465	None

Table 5-10
Summary of IPC for Radiodetermination Services

Systems Services	Frequency Bands	Interference Protection CW/Noise	Interference Protection Pulse Other	Reference bandwidth	% Time	Source Documents	Comments
Radar Altimeters	4200-4400 MHz	S/(N+I) ≥ 12 dB CW Systems, S/(N+I) ≥ 6 dB Pulsed Systems	N/S	System IF Bandwidth	N/S	Manufacturers Brochures	Not much information available
Aeronautical Radionavigation (MLS)	5030-5091 MHz	I ≤ –134 dBm	N/S	26 kHz	N/S	ICAO Radionavigation Aids Annex 10 Vol. 1, NTIA RPT 01-143	Includes 6 dB of safety Margin
Radiolocation, Aeronautical Radionavigation, and Meteorological	5280-5850 MHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1638	New Recommendation in June 2003
Radiodetermina-tion	8500-10500 MHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	REC. ITU-R M.XXX	Preliminary DNR In ITU WP8B
Radionavigation and Radionavigation	13.75-14 GHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1644	None
Radionavigation	31.8-34.4 GHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1466	None
Radiodetermina-tion	33.4-36 GHz	I/N ≤ –6 dB	N/S	System IF Bandwidth	N/S	Rec. ITU-R M.1640	None

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[3] Rec. ITU-R M. 1463, *Characteristics of and Protection Criteria for Radars Operating in the Radiodetermination Service in the Frequency Band 1215-1400 MHz* (2000).

[4] Rec. ITU-R M. 1464, *Characteristics of and Protection Criteria for Radionavigation and Meteorological Radars Operating in the Band 2700-2900 MHz* (2003).

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[6] Rec. ITU-R M. 1460, *Technical and Operational Characteristics and Protection Criteria of Radiodetermination and Meteorological Radars in the 2900-3100 MHz band* (2000).

[7] Rec. ITU-R M. 1465, *Characteristics of, and Protection Criteria for Radars Operating in the Radiodetermination Service in the Frequency Band 3100-3700 MHz* (2000).

[8] Rec. ITU-R M. 1638, *Characteristics of and protection criteria for sharing studies for radiolocation, aeronautical radionavigation and meteorological radars operating in the frequency bands between 5250 and 5850 MHz* (2003).

[9] Rec. ITU-R M. 1644, *Technical and operational characteristics, and criteria for protecting the mission of radars in the radiolocation and radionavigation service operating in the frequency band 13.75-14 GHz* (2003).

[10] Rec. ITU-R M. 1466, *Technical and Operational Characteristics of Radars Operating in the Radionavigation Service in the Frequency Band 31.8-33.4 GHz* (2003).

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[14] Report ITU-R M.2032, *Tests illustrating the Compatibility between Maritime Radionavigation radars and Emissions from radiolocation Radars in the Band 2900-3100 MHz* (2002).

[15] Rec. ITU-R M. 1372-2, *Efficient Use of the Radio Spectrum by Radar Stations in the Radiodetermination Service* (2003).

[16] *Revision of Part 15 of Commission's Rules Regarding Ultra-Wide-Band Transmissions Systems, First Report and Order,* ET Docket No. 98-153, 17 F.C.C. Rcd. 7435 (2002)

[17] NTIA Special Publication 01-43, *Assessment of Compatibility Between Ultrawideband Devices and Selected Federal Systems,* (2001).

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[19] Rec. ITU-R SM. 1009-1, *Compatibility between the Sound-Broadcasting Service in the Band 87-108 MHz and the Aeronautical Services in the Band 108-137 MHz* (1995).

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[23] *International Standards and Recommended Practices Annex 10 to the Convention on International Civil Aviation,* Volume 1 (Radio Navigation Aids) Fifth Edition (1996).

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[25] RTCA/DO-181A, *Minimum Operational Performance Standards for Air Traffic Control Radar Beacon System/ Mode Select (ATCRBS/Mode S) Airborne Equipment,* RTCA (January 1992).

[26] Rec. ITU-R M. 1477, *Technical and Performance Characteristics of Current and Planned Radionavigation-Satellite Service (Space-to-Earth) and Aeronautical Radionavigation Service Receivers to be considered in Interference Studies in the Band 1559-1610 MHz* (2000).

[27] RTCA/DO-229B, *Minimum Operational Performance Standard for GPS/Wide area Augmentation System Airborne Equipment,* RTCA (January 1996).

[28] IEC 61108-1**,** *Global Navigation Satellite System (GNSS), Part 1: Global Positioning System (GPS) Receiver Equipment Performance Standard, Methods of Testing and Required Results,* International Electrotechnical Commission (July 2003).

[29] Rec. ITU-R M.1479, *Technical Characteristics and Performance Requirements of Current and Planned Radionavigation-Satellite Service (Space-to-Space) Receivers to be Considered in Interference Studies in the Frequency Bands 1215-1260 MHz and 1559-1610 MHz* (2000).

SECTION 6
BROADCASTING AND BROADCASTING-SATELLITE SERVICES

6.1 INTRODUCTION

This section describes the IPC from various sources for the broadcasting service (BS) and broadcasting-satellite service (BSS). Although there are several frequency bands below 30 MHz allocated to terrestrial broadcasting for federal use, none are allocated for use by the federal government above 30 MHz for either terrestrial or satellite broadcasting. The IPC are provided herein to facilitate sharing feasibility studies with non-federal BS or BSS receivers. With few exceptions, available IPC values for the BS and BSS are limited to consideration of interfering signals from within the same radio service. The IPC for the BS and BSS are generally specified in terms of C/I values.

6.2 BROADCASTING SERVICE

The BS consists of radio or television broadcasting from terrestrial stations for direct reception by the general public.[a] The BS is presently limited to the frequency bands between 30 MHz and 30 GHz shown in Table 6-1.[b]

Table 6-1

U.S. BS Allocations between 30 MHz and 30 GHz

Bands (MHz)	Service
54-72	TV (channels 2-4)
76-88	TV (channels 5-6)
88-108	FM radio (channels 201-300)
174-216	TV (channels 7-13)
470-608	TV (channels 14-36)
614-746	TV (channels 38-59)
746-806	TV (channels 60-69)[c]

This table shows all of the BS allocations in the United States within the defined frequency range, which are discussed in the following subsections.

a In addition to broadcasting, other types of transmissions are permissible including various data services under FCC regulations.

b All bands are exclusively for non-federal use.

c Television channels 60 through 69 are to be reallocated for commercial LMR and public safety use after the digital television transition date, which is no earlier than December 31, 2006.

6.2.1 Broadcast Television

Spectrum allocated for broadcast television is divided into 6 MHz channels ranging from television channels 2 through 69. Conventional analog transmissions will be replaced by digital television (DTV) over time. Under the transition plan, broadcasters are assigned a locally vacant channel for DTV while temporarily keeping their current analog channel.

The IPC for television are contained primarily in ITU-R Recommendations and FCC Rules (Title 47 CFR, Part 73). In the ITU-R Recommendations, the IPC are listed for 3 different digital television standards: ATSC (Advanced Television Systems Committee), DVB-T (Digital Video Broadcasting-Terrestrial), and ISDB-T (Integrated Service Digital Broadcasting-Terrestrial). DVB-T was adopted by Europe, Africa, Australia, and Greenland. ISDB-T was adopted by Japan. ATSC was adopted by the United States and Canada, thus, this report will focus on ATSC IPC. Analog TV resolutions of 525 and 625 lines are addressed in the ITU, but this report will address only the 525 line M/NTSC analog standard used within the United States.

IPC for DTV have been developed for continuous and tropospheric interfering signals. Continuous interfering signals are defined as long-term interfering signals that are exceeded for 50% or more of the time and generally serve as the baseline for establishing protection criteria. Tropospheric interfering signals are defined as short-term interfering signals that are exceeded for no more than 1 to 10% of the time. In all cases, the IPC for short-term tropospheric interference permit a lower C/I, than that for continuous interfering signals.

6.2.1.1 Television IPC in ITU-R Recommendations

Rec. ITU-R BT.1368 provides IPC for the planning of DTV with respect to analog television.[1] Different IPC are required for planning DTV because the geographic distributions of field strength for DTV signals are not the same as those applicable to analog television signals. Table 6-2 defines IPC for protection of ATSC from ATSC for co-channel and adjacent channel conditions.

Table 6-2

IPC for Protection of ATSC from ATSC Interference

Unwanted Digital Channel	Continuous and Tropospheric Interfering Signals
Lower Adjacent	C/I ≥ –27 dB
Co-Channel	C/I ≥ 15, 19[i] dB
Upper Adjacent	C/I ≥ –27 dB
[i]Based on I/N = 0 dB	

Table 6-3 defines IPC for protection of ATSC from NTSC for cochannel and adjacent channel conditions.

Table 6-3

IPC for Protection of ATSC from NTSC Interference

Unwanted Digital Channel	Continuous and Tropospheric Interfering Signals
Lower Adjacent	C/I ≥ –48 dB
Co-Channel	C/I ≥ 2, 7[i] dB
Upper Adjacent	C/I ≥ –49 dB
[i]Based on use of a comb filter and C/N ≥ 19 dB	

Table 6-4 defines IPC for protection of NTSC from ATSC under cochannel and adjacent channel sharing conditions and only short-term IPC are specified.

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Table 6-4

IPC for Protection of NTSC from ATSC Interference

Unwanted Digital Channel	Tropospheric Interfering Signals (1-10% of time)
Lower Adjacent	C/I ≥ –16 dB
Co-Channel	C/I ≥ 34 dB
Upper Adjacent	C/I ≥ –17, –12[i] dB
[i]For protection of NTSC sound signals	

In the case of interfering signals using an upper adjacent digital channel into an NTSC channel in Table 6-4, the NTSC audio signal degrades more than the video signal and requires a more restrictive IPC.

Rec. ITU-R BT.655 lists IPC for protection of analog television from analog vision and sound signals.[2] Unless otherwise stated, these IPC address tropospheric interfering signals. Where IPC for continuous interfering signals are not available, yet required due to substantially non-fading unwanted signals, the tropospheric values of Table 6-5 increased by 10 dB may be used.

Table 6-5

IPC for Protection of NTSC from NTSC Interference

Unwanted Channel	Tropospheric Interfering Signals (1-10% of Time)
Lower Adjacent	C/I ≥ –13 dB
Co-Channel	C/I ≥ 45 dB
Upper Adjacent	C/I ≥ –10 dB

When the interfering source is a CW signal, a vision signal positive modulated, or FM-sound, and the wanted signal is a vision signal negative modulated, the IPC in Table 6-6 apply.[d] If the interferer is a vision signal negative modulated or an AM-sound signal, a –2 dB and +4 dB offset, respectively, can be applied to the IPC values in Table 6-6.

Table 6-6

IPC for Protection of Negative Modulated Vision NTSC Signal from CW, Positive Modulated Vision NTSC, and FM Sound Signals

Δf (MHz)	–1.5	–1.0	–.75	0.3	1.0	2.5	3.0	3.5	3.7	4.1	4.5
C/I (dB)	0	30	40	50	50	37	45	50	50	45	15
Δf = unwanted carrier frequency minus wanted carrier frequency											

Table 6-7 describes IPC for the case of a wanted FM sound signal and unwanted CW or FM sound carrier with various frequency offsets.

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[d] Vision modulation may be either positive or negative. With positive modulation, the sync pulse tips are held at the zero-modulation level, whilst peak white is 100% and black level around 30%. With negative modulation, the sync tips are at 100%, black level around 77% and peak white 20%. This method has the advantage that there is a portion of the waveform that is always at 100% modulation, so that the receiver can measure the carrier strength and adjust its automatic gain control accordingly.

Table 6-7

IPC for an NTSC Wanted FM Sound Signal Interfered with by an Unwanted CW or FM Sound Carrier

Wanted Sound Signal		Frequency Difference between Unwanted Carrier and Wanted Sound Carrier (kHz)			
		0	15	50	250
FM	Tropospheric (C/I):	32 dB	30 dB	22 dB	–6 dB
	Continuous (C/I):	39 dB	35 dB	24 dB	–6 dB

6.2.1.2 Television IPC in FCC Rules

Section 73.525 of the FCC Rules defines protection requirements for NTSC TV channel 6 from FM radio signals for cochannel and adjacent channel operation as shown in Table 6-8.[3]

Table 6-8
IPC for Protection of NTSC Channel 6 from FM Radio Interference

Unwanted Channel	C/I
Co-channel:	
no offset	39 dB
normal offset[i]	22 dB
Adjacent-Channel:	–12 dB
[i] TV carrier offset by 10 kHz (Section 73.606)	

Section 73.623 of the FCC Rules defines IPC for various combinations of analog and DTV as shown in Table 6-9.[4]

Table 6-9
IPC for Protection of Analog and DTV

Unwanted Channel	C/I
Co-channel:	
DTV into analog TV	34 dB
Analog TV into DTV	2 dB
DTV into DTV	15 dB
First Adjacent Channel:	
Lower DTV into analog TV	–14 dB
Upper DTV into analog TV	–17 dB
Lower analog TV into DTV	–48 dB
Upper analog TV into DTV	–49 dB
Lower DTV into DTV	–28 dB
Upper DTV into DTV	–26 dB

According to Section 90.545 of the FCC regulations, public safety base, control, and mobile transmitters in the 764-776 MHz and 794-806 MHz bands are subject to the IPC to protect existing analog TV and DTV broadcast stations transmitting on TV channels 62, 63, 64, 65, 67, 68, and 69 as described in Table 6-10.[5]

Table 6-10

IPC for Protection of Analog and DTV Stations from Public Safety Transmissions in 764-776 and 794-806 MHz Bands

Unwanted Channel	C/I
Co-channel:	
Analog TV[i]	40 dB
DTV[ii]	17 dB
First Adjacent Channel:	
Analog TV[i]	0 dB
DTV[ii]	–23 dB

[i] At the hypothetical Grade B contour (64 dBµV/m) (85.5 km) of the analog TV station
[ii] At the equivalent Grade B contour (41 dBµV/m) (88.5 km) of the DTV station

6.2.2 FM Radio Broadcast

There is a similar thrust toward digital in the FM radio broadcast band except that there are no plans for reallocation. There are and will continue to be 101 FM radio channels numbered from 200 to 300 with each channel being 200 kHz wide. Channel 200 is centered at 87.9 MHz; channel 201 is 88.1 MHz, and so forth through channel 300, which is centered at 107.9 MHz. Channels 200 to 220 (87.9 to 91.9 MHz) are available for non-commercial educational purposes.[e] The transition to digital will allow broadcasters to transmit both analog and digital versions of their signal in the same 200 kHz channel. This method, called IBOC (in-band on-channel), allows FM stations to transmit the digital signal on the sidebands above and below the FM band center frequency. During hybrid operation, existing (analog) receivers still continue to receive the analog signal. New receivers being developed are expected to incorporate both modes of reception. If the digital signal cannot be decoded or is lost by the receiver, the new receiver will automatically switch to the analog FM signal.

The following subsections list IPC (C/I) of radio frequency signals at the receiver input, and are specifically chosen such that they achieve a defined level of demodulated audio frequency S/I at the receiver output.

6.2.2.1 Broadcast FM Radio IPC in ITU-R Recommendations

Rec. ITU-R BS.412 shows a list of IPC to protect monophonic and stereophonic desired signals from continuous and tropospheric interfering signal sources.[6] The interfering signal sources are other broadcast FM radio signals. As expected the IPC shown in Table 6-11 decrease with increasing frequency separation between the desired and undesired carriers, with the exception of the stereophonic case where the IPC decreases only after first increasing through the first 50 kHz of separation. The 75 kHz maximum deviation associated with the IPC in Table 6-11 corresponds to the limit for FM radio broadcasting within the United States.[f]

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[e] Channel 200 (87.9 MHz) is available by certain Class D stations only on a non-interference basis to TV Channel 6 and adjacent channel non-commercial educational FM stations.

[f] The 75 kHz maximum frequency deviation is specified under “Percentage modulation” in 47 CFR 73.310.

Table 6-11
FM Radio Broadcasting IPC

Carrier Frequency Separation (kHz)	C/I (dB) Using Maximum Frequency Deviation of ±75 kHz			
	Monophonic		Stereophonic	
	Continuous	Tropospheric	Continuous	Tropospheric
0	36.0	28.0	45.0	37.0
25	31.0	27.0	51.0	43.0
50	24.0	22.0	51.0	43.0
75	16.0	16.0	45.0	37.0
100	12.0	12.0	33.0	25.0
125	9.5	9.5	24.5	18.0
150	8.0	8.0	18.0	14.0
175	7.0	7.0	11.0	10.0
200	6.0	6.0	7.0	7.0
225	4.5	4.5	4.5	4.5
250	2.0	2.0	2.0	2.0
275	–2.0	–2.0	–2.0	–2.0
300	–7.0	–7.0	–7.0	–7.0
325	–11.5	–11.5	–11.5	–11.5
350	–15.0	–15.0	–15.0	–15.0
375	–17.5	–17.5	–17.5	–17.5
400	–20.0	–20.0	–20.0	–20.0

6.2.2.2 Broadcast FM Radio IPC in FCC Regulations

The FCC Part 73 Rules define sharing criteria between FM radio stations in terms of minimum distance separations and do not specify general IPC values. However, as an exception defined in Sections 73.213 and 73.215, stations at locations authorized prior to November 16, 1964, that did not meet the separation distances required by Section 73.207 and have remained continuously short-spaced[g] since that time must meet the requirements defined in Table 6-12.[7]

[g]A site that does not meet the minimum separation requirement is “short spaced”.

TABLE 6-12

IPC for Protection of Broadcast Radio from other Broadcast Radio Stations[h]

Unwanted Channel	C/I
Co-channel [i]	20 dB
First Adjacent Channel [ii]	6 dB
[i]where the desired signal is based on field strength levels at 50% of all locations for 50% of the time [ii]where the undesired signal is based on a field strength levels at 50% of their locations for 10% of the time	

6.3 BROADCASTING-SATELLITE SERVICE

The Broadcasting-Satellite Service (BSS) broadcasts radio or television programming from earth orbiting satellites either directly to individual consumer households or to community antenna television (CATV) feeds. Currently there are BSS allocations between 30 MHz and 30 GHz serving the United States and Possessions in the following bands:[i]

2310-2360 MHz[j]
2500-2690 MHz[k]
12.2-12.7 GHz
17.3-17.7 GHz[l]

The IPC for the BSS are typically expressed as wanted-to-unwanted signal power ratios (C/I) at the receiver input. The majority of these IPC are intended to protect against long-term interfering signals. Short-term IPC allow higher interfering signal levels, but for only a limited percentage of time. Some of these short-term IPC also limit the maximum amount by which the threshold may be exceeded so that the degradation may not actually result in a loss of service (outage) under otherwise ideal conditions. The IPC can also be expressed as a power flux density (pfd) within the BSS

[h] IPC for radio stations not meeting the distance separation requirements.

[i] All of these bands are allocated to the BSS for non-federal use only.

[j] According to allocation footnote US327, the band 2310-2360 MHz is allocated to the BSS (sound) and complementary terrestrial BS on a primary basis. Such use is limited to digital audio broadcasting and is subject to the provisions of Resolution 528 of the ITU RR.

[k] According to allocation footnote NG101, the band 2310-2360 MHz is allocated to the BSS (sound) and complementary terrestrial BS on a primary basis. Such use is limited to digital audio broadcasting and is subject to the provisions of Resolution 528 of the ITU RR.

[l] This allocation will come into effect in 2007 (see allocation footnote NG163).

service area. In most of these cases the pfd is determined from C/I criteria, thus, C/I is the primary IPC listed in this section.

One form of BSS IPC is expressed as overall C/I. The overall C/I value is the ratio of the wanted carrier power to the sum of all interfering signals in a given channel including both the feeder up links and service down links. This is depicted in equation (6-1).

$$\left(\frac{C}{I}\right)_{Overall} = \left(\left(\frac{C}{I}\right)_{Up}^{-1} + \left(\frac{C}{I}\right)_{Down}^{-1}\right)^{-1} \qquad (6\text{-}1)$$

Where $(C/I)_{overall}$, $(C/I)_{up}$, and $(C/I)_{down}$ are numerical (not decibel) carrier to interfering signal power ratios for the overall end-to-end link, the up link, and down link, respectively.

IPC for the BSS are expressed for adjacent channel as well as co-channel interfering signals. Co-channel IPC have no carrier frequency offset, which is defined as the difference between the unmodulated carrier frequencies of the unwanted and wanted signals if the same type of modulator is used in both channels. Adjacent-channel IPC are determined through a series of measurements made with frequencies of the unwanted signal varying approximately ±30 MHz from the wanted signal. Rec. ITU-R BO.1293 gives instructions on how to create adjacent channel interfering signal masks for protection of the BSS.[8]

IPC for video signals are determined through subjective means as described in Rec. ITU-R BO.600.[9] The only noise that should be present on the picture when assessing protection ratios is the receiver thermal noise. The protection ratios are determined based on pictures having a signal-to-unweighted-noise ratio of not less than 36 dB, in order that system performance should not be limited by possible masking of interfering signals by noise.

The IPC for sound transmissions are determined through measurement by means of an objective method. Noise is measured after demodulation in order to obtain the condition that the signal-to-weighted-noise ratio within the sound channel does not exceed a specified value.[m] Table I of ITU-R BO.634-4 lists the parameters influencing the protection ratio for sound signal together with a suggested reference case to establish a common set of test conditions for measurements made by different administrations.[10] ex-CCIR Report 796 specifies a measurement method for determination of IPC for sound.[11]

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[m] Weighting refers to the practice of filtering prior to measurement to reduce certain noise frequency components in a manner corresponding to human audio perception. Without weighting, the true S/N would be underestimated, because humans cannot perceive all the noise entering the measurement equipment.

The majority of IPC for BSS are defined for protecting analog signals. However, in the United States, BSS is implemented using digital techniques.

The IPC for the BSS are primarily found in the Radio Regulations (RR) and ITU-R Recommendations of the BO Series. The following sections describe the IPC by source. Key factors that influence the establishment of IPC values, including interfering signal type, allocation status of the interferer, and duration of the interfering signals, are also provided when available.

6.3.1 Appendix 30 (AP30) of the ITU Radio Regulations[12]

Annex 3 of AP30 shows the IPC applicable for protecting the BSS from all types of terrestrial interfering signals.[13] Figure 6-1 depicts the IPC and shows that there is a carrier frequency offset dependence for all terrestrial interfering signals except from amplitude modulated multi-channel television systems, in which case the IPC is a constant C/I = 35 dB. For all cases, the IPC are only applied when the necessary bandwidth of the terrestrial station overlaps the necessary bandwidth of the BSS assignment.

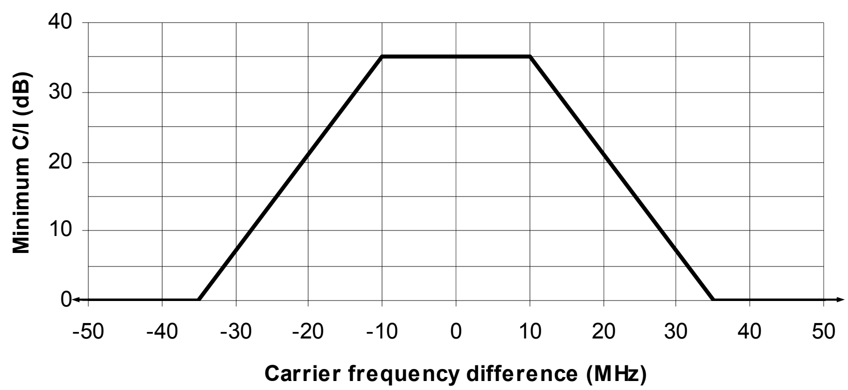

Figure 6-1. Protection Ratio for BSS against a single entry terrestrial service (except AM multi-channel TV systems)

In Section 3.4 of Annex 5 of AP30, the following aggregate IPC specify C/I values for protection of analog and digital assignments from analog television signals: 24 dB (co-channel), 16 dB (adjacent channel). The following IPC specify C/I values for protection of digital assignments from digital emissions: 21 dB (co-channel) 16 dB (adjacent channel).

For protection of FM-TV from other FM-TV transmissions, Figure 6-2 shows an IPC template of C/I values as a function of carrier frequency offset.

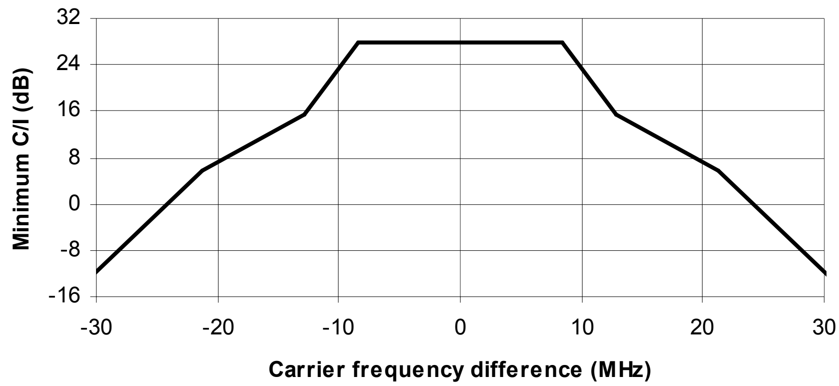

Figure 6-2. Protection Ratio template (FMTV/FMTV), for planning of BSS systems in Region 2

Section 3 of Annex 1 of AP30 includes a section on IPC protecting the BSS in Regions 1 and 2 in the band 12.2-12.5 GHz and in Region 3 in the band 12.5-12.7 GHz from other proposed like assignments.[14] These IPC are intended to protect assignments in Regions 1 and 3 from proposals in Region 2, and vice versa.

Annex 6 of AP30 provides protection requirements for sharing between services in the 12 GHz band. The IPC are provided as C/I with the stipulation that interfering signal levels shall not be exceeded for 99% of the worst month. The C/I values for BSS protect TV/FM signals from TV/FM signals of the BSS, FSS, FS, and BS. The C/I values listed are 30 dB for aggregate interfering signals, and 35 dB for single-entry interfering signals. Figure 6-3 shows how much these values are reduced as a function of carrier frequency offset.

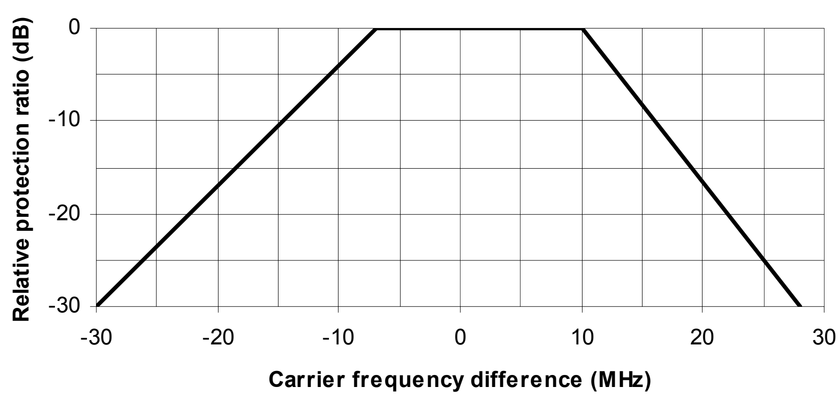

Figure 6-3. Reference case protection ratios relative to co-channel values

6.3.2 Recommendation ITU-R BO.1297[15]

This Recommendation suggests that the IPC in RR AP30 and AP30A for BSS and associated feeder links were inadequate due to technological improvements made in the BSS. It proposes the IPC shown in Table 6-13. All IPC are specified as C/I where I represents the aggregate interfering signal. The IPC for the overall path are based on equation (6-1).

Table 6-13

Aggregate Protection Ratios for Planning Revision of RR AP30 and AP30A in Regions 1 and 3

	Co-channel Protection Criteria	Adjacent Channel Protection Criteria
Feeder link path	C/I ≥ 30 dB	C/I ≥ 22 dB
Down link path	C/I ≥ 24 dB	C/I ≥ 16 dB
Overall path	C/I ≥ 23 dB	C/I ≥ 15 dB

6.3.3 Recommendation ITU-R BO.1444[16]

This Recommendation provides guidance for protecting the 12 GHz BSS and associated 17 GHz feeder links from the earth and space station emissions of all non-GSO (NGSO) FSS satellite networks operating in the same frequency band. It states that these NGSO FSS emissions may be responsible for at most 10% of the time allowance(s) for unavailability of the given C/N value(s) as specified in the performance objectives of the desired network, where N is the total noise level in the noise bandwidth associated with the wanted carrier including all other non-time-varying interfering signals. This seems to indicate that NGSO FSS can exceed a C/(N+I) which is equal to the required BSS C/N (including margins) for 10% of the permitted outage, where I only includes the aggregate of NGSO FSS emissions. This is less strict than requiring that I include other unwanted NGSO FSS networks.

The Recommendation also indicates that at no time should interfering signals lead to a loss of video picture continuity in the desired digital GSO BSS and associated feeder-link network under clear-sky conditions. Loss of video picture continuity includes error concealment mechanisms such as “freeze frame” (repeat last frame), blank (black) frame, or other techniques. The clear sky link margins above these video picture continuity thresholds must also be specified. If none are indicated, 1.5 dB is assumed. ITU-R BO.1444 also points out that the impact of interfering signals on degradation is dependent on rain. Specifically, rain increases system noise temperature and attenuates the interfering and desired signals.

6.3.4 FCC Report and Order 00-418[17]

Pursuant to this document, Section 101.105 of CFR Title 47 allows MVDDS transmitters to increase Direct Broadcast Satellite (DBS) outage at 12 GHz by up to 2.86% or up to 10 minutes per month.[n] Certain DBS providers have proposed that the 10% additional outage applied to the aggregate from all other competing uses of the 12 GHz band, whereas the 2.86% additional outage applied to any one provider (e.g. MVDDS).[18] Included in that document is a section (Appendix H) that proposes a method for converting percentage of unavailable time into a C/I value.

6.3.5 Mitre Technical Report[19]

The Mitre Corporation was hired by the FCC to study the DBS and MVDDS compatibility issue.[20] Among other things, the report created a rain attenuation model and used it to determine minimum C/I criteria for various U.S. cities as a function of percentage increase of unavailability of a particular DBS satellite. Table 6-14 represents the case where MVDDS increases DBS unavailability by 10%. These values are based on equation (6-2) below, where the effects of MVDDS are included in an effective rain margin, A_{eRm}. For their study, Mitre assumed that the interfering signal was not attenuated during a DBS rain event.[o]

Table 6-14

Minimum C/I to Satisfy 10% Additional Link Outage (MVDDS interfering with DBS)

Location	Minimum C/I (dB)
Boston, MA	23.8
Chicago, IL	23.7
Denver, CO	27.3
Fargo, ND	25.7
Houston, TX	22.4
Los Angeles, CA	22.1
Miami, FL	21.9
Phoenix, AZ	21.6
Seattle, WA	25.5
Washington, D.C.	22.9

$$\left(\frac{C}{I}\right)_{required} = \left(\frac{C}{I}\right)_{rainy\ sky} + A_{eRm} \qquad (6\text{-}2)$$

[n] MVDDS refers to Multi-channel Video Distribution and Data Service.

[o] DBS earth stations were pointed toward the southern hemisphere, whereas MVDDS sites were assumed to be to the north, and possibly unaffected by the same rain fronts.

In Equation (6-2), $(C/I)_{required}$ is the minimum acceptable single-entry clear-sky IPC, $(C/I)_{rainy\ sky}$ are the IPC in the presence of rain without considering the effects of MVDDS, and A_{eRm} is the effective rain margin plus another margin to account for the increased aggregate due to the presence of MVDDS.[p]

6.3.6 Spectrum XXI

Spectrum XXI is a program intended for use by all government agencies to aid in submitting systems for spectrum authorization by NTIA. Included in the program is an IPC table to aid in interference analyses. To protect broadcasting systems Spectrum XXI recommends the use of I/N = –10 dB. This IPC is believed to be a conservative value intended for an initial test for harmful interference. If a potential interference source passes this test, compatibility is assumed without any further analyses.

6.3.7 Further Study

More work must be done to determine appropriate IPC involving digital signals. ITU-R Report 634-4 suggests the test matrix given in Table 6-15:

Table 6-15

Wanted and Unwanted Signal Interactions Requiring Further Study

Wanted Signal	Unwanted Signal
Digital	Digital
Digital	FM
FM	Digital
Digital	AM-VSB[q]
AM-VSB	Digital

Rec. ITU-R BO.600 provides a basis for further studies needed to define more precisely the test conditions and procedures for developing BSS IPC for digital modulation. More study is also needed to determine IPC for protection of digital BSS signals from pulsed interfering signals due to planned adjacent band reallocation at 17 GHz.

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[p] Rain margin (A_{Rm}) simply accounts for the decrease in C due to rain. A_{eRm} also accounts for the increase in I due to the presence of MVDDS.

[q] VSB refers to vestigial side-band.

6.4 SUMMARY

Table 6-16 contains a summary of IPC for the BS and BSS.

TABLE 6- 16
Co-channel IPC Summary Table for BS and BSS

Service/Systems	Frequency Bands	Interference Protection		Reference Bandwidth	% Time	Source Document	Comments
		CW and Noise	Pulse/ Other [i]				
BS (ATSC)	54-794 MHz	N/S	C/I ≥ 15 dB	N/S	>50	Rec. ITU-R BT.1368	Interferer is ATSC
BS (ATSC)	54-794 MHz	N/S	C/I ≥ 19 dB	N/S	>50	Rec. ITU-R BT.1368	Interferer is ATSC, based on I/N ≥ 0dB
BS (ATSC)	54-794 MHz	N/S	C/I ≥ 2 dB	N/S	>50	Rec. ITU-R BT.1368	Interferer is NTSC
BS (ATSC)	54-794 MHz	N/S	C/I ≥ 7 dB	N/S	>50	Rec. ITU-R BT.1368	Interferer is NTSC, based on comb filter and C/N = 19 dB
BS (NTSC vision)	54-794 MHz	N/S	C/I ≥ 34 dB	N/S		Rec. ITU-R BT.1368	Interferer is ATSC
BS (NTSC)	54-794 MHz	N/S	C/I ≥ 45 dB	N/S	1-10	Rec. ITU-R BT.655	Interferer is analog vision and sound
BS (NTSC)	54-794 MHz	N/S	C/I ≥ 55 dB	N/S	>50	Rec. ITU-R BT.655	Interferer is analog vision and sound
BS (TV FM sound)	54-794 MHz	C/I ≥ 32 dB	C/I ≥ 32 dB	N/S	1-10	Rec. ITU-R BT.655	Interferer is CW or FM sound
BS (TV FM sound)	54-794 MHz	C/I ≥ 39 dB	C/I ≥ 39 dB	N/S	>50	Rec. ITU-R BT.655	Interferer is CW or FM sound
BS (TV channel 6)	54-794 MHz	N/S	D/U ≥ 39 dB	N/S	N/S	Part 73.525	Interferer is FM radio
BS (analog TV)	54-794 MHz	N/S	D/U ≥ 34 dB	N/S	N/S	Part 73.623	Interferer is DTV
BS (DTV)	54-794 MHz	N/S	D/U ≥ 2 dB	N/S	N/S	Part 73.623	Interferer is analog TV
BS (DTV)	54-794 MHz	N/S	D/U ≥ 15 dB	N/S	N/S	Part 73.623	Interferer is DTV

TABLE 6- 16
Co-channel IPC Summary Table for BS and BSS

Service/Systems	Frequency Bands	Interference Protection		Reference Bandwidth	% Time	Source Document	Comments
		CW and Noise	Pulse/ Other [i]				
BS (NTSC)	764-776 MHz 794-806 MHz	N/S	D/U ≥ 40 dB	N/S	N/S	Part 90.545	Interferer is public safety, based on Grade B contour
BS (DTV)	764-776 MHz 794-806 MHz	N/S	D/U ≥ 17 dB	N/S	N/S	Part 90.545	Interferer is public safety, based on Grade B contour
BS (stereo FM radio)	88-108 MHz	N/S	C/I ≥ 45 dB	N/S	N/S	Rec. ITU-R BS.412	Interferer is BS (stereo FM), long-term
BS (stereo FM radio)	88-108 MHz	N/S	C/I ≥ 37 dB	N/S	N/S	Rec. ITU-R BS.412	Interferer is BS (stereo FM), short-term
BSS earth station	11.7-12.5 GHz	N/S	C/I ≥ 21 dB	N/S	N/S	Article 11, AP30-61	Based on WRC 2000
BSS earth station	12.2-12.7GHz (Region 2)	C/I ≥ 35 dB	N/S	N/S	N/S	Annex 3, AP30-88	Applies to single entry terrestrial interferers whose carrier frequency is within 10 MHz of BSS
BSS earth station (analog and digital)	Any	N/S	C/I ≥ 24 dB	N/S	N/S	AP30-109	Interferer is aggregate from analog BSS
BSS earth station (digital)	All Bands	N/S	C/I ≥ 21 dB	N/S	N/S	AP30-110	Interferer is digital BSS
BSS earth station (FM/TV)	All Bands	N/S	C/I ≥ 28 dB	N/S	N/S	AP30-111	Interferer is BSS FM/TV

TABLE 6- 16
Co-channel IPC Summary Table for BS and BSS

Service/Systems	Frequency Bands	Interference Protection		Reference Bandwidth	% Time	Source Document	Comments
		CW and Noise	Pulse/ Other [i]				
BSS space station	17.3-18.1 GHz	N/S	I/N ≥ –14 dB	N/S	N/S	AP30A-128	Interferer is FSS or BSS space station
BSS space station	17.8-18.1 GHz	N/S	I/N ≥ –15.2 dB	N/S	N/S	AP30A-128	Interferer is FSS earth station
BSS TV/FM	12 GHz	N/S	C/I ≥ 30 dB aggregate C/I ≥ 35 dB single-entry	N/S	N/S	AP30-131	Interferer is fixed or broadcasting TV/FM
BSS earth stations	17.3-17.8 GHz	N/S	I/N ≥ –18 dB	N/S	N/S	ITU-R Doc 4-9-11/90-E	Interferer is FSS earth station to NGSO
BSS Feeder Link	All Bands	N/S	C/I ≥ 30 dB	N/S	N/S	Rec. ITU-R BO.1297	Interferer is BSS. This is an aggregate IPC
BSS earth stations	12 GHz	N/S	C/I ≥ 27.3 dB	N/S	10%	Mitre Technical Report	Interferer is MVDDS limited to 10% of outage
Broadcasting	All Bands	I/N = -10 dB	I/N ≤ -10 dB	N/S	N/S	Spectrum XXI	Conservative criterion for a first level interference analysis.

[i] Other refers to interference from BS and BSS system.

REFERENCES

[1] Rec. ITU-R BT.1368, *Planning criteria for digital terrestrial television services in the VHF/UHF bands* (2002).

[2] Rec. ITU-R BT.655, *Radio-frequency protection ratios for AM vestigial sideband terrestrial television systems interfered with by unwanted analog vision signals and their associated sound signals* (2000).

[3] 47 CFR 73.525, *TV Channel 6 protection,* Federal Communications Commission (October 2002).

[4] Telecommunications, Part 73, Section 623, *DTV applications and changes to DTV allotments,* Federal Communications Commission (October 2002).

[5] 47 CFR 90.545, *TV/DTV interference protection criteria,* Federal Communications Commission (October 2002).

[6] Rec. ITU-R BS.412, *Planning standards for terrestrial FM sound broadcasting at VHF* (1998).

[7] 47, CFR 73.213, Federal Communications Commission (2002); 47 CFR 73.215, *Contour protection for short spaced assignments*, Federal Communications (2002).

[8] Rec. ITU-R BO.1293-1, *Protection Masks and Associated Calculation Methods for Interference into Broadcast-Satellite Systems Involving Digital Emissions* (2000).

[9] Rec. ITU-R BO.600-1, *Standardized set of test conditions and measurement procedures for the subjective and objective determination of protection ratios for television in the terrestrial broadcasting and the broadcasting-satellite services* (1986).

[10] Reports of the CCIR, Annex to Volumes X and XI – Part 2, Report 634-4, *Broadcasting-Satellite Service (Sound and Television) Measured interference protection ratios for planning television broadcasting systems* (1990).

[11] Recommendations and Reports of the CCIR, Volume X, Broadcasting Service (Sound), Report 796, *Determination of Radio-Frequency Protection Ratio for Frequency-Modulation Broadcasting Receivers* (1978).

[12] Appendix 30, of the ITU Radio Regulations, *Provisions for all services and associated Plans and List for the broadcasting-satellite service in the frequency bands 11.7-12.2 GHz (n Region 3), 11.7-12.5 GHz (in Region 1) and 12.2-12.7 GHz (in Region 2)* (2001).

[13] Appendix 30 of the ITU Radio Regulations, Annex 3, *Method for determining the limiting interfering power flux-density at the edge of a broadcasting-satellite service area in the frequency bands 11.7-12.2 GHz. (in Region 3), 11.7-12.5 GHz (in Region 1) and 12.2-12.7 GHz (in Region 2) and for calculating the power flux-density produced there by a terrestrial station* (2001).

[14] Appendix 30 of the ITU Regulations, Annex 1, Section 3, *Limits to the change in power flux-density to protect the broadcasting-satellite service in Regions 1 and 2 in the band 12.2-12.5 GHz and in Region 3 in the band 12.5-12.7 GHz* (2001).

[15] Rec. ITU-R BO.1297, *Protection Ratios to be Used for Planning Purposes in the Revision of the Appendices 30 (Orb-85) and 30A (Orb-88) Plans of the Radio Regulations in Regions 1 and 3* (1997).

[16] Rec. ITU-R BO.1444, *Protection of the BSS in the 12 GHz band and associated feeder links in the 17 GHz band from interference caused by non GSO FSS systems* (2000).

[17] *Authorizing Multi Video Distribution and Data Service in the Direct Broadcast Satellite Band at 12 Ghz, First Report and Order and Further Notice of Proposal Rule Making*, ET Docket No. 98-206, RM-9147, RM-9245, FCC 00-418, 16 F.C.C. Rcd 4096 (2000).

[18] *Amendments of parts 2 and 25 of the Commission 's Rules to permit operation of NGSO FSS systems co-frequency with GSO and terrestrial systems in the Ku-band frequency range*; For the Memorandum Opinion and Order, ET Docket No. 98-206. FCC, 03-97, 18 F.C.C. Rcd.8428, 8435, n. 47 (2003).FCC 03-97 (FCC 03-97), page 7, footnote 47 for more information.

[19] Mitre Technical Report, *Analysis of Potential MVDDS Interference to DBS in the 12.2-12.7 GHz Band,* Mitre Corporation, McLean, Virginia (April 2001).

[20] FCC 03-97, §7.

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SECTION 7
MOBILE AND MOBILE SATELLITE SERVICES

7.1 INTRODUCTION

Various station classes operate in the Mobile Service (MS) and the Mobile Satellite Service (MSS) within the 30 MHz to 30 GHz frequency range. The MS is further subdivided into the following services: land mobile (LMS), maritime mobile (MMS), aeronautical mobile (AMS), aeronautical mobile route (AM(R)S),[a] and aeronautical mobile off-route (AM(OR)S) services.[b] The MSS includes the following services: land mobile-satellite (LMSS), maritime mobile-satellite (MMSS), aeronautical mobile-satellite (AMSS), aeronautical mobile-satellite route (AMS(R)S), and aeronautical mobile-satellite off-route (AMS(OR)S) services.

7.2 MOBILE SERVICE

7.2.1 Mobile Service in General

For the MS, the nature of the interfering signal source (i.e., CW, noise, pulse, and impulse) was not always defined with the IPC in the various reference sources. The IPC extracted from the references are for co-channel operations unless otherwise stated. The percentages of time and locations for which the IPC apply were not provided in most cases.

- **NTIA Manual (Annex I)**

Annex I of the NTIA Manual describes a procedure to evaluate interference in the 162-174 MHz and 406-420 MHz bands, both of which have a primary allocation for the MS.[1] Annex I provides receiver sensitivity (desired signal power) values in the presence of low, average, and high noise environments.[c] These values are also intended to represent interfering signal thresholds. Table 1 of Annex I states that unacceptable interference may result if predicted received interfering signal power levels exceeds this threshold for more than 10% of the time at 50% of the locations.

- **Spectrum XXI**

For digital mobile systems Spectrum XXI[d] uses I/N = –6 dB for the MS.[2] This is

[a] The R designation indicates communications relating to safety and regularity of flights primarily along national or international civil air routes.
[b] The (OR) designation indicates communications primarily outside national or international civil air routes.
[c] This noise refers to the RF noise environment.
[d] Spectrum XXI is a program intended for use by all government agencies to aid in submitting systems for spectrum approval by NTIA.

based on allowing interfering signals to cause a 1 dB increase in the receiver noise level. For analog mobile systems, an IPC of I/N = 0 dB is specified.

- **ITU Report**

CCIR Report 826 shows IPC for AM and FM voice systems and interfering signals from direct sequence (DS) and frequency hopping (FH)[e] spread spectrum transmissions and similar interfering signal sources.[3] Characteristics of the desired signals analyzed are shown in Table 7-1.

Table 7-1

Characteristics of Mobile Systems Analyzed

Modulation Type[i]	Receiver IF Bandwidth (kHz)	Receiver Antenna Gain (dBi)	Receiver Noise Figure (dB)	Modulation Index	Peak Deviation (kHz)	E.I.R.P. (dBm)
A3E	8	3	6	1.0	N/S	50
F3E	16	3	6	1.67	±5	50
[i] A3E indicates amplitude modulated double-sideband analog voice. F3E indicates frequency modulated analog voice.						

Table 7-2 provides the range of pulse widths and repetition rates over which the measurements were taken to determine the IPC for FH interfering signals. All IPC associated with this source are listed in Table 7-3 according to two performance levels. The two performance levels were taken to be articulation index (AI) values of 0.7 and 0.9, where AI is a measure of voice intelligibility. The 0.7 AI threshold value marks the point at which degradation to intelligibility begins to appear, and the 0.9 value is the threshold between marginally commercial and good commercial quality. The IPC stated are conservative values insofar as they are the greatest S/I required to ensure an AI of at least 0.7 or 0.9 for all values of pulse width, pulse repetition frequency and off-tuning for which measurements had been performed.

Table 7-2

Parameter Ranges for FHSS Interfering Signal Measurements

Modulation Type	Pulse Width (μs)		Pulse Repetition Frequency (pps)	
	From	To	From	To
A3E	5	1000	10	400
F3E	1	1000	40	1000

[e] The FH signal was treated as a pulsed signal.

Table 7-3

IPC to Protect against Various Interfering Signal Types

Modulation Type	IPC for Interference Type[i]			Comments
	Same	DSSS	FHSS	
A3E	S/I ≥ 7 dB for AI = 0.7	S/I ≥ 21 dB for AI = 0.7	S/I ≥ 19 dB for AI = 0.7	S/N ≥ 45 dB is assumed for the protected system.
	S/I ≥ 13 dB for AI = 0.9	S/I ≥ 28 dB for AI = 0.9	S/I ≥ 31 dB for AI = 0.9	
F3E	S/I ≥ 6 dB for AI = 0.7	S/I ≥ 8 dB for AI = 0.7	S/I ≥ 19 dB for AI = 0.7	S/N ≥ 22 dB is assumed for the protected system.
	S/I ≥ 20 dB for AI = 0.9	S/I ≥ 15 dB for AI = 0.9	S/I ≥ 30 dB for AI = 0.9	

[i] DSSS is direct sequence spread spectrum, FHSS is frequency hopping spread spectrum, "Same" indicates that the interfering signal has the same modulation as the desired signal.

7.2.2 Land Mobile Service

The following subsections describe IPC for protection of the LMS.

7.2.2.1 Federal Government Standards

- **National Telecommunications and Information Administration**

Appendix D of NTIA Spectrum Reallocation Final Report listed indoor and outdoor interfering signal thresholds at –117 and –119 dBm, respectively for personal communications services (PCS) operating at 1850-1990 MHz.[4] This assumed an allocation of 10% of the total interference budget to external interfering signal sources. These threshold values were extracted from Rec. ITU-R M.687.[5]

NTIA Special Publication 01-46 "The Potential for Accommodating Third Generation Mobile Systems in the 1710-1850 MHz Band" provides two IPC thresholds for IMT-2000 Mobile and Base Stations that are listed in Table 7-5, depending on the type of modulation and access technique.[6] For example, for mobile stations, an I value of -110 dBm for Code Division Multiple Access (CDMA) for a bandwidth of 1.25 MHz, and an I value of -131 dBm (Enhanced Data Rates for GSM Evolution Edge) for a 0.03 MHz bandwidth for land mobile base stations. The thresholds provided in the report were the most recent industry-approved characteristics, but actual 3G systems may have different parameters.

NTIA TM 87-122 presents operational and performance characteristics of radios equipped with the Data Encryption Standard.[7] A portion of the report describes a capture effect inherent in FM systems that causes the wanted signal to reduce interference from the unwanted signal when the received wanted signal is stronger than the unwanted signal by the amount of the capture ratio. For the analog mode the capture ratio varied from 2 dB at a high S/N to 5 dB at a low S/N. In the digital mode the capture ratios ranged between 2 and 15 dB for high and low S/N conditions respectively.

- **Federal Communications Commission**

The following FCC Rules from Title 47 of the Code of Federal Regulations, were investigated for potential IPC: Part 22 (Public Mobile Services), Part 24 (Personal Communications Services), Part 27 (Miscellaneous Wireless Communications Services), Part 80 (Stations in the Maritime Service) Part 90 (Private Land Mobile Radio Services), Part 95 (Personal Radio Services).

Section 90.187 of the Commission Rules discusses interference from trunked systems to conventional VHF and UHF networks. A subsection defines objectionable interference as occurring when the interfering signal contour (19 dBμ for VHF, and 21 dBμ for UHF) of a proposed trunked station would intersect the service contour (37 dBμ for VHF, and 39 dBμ for UHF) of an existing station. This is equivalent to a protection ratio of 18 dB.

Section 80.773 of the Commission Rules states that a VHF public coastal station that shares a frequency with an incumbent private land mobile radio (PLMR), the coastal station must provide a 10 dB or greater protection ratio with respect to the PLMR signal level.

7.2.2.2 Industry Association Standards

Telecommunications Industry Association (TIA)

TIA TSB 88-A provides a section called "Interference Prediction" which states: "It is assumed that for any modulation combination, it is valid to treat adjacent channel interference as additional noise power that enters a receiver's IF filter".[8] Interference between different modulation types may be calculated based on the power spectrum of the given transmitter modulation and the IF filter selectivity and IF C/N for a specified channel performance criterion (CPC)[f] in a Rayleigh faded channel. The C/(I+N) then becomes a predictor of CPC." TIA TSB 88-A provides a list of various modulation types with associated IPC for various delivered audio quality (DAQ)[g] ratings and desired BER. Portions of the contents of this table are listed in Table 7-5.

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[f] CPC is a measure of the BER and vehicular Doppler fading rate required to deliver a specific mean opinion score (MOS) for the specific modulation.

[g] DAQ is a measure similar to Circuit Merit with additional definitions for digitized voice and a static SINAD equivalent intelligibility when subjected to multipath fading.

7.2.2.3 International Recommendations

International Telecommunication Union

Rec. ITU-R M.687-2 estimates the level of interfering signals in IMT-2000 receivers that can be tolerated using a link power budget based on personal mobile systems being interference limited, rather than noise limited. As a basis for IPC, 10% of the total interference budget is allocated to the external interfering signal sources. The IPC specify maximum permissible aggregate interfering signal power levels that can be received by personal stations without significantly degrading the quality of service.

Rec. ITU-R M.1073 deals with LMS cellular communications in the bands at 800, 900, 1800, and 1900 MHz ranges.[9] Section 4.4 indicates that a co-channel protection ratio of C/I = 9 dB is permissible and accommodates a possible cellular frequency reuse corresponding to a 9-cell cluster.

Rec. ITU-R M.1388 provides a coordination threshold level to protect a digital system in the LMS, which is already operating in the 1452-1492 MHz band in one country from proposed space stations in the Broadcasting Satellite Service.[10] The threshold is –150 dB(W/m^2) in 4 kHz bandwidth for all angles of arrival and applies as a general protection criterion for the LMS in that band until additional studies are completed.

Annex 2 of Rec. ITU-R SM.851 provides IPC for protection of land mobile services from the BS.[11] The listed IPC protect only analog and some digital voice land mobile systems from analog AM vestigial sideband television and analog FM audio broadcasting signals. For television signals, IPC are specified for land mobile channels that fall within 0.5 MHz of the vision carrier. For FM audio broadcasting signals, IPC are listed as a function of frequency separation between carriers of the two services. Rec. ITU-R SM. 851 also notes that since the IPC are based on interfering signals using the same type of modulation as the wanted signal, correction factors may be required before applying them to sharing with the BS. The IPC from this source are listed in Table 7-5.

7.2.3 Maritime Mobile Service

The following subsections list IPC for protection of MMS systems.

7.2.3.1 Federal Agencies

- **National Telecommunications Information Administration**

NTIA Report 99-362 evaluates the performance of various 25 kHz marine radios.[12] Specifically, the objectives of this report were to:

1) measure the SINAD of marine radios operating in a shipboard environment;

2) identify the sources of interference and interference mechanisms; and
3) investigate ways to mitigate and preclude the interference.

NTIA Report 00-376 investigates EMC between marine automatic identification (AIS) and public correspondence (PC) systems in the maritime mobile VHF band.[13] Both closed system and radiated tests were performed on PC and AIS operations for different frequency offsets. The test results were given in terms of interference-to-signal (I/S) power ratios for different test conditions and scenarios. Further evaluation is required to determine if IPC can be developed from the test results.

NTIA Report 00-343 assesses the compatibility between 25 and 12.5 kHz channelized marine VHF radios.[14] Specifically, the objectives of the report were to:

1) determine the susceptibility of various 12.5 kHz and 25 kHz radios to adjacent/interstitial channel interference, and
2) evaluate the interoperability of various 12.5 kHz and 25 kHz radios.

Both bench and radiated tests and results were conducted and results were provided in terms of S/I values. Further evaluation is required to determine if IPC can be developed from the test results.

NTIA Report 99-363 assesses various 25 kHz radios to determine compliance with the performance standards for marine VHF radio receivers contained in International Electrotechnical Commission (IEC) document 1097-7.[15] Specifically, tests were performed to determine: sensitivity, co-channel rejection ratio, adjacent channel selectivity, intermodulation response, and blocking. Testing results are provided in terms of I/S power ratios. Further evaluation is required to determine if IPC can be developed from the test results.

- **Federal Communications Commission**

Section 80.773 of the FCC Rules "Co-channel interference protection" states "Where a VHF public coast station geographic area licensee shares a frequency with an incumbent VHF public coast station licensee, the ratio of desired to undesired signal strengths must be at least 12 dB within the service area of the station." These IPC are listed in Table 7-5.

7.2.4 Aeronautical Mobile Service

The following subsections describe IPC for protection of AMS systems.

7.2.4.1 International Recommendations

International Civil Aviation Organization (ICAO)

ICAO Annex 10, Volume V specifies provisions concerning the deployment of

VHF frequencies and avoidance of harmful interference.[16] Section 4.1.5.1 indicates that points at the protection heights and at the limit of the functional service range of each facility are separated by distances not less than that required to provide a desired to undesired signal power ratio of 14 dB. Attachment A to that section states that the application of the 14 dB planning criteria assumes that it is highly unlikely that two aircraft will be at the maximum edge of their respective service volumes and at the closest point between these two volumes.

7.3 MOBILE SATELLITE SERVICE

For the MSS, the only sources of IPC are the ITU-R M series Recommendations. For digital MSS carriers, the IPC are specified as apportionment of the total noise. A summary of these Recommendations for various types of systems is listed in Table 7-4.

Table 7-4

List of ITU-M Recommendations Related to IPC for the MSS

	ITU-R Recommendations	
System	**Performance Objective**	**Interfering Signal Power Apportionment**
MMSS voice circuit	M.547[17]	N/S
MMSS telegraph	M.552[18]	N/S
GSO/AMSS non-ISDN	M.1229[19]	M.1183[20]
GSO/AMS(R)S	M.1037[21]	M.1234[22]
GSO/MSS ISDN	M.1476[23]	M.1183
GSO/MSS non-ISDN	M.1181[24]	M.1183
NGSO/MSS downlink	M.1230[25]	M.1231[26], M.1232[27]
NGSO/MSS Cospas-SarSat uplink	M.1478[28]	M.1478

7.3.1 Geostationary Satellite Service

From Rec. ITU-R M.1183, for a GSO/MSS digital channel in the 1-3 GHz band, the permissible levels of interference caused by other GSO/MSS systems and GSO/FSS systems should exceed the levels shown in Table 7-6 for no more than (100-x)% of any month. Here x is the percentage of time availability as defined under the relevant ITU-R Recommendations on performance objectives (Table 7-4). The total noise power is defined as the noise power at the input of the demodulator, which gives rise to the desired performance.

From Rec. ITU-R M.1234, for a GSO/AMS(R)S digital channel in the bands 1545 to 1555 MHz and 1646.5 to 1656.5 MHz, the permissible level of interference caused by other AMS(R)S, AMSS, and FSS should not exceed:

- for aggregate interfering signals, 20% of total noise power,

* for single-entry interfering signals, 6% of total noise power.

Here the total noise power is defined as the noise power at the input to the demodulator, which would give rise to the BER performance objective specified in Rec. ITU-R M.1037.

7.3.2 Nongeostationary Satellite Service - Downlink

From Rec. ITU-R M.1231, for FDMA and spread spectrum multiple access (SSMA) NGSO/MSS downlinks in the 137-138 MHz band, the maximum aggregate interfering signal level at the input of the receiving antenna is specified in Table 7-6. The data are derived based on two sample systems addressed in Rec. ITU-R M.1231.

From Rec. ITU-R M.1232, for FDMA or SSMA NGSO/MSS downlinks in the 137-138 MHz band, the maximum single-entry interfering signal level at the input of the receiving antenna from a NGSO/MSS system or any non-MSS system is specified in Table 7-6. These IPC are derived assuming two interfering NGSO/MSS systems and one interfering terrestrial system.

7.3.3 NGSO Satellite Service (Cospas-Sarsat Uplink)

From Rec. ITU-R M.1478, the protection criteria for Cospas-Sarsat uplinks operating in the 406-406.1 MHz band are specified in terms of interfering signal power flux density (pfd) or spectral pfd (spfd) at the Cospas-Sarsat satellite receive antenna. These IPC are listed in Table 7-6.

7.4 SUMMARY

A summary of the IPC for the MS and MSS are provided in Tables 7-5 and 7-6 respectively.

Table 7-5
Summary of IPC for Digital Channels in the Mobile Services

<table>
<tr><th rowspan="2">Systems/ Services</th><th rowspan="2">Frequency Bands</th><th colspan="2">Interference Protection</th><th rowspan="2">Reference bandwidth</th><th rowspan="2">% Time</th><th rowspan="2">Source Document</th><th rowspan="2">Comments</th></tr>
<tr><th>CW/Noise</th><th>Pulse/ Other</th></tr>
<tr><td>Mobile</td><td>162-174 and 406.1-420 MHz</td><td>I/N ≤ 0 dB</td><td>N/S</td><td>IF Passband</td><td>10</td><td>NTIA Manual Annex I</td><td>I/N of 0 dB should not be exceeded at more than 50% of locations</td></tr>
<tr><td>Mobile (Digital)</td><td>30-1215 MHz</td><td>I/N ≤ –6 dB</td><td>N/S</td><td>IF Passband</td><td>N/S</td><td>Spectrum XXI</td><td>N/S</td></tr>
<tr><td>Mobile (Analog)</td><td>30-1215 MHz</td><td>I/N ≤ 0 dB</td><td>N/S</td><td>IF Passband</td><td>N/S</td><td>Spectrum XXI</td><td>N/S</td></tr>
<tr><td rowspan="4">Mobile (AM Double-Sideband Voice)</td><td rowspan="4">All</td><td>S/I ≥ 21 dB (AI = 0.7)</td><td>S/I ≥ 19 dB (AI = 0.7)</td><td rowspan="2">N/S</td><td rowspan="2">N/S</td><td rowspan="4">CCIR Report 826</td><td rowspan="2">Assumes S/N ≥ 45 dB. IPC for “pulse/other” are for pulse interfering signals.</td></tr>
<tr><td>S/I ≥ 28 dB (AI = 0.9)</td><td>S/I ≥ 31 dB (AI = 0.9)</td></tr>
<tr><td rowspan="2">N/S</td><td>S/I ≥ 7 dB (AI = 0.7)</td><td rowspan="2">N/S</td><td rowspan="2">N/S</td><td rowspan="2">Assumes S/N ≥ 45 dB. IPC for “pulse/other” are for A3E interfering signals.</td></tr>
<tr><td>S/I ≥ 13 dB (AI = 0.9)</td></tr>
<tr><td rowspan="4">Mobile (FM Voice)</td><td rowspan="4">All</td><td>S/I ≥ 8 dB (AI =0.7)</td><td>S/I ≥ 19 dB (AI = 0.7)</td><td rowspan="2">N/S</td><td rowspan="2">N/S</td><td rowspan="4">CCIR Report 826</td><td rowspan="2">Assumes S/N ≥ 22 dB. IPC for “pulse/other” are for pulse interfering signals.</td></tr>
<tr><td>S/I ≥ 15 dB (AI = 0.9)</td><td>S/I ≥ 30 dB (AI = 0.9)</td></tr>
<tr><td rowspan="2">N/S</td><td>S/I ≥ 6 dB (AI = 0.7)</td><td rowspan="2">N/S</td><td rowspan="2">N/S</td><td rowspan="2">Assumes S/N ≥ 22 dB. IPC for “pulse/other” are for F3E interfering signal.</td></tr>
<tr><td>S/I ≥ 20 dB (AI = 0.9)</td></tr>
</table>

Table 7-5(cont)
Summary of IPC for Digital Channels in the Mobile Services

		CW/Noise	Pulse/ Other				
Land Mobile (IMT-2000 and PCS personal stations)	Below 3 GHz	I ≤ –117 dBm (Indoor)	N/S	N/S	N/S	Rec. ITU-R M.687 and NTIA Special Publication 95-32	Maximum permissible aggregate interfering signal power levels that can be received without significantly degrading the quality of service.
		I ≤ –119 dBm (Outdoor)					
Land Mobile (IMT 2000 Mobile Stations)	Below 3 GHz	I ≤ –110 dBm (CDMA 2000 1X)	N/S	1.25 MHz	N/S	NTIA Special Publication 01-46	Desired signal at sensitivity level, I/N ≤ –6 dB
		I ≤ –105 dBm (CDMA 2000 3X)	N/S	3.75 MHz			
		I ≤ –111 dBm (TD-CDMA)	N/S	3.84 MHz			
		I ≤ –105 dBm (W-CDMA)	N/S	N/S			

Table 7-5(cont)
Summary of IPC for Digital Channels in the Mobile Services

Systems/ Services	Frequency Bands	Interference Protection		Reference bandwidth	% Time	Source Document	Comments
		CW/Noise	Pulse/ Other				
Land Mobile (IMT 2000 Mobile Stations)	Below 3 GHz	I ≤ –94 dBm (CDMA 2000 1X)	N/S	1.25 MHz	N/S	NTIA Special Publication 01-46	Desired signal 10 dB above sensitivity level
		I ≤ –90 dBm (CDMA 2000 3X)	N/S	3.75 MHz	N/S		
		I ≤ –92 dBm (TD-CDMA)	N/S	3.84 MHz			
		I ≤ –89 dBm (W-CDMA)	N/S	N/S			
Land Mobile (IMT 2000 Base Stations)	Below 3 GHz	I ≤ –114 dBm (CDMA 2000 1X)	N/S	1.25 MHz	N/S	NTIA Special Publication 01-46.	Desired signal at sensitivity level, I/N ≤ –6 dB
		I ≤ –109 dBm (CDMA 2000 3X)	N/S	3.75 MHz			
		I ≤ –131 dBm (UWC)	N/S	0.03 MHz			
		I ≤ –123 dBm (UWC)*	N/S	0.22 MHz			
		I ≤ –115 dBm (TD-CDMA)	N/S	3.84 MHz			

Table 7-5(cont)
Summary of IPC for Digital Channels in the Mobile Services

Systems/ Services	Frequency Bands	Interference Protection		Reference bandwidth	% Time	Source Document	Comments
		CW/Noise	Pulse/ Other				
Land Mobile (IMT 2000 Base Stations)	Below 3 GHz	I ≤ –98 dBm (CDMA 2000 1X)	N/S	1.25 MHz	N/S	NTIA Special Publication 01-46.	Desired signal 10 dB above sensitivity level
		I ≤ –93 dBm (CDMA 2000 3X)	N/S	3.75 MHz			
		I ≤ –115 dBm (UWC)	N/S	0.03MHz			
		I ≤ –107 dBm (UWC)	N/S	0.22 MHz			
		I ≤ –96 dBm (TD-CDMA)	N/S	3.84 MHz			
Land Mobile	N/S	S/I ≥ 2 dB (A) S/I = 4 dB (D)	N/S	N/S	N/S	NTIA TM 87-122	high S/N
		S/I ≥ 5 dB (A) S/I = 15 dB (D)	N/S	N/S	N/S		low S/N
Land Mobile	N/S	N/S	S/I ≥ 18 dB	N/S	N/S	47 CFR 90.187	Interfering signal source is a trunked radio.
Land Mobile	VHF	N/S	S/I ≥ 10 dB	N/S	N/S	47 CFR 80.773b	Interferer is a public coast station.

Table 7-5(cont)
Summary of IPC for Digital Channels in the Mobile Services

Systems/ Services	Frequency Bands	Interference Protection		Reference bandwidth	% Time	Source Document	Comments
		CW/Noise	Pulse/ Other				
C4FM[I] (IMBE)	VHF, UHF	$\frac{C}{I+N}$ ≥16.5 dB [II]	N/S	12.5 kHz	N/S	TSB88-A Table A-1	Values are for a DAQ = 3.4. This is the criteria assumed for federal government operations at the boundary of a protected service area as stated in TSB88-A (Table 1). Other values for differing DAQ are provided in TSB-88 A Table A-1.
CQPSK[III] (IMBE)	VHF, UHF	$\frac{C}{I+N}$ ≥16.5 dB [II]	N/S	12.5 kHz	N/S	TSB88-A Table A-1	
π/4[IV] DQPSK (IMBE) TDMA	VHF, UHF	$\frac{C}{I+N}$ ≥15.2 dB [II]	N/S	12.5 kHz	N/S	TSB88-A Table A-1	
EDACS®[V] (IMBE)	VHF, UHF	$\frac{C}{I+N}$ ≥16.7 dB [VI]	N/S	12.5 kHz	N/S	TSB88-A Table A-1	
CVSD "XL"[VII]	VHF, UHF	$\frac{C}{I+N}$ ≥ 12 dB [VIII]	N/S	25 kHz	N/S	TSB88-A Table A-1	
C4FM[IX] (VSELP)	VHF, UHF	$\frac{C}{I+N}$ ≥17.4 dB [X]	N/S	12.5 kHz	N/S	TSB88-A Table A-1	
Cellular	800, 900, 1800, 1900	C/I≥9 dB	N/S	N/S	N/S	Rec. ITU-R M.1073	N/S
Digital LMS	1452-1492	pfd ≤ –150 $W/m^2/4$ kHz	N/S	N/S	N/S	Rec. ITU-R M.1388	Rec. notes that further IPC development is needed.

Table 7-5(cont)
Summary of IPC for Digital Channels in the Mobile Services

	Frequency Bands	Interference Protection		Reference bandwidth	% Time	Source Document	Comments
		CW/Noise	Pulse/ Other				
Analog speech, 12.5-25 kHz channels	VHF, UHF	C/I ≥ 10 dB	N/S	N/S	N/S	Rec. ITU-R SM.851-1 (provides additional IPC for non-co-channel operation)	For protection against analog AM vestigial sideband TV and FM sound broadcasting
π/4 QPSK, 50 kHz channels, 3 x 10^{-2} BER	VHF, UHF	C/I ≥ 11 dB	N/S	N/S	N/S		For protection against analog AM vestigial sideband TV and FM sound broadcasting. For C/N including margin
		C/I ≥ 17 dB	N/S	N/S	N/S		For protection against analog AM vestigial sideband TV and FM sound broadcasting. For faded C/N
GMSK, BT = 0.3, 200 kHz channels	VHF, UHF	C/I ≥ 9 dB	N/S	N/S	N/S		For protection against analog AM vestigial sideband TV and FM sound broadcasting.
Public Correspond-ence and Automatic Identification Systems	VHF	N/S	I/S Values	N/S	N/S	NTIA Report 00-376	Further analysis is required to determine if IPC can be developed.

Table 7-5(cont)
Summary of IPC for Digital Channels in the Mobile Services

Systems/ Services	Frequency Bands	Interference Protection		Reference bandwidth	% Time	Source Document	Comments
		CW/Noise	Pulse/ Other				
25 kHz/12.5 kHz VHF Radios	VHF	N/S	S/I Values	N/S	N/S	NTIA Report 97-343	Further analysis is required to determine if IPC can be developed.
25 kHz Radios	VHF	N/S	S/I Values	N/S	N/S	NTIA Report 99-363	Further analysis is required to determine if IPC can be developed.
Public coast station	VHF	N/S	C/I ≥ 12 dB	N/S	N/S	47 CFR 80.773a	This applies to a subsequent coast station's allowable signal level within the service area of the incumbent [may not be true IPC].
AMS	17.975-137 MHz	N/S	D/U ≥ 14 dB	N/S	N/S	ICAO Annex 10, Vol. 5, 4.1.5.1, page 8	Intended to establish distance separation between aeronautical facilities.

Table 7-5(cont)
Summary of IPC for Digital Channels in the Mobile Services

D= Digital; A=Analog
* UWC refers to the IMT-2000 Radio Interface "UWC-136".
[I] C4FM/IMBE/VSELP = A 4-ary FM modulation technique that produces the same phase shift as a compatible CQPSK modulation technique. Consequently, the same receiver may receive either modulation. IMBE-The acronym for Improved Multi Band Excitation, the project 25 standard vocoder per ANSI/TIA/EIA-102.BABA. "A voice coding technique based on Sinusoidal Transform Coding (analog to digital voice conversion)."
[II] BER = 2%
[III] CQPSK: = The acronym for Compatible, Quadrature Phase Shift Key (QPSK) AM. An emitter that uses QPSK-c modulation that allows compatibility with a frequency discriminator detection receiver.
[IV] π/4 DQPSK = The acronym for "Differential Quadrature Phase Shift Keying", "Quadrature" indicates that the phase shift of the modulation is a multiple of 90 degrees. Differential indicates that consecutive symbols are phase shifted 45 degrees (π/4) from each other.
[V] EDACS = Enhanced Digital Access Communication System
[VI] BER = 2.8 %
[VII] CVSD = Continuously variable slope delta modulation: A type of delta modulation in which the size of the steps of the approximated signal is progressively increased or decreased as required to make the approximated signal closely match the input analog wave.
[VIII] BER = 3%
[IX] VSELP -Vector-Sum-Excited Linear Prediction
[X] BER = 1.4%

Table 7-6

Summary of IPC for Digital Channels in the MSS

Services /Systems	Frequency Bands	Interference Protection		Reference Bandwidth	% Time	Source Document	Comments
		CW/ Noise-like	**Pulse/ Other**				
GSO/MSS, GSO/AMS(R)S	1-3 GHz	I_{agg}/N_{BER}[i] ≤ –6.2 dB	N/S	N/S	N/S	Recs. ITU-R M.1183, M.1234	MSS system without frequency reuse. I_{agg} from other MSS systems and FSS systems.
		I_{agg}/N_{BER} ≤ –7 dB					Victim system with frequency reuse. I_{agg} from other MSS systems and FSS systems.
		I_{se}/N_{BER} ≤ –12.2 dB					I_{se} from another MSS system or FSS system.
GSO/AMS(R)S	1545-1555 and 1646.5-1656.5 MHz	I_{agg}/N_{BER} ≤ –7 dB, I_{se}/N_{BER} ≤ –12.2 dB	N/S	N/S	N/S	Rec. ITU-R M.1234	I_{agg} and I_{se} from other AMS(R)S, AMSS, and FSS.
NGSO/MSS downlink	137-138 MHz	I_{agg} ≤ –142.1 dBW	N/S	44 kHz	20	Recs. ITU-R M.1231, M.1232	Victim system A [iv]
		$I_{se, NGSO/MSS}$[ii] ≤ –146.2 dBW					
		$I_{se, terrestrial}$[iii] ≤ –147.3 dBW					

Table 7-6(cont)
Summary of IPC for Digital Channels in MSS

Services /Systems	Frequency Bands	Interference Protection		Reference Bandwidth	% Time	Source Document	Comments
		CW/ Noise-like	Pulse/ Other				
NGSO/MSS downlink	137-138 MHz	$I_{agg} \leq -133.4$ dBW	N/S	44 kHz	0.25	Recs. ITU-R M.1231, M.1232	Victim system A
		$I_{se,\ NGSO/MSS} \leq -133.8$ dBW			0.0625		
		$I_{se,\ terrestrial} \leq -133.8$ dBW			0.125		
		$I_{agg} \leq -155.3$ dBW	N/S	19.2 kHz	20		Victim system B [v]
		$I_{se,\ NGSO/MSS} \leq -159.9$ dBW					
		$I_{se,\ terrestrial} \leq -160.6$ dBW					
		$I_{agg} \leq -144.\ 5$ dBW			0.25		
		$I_{se,\ NGSO/MSS} \leq -144.7$ dBW			0.0625		
		$I_{se,\ terrestrial} \leq -144.8$ dBW			0.125		
		$I_{agg} \leq -134.5$ dBW	N/S	885 kHz	20		Victim system C [vi]
		$I_{se,\ NGSO/MSS} \leq -138.5$ dBW					
		$I_{se,\ terrestrial} \leq -141.5$ dBW					
		$I_{agg} \leq -128.5$ dBW			0.25		

Table 7-6(cont)
Summary of IPC for Digital Channels in MSS

Services /Systems	Frequency Bands	Interference Protection		Reference Bandwidth	% Time	Source Document	Comments
		CW/ Noise-like	Pulse/ Other				
NGSO/MSS downlink	137-138 MHz	$I_{se,\ NGSO/MSS} \leq$ –129 dBW	N/S	885 kHz	0.0625	Recs. ITU-R M.1231, M.1232	Victim system C
		$I_{se,\ terrestrial} \leq$ –129.5 dBW			0.125		
COSPAS/SARSAT	406-406.1 MHz	Max spfd ≤ –198.6 dBW/(m^2·Hz)	N/S	N/A	N/S	Rec. ITU-R M.1478	Interfering system A [vii]
		Max pfd = –185.8 dBW/m^2		19 Hz			Interfering system B [viii]
COSPAS/SARSAT		Max spfd = –200.8 dBW/(m^2·Hz)		N/A			Interfering system A
		Max pfd = –176.6 dBW/m^2		40 Hz			Interfering system B

i. I_{agg}: aggregate interfering signal power; N_{BER}: total noise power giving rise to the objective BER; I_{se}: single-entry interfering signal power.
ii. $I_{se,\ NGSO/MSS}$: single-entry interfering signal from other NGSO/MSS systems.
iii. $I_{se,\ terrestrial}$: single-entry interfering signal from terrestrial systems.
iv. Victim system A: OQPSK/FDMA transmission to gateway, 15 dBi horn antenna, elevation angle equal to or greater than 20˚.
v. Victim system B: BPSK/FDMA transmission to subscriber, 0 dBi monopole antenna with $\cos^2$ radiation pattern, elevation angle equal to or greater than 20˚.
vi. Victim system C: Minimum shift keying/direct sequence (MSK/DS)-SSMA transmission to gateway, 16 dBi antenna, elevation angle equal to or greater than 20˚.
vii. Interfering system A: broadband system using adjacent frequency bands.
viii. Interfering system B: spurious emission from narrow-band system below 406 MHz.

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SECTION 8
SCIENCE SERVICES

8.1 INTRODUCTION

Science services include the space research service, inter-satellite service, space operations service, meteorological aids service, Earth exploration-satellite (EES) and meteorological-satellite (METSAT) services, and radio astronomy service. Space research services include deep space, near earth and data relay satellite (DRS) satellite services. EES and METSAT services include command and data, space-to-Earth data, data dissemination and direct readout, and passive and active sensors. Various ITU-R Recommendations specify IPC for these services for noise-like or CW-type interfering signals in a specified reference bandwidth. No IPC were found for pulse or impulse type interfering signals.

8.2 SPACE RESEARCH SERVICE

The space research service supports diverse scientific and technology programs that provide information about the solar system, the nature and structure of the universe, and the origin and fate of matter. The systems include manned and unmanned spacecraft, communication networks on the surface of the Earth, and spacecraft in various orbits or trajectories. Spacecraft further than 2 X 10^6 km from the Earth are referred to as “deep space” spacecraft.

The phases of space research missions potentially having different requirements include pre-launch checkout, launch operations, transfer operations, on-orbit operations and landing operations. Communication links for command, telemetry and tracking data are variously required between co-orbiting spacecraft and between the spacecraft and earth stations either directly or through Data Relay Satellites (DRS).

Phase-lock loops are extensively used in space research communication systems. Because a strong interfering signal component can cause the receiver to lock to the interfering signal rather than the desired signal, narrow reference bandwidths are specified in the IPC. Protection criteria for space research services are given in Recs. ITU-R SA.363, SA.609, SA.1155, SA.1157, and SA.1396.[1]

8.2.1 Deep-Space Research

IPC for deep-space research systems are given in Rec. ITU-R SA.1157. There are four receiver subsystems in deep-space earth stations that are particularly sensitive to interfering signals: maser pre-amplifier, carrier tracking loop, telemetering subsystem and ranging subsystem. To ensure proper operation, each of the four subsystems must be protected against interference. The IPC specifies the amount of interfering signal power that will result in a maximum acceptable degradation of performance.

The gain of maser pre-amplifiers typically used in deep space earth station receivers is reduced by strong interfering signals, which also results in non-linear operation. The response of the carrier tracking loop is an increase in phase error and jitter that can cause loss of lock. The degradation of telemetry bit error performance and ranging accuracy as a result of interfering signals can be expressed in terms of a reduction in signal-to-noise ratio. Table 8-1 summarizes the maximum acceptable performance degradation.

Table 8-1

Maximum Acceptable Degradation of Receiver Subsystems

Receiving Subsystem	Maximum Acceptable Degradation
Maser pre-amplifier Carrier tracking	1 dB gain compression 10^{o} loop static phase error or peak phase jitter
Telemetry	1 dB equivalent reduction in symbol energy to noise spectral density increase ($\Delta E/N_o = -1$ dB)
Ranging	1 dB equivalent reduction in symbol energy to noise spectral density increase ($\Delta E/N_o = -1$ dB)

The amount of interfering signal power that can cause the degradation shown in Table 8-1 is given in Annex 2 of Rec. ITU-R SA.1157 for CW and noise-like interfering signals. Table 8-2 shows the maximum allowable interference-to-carrier ratio (I/C), interference-to-signal ratio (I/S) or interference-to-noise ratio (I/N) that corresponds to maximum acceptable degradation of carrier tracking, telemetry and ranging subsystems. From Table 8-2, the maximum allowable CW interfering signal power is dictated by the carrier tracking loop. For carrier tracking, the maximum permissible power of noise-like interfering signals have been calculated from maximum I/C, receiver noise spectral density, carrier tracking loop bandwidth and minimum C/N ratio required for carrier tracking. The resulting IPC are summarized in Table 8-3.

Table 8-2

Basis for IPC for CW and Noise-like Interfering Signals at Deep Space Earth Stations

Subsystem (criterion)	Interfering Signal Type	IPC
Carrier tracking (10° added peak phase jitter)	CW Noise-like	I/C ≤ – 15 dB I/N ≤ + 2.3 dB
Telemetry (1 dB reduction in E/N_o from interfering signal in carrier tracking loop)	CW	I/C ≤ – 1.5 dB
Telemetry (1 dB reduction in E/N_o from interfering signal in telemetry detection bandwidth)	CW Noise-like	I/S ≤ –11 dB I/N ≤ – 5.9 dB
Ranging (1 dB reduction in E/N_o from interfering signal in carrier tracking loop)	CW	I/C ≤ – 5 dB
Ranging (1 dB reduction in E/N_o from interfering signal in range estimator bandwidth)	CW Noise-like	I/S ≤ – 7.1 dB I/N ≤ – 5.9 dB

The IPC for deep-space station receivers are based on an I/N of 0 dB. Unlike for the space-to-Earth links, substantial power margins are available on the Earth-to-space links.

8.2.2 Near Earth Space Research

The permissible I/N ratio in a near-earth space research communication link is determined by the portion of the link margin allocated to interfering signals. Typical link margins range from 3 to 6 dB for frequencies below 10 GHz and larger margins are used at higher frequencies. Interference can be harmful if the link power margin is decreased by more than 1 dB. This corresponds to an I/N of –6 dB. The reference bandwidth for the IPC depends upon the smallest bandwidth likely to be employed. For manned space missions, a loss of more than 5 minutes of communication during critical periods of the mission would seriously affect the mission. To prevent interference for longer than 5 minutes per day, it is necessary not only to consider the worst hour in the year, but the worst 5 minutes within that hour. This corresponds to 0.001% of the time for manned space missions, whereas, for unmanned space missions up to 0.1% of outage can be tolerated.

In the 1-20 GHz range, the system noise temperature of receiving earth stations is typically as low as 70 K. Below about 1 GHz, cosmic noise increases the operating noise temperature of the system at a rate of about 20 dB per decade of decreasing frequency. The system noise temperature of a permissible space-station receiver is usually 600 K or more, partly due to the fact that the spacecraft antenna points at the Earth (290 K). The resulting IPC for near-earth research are given in Rec. ITU-R SA.609 and summarized in Table 8-3.

8.2.3 Data Relay Satellites

Data relay satellites operate in the space research, space operation, Earth exploration-satellite (EES) and the fixed-satellite (FSS) services. A link margin reduction of 0.4 dB has been used as a basis for the IPC. This corresponds to an I/N within the reference bandwidth of –10 dB. The IPC for data relay satellite systems are given in Rec. ITU-R SA.1155, and summarized in Table 8-3.

8.2.4 Telecommunication Links in the 37-40 GHz Bands

The frequency bands 37-38 GHz and 40-40.5 GHz have been allocated to the space research service on a primary basis worldwide. These bands are intended to be used for high-rate digital data transfer of telemetry, voice, and video between the Earth and other planetary bodies such as the Moon and Mars to support manned exploration. Further, the 37-38 GHz band is to be used for high-rate data transfer from an earth-orbiting S-VLBI station. Data rates of the order of 100 Mbits/s from planetary ranges, 500 Mbits/s for lunar ranges and 1000 Mbits/s from S-VLBI station to earth are expected.

For space-to-Earth links, typical link power margins are 2 to 4 dB. Therefore, during desired signal fading, interference can be severe if the link margin is lowered by more than 1 dB. This corresponds to an I/N ratio of about -6 dB. For Earth-to-space links, which are not power limited, up to 3 dB degradation may be tolerated (I/N of 0 dB). The reference bandwidths for earth-station and space-station receivers are 1 Hz and 20 Hz respectively. The percentage of time during which these thresholds may be exceeded are 0.001% of time for manned missions and 0.1% of time for unmanned missions.

In the 37-38 GHz region, the IPC are based on a 60 K system noise temperature for receiving earth stations. In the 40-40.5 GHz range, the IPC for space research space station are derived from a noise temperature of 200 K and an I/N ratio of 0 dB. The IPC for space research service in the 37-40 GHz range are given in Rec. ITU-R SA.1396 and are summarized in Table 8-3.

8.3 SPACE OPERATION SERVICE

The space operation service is a radiocommunication service concerned exclusively with the operation of spacecraft, in particular tracking, telemetry and telecommand. These functions are normally provided within the frequency allocations for the services in which the space station is operating. The preferred frequency bands for space operations lie approximately between 1 and 8 GHz. Lower frequencies are sometimes used for spacecraft that do not require high precision tracking. Frequencies above 10 GHz are suitable for space operation services during the re-entry of spacecraft into the atmosphere of the Earth.

The reference bandwidth is based on phase-locked loop receivers having equivalent noise bandwidths of between a few hundred Hz and a few kilohertz. A value of 1 kHz has been adopted for the reference bandwidth. Generally, the percentage of time during which space operation links can tolerate interfering signal power above the protection level is fixed at 1% per day, approximately equivalent to 15 minutes per day. However, interference lasting for 15 consecutive minutes may be intolerable during critical stages.

Above 1 GHz, the total noise temperature of earth stations is 100 K. The IPC are based on that noise temperature and an I/N of –5 dB. Since the power of earth station transmitters can generally be increased within limits imposed by the Radio Regulations on-board receivers do not always operate at maximum sensitivity. The protection of space station receivers is therefore expressed in terms of protection ratios and the IPC are based on an S/I ratio of 20 dB. IPC for space operation systems are given in Rec. ITU-R SA.363 and are summarized in Table 8-3.

8.4 METEOROLOGICAL AIDS

The term MetAids is used to describe a variety of meteorological equipment, such as, radiosondes, dropsondes, rocketsondes and weather radars. IPC for weather radars are discussed separately in Section 5 due to their similarity to radiodetermination service radars. Other MetAids are flown worldwide for the collection of upper atmosphere meteorological data for weather forecasts, ozone monitoring, and other applications.

IPC for MetAids are based on the link margin at the maximum slant range. The first level of interfering signal power is the level associated with loss of receiver lock, which may be exceeded only for 0.02% of time. The second level of interfering signal power is the level at which loss of data will occur. The percentage of time for this occurrence may be obtained from the user's data availability objectives, typically 1.25% of time for radiosondes and 0.03% for dropsondes. The third interfering signal level will be the long-term level, at 20% of the time, which may result in data loss during desired signal fading. The IPC and underlying calculation methodology are given in Rec. ITU-R SA.1263.[2]

8.5 EARTH EXPLORATION-SATELLITE AND METEOROLOGICAL SATELLITE SERVICES

Systems in earth exploration-satellite service (EES) and meteorological satellite service (METSAT) utilize transmission systems having various Earth-to-space, space-to-space, and space-to-Earth links. These services support data collection, data dissemination, interrogation of data collection platforms, passive sensing, active sensing, direct data readout and recorded data acquisition. The methodology for determining IPC is given in Rec. ITU-R SA.1022.[3]

8.5.1 Space-to-Earth Data Transmission Systems Using Low-Earth Orbit

Using the performance criteria for space-to-Earth data transmission systems given in Rec. ITU-R SA.1025 and the methodology given in Rec. ITU-R SA.1022, IPC have been developed for METSAT and EES in different bands.[4]

For METSAT service in the 137-138 MHz band, the automatic picture transmission (APT) system uses analog modulation with a bandwidth of 50 kHz and is planned to be phased out in 2005. Its replacement is the low resolution picture transmission (LRPT) system which uses digital modulation with a nominal data rate of 72 kbit/s. Two types of earth stations are used in this band, one with an unsteered low gain antenna for reception of local data and the other with a steerable medium gain antenna for reception of regional data.

For METSAT service in the 400.15-401 MHz band, data from spacecraft sensors is multiplexed into a data stream at a rate of 88.75 kb/s. The typical earth stations are mobile with 0 dBi antenna gain.

For METSAT service in the 1670-1710 MHz band and EES in the 1690-1710 MHz band, the high resolution picture transmission (HRPT) system and the command and data acquisition system (CDA) use small and large earth stations respectively. For the large station, a 2.667 Mbit/s data rate is used and for the small station a data rate of 0.667 Mbit/s is used, and higher data rates are planned.

In the 7450-7550 MHz a global recorded data (GRD) system expected to be implemented around 2005. IPC are based on the system design parameters.

The EES service at 8025-8400 MHz uses two systems. For “System A,” a major data acquisition facility receives stored data and the low cost facility receives real time regional data. For “System B,” a major data acquisition facility is also used to receive wideband (420 Mbit/s) direct data readout.

The IPC for space-to-Earth data transmission systems operating in METSAT and EES services using satellites in low-Earth orbits are given in Rec. ITU-R SA.1026 and are summarized in Table 8-3.[5]

8.5.2 Data Dissemination and Direct Data Readout Systems Using Geostationary Satellites

For direct readout systems, all of the interfering signals enter the receiving earth station directly. (The data originates at the satellite and none is received via satellite retransmission.) Dissemination of high-resolution processed data and lower resolution weather facsimile (WEFAX) data is affected by the interfering signal power received at the station via the satellite as well as directly by the earth station in the 1670-1710 MHz band. These data are up-linked to the satellite in the 2025-2110 MHz band, and relayed, along with interfering signals entering the satellite in the same band, to the earth station receivers via fixed gain satellite transponders.

For links in the EES and MetSat services using geostationary orbits, the performance objectives are given in Rec. ITU-R SA.1159.[6] IPC have been determined using the methodology given in Rec. ITU-R SA.1022. The IPC for data dissemination and direct data readout systems in the EES and METSAT services are given in Rec. ITU-R SA.1160-2 and are summarized in Table 8-3.[7]

8.5.3 Service Links in Data Collection Systems

Systems for data collection and platform location in the EES and METSAT services collect data for users needing information from a variety of sources, which may be located anywhere in the world. Two types of orbits are used: low earth orbits (LEO) and geostationary-satellite orbit (GSO). The GSO systems provide data with a delivery delay of typically 5 minutes, but do not cover the polar region. The LEO systems offer worldwide coverage as well as the platform location with a delivery delay of up to 1 to 3 hours.

Telecommunication requirements and performance objectives for service links in data collection and platform location are given in Rec. ITU-R SA.1162.[8] Using the methodology described in Rec. ITU-R SA.1022, the IPC are given in Rec. ITU-R SA.1163 and are summarized in Table 8-3.[9]

8.5.4 Command and Data Transmission System

For all command and data transmission systems in bands other than those treated in Recs. SA.1026, SA.1160 and SA.1163, the IPC for earth receiving sites and for near-earth spacecraft are given in Rec. ITU-R SA.514 and are summarized in Table 8-3.[10]

8.5.5 Satellite Passive Remote Sensing

Passive sensing is the measurement of natural emissions from the Earth and its atmosphere. Certain frequency bands coinciding with these emissions have been allocated for spaceborne passive microwave remote sensing. These include some absorption bands for atmospheric gases (O_2 and H_2O). Measurements in the absorption band are extremely vulnerable to interference because there is very little possibility to detect and reject data that are contaminated by interference. The use of contaminated data in numerical weather prediction (NWP) would have an adverse effect on the quality of weather forecasting.

The sensitivities of radiometric passive sensors are generally expressed as a temperature differential, ΔT_e. The minimum discernable power change is given by:

$$\Delta P = k \, \Delta T_e \, B \qquad \text{Watts} \qquad (8\text{-}3)$$

Where, k is the Boltzmann's constant and B is the receiver bandwidth in Hz. Harmful interference to passive sensors may occur when unwanted signal levels exceed 20% of ΔP, which is a basis for the IPC. Measurement sensitivities suitable for passive sensing of land, oceans and atmosphere within their allocated bands are given in Rec. ITU-R SA.1028.[11] The permissible interference levels and reference bandwidths are given in Rec. ITU-R SA.1029, and are summarized in Table 8-3.[12]

8.5.6 Spaceborne Active Microwave Remote Sensors

The performance requirements for active sensors can be stated in terms of measurement precision and availability. The performance criteria for various active sensors are as follows.

Synthetic Aperture Radars (SAR): near 400 MHz, a performance criterion for SARs is to collect SAR imagery with a minimum reflectivity of –39 dB.

Altimeters: near 5.3 GHz, 13-14 GHz and 35.5-36.0 GHz, a performance criterion for altimeters is to measure the sea level with a precision of at least 3 cm. An increase in height noise of 0.1 cm, corresponding to 4% degradation in height noise in the presence of a systematic height noise of 2-2.4 cm, would be consistent with mission objectives.

Scatterometers: near 5.3 GHz, 13-14 GHz and 35.5-36.0 GHz, the performance criterion for scatterometers is measurement of wind speeds greater than or equal to 3 m/s.

Precipitation radars: the science requirement for precipitation radars is to achieve, after data processing, measurement of rain rates equal to or greater than 0.7 mm/h in the 13-14 GHz band and 0.15 mm/h in the 35.5-36.0 GHz band. An increase in measurable rain rate to 0.75 mm/h in the 13-14 GHz band and 0.2 mm/h in the 35.5-36.0 GHz band would not materially affect the data and would be acceptable as a basis for IPC.

Cloud profiling radars: at 35.5-36.0 GHz and 94-94.1 GHz, the performance criterion for cloud profiling radars is to measure the reflectivity profile for all clouds within the field of view with a minimum reflectivity of -30 dBZ. A degradation of minimum measurable reflectivity (Z_{min}) by less than 10% due to interference would be consistent with mission objectives.

IPC for active sensors and their technical bases are given in Rec. ITU-R SA.1166-2.[13] The IPC are given in Table 8-3.

8.6 RADIO ASTRONOMY

Radio astronomical measurements are made from the Earth's surface from 2 MHz to 800 GHz and from space platforms at frequencies which extend down to lower than 10 kHz.

The sensitivity of the receivers used for radio astronomy greatly exceeds the sensitivity of typical communications and radar equipment. The sensitivity is defined by the smallest power level change ΔP at the input which can be detected and measured. The interfering signal threshold levels are defined as the interfering signal level which introduces an error of 10% in the measurement of ΔP. The IPC are based on assumed integration time of 2000 seconds and 0 dBi antenna gain toward the interferer. Integration times actually used in astronomical observations cover a wide range of values. The IPC for radio astronomical measurements are given in Rec. ITU-R RA.769.[14]

Interfering signals received by widely-spaced antennas used for Very Long Baseline Interferometry (VLBI) will undergo different relative time delays before they are recombined. Compared to a single antenna radio telescope, the interferometer has a greater degree of immunity, which increases with the size of the array in wavelengths. In VLBI, the separation of antennas is such that the chance of occurrence of correlated interfering signals is very small. The tolerable interfering signal level is determined by the requirement that the power level of the interfering signals should be less than 1% of the receiver noise power to prevent serious errors. Large interferometers and arrays are generally used to study discrete high brightness sources, with angular dimensions no more than a few tenths of a second of arc for VLBI. The IPC for VLBI are given in Rec. ITU-R RA.769.

8.7 SUMMARY

Table 8-3 provides a summary of the IPC for the science services.

Table 8-3
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection[i] CW & Noiselike	Interference Protection[i] Pulse Other	Reference BW	% Time	Source Document	Comments
SPACE RESEARCH SERVICE							
Deep Space Research Earth Stations	2.3 GHz	I ≤ –222 dBW	N/S	1 Hz	0.001	Rec. ITU-R SA.1157	None
	8.4 GHz	I ≤ –220 dBW	N/S				
	13.0 GHz	I ≤ –220 dBW	N/S				
	32.0 GHz	I ≤ –216 dBW	N/S				
Deep Space Research Space Stations	2.1 GHz	I ≤ –191 dBW	N/S	20 Hz	0.001	Rec. ITU-R SA.1157	None
	7.2 GHz	I ≤ –189 dBW	N/S				
	17.0 GHz	I ≤ –186 dBW	N/S				
	34.5 GHz	I ≤ –184 dBW	N/S				
Near Earth Research Earth Stations	1-20 GHz	I ≤ –216 dBW	N/S	1 Hz	0.001 Manned 0.1 Un-manned	Rec. ITU-R SA.609I	I increases 20 dB per decreasing frequency decade below 1 GHz
	Below 1 GHz	See comments	N/S				
Near Earth Research Space Stations	100 MHz-30 GHz	I ≤ –177 dBW	N/S	1 kHz	0.1	Rec. ITU-R SA.609	None

[i] Unless otherwise indicated, IPC represents maximum allowable power density at the receiver terminals.

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection		Reference BW	% Time	Source Document	Comments
		CW & Noiselike	Pulse Other				
Data Relay Satellite Forward Inter-Orbit Link User Spacecraft	2.025-2.110 GHz	I ≤ –181 dBW	N/S	1 kHz	0.1	Rec. ITU-R SA.1155	None
	13.5-13.8 GHz	I ≤ –178 dBW	N/S				
	22.55-23.55 GHz	I ≤ –178 dBW	N/S				
Data Relay Satellite Return Inter-Orbit-Link	2.200-2.290 GHz	I ≤ –181 dBW	N/S	1 kHz	0.1	Rec. ITU-R SA.1155	None
	14.89-15.18 GHz	I ≤ –178 dBW	N/S				
	25.25-27.5 GHz	I ≤ –178 dBW	N/S				
Data Relay Satellite Forward Feeder Link	14.35-15.35 GHz	I ≤ –167 dBW	N/S	1 kHz	0.1	Rec. ITU-R SA.1155	None
	27.0-30.0 GHz	I ≤ –169 dBW	N/S				
Data Relay Satellite Return Feeder Link	10.81-10.86 GHz	I ≤ –176 dBW	N/S	1 kHz	0.1	Rec. ITU-R SA.1155	None
	13.4-14.05 GHz	I ≤ –176 dBW	N/S				
	17.2-21.2 GHz	I ≤ –172 dBW	N/S				
Space Research Earth Station	37-38 GHz	I ≤ –217 dBW	N/S	1 Hz	0.1 Un-manned 0.001 Manned	Rec. ITU-R SA.1396	None
Space Research Space Station	40-40.5 GHz	I ≤ –193 dBW	N/S	20 Hz	0.1	Rec. ITU-R SA 1396	None

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection CW & Noiselike	Interference Protection Pulse Other	Reference BW	% Time	Source Document	Comments
SPACE OPERATIONS SERVICE							
Earth Station	1-30 GHz	I ≤ -184 dBW	N/S	1 kHz	1	Rec. ITU-R SA.1263	I increases 20 dB per decreasing frequency decade below 1 GHz
	0.1-1 GHz	See Comments	N/S				
Space Station	100 MHz-30 GHz	S/I ≥ 20 dB	N/S	1 kHz	1	Rec. ITU-R SA.363-5	None
METEOROLOGICAL AIDS							
Radio Direction Finding Radiosonde	1669.4-1700 MHz	I ≤ –135.3 dBW	N/S	1.3 MHz	0.02	Rec. ITU-R SA.1263	None
	1669.4-1700 MHz	I ≤ –148.5 dBW	N/S		1.25		
	1669.4-1700 MHz	I ≤ –149.4 dBW	N/S		20		
NAVAID Radiosonde Directional Receiver Antenna	400.15-406 MHz	I ≤ –140.6 dBW	N/S	300 kHz	0.02	Rec. ITU-R SA.1263	None
	400.15-406 MHz	I ≤ –149.6 dBW	N/S		1.25		
	400.15-406 MHz	I ≤ –154.9 dBW	N/S		20		
Omni-Directional Receiver Antenna	400.15-406 MHz	I ≤ –141.9 dBW	N/S	300 kHz	0.02	Rec. ITU-R SA.1263	None
	400.15-406 MHz	I ≤ –154.4 dBW	N/S		1.25		
	400.15-406 MHz	I ≤ –156.1 dBW	N/S		20		

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection: CW & Noiselike	Interference Protection: Pulse Other	Reference BW	% Time	Source Document	Comments
Airborne Dropsonde	400.15-406 MHz	I ≤ –153.3 dBW	N/S	20 kHz	0.02	Rec. ITU-R SA.1263	None
	400.15-406 MHz	I ≤ –161.5 dBW	N/S		0.03		
	400.15-406 MHz	I ≤ –167.1 dBW	N/S		20		
Rocketsonde	400.15-406 MHz	I ≤–124.9 dBW	N/S	3 MHz	0.02	Rec. ITU-R SA.1263	None
	400.15-406 MHz	I ≤ –125.5 dBW	N/S		0.03		
	400.15-406 MHz	I ≤ –134.7 dBW	N/S		20		
EARTH EXPLORATION AND METEOROLOGICAL SATELLITE SERVICES (EES/METSAT)							
Command Data Earth Station	1-10 GHz	I ≤ –154 dBW	N/S	1 MHz	1	Rec. ITU-R SA.514	I increases 20 dB per decreasing frequency decade below 1 GHz
	Below 1 GHz	See Comments	N/S				
Command Data Near Earth Spacecraft	0.3-10 GHz	I ≤ –161 dBW	N/S	1 kHz	0.1	Rec. ITU-R SA.514	I increases 20 dB per decreasing frequency decade below 0.3 GHz.
	Below 0.3 GHz	See comments	N/S				

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection		Reference BW	% Time	Source Document	Comments
		CW & Noiselike	Pulse Other				
Space to Earth Data Earth Stations Direct Data Readout	137-138 MHz	I ≤ –151 dBW	N/S	50 kHz	20	Rec. ITU-R SA.1026	Analog receiver 2 dBic antenna gain[ii]
	137-138 MHz	I ≤ –145 dBW	N/S		0.025		
	137-138 MHz	I ≤ –141 dBW	N/S	150 kHz	20		Digital receiver 10 dBic antenna gain
	137-138 MHz	I ≤ –133 dBW	N/S		0.25		
	137-138 MHz	I ≤ –142 dBW	N/S		20		Digital receiver 2 dBic antenna gain
	137-138 MHz	I ≤ –136 dBW	N/S		0.025		
	400.15-401.00 MHz	I ≤ –158 dBW	N/S	177.5 kHz	20		Digital receiver 0 dBic antenna gain
	400.15-401.00 MHz	I ≤ –147 dBW	N/S		0.025		
	1696-1710 MHz	I ≤ –147 dBW	N/S	2668 kHz	20		29.8 dBic antenna gain
	1696-1710 MHz	I ≤ –138 dBW	N/S		0.025		
	8025-8400 MHz	I ≤ –136 dBW	N/S	40 MHz	20		42.5 dBic antenna gain System A

[ii] For analog and digital receivers with 2 dBic antenna gain, the interfering signal power levels (dBW) in the reference bandwidths are specified for reception at elevation angles greater than or equal to 25°.

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection		Reference BW	% Time	Source Document	Comments
		CW & Noiselike	Pulse Other				
Space to Earth Data Earth Stations Direct Data Readout (cont.)	8025-8400 MHz	I ≤ –125 dBW	N/S	40 MHz	0.25	Rec. ITU-R SA. 1026	56.3 dBic antenna System B
	8025-8400 MHz	I ≤ –125 dBW	N/S		20		
	8025-8400 MHz	I ≤ –116 dBW	N/S		0.25		
	25.5-27.0 GHz	I ≤ –137 dBW	N/S	10 MHz	20		42.5 dBic antenna gain
	25.5-27.0 GHz	I ≤ –120 dBW	N/S		0.25		
High-speed Direct Data Readout	25.5-27.0 GHz	I ≤ –136 dBW	N/S	10 MHz	20	Rec. ITU-R SA. 1026	42.5 dBic antenna gain
	25.5-27.0 GHz	I ≤ –122 dBW	N/S		0.25		
Recorded Data Acquisition	1696-1710 MHz	I ≤ –128 dBW	N/S	5334 kHz	20	Rec. ITU-R SA. 1026	46.8 dBic antenna gain
	1696-1710 MHz	I ≤ –121 dBW	N/S		0.025		
	7750-7850 MHz	I ≤ –128 dBW	N/S	100 MHz	20		54.0 dBic antenna gain
	7750-7850 MHz	I ≤ –115 dBW	N/S		0.025		
	8025-8400 MHz	I ≤ –131 dBW	N/S		20		55.2 dBic antenna gain
	8025-8400 MHz	I ≤ –117 dBW	N/S		0.025		

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection CW & Noiselike	Interference Protection Pulse Other	Reference BW	% Time	Source Document	Comments
Recorded Data Acquisition (cont.)	25.5-27.0 GHz	I ≤ –134 dBW	N/S	10 MHz	20	Rec. ITU-R SA. 1026	55.2 dBic antenna gain
	25.5-27.0 GHz	I ≤ –118 dBW	N/S		0.25		
Direct Data Readout Space-to-earth	1670-1710 MHz	I ≤ –153.8 dBW	N/S	2.6 MHz	20	Rec. ITU-R SA. 1160	High gain antenna
	1670-1710 MHz	I ≤ –148.6 dBW	N/S		0.025		
	25.5-27.0 GHz	I ≤ –131.7 dBW	N/S	10 MHz	20		
	25.5-27.0 GHz	I ≤ –116.3 dBW	N/S		0.25		
Data Dissemination Space-to-earth	1670-1710 MHz	I ≤ –167.5 dBW	N/S	4 kHz	20	Rec. ITU-R SA. 1160	Low gain antenna
	1670-1710 MHz	I ≤ –160.4 dBW	N/S		0.025		
	1670-1710 MHz	I ≤ –153.4 dBW	N/S	2.11 MHz	20		High gain antenna
	1670-1710 MHz	I ≤ –148.1 dBW	N/S		0.025		
Command Data Acquisition (CDA) Station Earth-to-space	2025-2110 MHz	I ≤ –136.7 dBW	N/S	2.11 MHz	20	Rec. ITU-R SA. 1160	High resolution data
	2025-2110 MHz	I ≤ –133.4 dBW	N/S		0.025		

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection CW & Noiselike	Interference Protection Pulse Other	Reference BW	% Time	Source Document	Comments
Command Data Acquisition (CDA) Station Earth-to-space (cont.)	2025-2110 MHz	I ≤ –147.8 dBW	N/S	4 kHZ	20	Rec. ITU-R SA. 1160	WEFAX data
	2025-2110 MHz	I ≤ –140.7 dBW	N/S		0.025		
Service Data Collection Links Non-GSO Space Station	401-403 MHz	I ≤– 178.8 dBW	N/S	1.6 kHZ	20	Rec. ITU-R SA.1160	Low-gain antenna
	401-403 MHz	I ≤ –174.7 dBW	N/S		0.1		
Service Data Collection Links GSO Space Station	401-403 MHz	I ≤ –187.4 dBW	N/S	100 Hz	20	Rec. ITU-R. SA.1163	
	401-403 MHz	I ≤ –173.4 dBW	N/S	4 kHz	0.1		
Command and Data Acquisition Station (CDA)	2025-2110 MHz	I ≤ –188.9 dBW	N/S	100 Hz	20	Rec. ITU-R SA.1163	None
	2025-2110 MHz	I ≤ –183.7 dBW	N/S		0.025		
Service Links Earth Station Non-GSO Data Collection	137-138 MHz	I ≤ –158.3 dBW	N/S	8.32 kHz	20	Rec. ITU-R SA.1163	None
	137-138 MHz	I ≤ –151.1 dBW	N/S		0.1		
GSO Data Collection CDA Station	1670-1690 MHz	I ≤ –194.0 dBW	N/S	100 Hz	20		
	1670-1690 MHz	I ≤ –181.5 dBW	N/S		0.025		

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection		Reference BW	% Time	Source Document	Comments
		CW and Noiselike	Pulse Other				
GSO Data Platform Collection Integration	460-470 MHz	I ≤ –187.3 dBW	N/S	100 Hz	20	Rec ITU-R. SA.1163	None
	460-470 MHz	I ≤ –182.1 dBW	N/S		0.1		
Passive Sensor	Near 1.4 GHz	I ≤ –171 dBW	N/S	27 MHz	See Footnote[iii]	Rec. ITU-R SA. 1029	None
	Near 2.7 GHz	I ≤ –174 dBW	N/S	10 MHz			
	Near 4 GHz	I ≤ –161 dBW	N/S	100 MHz			
	Near 6 GHz	I ≤ –164 dBW	N/S				
	Near 11 GHz	I ≤ –163 dBW	N/S	20 MHz			
	Near 15 GHz	I ≤ –166 dBW	N/S	50 MHz			
	Near 18 GHz	I ≤ –155 dBW	N/S	100 MHz			
	Near 21 GHz	I ≤ –163 dBW	N/S				
	22.235 GHz	I ≤ –160 dBW	N/S				

[iii] In shared bands, the specified interfering signal power levels may be exceeded for no more than 5% of all measurement cells where data loss occurs randomly and for no more than 1% where loss occurs systematically. The specified interfering signal levels may be exceeded for no more than 0.001% time for three dimensional measurements of atmospheric temperature or gas concentration.

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection CW & Noiselike	Interference Protection Pulse Other	Reference BW	% Time	Source Document	Comments
Passive Sensor (cont).	Near 24 GHz	I ≤ –163 dBW	N/S	100 MHz	See Footnote[iv]	Rec. ITU-R SA. 1029	None
	Near 31 GHz	I ≤ –163 dBW	N/S				
	Near 37 GHz	I ≤ –156 dBW	N/S	100 MHz	See Footnote [iv]	Rec. ITU-R SA. 1029	N/S
	50.2-50.4 GHz	I ≤ –161 dBW	N/S	100 MHz	N/S	N/S	≤–166 dBW for pushboom sensors
	52.6-59.0 GHz	I ≤ –161 dBW	N/S				
	60.3-61.3 GHz	I ≤ –161 dBW	N/S				
	Near 90 GHz	I ≤ –153 dBW	N/S	200 MHz	See Footnote[iv]	Rec. ITU-R SA. 1029	None
	100.49-380.20 GHz	I ≤ –160 dBW	N/S	200 MHz		Rec. ITU-R SA. 1029	Several discrete frequency bands
Active Sensors Synthetic Aperture Radar (SAR)	Near 400 MHz	I ≤ –138 dBW	N/S	10 MHz	N/S	Rec. ITU-R SA.1166	None

[iv] In shared bands, the specified interfering signal levels may be exceeded for no more than 5% of all measurement cells where data loss occurs randomly and for no more than 1% where loss occurs systematically. The specified interfering signal levels can be exceeded for no more than 0.001% time for three dimensional measurements of atmospheric temperature or gas concentration.

Table 8-3(cont)
Summary of Interference protection criteria for science services

Service Systems	Frequency Bands	Interference Protection CW & Noiselike	Interference Protection Pulse Other	Reference BW	% Time	Source Document	Comments
Altimeters	Near 5.3 GHz	I ≤ –123 dBW	N/S	100 MHz	N/S	Rec. ITU-R SA.1166	None
	13.0-14.0 GHz	I ≤ –119 dBW	N/S	320 MHz			
	35.5-36.0 GHz	I ≤ –112 dBW	N/S	450 MHz			
Scatterometers Spot-beam antenna	Near 5.3 GHz	I ≤ –155 dBW	N/S	10 kHz	N/S	Rec. ITU-R SA.1166	None
	13.0-14.0 GHz	I ≤ –155 dBW	N/S				
	35.5-36.0 GHz	I ≤ –158 dBW	N/S				
Precipitation Radars	13.0-14.0 GHz	I ≤ –150 dBW	N/S	600 kHz	N/S	Rec. ITU-R SA.1166	None
	35.0-36.0 GHz	I ≤ –152 dBW	N/S				
Cloud Profiling Radars	35.5-36.0 GHz	I ≤ –155 dBW	N/S	300 kHz	N/S	Rec. ITU-R SA.1166	None
	94-94.1 GHz	I ≤ –155 dBW	N/S				

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection		Reference BW	% Time	Source Document	Comments
		CW & Noiselike	Pulse Other				
RADIO ASTRONOMICAL MEASUREMENTS							
Radio Astronomy	13.36-13.41 MHz	I ≤ –248 dBW	N/S	1 Hz	N/S	Rec. ITU-R RA.769	None
	25.55-26.70 MH	I ≤ –249 dBW	N/S				
	73.0-74.6 MHz	I ≤ –258 dBW	N/S				
	150.05-153.0 MHz	I ≤ –259 dBW	N/S				
	322.0-328.6 MHz	I ≤ –258 dBW	N/S				
	406.1-410.0 MHz	I ≤ –255 dBW	N/S				
	608-614 MHz	I ≤ –253 dBW	N/S				
	1400-1427 MHz	I ≤ –255 dBW	N/S				
	1610.6-1613.8 MHz	I ≤ –238 dBW	N/S				
	1.66-1.67 GHz	I ≤ –251 dBW	N/S				
	2.69-2.7 GHz	I ≤ –247 dBW	N/S				
	4.99-5.0 GHz	I ≤ –241 dBW	N/S				

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection CW & Noiselike	Interference Protection Pulse Other	Reference BW	% Time	Source Document	Comments
Radio Astronomy (cont.)	10.6-10.7 GHz	I ≤ –240 dBW	N/S	1 Hz	N/S	Rec. ITU-R RA.769	None
	15.35-15.4 GHz	I ≤ –233 dBW	N/S				
	22.1-22.5 GHz	I ≤ –233 dBW	N/S				
	23.6-24.0 GHz	I ≤ –233 dBW	N/S				
	31.3-31.8 GHz	I ≤ –228 dBW	N/S				
	42.5-43.5 GHz	I ≤ –227 dBW	N/S				
	86-92 GHz	I ≤ –222 dBW	N/S				
	105-116 GHz	I ≤ –222 dBW	N/S				
	182-185 GHz	I ≤ –216 dBW	N/S				
	217-231 GHz	I ≤ –215 dBW	N/S				
	265-275 GHz	I ≤ –213 dBW	N/S				

Table 8-3(cont)
Summary of Interference protection criteria for science services

Services Systems	Frequency Bands	Interference Protection		Reference BW	% Time	Source Document	Comments
		CW & Noiselike	Pulse Other				
Very Long Baseline Interferometry (VLBI)	325.3 MHz	I ≤ –215 dBW	N/S	1 Hz	N/S	Rec. ITU-R RA.769	None
	611 MHz	I ≤ –211 dBW	N/S				
	1413.5 MHz	I ≤ –209 dBW	N/S				
	2695 MHz	I ≤ –204 dBW	N/S				
	4995 MHz	I ≤ –198 dBW	N/S				
	10650 MHz	I ≤ –192 dBW	N/S				
	15375 MHz	I ≤ –187 dBW	N/S				
	23800 MHz	I ≤ –192 dBW	N/S				
	43000 MHz	I ≤ –173 dBW	N/S				
	86000 MHz	I ≤ –166 dBW	N/S				

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[2] Rec. ITU-R SA.1263, *Interference Criteria for Meteorological Aids Operated in the 400.15-406 MHz and 1668.4-1700 MHz Bands* (1997).

[3] Rec. ITU-R SA.1022-1, *Methodology for Determining Interference Criteria for Systems in the Earth Exploration-Satellite and Meteorological-Satellite Services* (1999).

[4] Rec. ITU-R SA.1025-3, *Performance Criteria for Space-to-Earth Data Transmission Systems Operating in the Earth Exploration-Satellite and Meteorological-Satellite Services using Satellite in Low-Earth Orbit* (1999).

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[6] Rec. ITU-R SA.1159-2, *Performance Criteria for Data Transmission and Direct Data Readout Systems Operating in the Earth Exploration-Satellite and Meteorological-Satellite Services using Satellites in Geostationary Orbit* (1999).

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[8] Rec. ITU-R SA.1162-1, *Telecommunication Requirements and Performance Criteria for Service Links in Data Collection and Platform Location Systems in the Earth Exploration-Satellite and Meteorological-Satellite Services* (2003).

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[12] Rec. ITU-R SA.1029-1, *Interference Criteria for Satellite Passive Remote Sensing* (2003).

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[14] Rec. ITU-R RA.769-1, *Protection Criteria Used for Radioastronomical Measurements* (2003).