NTIA Report 03-404

RECEIVER SPECTRUM STANDARDS
Phase 1 – Summary of Research into Existing Standards

technical report

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

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RECEIVER SPECTRUM STANDARDS
Phase 1 - Summary of Research into Existing Standards

Bernard Joiner

U.S. Department of Commerce
Donald Evans, Secretary
Michael D Gallagher, Acting Assistant Secretary
for Communications and Information

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EXECUTIVE SUMMARY

As part of the overall spectrum management process, the National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC) have developed radio regulations to help ensure that the various radio services operate compatibly in the same environment without unacceptable levels of radio frequency interference. These regulations generally focus on sharing spectrum and the interfering potential of transmitters. Less attention has been given to the regulation of receiver parameters and the associated non-cochannel interference issues.

In recent years, there have been a growing number of cases of non-cochannel interference that has been caused by inadequate performance of receivers instead of by transmitter performance. One element in the prevention of non-cochannel interference is the design and use of quality receivers that are less susceptible to interference. Receivers are often vulnerable to interference from non-cochannel signals because of inadequate selectivity. This has resulted in complaints of interference, sometimes requiring legitimate transmitting stations to cease or limit their operation even when a poor performing receiver is mainly at fault. In addition to interference problems, the lack of receiver standards has hindered efficient management of the spectrum by putting restraints on adjacent channel assignments in many areas.

The objective of this task is to undertake a broad review of receiver spectrum standards to characterize their status and to explore needs and options for promoting the use of more interference-robust receivers. The first phase includes the identification of existing standards, both mandatory and voluntary. This report presents the results of this first phase. The second phase will examine the underlying requirements, assess trade-offs among potential regulatory approaches and develop appropriate recommendations.

With the exception of certain television services, the FCC has not published receiver spectrum standards and has allowed the marketplace to determine the appropriate receiver specifications. Realizing that poorly designed receivers can cause interference and limit the number and type of transmitters that can operate within a given environment, the FCC is now considering the adoption of receiver standards. On March 13, 2003, the FCC adopted a Notice of Inquiry (NOI) to this effect. The NOI requests, *inter alia*, comments on standards that could be mandatory or voluntary.

NTIA, on the other hand, has receiver spectrum standards for most Federal users of the radio spectrum. NTIA has taken the approach that, for Federal users, the performance of both the transmitter and the receiver should be regulated. This approach to management of the radio spectrum emphasizes prevention of interference and improved spectrum management. Federal agencies generally comply with the NTIA standards, with some agencies implementing even stricter standards.

Industry associations and standards setting bodies have published receiver spectrum standards for some radio services. Many manufacturers adhere to these standards in the interest

of providing systems that perform adequately in adverse operational environments. However, few standards exist for many non-Federal services and frequency bands.

Many foreign countries have implemented receiver spectrum standards. Usually, rather than developing standards themselves, they adopt standards issued by the various international industry and inter-governmental associations.

The second phase of this study and follow-up work will include an examination of the need for standards, working with the FCC to establish standards or other means for preventing non-cochannel interference and promoting efficient use of the spectrum, updating the Federal standards in the NTIA manual, and the initiation of a program for greater promulgating emission characteristics in the Federal bands.

GLOSSARY

ADF	Automatic Direction Finding
AGC	Automatic Gain Control
AM	Amplitude Modulated
CB	Citizens Band
CEA	Consumer Electronics Association
CW	Continuous Wave
dB	decibels
dBm	decibels above one milliwatt
dBW	decibels above one watt
DME	Distance Measuring Equipment
DOD	Department of Defense
EIA	Electronic Industries Association
EMC	Electromagnetic Capability
ETSI	Electronic Telecommunications Standards Institute
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCC	Federal Communications Commission
FM	Frequency Modulation
HF	High Frequency (3 to 30 MHz)
ICAO	International Civil Aviation Organization
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ILS	Instrument Landing System
IM	Intermodulation
IMO	International Maritime Organization
ITU	International Telecommunications Union
kHz	Kilohertz
kW	Kilowatt
MF	Medium Frequency (.3 to 3 MHz)
MHz	Megahertz
MIL-STD	Military Standard
NDB	Non-Directional Beacon
NTIA	National Telecommunications and Information Administration
PCS	Personal Communications Service
PM	Phase Modulated
RTCA	Radio Technical Commission for Aeronautics
RTCM	Radio Technical Commission for Maritime Services
SMR	Specialized Mobile Radio
TIA	Telecommunications Industry Association
TSO	Technical Standard Order
UHF	Ultra High Frequency (300 to 3000 MHz)
VHF	Very High Frequency (30 to 300 MHz)

VOR	VHF Omni-directional Range
μvolt	Microvolt
V/m	Volts per meter

Section 1
INTRODUCTION

1.1 Background

As part of the overall spectrum management process, NTIA and the FCC have developed radio regulations to facilitate operation of various radio services in the same environment without unacceptable levels of radio interference. These regulations generally focus on sharing spectrum and the interfering potential of transmitters. Less attention has been given to the regulation of receiver parameters and the associated non-cochannel interference issues.

In recent years, there have been a number of cases of non-cochannel[1] interference that have been caused by the inadequate performance of receivers instead of by transmitter performance. One element in the prevention of non-cochannel interference and improvement in spectrum utilization efficiency is the design and use of receivers that are less susceptible to interference. Some of the reasons why these interference and efficiency problems are now becoming apparent may include:

1) continued dramatic increase in overall spectrum use;

2) mix of analog and digital technologies that have different spectral requirements, channel plans and interference suppression capabilities;

3) introduction of new services and systems without adopting standards needed for electromagnetic compatibility with incumbent services and systems;

4) design tradeoffs favoring inexpensive radio equipment rather than good equipment performance;

5) reduction or loss of previously available guard bands;

6) equipment manufacturers' lack of knowledge of characteristics of equipment operating in the same or adjacent bands;

7) increased receiver front-end bandwidth associated with greater tuning range of certain receivers; and

8) different system channel plans in the same band e.g. specialized mobile radio (SMR) and public safety operations sharing the 800 MHz band.[2]

Receiver designs that do not take into adequate account the operational environment are often vulnerable to interference from non-cochannel signals because of inadequate dynamic range or selectivity within the Radio Frequency (RF) or Intermediate Frequency (IF) stages of the receiver. Some examples of interference due to inadequate receiver design that have been investigated by NTIA include the following:

1) Fixed-satellite service receiving earth stations that use low noise preamplifiers at the antenna and have little or no filtering prior to active components,[3]

2) Digital radio relay receivers that use low noise preamplifiers and have little or no filtering prior to active components,[4]

3) Unlicensed Part 15 receivers, such as garage door openers, that use very wide bandwidths,[5]

4) Analog television and other consumer receivers with generally very poor RF selectivity,[6] and

5) VHF maritime receivers with insufficient selectivity.[7]

In the U.S. regulatory environment, it sometimes is not clear whether interference problems resulting from design faults in the receiver are the responsibility of the receiver owner or the transmitter owner to resolve. Without standards, the quality of the receiver and its interference susceptibility is left to the buyer of a piece of radio equipment as an aspect of market-place choices. Nevertheless, user reaction to interference, in some cases public reaction, may place the onus on changing transmitter operations regardless of the actual cause of the interference.

The increased demands placed on the radio spectrum require effective spectrum management. Currently, efficient spectrum utilization is not achieved due to limitations on the assignment of adjacent or semi-adjacent channels in the same or nearby areas in some services. This results in many potential assignments being unavailable. One well-known example is the practice by the FCC not to assign adjacent analog television channels in the same area due to poor receiver selectivity. Had television receiver standards been implemented, this frequency assignment constraint would not have been necessary and there would have been adequate television channels to satisfy demand.[8]

In response to the *Omnibus Budget Reconciliation Act of 1993* and the *Balanced Budget Act of 1997*, NTIA identified a total of 255 MHz of Federal spectrum for reallocation to the private sector to provide additional spectrum for emerging telecommunications technologies and to help balance the Federal budget through subsequent auction of the identified bands.[9] Because of the large spectrum requirements of the Federal Government and the mandate to avoid excessive costs or serious degradation to Federal operations, most of these bands were identified with some degree of encumbrance. These encumbrances include continued Federal operations within certain bands at specific sites and continued Federal operations in adjacent bands. Introduction of new services and systems in the 17 bands identified for reallocation will open up a significant number of potential adjacent band interference problems. In the *Spectrum Reallocation Final Report*, NTIA recognized the potential problems and recommended that effective receiver standards, either regulatory or established by industry, be developed for new technologies operating in the reallocated bands adjacent to high-power Federal systems.[10]

Domestically, there has been no clear consensus regarding the best means to assure development and use of suitably designed receivers. Previously, the FCC declined to mandate standards for commercial receivers, stating that the pressures of the marketplace provide the best means to accomplish this goal. In some commercial areas, such as Personal Communications Service (PCS), system designers have successfully applied receiver standards. In other areas, especially where the consumers have access to products that achieve significantly different levels of performance, the lack of known standards and compliance may make it difficult for them to make an informed choice.

1.2 Objectives

The objective of Phase 1 of this task was to undertake a broad review of receiver spectrum standards to characterize their status, both domestically and internationally. This Report presents the results of this phase.

Phase 2 will explore various alternatives and options to promote the use of receivers that are compatible with their operating environment, especially in commercial bands adjacent to Federal bands in which Federal high power equipment is operated. That phase will examine effectiveness trade-offs of various regulatory and voluntary approaches and develop appropriate recommendations.

1.3 Approach

Existing standards were compiled and reviewed in order to categorize the various types of standards and associated regulatory frameworks. In the sections that follow, particularly the tables, concise examples of different types of receiver standards are provided. For application of a standard, the complete referenced document should be consulted.[11]

Section 2
TECHNICAL BACKGROUND

This report focuses on potential non-cochannel interference of an unwanted transmitter on a victim receiver, and the standards that recommend receiver design parameters to prevent that interference.

There are two modes whereby an undesired transmitter can interfere with a non-cochannel receiver. The first mode, usually regulated via limits on emissions outside the transmitter's authorized bandwidth, involves unwanted emissions from the transmitter falling in the receiver's tuned channel. The second mode involves several possible undesired responses of the receiver to the fundamental emissions in the transmitter's tuned channel. These modes are generally independent, the former being dependent on the transmitter's modulation and output filtering, and the latter on the receiver's selectivity, dynamic range, and intermodulation rejection capability. It is this second mode that is the subject of this report.

These non-cochannel interference mechanisms include:

- feed through of non-cochannel signals to the demodulator due to inadequate selectivity (filtering) at RF and IF stages;
- blocking due to an undesired very strong signal saturating the first amplifier stages and causing severe distortion
- receiver desensitization resulting from erroneous automatic gain control responses to non-cochannel signals;
- gain compression due to inadequate RF selectivity and dynamic range;
- spurious responses (to non-cochannel signals that mix with locally generated signals and fall within the receiver passband); and
- intermodulation of the desired and non-cochannel signals or two or more non-cochannel signals in non-linear stages of a receiver (e.g., in connection with gain compression).

The definitions of terms used to specify receiver standards vary among standardization bodies, especially for technical definitions that describe the means for measuring compliance. Thus, the source documents and associated publications, as well as the *IEEE Standard Dictionary of Electrical and Electronics Terms*, ITU Recommendation SM.332-4, *Selectivity of Receivers*, and Federal Standard 1037C, *Telecommunications: Glossary of Telecommunications Terms*, should be consulted for proper interpretation and application of the standards. Following are generalized definitions for receiver parameters and other technical terms used in this report:

- Adjacent Channel – A channel with bandwidth equal to, and abutting the desired signal channel.

- Adjacent Channel Rejection (attenuation) – The ability of a receiver to reject signals in the adjacent channel.

- Adjacent Channel Selectivity – The ability of a receiver to discriminate between a desired signal and an undesired signal in an adjacent channel.

- Blocking – Saturation of the front end amplifier stage of a receiver by an undesired signal on a frequency different from that of the desired signal, thereby causing severe distortion and other non-linear effects that prevent proper operation of the receiver. This is also called the receiver saturation or blanking.

- Cross Modulation – The appearance of modulation from an unwanted signal on the desired signal.

- Image Frequency (of a heterodyne receiver) – The frequency removed from the local oscillator frequency, in the direction opposite to the direction of the desired signal frequency, by an amount equal to the intermediate frequency (i.e., difference between the desired channel frequency and the local oscillator frequency).

- Image Frequency Rejection – The ability of a receiver to reject signals at the image frequency.

- Intermodulation Rejection – The ability of a receiver to reject intermodulation products produced by the mixing of two or more signals at the input to the receiver.

- Necessary Bandwidth – For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at the rate and with the quality required under specified conditions.

- Non-Cochannel Signal – Any signal or portion of a signal falling outside the authorized bandwidth of the desired signal.

- Occupied Bandwidth – The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage $\beta/2$ of the total mean power of a given emission. Unless otherwise specified, the value of $\beta/2$ should be taken as 0.5%. β equals the percentage of power outside the occupied bandwidth frequency limits.

- Out-of-Band Emission – Emission on a frequency or frequencies immediately outside the necessary bandwidth that result from the modulation process, but excluding spurious emissions.

- Selectivity – Rejection (attenuation) of an undesired signal at frequencies close to the desired signal frequency. It is often specified as the amount of frequency difference between desired and undesired signals needed to produce a specified attenuation of the undesired signal.

- Sensitivity Depression or Desensitization – The level of a non-cochannel signal that increases a receiver signal power threshold or decreases receiver gain by a defined amount.

- Spurious Emission – Emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions.

- Spurious Response – Undesired receiver response resulting from mixing of the local oscillator and undesired signals. This includes the response to undesired signals at the image frequency.

- Unwanted Emissions – Both spurious emissions and out-of-band emissions.

Section 3
FEDERAL AGENCY STANDARDS

3.1 National Telecommunications And Information Administration (NTIA)

NTIA is responsible for managing Federal Government use of the radio spectrum. Its regulations, pertaining to Federal Government use of the frequency spectrum, are contained in the *Manual of Regulations and Procedures for Federal Radio Frequency Management*.[12]

The NTIA Manual provides receiver standards for most fixed systems below 15 GHz, most mobile systems below 420 MHz, and most radar systems as shown in Table 1. Generally, these standards include requirements for selectivity, spurious response rejection, and intermodulation rejection. These standards cover a large percentage of the authorized assignments in the Government Master Frequency File,[13] including the most congested Very High Frequency (VHF) and Ultra High Frequency (UHF) bands.

Table 1. Summary of NTIA Receiver Standards

NTIA Manual Section	Frequency Band	Service	Parameter	Requirement
3.9.7	162-174 MHz	VHF Inter-national Boundary and Water Commission	Selectivity	90 dB
			Intermodulation Rejection	80 dB
			Spurious & Image Rejection	100 dB
5.3.1	HF 3 – 30 MHz	Fixed & Mobile	Selectivity	The pass band shall be no greater than the authorized bandwidth of emission and the slope of the selectivity outside the pass band shall be 100 dB/kHz
5.3.3	406.1 - 420 MHz, 932-935/941-944 MHz, 1.71 - 15.35 GHz	Fixed	Spurious Rejection	The receiver unwanted signals shall be attenuated at least 60 dB relative to the receiver sensitivity at the center of the pass band
			Selectivity	The 3 dB receiver bandwidth should be commensurate with the authorized emission bandwidth plus twice the frequency tolerance of the transmitter. The 60 dB receiver bandwidth shall not exceed five times the 3 dB receiver bandwidth

Table 1. Summary of NTIA Receiver Standards (continued)				
NTIA Manual Section	Frequency Band	Service	Parameter	Requirement
5.3.5.1	29.7-50 MHz, 162-174 MHz, 406.1-420 MHz	Fixed & Mobile (Wide Band)	Spurious Rejection	All exc. portable: 85 dB Portable: 50-60 dB (depending on band)
			Adjacent Channel Rejection (Analog)	All exc. portable: 80 dB Portable: 50-70 dB
			Adjacent Channel rejection (Digital)	All exc. portable: 50-55 dB Portable: 50 dB
			Intermodulation Rejection	All exc. portable: 60-70 dB Portable: 50 dB
5.3.5.2	138-150.8 MHz, 162-174 MHz, 406.1-420 MHz	Fixed & Mobile (Narrow Band)	Spurious Rejection	All exc. portable: 70 dB Portable: 60 dB
			Adjacent Channel Rejection	All exc. portable: 60-70 dB Portable: 50-60 dB
			Intermodulation Rejection	All exc. portable: 70 dB Portable: 50 dB
5.5.2	2.9-40 GHz	Radars (Criteria B)	Selectivity	The overall receiver selectivity characteristics shall be commensurate with or narrower than the transmitter bandwidth
			Spurious Rejection, excluding image	50 dB, except where broadband front ends are required
			Stability	Frequency stability of receivers shall be commensurate with, or better than that of the associated transmitter

Table 1. Summary of NTIA Receiver Standards (continued)				
NTIA Manual Section	Frequency Band	Service	Parameter	Requirement
5.5.3	All Radar Bands	Radars (Criteria C)	Selectivity	The overall receiver selectivity characteristics shall be commensurate with or narrower than the transmitter bandwidth. Receivers shall be capable of switching bandwidth limits to appropriate values whenever the transmitter bandwidth is switched
			Spurious Rejection, excluding image	60 dB
			Image rejection	50 dB
			Stability	Frequency stability of receivers shall be commensurate with, or better than that of the associated transmitter
5.5.4	2.7-2.9 GHz	Radars (Criteria D)	Selectivity	The overall receiver selectivity characteristics shall be commensurate with or narrower than the transmitter bandwidth. Receivers shall be capable of switching bandwidth limits to appropriate values whenever the transmitter bandwidth is switched
			Spurious Rejection, excluding image	60 dB
			Image Rejection	50 dB
			Stability	Frequency stability of receivers shall be commensurate with, or better than that of the associated transmitter

Table 1. Summary of NTIA Receiver Standards (continued)				
NTIA Manual Section	Frequency Band	Service	Parameter	Requirement
			Receiver Interference Suppression Circuitry	Radar systems should have provisions incorporated into the system to suppress pulsed interference. The following information is intended for use as an aid in the design and development of receiver signal processing circuitry or software to suppress asynchronous pulsed interference. A description of the parametric range of the expected environmental signal characteristics at the receiver IF output is: Peak I/N ratio:<50 dB Pulse width: 0.5 to 4.0 μs PRF: 100 to 2000 pps
5.5.5	449 MHz	Radar (Criteria E, Wind Profiler Radars)	Selectivity	The 3 dB receiver bandwidth should be commensurate with the authorized emission bandwidth plus twice the transmitter frequency tolerance of 10 parts per million (ppm). The 60 dB receiver bandwidth shall be commensurate with the 60 dB emission bandwidth. Receivers shall be capable of switching bandwidth limits to appropriate values whenever the transmitter bandwidth is switched
			Spurious rejection, excluding image	60 dB
			Image Rejection	50 dB
			EMC Provision	Radars shall have the capability to tolerate incoherent pulsed interference of duty cycles less than 1.5 percent such that peak interfering signal levels 30 dB greater than the receiver noise level at the IF output will not degrade performance

Table 1. Summary of NTIA Receiver Standards (continued)				
NTIA Manual Section	Frequency Band	Service	Parameter	Requirement
8.2.29	156-162 MHz	Maritime Mobile	Adjacent Channel Selectivity	70 dB fixed 40 dB portable
			Spurious Rejection	85 dB fixed 50 dB portable
Note: This table is a summary only. Reference should be made to the NTIA Manual for the full text of the standard.				

3.2 Federal Communications Commission (FCC)

The FCC is responsible for regulation of spectrum use by the private sector and non-Federal agencies. Its regulations are published in Title 47 of the *Code of Federal Regulations*. Generally, the FCC has not mandated receiver standards in the past. Instead, it has relied on the market place to encourage manufacturers to design receivers to whatever specifications are required for market place acceptance. Two exceptions have been in the area of cable-ready television receivers and unlicensed devices authorized under FCC Part 15 rules.

The FCC established the Spectrum Policy Task Force to study methods of improving spectrum management. This Task Force recommended that the FCC consider adopting receiver spectrum standards. The FCC has recently released a Notice of Inquiry (NOI) on this subject.[14]

Part 15.17 of the FCC rules, Radio Frequency Devices, has receiver standards pertaining to non-licensed devices. It advises parties responsible for equipment compliance to consider the proximity and the high power of non-government licensed radio stations, such as broadcast, amateur, land mobile, and non-geostationary mobile satellite feeder link earth stations, and U.S. Government radio stations, which could include high-powered radar systems, when choosing operating frequencies during the design of their equipment to reduce the susceptibility to receive harmful interference. Information on non-government use of the spectrum can be obtained by consulting the Table of Frequency Allocations in the FCC rules. Information on U.S. Government operations can be obtained by contacting the Director for Spectrum Plans and Policy within the National Telecommunications and Information Administration.[15]

This is an example of an approach to prevent interference, which is based on the expectation that manufacturers or operators characterize the electromagnetic environment in which the receiver will operate and develop appropriate voluntary standards or equipment specifications for receiver compatibility.

Part 15.118 of the FCC rules on cable ready consumer electronics equipment gives standards for receivers labeled as cable ready. It provides very detailed requirements and

measurement methods for adjacent channel interference, image channel interference, direct pickup interference, and tuner overload.[16]

In another area, while not setting a standard, the FCC's October 1984 Memorandum Opinion and Order for changes to rules related to educational FM stations recognized the work of the Electronic Industry Association/Consumer Electronics Group (EIA/CEG). The FCC acknowledges that it considers this work essential because insufficient information is now available to allow the drafting of standards for this service. The FCC recommends that the EIA Committee fill that void by providing guidance for improved receivers. The FCC emphasizes this point by stating that "if the industry, for whatever reasons, is unable or unwilling to set its own receiver standards, it may be necessary for the FCC to step in." The Order further states that "the FCC may, upon review, determine that voluntary compliance by receiver manufacturers with EIA guidelines is appropriate, and we may be able to begin relaxing the assignment criteria as market penetration of the improved receivers expands."[17] Ultimately, it could also decide to provide interference protection only to those receivers meeting minimum interference standards.

3.3 Department Of Defense (DOD)

Receiver standards for the military are published by the U.S. Department of Defense. They pertain to all procurements by the various military departments. The primary DOD receiver spectrum standards are contained in two documents: MIL-STD 461E, *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipmen*t, and MIL-STD 469B, *Radar Engineering Interface Requirement, Electromagnetic Compatibility.*

MIL-STD 461E is the primary military standard relating to receiver spectrum standards.[18] The provisions of this standard primarily concern high-level radiation that may cause damage to the receiver, but Appendix A gives examples of various limits for different conditions for susceptibility to non-cochannel emissions. It includes a requirement to provide normal operation with an unwanted signal of 0 dBm outside of the tuning range of the receiver and also for an unwanted signal of 80 dB above the desired signal within the tuning range. There is also a cross modulation requirement for continued operation with a Carrier-to-Interference power ratio (C/I) of -66 dB. It also includes limits for bulk cable injection, power line interference, and general environmental levels. It provides detailed test procedures for measuring receiver parameters.

The second standard, MIL-STD 469B, contains receiver bandwidth, spurious responses, and image rejection for various classes of radars.[19] The standard and requirements are shown in Table 2. Many of these standards are derived from the NTIA standards.

Table 2. MIL-STD 469B Requirements for radar receivers

Radar category[20]	Group[21]	Requirements
1	B, C, D	The overall receiver selectivity characteristics shall be more narrow than the transmitter bandwidth described in tables IV, V, and VI[22] for the respective group. The minimum frequency range over which the receiver acceptance bandwidth and susceptibility requirements apply shall be the F_{MIN} to F_{MAX} range in table VI.
1	B	Receiver rejection of spurious responses, other than image responses, shall be 50 dB or better except where broadband front ends are required operationally.
1	C, D	Receivers shall be capable of switching bandwidth limits to appropriate values whenever the transmitter bandwidth is switched (pulse shape changed). Receiver image rejection shall be at least 50 dB; rejection of all other spurious responses shall be at least 60 dB.
2	B,C	The required acceptance bandwidth is the receiver acceptance bandwidth which includes the fundamental frequency response and extends from the lowest to the highest frequencies on the selectivity curve outside of which all other responses are at least 80 dB below the fundamental frequency response. Required acceptance bandwidths are listed: Type modulation — Required acceptance bandwidth (MHz) Non-FM pulse — 20/t FM pulse — 20d/t CW — $3 \times 10^{-4} F_o$ FM/CW — $3 \times 10^{-4} F_o + B_d$ The radar receiver shall not exhibit any undesired response when subjected to signals outside the acceptance bandwidth. RF preselection shall be employed except where broadband front ends are required operationally. The requirement for broadband front ends will be determined by the contracting activity and incorporated into the equipment or subsystem request-for-proposal, specification, contract, or order. The minimum frequency range over which the receiver susceptibility characteristics apply shall be the F_{MIN} to F_{MAX} range in table VI for Category 2 radars.

3.4 Federal Aviation Administration (FAA)

The Federal Aviation Administration is responsible for regulations pertaining to flight operations. For communications and navigation equipment, the FAA publishes Technical Standard Orders (TSOs) which refer to Radio Technical Commission for Aeronautics (RTCA) standards for their technical requirements.[23] Some of the TSOs are voluntary, at least for certain

applications, and some are mandatory. For instance, in order to be identified with the applicable TSO marking, TSO-C32d prescribes that HF radio receiving equipment must meet the standards set forth in RTCA Document No. DO-163, *Minimum Performance Standards - Airborne High Frequency Radio Communications Transmitting and Receiving Equipment Operating Within the Radio Frequency Range 1.5-30 Megahertz.*[24] For their own receivers, the FAA uses procurement specifications for VHF/UHF AM Air/Ground Radio Communication Receivers. The specifications are given in Table 3.[25]

Table 3. FAA VHF/UHF AM Air/Ground Radio Communication Receiver Specifications

Parameter	Requirement
Selectivity, +/- 9 kHz	6 dB
Selectivity, +/- 25 kHz	60 dB
Spurious response rejection	70 dB
Desensitization	80 dB
Intermodulation rejection	75 dB
Cross Modulation rejection (+/- 0.5 MHz)	70 dB
Cross Modulation rejection (+/- 1.0 MHz)	75 dB
Cross Modulation rejection (+/- 1.5 MHz)	80 dB

3.5 Department Of Agriculture

The Department of Agriculture has requirements given in their *Minimum Standard Specifications for Analog Only FM Land Mobile Radio Communications Equipment*.[26] Test methods and definitions are based primarily on TIA/EIA–603–A, *Land Mobile FM or PM Communications Equipment Measurements and Performance Standards* but include additional limits. These specifications are given in Table 4, Table 5, and Table 6.[27] The Department of Agriculture specifications are unique because they have separate specifications for Economy, Standard, and High Performance equipment. This concept may also be applicable for the private sector because it could enable consumers to make purchase decisions based on required performance and cost.

Table 4. Department of Agriculture VHF Low-Band Receiver Specifications

Parameter	Type	Economy	Standard	High Performance
Adjacent Channel Selectivity	Portable	70 dB	N/A	75 dB
	Mobile	70 dB	80 dB	85 dB
	Base	N/A	85 dB	85 dB
Spurious Rejection	Portable	65 dB	N/A	70 dB
	Mobile	80 dB	80 dB	90 dB
	Base	N/A	85 dB	100 dB
Intermodulation Rejection	Portable	60 dB	N/A	65 dB
	Mobile	70 dB	75 dB	75 dB
	Base	N/A	75 dB	75 dB
Note: N/A = Not Applicable				

Table 5. Department of Agriculture VHF High-Band Receiver Specifications

Parameter	Type	Wideband			Narrowband		
		Economy	Standard	High Performance	Economy	Standard	High Performance
Adjacent Channel Selectivity	Portable	70 dB	75 dB	75 dB	60 dB	63 dB	65 dB
	Mobile	70 dB	80 dB	85 dB	70 dB	70 dB	73 dB
	Base	85 dB	85 dB	85 dB	78 dB	78 dB	80 dB
	Aviation	80 dB	N/A	N/A	70 dB	N/A	N/A
Spurious Rejection	Portable	70 dB	70 dB	75 dB	70 dB	70 dB	75 dB
	Mobile	80 dB	80 dB	90 dB	80 dB	80 dB	80 dB
	Base	80 dB	85 dB	100 dB	80 dB	85 dB	100 dB
	Aviation	85 dB	N/A	N/A	80 dB	N/A	N/A
Intermodulation Rejection	Portable	65 dB	65 dB	75 dB	65 dB	65 dB	65 dB
	Mobile	70 dB	75 dB	75 dB	70 dB	70 dB	70 dB
	Base	75 dB	75 dB	75 dB	70 dB	70 dB	75 dB
	Aviation	70 dB	N/A	N/A	70 dB	N/A	N/A

Table 6. Department of Agriculture UHF Receiver Specifications

Parameter	Type	Wideband			Narrowband		
		Economy	Stan-dard	High Perfor-mance	Economy	Stan-dard	High Perfor-mance
Adjacent Channel Selectivity	Portable	70 dB	N/A	75 dB	60 dB	N/A	65 dB
	Mobile	70 dB	80 dB	85 dB	70 dB	70 dB	73 dB
	Base	75 dB	85 dB	85 dB	75 dB	78 dB	80 dB
	Aviation	80 dB	N/A	N/A	70 dB	N/A	N/A
Spurious Rejection	Portable	70 dB	N/A	75 dB	70 dB	N/A	75 dB
	Mobile	80 dB	80 dB	90 dB	80 dB	80 dB	80 dB
	Base	75 dB	85 dB	100 dB	75 dB	85 dB	100 dB
	Aviation	85 dB	N/A	N/A	80 dB	N/A	N/A
Intermod-ulation Rejection	Portable	65 dB	N/A	75 dB	65 dB	N/A	65 dB
	Mobile	70 dB	75 dB	75 dB	70 dB	70 dB	70 dB
	Base	70 dB	75 dB	75 dB	70 dB	70 dB	75 dB
	Aviation	70 dB	N/A	N/A	70 dB	N/A	N/A

Section 4
U.S. INDUSTRY ASSOCIATION STANDARDS

4.1 Telecommunications Industry Association (TIA)

The Telecommunications Industry Association, in conjunction with the Electronic Industries Association (EIA), publishes recommended standards designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers, facilitating interchangeability and improvement of products, and assisting purchasers in selecting and obtaining with minimum delay, the proper products for their particular needs. Adherence to their standards, which is very widespread, is entirely voluntary. There is close coordination between TIA and the various international standards organizations. Some examples from their standards include the following:

TIA/EIA TSB 10-F, *Interference Criteria for Microwave Systems* provides a methodology and criteria for properly coordinating microwave systems in merged bands. This bulletin provides guidance and examples for interference protection and coordination in the microwave bands but it does not give specific receiver standards.[28]

TIA /EIA -690, *Recommended Minimum Standards for 800 MHz Cellular Subscriber Units* provides minimum standards for cellular subscriber units. It includes the receiver requirements shown Table 7.[29]

Table 7. TIA-690 Requirements for 800 MHz Cellular Subscriber Units

Parameter	Requirement
Adjacent channel rejection	16 dB
Semi-Adjacent channel rejection	60 dB
Intermodulation rejection	55 dB
Spurious Response Rejection	60 dB

TIA/ EIA–382–A, *Minimum Standards - Citizens Band Radio Service Amplitude Modulated (AM) Transceivers Operating in the 27 MHz Band* provides definitions, methods of measurement, and minimum standards for Citizens Band receivers. This standard includes requirements for receivers as shown in Table 8.[30]

Table 8. TIA-382-A Requirements for CB AM Transceivers in the 27 MHz Band

Parameter	Requirement
Adjacent channel rejection	35 dB
Alternate channel rejection	35 dB
Receiver desensitization immunity	35 dB
Spurious response rejection	30 dB
Cross Modulation rejection	25 dB
Intermodulation rejection	40 dB
Impulse Noise Limiter and Blanking	10 dB

TIA–603–A, Land *Mobile FM or PM Communications Equipment Measurements and Performance Standards* provides methods of measurements for receivers and gives detailed procedures on making measurements of adjacent channel rejection, offset channel selectivity, spurious response rejection, intermodulation rejection, and blocking rejection. This standard is widely referenced in the industry for methods of making measurements. This standard addresses Class B (standard performance) and Class A (high interference rejection) equipment as shown in Table 9. This is similar to the Department of Agriculture requirements for Economy, Standard, and High Performance equipment.[31]

Table 9. TIA-603-A Requirements for Land Mobile FM and PM Equipment

Type Service	Response	Applicable Channelization	Fixed	Mobile	Portable
Class A	Adj Channel rejection	>20 kHz	75 dB	75 dB	70 dB
Class B	Adj Channel rejection	>20 kHz	70 dB	70 dB	60 dB
Class A	Adj Channel rejection	15 kHz	65 dB	65 dB	65 dB
Class B	Adj Channel rejection	15 kHz	60 dB	60 dB	60 dB
Class A	Adj Channel rejection	12.5 kHz	45 dB	45 dB	45 dB
Class B	Adj Channel rejection	12.5 kHz	40 dB	40 dB	40 dB
Class A	Spurious rejection	N/A	75 dB	75 dB	75 dB
Class B	Spurious rejection	N/A	70 dB	70 dB	60 dB
Class A	Intermodulation rejection	N/A	75 dB	75 dB	70 dB
Class B	Intermodulation rejection	N/A	70 dB	70 dB	50 dB
All	Offset channel selectivity	N/A	20 dB	20 dB	20 dB
Class A	Blocking Rejection	N/A	90 dB	90 dB	80 dB
Class B	Blocking Rejection	N/A	80 dB	80 dB	70 dB

4.2 Consumer Electronics Association (CEA)

The CEA, in conjunction with the EIA, publishes standards related to consumer electronics. It has two standards applicable to receiver susceptibility: EIA/IS-31, *Recommended*

Design Guideline, Rejection of Educational Interference to Channel 6 Television Reception, and EIA/IS-16-A, *Immunity of Television Receivers and Video Cassette Recorders (VCRs) to Direct Radiation From Radio Transmissions, 0.5 to 30 MHz.*

The first standard, EIA/IS-31, establishes design guidelines for color television receivers and Video Cassette Recorders (VCR's) for providing rejection of educational and non-commercial Frequency Modulated (FM) broadcast interference.[32] It was prepared to permit more educational FM licenses to be awarded. It provides for three levels of desired television channel 6 reception with specific FM signals in the educational FM band of 88.1 to 91.9 MHz. It provides a chart plot of the undesired to desired signal power ratio that causes a noticeable level of interference vs. frequency offset of the FM channel from television channel 6.[33]

The second standard, EIA/IS-16-A, establishes performance guidelines for the immunity of television receivers and VCR's to radio transmissions below 30 MHz and provides recommended measurement procedures. It was established in response to the large number of complaints by consumers of interference from amateur radio, citizens band and AM radiobroadcast stations to television receivers in the early days of television. It states that an AM broadcast, amateur radio, or Citizens Band (CB) signal of 1 volt per meter (V/m), or any other emission within the 0.5 to 30 MHz band of 0.3 V/m shall not cause noticeable interference to either the video or the audio of a television receiver.[34]

4.3 Radio Technical Commission For Aeronautics (RTCA)

RTCA is an association of aeronautical organizations of the United States from both government and industry. It is dedicated to the advancement of aeronautics, seeking sound technical solutions to problems involving the application of electronics and telecommunications to aeronautical operations. The association's objective is to resolve conflicts by mutual agreement of its member organizations. RTCA is not an official agency of the United States government and its recommendations may not be regarded as statements of official government policy unless so enunciated by the government organization or agency having statutory jurisdiction over any matters to which the recommendations relate. Many RTCA recommendations are indeed included in TSO's of the FAA.

RTCA has numerous standards for avionics. Due to the critical nature and safety of flight issues related to aviation communication and navigation, RTCA standards are considerably more detailed than most other standards. Below is a representative sample of RTCA standards relating to receiver susceptibility to interference.

4.3.1 RTCA/DO-143, *Minimum Operating Performance Standards for Airborne Radio Marker Receiving Equipment Operating on 75 MHz*

RTCA/DO-143 has requirements for sensitivity depression, cross modulation, and spurious response for receivers operated in the landing approach mode. There are also additional requirements for receivers operated in the enroute mode. As an example, requirements for

sensitivity depression caused by out of band broadcast signals include requirements that the level of a standard test signal required to produce receiver threshold shall not increase more than 4 dB when there is added a channel 4 or 5 television signal having a level of 3.5 volts, and also that the level of a standard test signal required to produce receiver threshold shall not increase more than 4 dB when a 0.5 volt FM RF signal is present between 72.02 to 74.58 MHz and 75.42 to 75.98 MHz.[35]

4.3.2 RTCA/DO-177, *Minimum Operating Performance Standards for Airborne Receiving Equipment for Microwave Landing Systems*

RTCA/DO-177 has non-cochannel interference rejection standards that require that normal operational specifications shall be met in the presence of clear wave signals between 5000 MHz and 5250 MHz, at -55 dBW, excluding the band 5030 to 5091.7 MHz. Normal operational specifications shall also be met with interfering signals between 5250 MHz and 12.4 GHz at -20 dBm. Normal operational specifications shall also be met in the presence of C-Band weather radars in the 5350 to 5470 MHz band.[36]

4.3.3 RTCA/DO-179, *Minimum Operating Performance Standards for Airborne Radio Direction Finding Equipment*

RTCA/DO-179 applies to AM equipment operating in the Medium Frequency (MF) bands. It gives receiver selectivity requirements to be met in the presence of RF signal field strengths producing a defined receiver output at specified frequencies off resonance. Two criteria are given, one for simply being able to receive the non-directional beacon (NDB) audio, and the second for a maximum bearing error permitted in the automatic direction finding (ADF) mode as shown in Table 10. This standard also contains spurious response rejection requirements for signals from 50 kHz to 150 MHz as shown in Table 11 and cross modulation requirements as shown in Table 12.[37]

Table 10. RTCA DO-179 Selectivity requirements of for ADF Receivers

Carrier offset frequency	NDB mode	ADF mode
0 kHz	0 dB	NA
1 kHz	0 dB	-10 dB
1.5 kHz	6 dB	-4 dB
2 kHz	12 dB	2 dB
3 khz	27 dB	17 dB
4 kHz	42 dB	32 dB
5 kHz	57 dB	47 dB
6 kHz	72 dB	62 dB
7 kHz	>80 dB	>70 dB

Table 11. RTCA DO-179 Spurious Response requirements for ADF Receivers

Carrier tuning range	Response attenuation
190 – 850 kHz	80 dB
> 850 kHz	60 dB

Table 12. RTCA DO-179 Cross Modulation Requirements for ADF Receivers

Frequency Range	Undesired modulated signal	Desired unmodulated signal (μvolts per meter)
50kHz - 550 kHz	100 μvolts/meter - 0.2 volt/meter	100 μvolts/meter - 0.2 volt/meter
550 kHz – 150 MHz	100 μvolts/meter - 1 volt/meter	100 μvolts/meter - 0.2 volt/meter
Note: μvolts = microvolts		

4.3.4 RTCA/DO-186A, *Minimum Operating Performance Standards for Airborne Radio Communications Equipment operating within the Radio Frequency Range 117.975 to 137 MHz*

RTCA/DO186A is an example of a standard that goes into great detail. It defines six classes of receivers, depending on the channelization and the capability of offset carrier operation. Some of the specifications include the following requirements:[38]

Skirt Bandwidth (Selectivity)

Class A receivers utilize a 50 kHz channel separation environment having offset carrier operation. Class B receivers utilize the same separation environment but not having offset carrier operation. For these receivers the requirement is that at a frequency displaced by 43 kHz on either side of the assigned channel frequency, the level of an input signal required to produce reference Automatic Gain Control (AGC) voltage shall be at least 60 dB greater than the level required to produce reference AGC voltage at the assigned channel frequency.

Class C receivers utilize a 25 kHz channel separation environment having offset carrier operation. For these receivers the requirement is that at frequencies displaced by 17 and 25 kHz on either side of the assigned channel frequency, the input signal level required to produce reference AGC voltage shall be at least 40 dB and 60 dB respectively, greater than the level required to produce reference AGC voltage at the assigned channel frequency.

Class D receivers utilize a 25 kHz channel separation environment not having offset carrier operation. For these receivers the requirement is that at a frequency displaced by 22 kHz on either side of the assigned channel frequency, the input signal level required to produce reference AGC voltage shall be at least 60 dB greater than the level required to produce reference AGC voltage at the assigned channel frequency.

Class E receivers utilize a 8.33 kHz channel separation environment not having offset carrier operation. For these receivers the requirement is that at a frequency displaced by 7.37 kHz on either side of the assigned channel frequency, the input signal level required to produce reference AGC voltage shall be at least 60 dB greater than the level required to produce reference AGC voltage at the assigned channel frequency.

Spurious Responses Rejection

In this standard, spurious response rejection requirements are given for an input signal level on an undesired frequency that is required to produce a detector-carrier AGC level equal to that required for a 6 dB signal-plus-noise to noise ratio on the desired channel. This input signal shall be not less than 10 millivolts when the undesired input signal frequency is within 108 to 137 MHz and is on any frequency within 18 kHz of any assignable channel. This requirement does not apply for input signals on the desired channel and the upper and lower adjacent channels or when the undesired input signal frequency is between 50 kHz and 1215 MHz, excluding the band 108 - 137 MHz.

Cross Modulation Rejection

With the simultaneous application of an unmodulated carrier at the desired channel frequency and a signal modulated 30 percent at 1,000 Hz (undesired signal), the receiver output, due to cross modulation, shall be at least 10 dB less than rated output. The desired channel signal shall be at any level between 20 and 500 μvolts, and the interfering signal (undesired) at a level of 10,000 μvolts at any frequency within 100 - 156 MHz. For Class E receivers, this includes the frequencies equivalent to the second higher and second lower channels to which the receiver can be tuned, but excludes the frequency range between these two channels.

Intermodulation Rejection

The standard has an intermodulation requirement for the simultaneous application of two unmodulated undesired signals within the range of 87.5 to 107.9 MHz, with levels at the receiver input terminals of -5 dBm. With the receiver audio compressor disabled, audio quieting shall be less than 6 dB.

Desensitization

Desensitization is defined for a -87 dBm signal at the receiver input modulated 30 percent with a 1 kHz tone and at the desired channel frequency. Under these conditions, the receiver signal-plus-noise to noise ratio shall not decrease to less than 6 dB in the presence of an unmodulated carrier having a level of -33 dBm at the receiver input terminals. This requirement applies at frequencies between 108 and 156 MHz, including the frequencies equivalent to the next higher and the next lower channels to which the receiver can be tuned, but excluding the frequency range between these two channels.

Likewise, the signal plus noise to noise ratio shall not decrease to less than 6 dB in the presence of a modulated carrier having a level of -7 dBm at the receiver input terminals and at

any frequency within the range 50 kHz through 1215 MHz, except for discrete spurious response frequencies. These exclude the frequencies within the range 87.5 - 156 MHz. At the discrete spurious response frequencies, the unmodulated carrier (undesired signal) shall have a level of -33 dBm at the receiver input terminals. In addition, the signal plus noise to noise ratio shall not decrease to less than 6 dB in the presence of an unmodulated carrier having a level of -5 dBm at the receiver input terminals and at frequencies between 87.5 and 107.9 MHz.

4.3.5 RTCA/DO-189, *Minimum Operating Performance Standards for Airborne Distance Measuring Equipment Operating Within the Radio Frequency Range of 960 to 1215 MHz*

RTCA/DO-189 has a recommendation for On and Off Channel Signal Rejection. It requires that the equipment meet specifications when two or more Distance Measuring Equipment (DME) ground signals are received on the same channel if one signal is 8 dB or greater in amplitude than the next stronger one. This is an example of a cochannel requirement. RTCA/DO-189 also has requirements for rejecting signals whose receive pulse pairs deviate more than 2 microseconds from the nominal spacing for any channels over the input level range from -41 dBm to the equipment's minimum sensitivity level. For pulse pairs that deviate by more than 5 microseconds, the requirement is for signals up to -33 dBm. There are also similar requirements for numerous other combinations of pulse rates, on and off channel frequency, and pulse pair spacing requirements. These are other examples of cochannel requirements. RTCA/DO-189 also has requirements for receiver susceptibility to CW interference. It requires that the equipment meet certain specifications when a CW signal having a level of -40 dBm is applied over the input frequency range of 90 kHz to 10,000 MHz, excluding frequencies within the 960 to 1215 MHz band.[39]

4.3.6 RTCA/DO-196, *Minimum Operating Performance Standards for VOR Receiving Equipment Operating Within the Radio Frequency Range of 108 to 117.95 MHz*

This standard has requirements for adjacent channel rejection, cross modulation rejection, intermodulation, spurious response, and desensitization. For adjacent channel rejection it requires that the bearing information shall not change by more than one degree when a desired signal is present and any of the following are present in an adjacent channel:

a) desired VOR signal of -93 dBm and an undesired first adjacent channel VOR signal of -113 to -59 dBm,

b) desired VOR signal between -93 and -53 dBm and an undesired second adjacent channel VOR signal of up to -33 dBm or 46 dB maximum above the desired signal,

c) desired VOR signal of -93 dBm and an undesired first adjacent channel localizer signal between -113 and -59 dBm, or

d) desired VOR signal between -93 and -3 dBm and an undesired second adjacent channel localizer signal up to -33 dBm or 46 dB maximum above the desired signal.

The standard requires that the bearing information shall not change by more than one degree when a desired signal is present at -83 to -33 dBm and an undesired VOR signal is present on any VOR frequency due to cross modulation. This excludes the first and second adjacent channels, and also an undesired standard audio test signal between 100 to 108 MHz and between 118 to 152 MHz at a level of -33 dBm.

The standard provides operating performance requirements for intermodulation rejection in the presence of commercial FM signals in the 88 to 108 MHz band.[40] The standard contains spurious response rejection requirements for undesired input signals between 50 kHz and 1215 MHz, with additional special requirements applying between 108 and 137 MHz. It requires that the receiver input level of an undesired signal needed to produce the same AGC level obtained with a -93 dBm desired signal not be less than -33 dBm. The standard also provides desensitization requirements for undesired signals up to -13 dBm for any frequency between 50 kHz and 1215 MHz, with lessened requirements between 108 to 118.5 MHz.[41]

4.3.7 RTCA/DO-229B, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*

RTCA/DO-229B provides receiver spectrum requirements for GPS receivers. Tables and graphs are included that show the interference levels to be expected as a function of signal type (CW, modulated, or pulse), frequency, pulse width, and bandwidth for in-band, near-band, and out-of-band interference.[42]

4.4 Radio Technical Commission For Maritime Services (RTCM)

The Radio Technical Commission for Maritime Services (RTCM) is an international non-profit scientific, professional, and educational organization. RTCM members include both non-government and government organizations. Although started in 1947 as a U.S. government advisory committee, RTCM is now an independent organization supported by members from all over the world. The RTCM attempts to keep members informed about regional and international maritime radionavigation and radiocommunication policy issues, regulatory changes, and technical standards development. It provides a forum in which government and non-government members can work together to develop technical standards and consensus recommendations concerning issues of particular concern. RTCM is actively engaged in the development of international standards for maritime radionavigation and radiocommunication systems.

RTCM Paper 87-99/SC117-SD*, Recommended Minimum Standards for Installed Maritime VHF Radiotelephone Equipment Operating in High Level Electromagnetic Environments* includes measurements made to determine if the requirements of IEC 1097 are adequate. The paper concludes that these standards are not adequate for operation in areas of

high electromagnetic interference, and recommends that stricter standards be developed. The paper itself, however, does not include any new specific recommendations.[43]

Section 5
INTERNATIONAL STANDARDS

5.1 International Telecommunication Union (ITU)

The ITU publishes *Radio Regulations* that are ratified to have treaty status by most of the countries of the world, including the United States. It also publishes recommendations developed by its Radiocommunications Sector (ITU-R) that are non-binding, unless they are incorporated into the Radio Regulations by reference. Most of the *Radio Regulations* regarding receivers are general in nature. Article 3 of the *Radio Regulations* provides technical characteristics of equipment.

Paragraph 3.3 of the *Radio Regulations* requires that transmitting and receiving equipment should be designed to take into account the technical characteristics of transmitting and receiving equipment likely to be employed in neighboring and other parts of the spectrum, provided that all technically and economically justifiable measures have been taken to reduce the level of unwanted emissions from the latter transmitting equipment and to reduce the susceptibility to interference of the latter receiving equipment.

Paragraph 3.12 of the *Radio Regulations* contains a requirement for receivers. This paragraph requires that receiving stations should use equipment with technical characteristics appropriate for the class of emission concerned and selectivity should be appropriate for the bandwidth of the transmitted signal.

Paragraph 3.13 of the *Radio Regulation* makes a specific point regarding interference into receivers. This paragraph requires that the performance characteristics of receivers should be adequate to ensure that they do not suffer from interference due to transmitters situated at a reasonable distance and which operate in accordance with these regulations.[44]

Recommendation ITU-R M.489-2, *Technical Characteristics of VHF Radiotelephone Equipment Operating in the Maritime Mobile Service in Channels Spaced by 25 kHz* contains various requirements for VHF maritime mobile radios. This recommendation specifies that adjacent channel rejection and spurious response rejection shall be at least 70 dB and that intermodulation rejection shall be at least 65 dB.[45]

Recommendation ITU-R IS.1009-1, *Compatibility Between the Sound-Broadcasting Service in the Band of about 87-108 MHz and the Aeronautical Services in the Band 108-137 MHz* contains recommendations for interference suppression of FM broadcast signals by VHF AM aeronautical receivers. This recommendation specifies criteria for compatibility between FM broadcast service and aeronautical services. It identifies four interference mechanisms as follows, and gives criteria for each.

- A1 Spurious emissions caused by one or more broadcasting transmissions,

- A2 Out-of-band and similar emissions close to the transmitting frequency caused by broadcasting transmissions,

- B1 Intermodulation generated as a result of a receiver being driven into non-linearity by broadcasting signals, and

- B2 Desensitization caused by one or more broadcasting transmissions.

A protection ratio of the difference between the expected VOR or ILS receive power and the power received from the broadcasting transmission is defined for each case. Two categories of receivers are included: those conforming to the 1985 ICAO Annex 10 standards and those conforming to the 1992 ICAO Montreal Task Group 12/1 recommendations. For A1 and A2 interference, the protection ratios for both categories of receivers are the same and are given in Table 13. For B1 interference, several formulas are given, depending on the type of intermodulation product and the category of receivers. These formulas contain a frequency offset correction term that is also given in Table 13. For B2 interference, formulas are given which include a frequency difference term.[46]

Table 13. ITU-R IS.1009-1 Recommendations for VOR/ILS Protection Ratios

Frequency difference between wanted signal and unwanted signal or intermodulation product. (kHz)	A1 Interference Protection Ratio (dB)	A2 Interference Protection Ratio (dB)	B1 Interference Correction Term (Montreal receivers)	B1 Interference Correction Term (ICAO ANNEX 10 receivers)
0	14	NA	0	0
50	7	NA	2	2
100	-4	NA	8	5
150	-19	-41	16	11
200	-38	-50	26	NA
250	NA	-59	NA	NA
300	NA	-68	NA	NA

Recommendation 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* includes chart plots of the maximum expected interference noise levels to be expected at GPS and similar receivers for interference studies. By implication, receivers that are not designed to accommodate these levels of noise may not be able to perform properly.[47]

Recommendation ITU-R SM.332-4, *Selectivity of Receivers* recommends that the bandwidth of the receiver shall be no wider than is essential for the transmission of the necessary modulation of the wanted signal without significant distortion. It also provides numerous definitions related to receiver selectivity and spurious response, but does not provide recommended values.[48]

5.2 International Civil Aviation Organization (ICAO)

The International Civil Aviation Organization, Volume 1 of Annex 10 to *The Convention on International Civil Aviation* has several sections on receiver spectrum standards.[49] Annex 10 requires that the ILS receiver design should provide correct operation when an undesired glide path signal, 150 kHz removed from the desired signal, exceeds the desired signal by up to 20 dB and when an undesired glide path signal, 300 kHz or further removed from the desired signal exceeds the desired signal by up to 40 dB.[50]

Annex 10 also specifies required localizer performance when undesired signals of 60 dB greater amplitude than the desired signal exist between 90 kHz and 107.8 kHz and also between 112.2 kHz and 1500 MHz. It also gives glide path receiver response when undesired signals of 60 dB greater than the desired signal exist between 90 kHz and 329 MHz and between 335.3 MHz and 1500 MHz.[51]

In addition, Annex 10 gives criteria for minimum geographic spacing between ground VOR stations. They are based on criteria for VOR receivers designed for 50 kHz channel spacing, which include the following:[52]

a) the desired signal exceeds an undesired co-channel signal by 20 dB or more;
b) an undesired signal, 50 kHz removed from the desired signal, exceeds the desired signal by up to 34 dB;
c) an undesired signal, 100 kHz removed from the desired signal, exceeds the desired signal by up to 46 dB; and
d) an undesired signal, 150 kHz or further removed from the desired signal, and exceeds the desired signal by up to 50 dB.

Annex 10 also gives interference immunity performance for ILS localizer receiving systems from VHF FM broadcast signals. Localizer receivers shall have adequate immunity to interference from two signal third order intermodulation products resulting from the following:

$2N_1 + N_2 + 72 < 0$ for signals between 107.7 and 108 MHz, and

$2N_1 + N_2 + 3*(24 - 20\log\left(\frac{\Delta f}{0.4}\right)) < 0$ for signals below 107.7 MHz,

where N_1 and N_2 are the levels in dBm of the two VHF FM signals at the ILS localizer receiver input.[53]

This document also states that DME receivers shall reject signals greater than 900 kHz removed from the desired channel nominal frequency and having amplitudes up to 42 dB above the threshold sensitivity.[54] It also provides minimum performance criteria for DME receivers when an unwanted signal is on the same frequency as the desired signal and 15 dB weaker, or plus or minus 2 kHz away and 4 dB weaker, or plus or minus 6 kHz or more away and 55 dB stronger.[55]

5.3 European Telecommunication Standard Institute (ETSI)

ETSI, the technical standards body under the European Conference of Postal and Telecommunications Administrations (CEPT), publishes European Technical Standards which are adopted by most regulatory authorities in Europe, as well as some non-European countries. Having common standards facilitates equipment testing and type acceptance in these countries. Following are excerpts from some of the ETSI standards that relate to receiver spectrum requirements. In these documents extreme test conditions have an extended temperature and power supply range compared to normal conditions.

ETS 300-162, *Electromagnetic compatibility and Radio spectrum Matters (ERM); Radiotelephone transmitters and receivers for Tuner overload in the maritime mobile service operating in VHF bands: Technical characteristics and methods of measurement* specifies the minimum requirements for shipborne VHF transmitters and receivers capable of voice and Digital Selective Calling (DSC) fitted with an external antenna connector for use on board ships. This standard specifies that radio receivers operating in the maritime mobile VHF band shall meet the performance standards given in Table 14.[56]

Table 14. ETS 300 162 Requirements for VHF Maritime Receivers

Parameter	Normal Conditions	Extreme Conditions
Adjacent channel rejection	70 dB	60 dB
Spurious response rejection	70 dB	NA
Intermodulation rejection	68 dB	NA
Blocking level	> 90 dBμV	NA

ETS 300 086, *Radio Equipment and Systems Land Mobile Service Technical characteristics and test conditions for radio equipment with an internal or external RF connector intended primarily for analogue speech* contains requirements for land mobile radios in the bands between 30 and 1000 MHz. It includes the requirements given in Table 15.[57]

Table 15. ETS 300 086 Requirements for Land Mobile Receivers

Parameter	Normal Conditions	Extreme Conditions
Co-channel Rejection for 20 or 25 kHz spacing	0 to -8 dB	0 to -8 dB
Co-channel Rejection for 12.5 kHz spacing	0 to -12 dB	0 to -12 dB
Adjacent channel rejection for 20 or 25 kHz spacing	70 dB	60dB
Adjacent channel rejection for 12.5 kHz spacing	60 dB	50 dB
Spurious rejection	70 dB	70 dB
Intermodulation rejection, base stations	70 dB	70 dB
Intermodulation rejection, mobile and portable	65 dB	65 dB
Blocking ratio	84 dB	84 dB

ETS 300 133-5, *Electromagnetic compatibility and Radio spectrum Matters (ERM); Enhanced Radio Message Systems (ERMES); Part 5: Receiver conformance specification* defines the receiver conformance specifications for ERMES. This standard includes the requirements for receivers shown in Table 16.[58]

Table 16. ETS 300 133-5 Requirements for ERMES Receivers

Parameter	Normal conditions	Extreme conditions
Adjacent channel selectivity	60 dB	50 dB
Spurious response immunity	76 dBμV/m	NA
Intermodulation immunity	70 dBμV/m	NA
Blocking immunity	84 dBμV/m	NA

ETS 300 249, *Satellite Earth Stations (SES); Television Receiver-Only (TVRO) equipment used in the Broadcasting Satellite Service (BSS)* gives minimum specifications for the standardization of the technical characteristics of satellite receiving only earth stations capable of receiving audio-visual signals and associated data. This standard recommends that for TVRO equipment the minimum field strength that produces interference shall not be less than 130 dBμV/m (dB above 1 microvolt per meter) for one type of TVRO receiver, and 125 dBμV/m for another type.[59]

ETS 301 390, *Fixed Radio Systems; Point-to–point and Point-to-Multipoint Systems; Spurious emissions and receiver immunity at equipment/antenna port of Digital Fixed Radio Systems* defines limits for receiver immunity for inter-working of digital fixed radio systems. This document recommends that a clear wave interferer at a level of + 30 dB with respect to the wanted signal shall not result in a BER greater than 10^{-5} for interfering signals removed by twice the co-polar channel spacing for point to point systems and five times the co-polar channel spacing for point to multi-point systems.[60]

ETS EN 300 698-1 *Electromagnetic compatibility and Radio Spectrum Matters (ERM); Radio telephone transmitters and receivers for the maritime mobile service operating in the VHF*

bands used on inland waterways; Part 1: Technical characteristics and methods of measurement provides the requirements in Table 17 for marine VHF radios. Measurements are to be made at the antenna terminal. This standard has an additional requirement from many others in that it provides a cochannel rejection requirement based on FM capture theory. [61]

Table 17. ETS EN 300 698-1 Requirements for VHF Maritime Radios

Parameter	Normal Conditions	Extreme Conditions
Cochannel rejection	0 to -10 dB	0 to -10 dB
Adjacent channel rejection	70 dB	60 dB
Spurious response rejection	70 dB	70 dB
Intermodulation rejection	68 dB	68 dB
Blocking	90 dBμvolt	90 dBμvolt

5.4 International Electrotechnical Commission (IEC)

The International Electrotechnical Commission (IEC) promotes and coordinates international standards. These often serve as a basis for national standardization and as references when drafting international tenders and contracts. IEC standards are often incorporated into regulations by reference or adopted in many countries, for instance, by the members of the European Union through CENELEC (European Committee for Electrotechnical Standardization). Either the TC 77 or the CISPR (International Special Committee on Radio Interference) prepare most of their standards. They work closely with national and regional standards organizations. In many cases, the IEC adopts standards prepared by other organizations, especially CENELEC. Likewise, many other standards organizations adopt the standards of the IEC. In the United States, the American National Standards Institute (ANSI) has adopted many of the IEC standards regarding radio frequency matters.

The IEC has both generic and service specific standards. Their generic standards provide minimum requirements that apply where there are no service specific standards. They also serve as a minimum guideline for specific standards, which can generally be no less strict than the generic standard. Many of the generic standards define the radio spectrum environment that equipment is expected to operate in. In describing the environment, the IEC refers to the "totality of electromagnetic phenomena existing at a given location." Environmental categories are (1) residential, commercial and light industrial and (2) industrial. The IEC has several standards that address receiver parameters, including the following:

IEC Standard 1097-7, *Global Maritime Distress and Safety System (GMDSS)-Part 7: Ship borne VHF Radiotelephone Transmitter and Receiver-Operational and Performance Requirements, Methods of Testing and Required Test Results* is a service specific standard referring to the VHF maritime service. It provides standards and test methods for parameters given in Table 18. This standard also requires that the immunity to interference of the receiver shall be such that the wanted signal is not seriously affected by unwanted signals.[62]

Table 18. IEC 1097-7 Requirements for GMDSS Rejection

Parameter	Requirement
Adjacent channel selectivity	70 dB
Spurious response rejection	70 dB
Intermodulation rejection	65 dB
Blocking level	90 dBμV/m

IEC 1000-2-3, *Electromagnetic Compatibility (EMC) Part 2: Environment Section 3: Description of the environment – Radiated and non-network-frequency-related conducted phenomena* is an example of a report that characterizes the unwanted signal environment and provides background information, subjects for consideration and guidelines to facilitate development of receiver specifications. It provides examples of electromagnetic fields to be expected in various environments. For instance, examples of field strengths from authorized transmitters included in this standard are shown below in Table 19. This report also has typical values for background noise as well as interfering fields from power lines and substations, lightning, electrostatic discharge, and other natural and man-made sources of noise.[63]

Table 19. IEC 1000-2-3 Requirements – Interfering Signal Environment

Service	Frequency Range (MHz)	ERP	Typical range of separation	Calculated field strength (V/m)
LF Broadcast and Maritime	0.014 – 0.5	2500 kW	2-20 km	5.5-0.55
AM Broadcast	0.2 – 1.6	50-800 kW	0.5-2 km	12.5-0.78
HF amateur	1.8 - 30	1 kW	10-100 m	22.1-2.21
HF communications, including SW broadcasting	1.6 - 30	10 kW	1-20 km	0.7-0.04
Citizens Band	27 - 28	12 W	10-100 m	2.4-0.24
Amateur VHF/UHF	50 - 52 144 - 146 432 - 438 1290 - 1300	1-8 kW	10-500 m	63-0.44
Fixed and Mobile communications	29 - 40 68 - 87 146 - 174 422 - 432 438 - 470 860 - 990	50-130 W	2-200 m	40-0.25
Portable telephones	1880 - 1990	5 W 1W (DECT)[64]	1-100 m 0.5-10 m	15.6-1.56 14-0.7
VHF TV	40 - 68 174 - 230	100-320 kW	0.5-2 km	8-1.11
FM Broadcast	88 - 108	100 kW	0.25-1 km	8.9-2.2
UHF TV	470 - 853	500 kW	0.5-3 km	10-1.6
Radar	1000 - 30000	1 kW-10 kW	2-20 km	350-1.6 (peak)
Note: V/m = Volts per meter				

IEC 1000-2-5, *Electromagnetic compatibility (EMC) Part 2: Environment – Section 5: Classification of electromagnetic environments Basic EMC publication* is another report that characterizes the receiver operating environment. It defines eight different categories of locations. For example, it defines location class type 2, typical of a residential-urban location, and provides a table of expected electromagnetic fields for various frequency bands and services for CW and for pulse signals.[65] The characteristics of a class type 2 location are as follows:

1) No amateur radio transmitter closer than 20 m
2) No broadcast transmitter operating below 1.6 MHz closer than 5 km
3) Possible presence of diathermy therapy equipment
4) Possible proximity of local substation
5) Possible proximity of audio/hearing aid systems

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques-radiated, radio-frequency, electromagnetic field immunity test* also attempts to characterize the environment. It provides methods and recommended equipment and facilities for measurements. It also provides typical transmitter parameters for various cellular and PCS systems and examples of protection distances and resulting test levels.[66]

IEC 61000-6-1, *Electromagnetic compatibility (EMC) – Part 6: Generic standards – Section 1: Immunity for residential, commercial and light-industrial environments* is an example of a generic standard. It provides test conditions for immunity to radiated fields and other sources of interference expected in the environment. One example is for a receiver to continue to operate normally when subjected to an electromagnetic field of 3 V/m at frequencies between 80 and 1000 MHz with 80 percent AM modulation by a 1 kHz tone.[67]

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Section 1: Immunity for industrial environments* is another generic standard, similar to IEC 61000-6-1, but for industrial environments. It requires the receiver to continue to operate normally when subjected to an electromagnetic field of 10 V/m at frequencies between 80 and 1000 MHz with 80 percent AM modulation by a 1 kHz tone.[68]

IEC 60945, *Maritime navigation and radiocommunications equipment and systems – General requirements – Methods of testing and required test results* is a service specific standard for the maritime services. It was prepared to provide guidance in performing measurements in compliance with International Maritime Organization (IMO) resolutions. It provides test methods and requirements. For example, it states a requirement that receivers operate without degradation in the presence of a 10 V/m signal anywhere between 80 MHz and 2 GHz. This standard also includes a table of radio equipment that should be expected to generate unwanted signals onboard ships.[69]

5.5 International Maritime Organization (IMO)

The IMO was established to provide machinery for cooperation among governments in the field of governmental regulation and practices relating to technical matters of all kinds

affecting shipping engaged in international trade and to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships. IEC 60945 was prepared to provide a means for demonstrating compliance with IMO requirements. For most radio services, the IMO *General Requirements and Performance standards for Shipborne Radiocommunications and Navigation Equipment* state that the immunity to interference of the receiver should be such that the wanted signal is not seriously affected by unwanted signals.[70]

Section 6
SUMMARY OF FINDINGS

In this study, NTIA examined the NTIA Manual, the FCC Rules and Regulations, FCC working group documents, military standards, industry association standards, and international standards to identify receiver spectrum standards. Here are NTIA's findings based on the results of this research.

NTIA includes Federal receiver standards in Chapter 5 of the NTIA Manual for radar and most non-tactical, fixed and mobile systems, especially for the more heavily congested bands. These standards apply to a large percentage of the frequency assignments included in the Government Master File. Areas where Federal receiver standards are not defined include: some radionavigation services; especially Criteria A radars (principally radars having less than 1 kW peak power, radars above 40 GHz, and man-portable radars); portions of the VHF and UHF bands; most mobile services above 420 MHz; and fixed services above 15.35 GHz. Federal organizations follow the requirements of the NTIA Manual, but several, such as the Department of Agriculture and the Department of Defense, have requirements that are more stringent. The FAA also imposes the recommendations of the RTCA in many instances.

Generally, the FCC has not mandated conformance with receiver spectrum standards. However, industry organizations, including TIA, CEA, RTCA, and RTCM, have set standards for specific services, particularly television, land mobile and cellular, aeronautical, maritime, and satellite services. These standards primarily deal with interference from other signals within the same service, but some directly address interference from other services. The primary examples of the latter are aeronautics standards for immunity to interference from VHF television stations. Unless incorporated in a Federal regulation, such as was done for certain RTCA standards by the FAA, these standards are voluntary in the United States.

In the international community, standards are generally developed in a voluntary framework, but are often incorporated by reference in national radio regulations in various countries, thereby becoming mandatory. The IEC, IMO, CEPT, and ETSI have developed standards. In addition to service specific standards, the IEC has several generic standards as well as standards that take the approach of defining the receiver operating environment to enable manufacturers or administrations to develop their own standards, specifications, or requirements.

Section 7
OBSERVATIONS AND RECOMMENDATIONS FOR PHASE 2 STUDY

7.1 Observations

7.1.1 Format of Receiver standards

Most receiver standards developed by NTIA and others are focused on minimizing susceptibility to non-cochannel interference. These standards generally limit interference susceptibility to signals outside of the assigned channel. Most standards can be categorized in one of two different classes.

The first class describes the "standard" environment(s) in which the receiver must be designed to operate. Typical parameters are given for adjacent band signals; high level signals, either in-band or out-of-band; and signals from other services within the same band.

The second class specifies minimal performance requirements for various receiver parameters, typically including adjacent channel rejection, semi-adjacent channel rejection, image frequency rejection, spurious response rejection, intermodulation response rejection, and blocking immunity.

For some bands, if the detailed characteristics of the signals that are likely to cause interference are known, then signal processing or other methods could be used to provide enhanced protection against that type of signal. Examples include the requirements relating to interference between television and FM broadcast services, and between broadcast and the VHF aeronautical services.

7.1.2 Classifications of Receiver standards

NTIA observed that there were two broad classifications of receiver minimum performance standards: service specific and generic. Many of the standards referenced in this report, for instance the TIA standards for land mobile radios given in section 4.1, are service specific. These pertain to the requirements and capabilities of receivers operated in a specific service. The other classification, generic standards, has several uses. These standards may serve as temporary standards until service-specific standards are developed, a basis for service specific standards, or permanent standards for cases where there are no service specific standards. In an example of a generic standard, as given in Table 20, two different levels of performance are shown. One would be high performance receivers designed to operate in areas of high RF interference, and the other for standard receivers designed to operate in less demanding environments.

Table 20. Example of a Generic Receiver Spectrum Standard

Requirement	Class A	Class B
Spurious response rejection	-70 dB	-50 dB
Adjacent channel rejection	-50 dB	-40 dB
Semi-Adjacent channel rejection	-80 dB	-60 dB
60 dB Selectivity BW_{60}[71]	< 3* BW_3	< 5* BW_3
Intermodulation rejection	-80 dB	-60 dB
Image frequency rejection	-70 dB	-50 dB
Blocking immunity	-70 dB	-50 dB

The sample standard given in Table 20 is meant to represent various existing standards included elsewhere in this report. Although the parameters are representative of what is reasonably achievable, they could easily be modified without changing the concept of this approach. Developing measurement methods that are generally applicable to a wide variety of radio services may pose a challenge.

7.1.3 Regulatory Approaches to Promoting or Ensuring Adequate Receiver Performance

Several regulatory approaches might be followed to prevent non-cochannel interference. Ultimately, they all will require the close cooperation of the FCC, NTIA, industry trade groups, service providers, and equipment manufacturers. They range from maintaining the status quo, to implementing full mandatory standards for each service across the spectrum. Responsibility for developing standards could be assumed by the regulatory agencies, primarily the FCC and NTIA, or entrusted to user groups. This section presents several alternative approaches. This list may not be exhaustive and it should be noted that combinations of several approaches are feasible.

7.1.3.1 Regulatory Mandated Standards

Either the regulatory agencies, industry associations, or both could develop standards that would become mandatory. The regulatory agencies could also implement a standard that has already been developed by an industry association. This is common in certain other countries where the national regulatory agencies adopt the appropriate standard developed by an international organization. A domestic example is the incorporation of RTCA standards by reference in FAA TSO's. If mandatory standards are adopted, then specific compliance measurement procedures, certification, and labeling requirements may also have to be mandated.

7.1.3.2 Voluntary Standards

This approach would generally rely on established industry associations or other bodies to develop standards as well as labeling and compliance measurement guidelines. These groups

could be encouraged to develop particular standards where appropriate. In some cases, several different performance levels could be developed. The TIA 603 standard is an example. Class A and Class B performance levels are shown, depending on the amount of interference protection required. Another example is the Department of Agriculture use of different requirements for economy, standard, and high performance receivers.[72]

Compliance with voluntary standards could be encouraged by regulations that explicitly give interference protection to receivers that meet the voluntary standard. Manufacturers could also be required to include labeling that identifies with what performance level a receiver complies. In addition, as the FCC did in its ruling on the EIA implementing voluntary standards on educational FM stations, the implication could be that voluntary standards could become mandatory if sufficient compliance is not obtained.[73]

7.1.3.3 Reliance on Insightful Manufacturers Specifications and Designs

Rather than setting standards, per se, manufacturers could be encouraged to design equipment that would perform adequately in the operational environments. This approach would require the dissemination of information on the RF environment.

This information could assist equipment manufacturers in designing equipment that is suitably tolerant of interfering signals operating in the same or adjacent bands. For instance, the information on currently authorized and anticipated users in each band could include such parameters as power levels, emission characteristics, antenna types, and location. Manufacturers, in the attempt to obtain the widest possible acceptance of their equipment, generally would be expected to design their equipment to operate properly in at least the most prevalent deployment situations. An example of this approach is in the IEC Standards as shown in Section 5.4 of this Report.

An example of an industry using insightful design to minimize susceptibility to interference is the case of using coding in garage door opener and similar receivers. The original openers responded to any signal in the receive pass band above a threshold. After many cases of unexpected operation caused by other signals both in band and adjacent band, most manufacturers started requiring a discrete code to be present in the receive signal to activate the opener. This provided interference protection against other signals, both in the same service and in other services.[74]

An example of the type of information that can be provided to describe the signal environment created by one particular service is the Navy's Cooperative Engagement Capability (CEC) system. This system will operate in the spectrum below the 4940 to 4990 MHz band that was recently reallocated to non-Federal use. The parameters in Table 21 were disseminated to describe the RF environment generated by the CEC system:

Table 21. Navy CEC system

Parameter	Requirement
Operating area.	The coordinates of eleven operating areas, generally near military facilities and coastal waters extending 30 nautical miles inland are defined
Maximum center frequency:	4929 MHz
Maximum EIRP	58 dBW
Out-of-band emissions at +/- 7.65 MHz from center frequency	-3 dBc
Out of band emissions at +/- 12.1 MHz from center frequency	-30 dBc
Out of band emissions > +/- 25.6 MHz from center frequency	<-145 dBc/Hz
Harmonics and Spurious	<-80 dBc

To some extent, this is the approach the FCC relies on in Title 47, Section 15.17, where they state that parties responsible for equipment compliance are advised to consider other transmitters and to design receivers to reduce the susceptibility for receiving harmful interference. This section goes on to state that the FCC Table of Frequency Allocations and the NTIA should be consulted to determine what is currently allocated.[75]

Likewise, section 2.4.4.1 of Annex 10 to the ICAO Convention requires that a receiver operate properly in the flight environment, although it does not specifically define the expected environment or indicate where pertinent information may be obtained.[76]

7.2 Recommendations for Future Study

This report presents the results of the first phase of this study, which is a summary of existing receiver standards. The second phase will examine several possible approaches to receiver standards, including those given in Section 7.1.3, above. Based on the findings of this first phase, it is recommended that this second phase focus on accomplishing the following tasks.

- NTIA should participate in the current FCC Notice of Inquiry on receiver standards. NTIA will also work with the various Federal agencies providing responses to this Phase 1 Report in an attempt to develop recommendations that are appropriate for all users.

- The central question to be answered is for what situations, if any, are receiver spectrum standards beneficial. As discussed in Section 1.1 of this Report, certain studies have indicated that inadequate receiver performance in the face of non-cochannel signals has been the cause of a number of interference situations. With the increased use of the spectrum and the increase in the number of potentially incompatible services utilizing the same or adjacent bands, this interference will likely get worse if nothing is done to prevent it. All significant factors should be assessed, including potential improvements in spectrum utilization efficiency and cost impact.

- If it is found that receiver standards generally provide a net benefit, NTIA should work with the FCC and Federal agencies to consider generic receiver standards that would apply to a wide variety of receiver types and radio services wherever specific receiver standards are not available.

- To further define the need for receiver spectrum standards, NTIA should continue studies to identify root causes of receiver susceptibility to non-cochannel interference for the various radio services based on case studies available by Federal agencies, the FCC, industry and consumer groups. Based on identified trends, strategies should be developed to mitigate identified problem areas. Some examples of areas that need to be further investigated were given in Section 1.1 of this Report.

- NTIA should undertake a thorough review and update to assure that Federal receiver standards currently included in Chapter 5 of the NTIA Manual are clear, up-to-date, verifiable, necessary, and promote the efficient use of the radio spectrum in accordance with established policies.

- NTIA should work with the FCC to consider developing a policy for inclusion in the NTIA Manual and the FCC Rules that clearly defines receiver protection rights, specifically linking such rights to meeting specific and/or generic receiver standards.

- To ensure that existing or proposed new receiver standards are properly applied, further study should be conducted to determine whether additional information or regulation is needed to guide receiver compliance measurements.

ENDNOTES

[1] In this report, a non-cochannel interfering signal is any signal not falling completely within the authorized bandwidth of the desired signal.

[2] *Improving Public Safety Communications in the 800 MHz Band,* WT Docket No. 02-55, Notice of Proposed Rulemaking, 17 FCCR 4873 (2002).

[3] National Telecommunications and Information Administration, *Analysis of Electromagnetic Compatibility Between Radar Stations and 4 GHz Fixed-Satellite Earth Stations*, NTIA Report No. 94-313 (July, 1994); Some receivers in space and microwave applications operate in a system with a small link budget, thus presenting difficulties with the use of filtering prior to low noise amplification.

[4] National Telecommunications and Information Administration, *Ground-Based Weather Radar Compatibility with Digital Radio-Relay Microwave Systems*, NTIA Report No. 90-260 (March 1990).

[5] National Telecommunications and Information Administration, *Measured Characteristics of Selected Non-Licensed Devices*, NTIA TM-91-149 (April 1991); Haley, J, *Navy can't close door jams*, Everett Herald (June 5, 1998).

[6] *FCC Interference Protection Public Workshop* (August 2, 2002) ("Workshop") Transcript (Tr.) at 133.

[7] National Telecommunications and Information Administration NTIA Report No. 99-362, *Evaluation of Marine VHF Radios: Performance in the Savannah, Ga. and New Orleans, La. Port Areas*, National Telecommunications and Information Administration (April 1999).

[8] Workshop, (Tr.).

[9] National Telecommunications and Information Administration, *Identification of Alternate Bands, Response to Title III of the Balanced budget act of 1997*, NTIA Special Publication 98-39 (November 1998).

[10] National Telecommunications and Information Administration, *Spectrum Reallocation Final Report, Response to Title VI – Omnibus Budget Reconciliation Act of 1993*, NTIA Special Publication 95-32, at v (February 1995).

[11] This report does not contain a complete rendition of the standard. In many cases, specific measurement techniques, definitions, and applications are provided in the standards but are not included here. Comparing standards based on the examples given here requires care, as different standards have different definitions and measurement requirements for the same parameters.

[12] National Telecommunications and Information Administration, *Manual of Regulations & Procedures for Federal Radio Frequency Management*, at Chapter 5 (May 2003).

[13] The Government Master File is the list of all frequency authorizations issued to government agencies. It does not include military tactical authorizations.

[14] *Interference Immunity Performance Specifications for Radio Receivers,* ET Docket No. 03-65, Notice of Inquiry, 18 FCCR 6039 (2003).

[15] 47 C.F.R. Part 15 Subpart A-General at Section 15.17.

[16] 47 C.F.R. Part 15 Subpart B-Unintentional Radiators at Section 15.118.

[17] *Changes in the Rules Relating to Noncommercial Educational FM Broadcast Stations,* FCC 85-328, Memorandum Opinion and Order, Docket No. 20735, (released, June 1985).

[18] MIL-STD 461E, *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*, Department of Defense, at Appendix A (August 1999).

[19] MIL-STD 469B, *Radar Engineering Interface Requirement, Electromagnetic Compatibility*, Department of Defense (June 1996).

[20] Category 1 standards apply to all radars and category 2 to those in critical EMC environments.

[21] Groups roughly correspond to the criteria listed in NTIA's *Manual of Regulations and Procedures for Federal Radio Frequency Management* for radars based on frequency, power, and other parameters.

[22] These tables in MIL-STD-469B provide emission limits for the radar transmitters.

[23] Section 4.3 of this report.

[24] TSO-C32d, *High Frequency (HF) Radio Communication Transmitting Equipment Operating Within the Radio Frequency Range of 1.5 to 30 Megahertz*, Federal Aviation Administration (April 1984).

[25] FAA-P-2883, *Purchase Description, VHF/UHF AM Air/Ground Radio Communication Receivers*, Federal Aviation Administration, at Section 3.2.1.2.1.8 (May 1993).

[26] *Minimum Standard Specifications For Analog Only FM Land Mobile Radio Communications Equipment*, Department Of Agriculture, Forest Service, at Sections 13.1 and 13.2 (2002).

[27] TIA/ EIA-603-A, *Land Mobile FM or PM Communications Equipment Measurements and Performance Standards*, Telecommunications Industry Association, at Sections 2.1 and 3.1 (August 2001) ("TIA/EIA-603-A").

[28] TIA/EIA TSB 10-F, *Interference Criteria for Microwave Systems*, Telecommunications Industry Association (June 1994).

[29] TIA/ EIA-690, *Recommended Minimum Standards for 800 MHz Cellular Subscriber Units,* Telecommunications Industry Association, at Section 2.3 (November 2000).

[30] TIA /EIA–382–A *, Minimum Standards - Citizens Band Radio Service Amplitude Modulated (AM) Transceivers Operating in the 27 MHz Band*, Telecommunications Industry Association, at Section 6 (October 1990).

[31] TIA/EIA-603-A at Sections 2.1 and 3.1.

[32] EIA/IS-31, *Recommended Design Guideline, Rejection of Educational Interference to Channel 6 Television Reception*, Electronic Industries Association (July 1987).

[33] This is the standard discussed in the FCC October 1984 Order in Docket No. 20735, discussed in Section 3.2 of this report.

[34] EIA/IS-16-A, *Immunity of Television Receivers and Video Cassette Recorders (VCRs) to Direct Radiation From Radio Transmissions, 0.5 to 30 MHz*, Electronic Industries Association (May 1987).

[35] DO-143, *Minimum Operating Performance Standards for Airborne Radio Marker Receiving Equipment Operating on 75 MHz*, RTCA, at Sections 2-10, 2-13, 2-14 (January 1970).

[36] DO-177, *Minimum Operating Performance Standards for Airborne Receiving Equipment for Microwave Landing Systems*, RTCA (1981).

[37] DO-179, *Minimum Operating Performance Standards for Airborne Radio Direction Finding Equipment*, RTCA (May 1982).

[38] DO-186A, *Minimum Operating Performance Standards for Airborne Radio Communications Equipment Operating Within the Radio Frequency Range 117.975 to 137 MHz*, RTCA (October 1995).

[39] DO-189, *Minimum Operating Performance Standards for Airborne Distance Measuring Equipment Operating Within the Radio Frequency Range of 960 to 1215 MHz*, RTCA, at Sections 2.10 and 2.11 (September 1985).

[40] These requirements are the same as those provided in Annex 10 to the ICAO convention given in Section 5.2 of this report.

[41] DO-196, *Minimum Operating Performance Standards for VOR Receiving Equipment Operating Within the Radio Frequency Range of 108 to 117.95 MHz*, RTCA, at Sections 2.2.2, 2.2.7, and 2.2.8 (March 1986).

[42] DO-229B, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*, RTCA, at Appendix C (October 1999).

[43] Paper 87-99/SC117-STD, *Recommended Standards for Installed Maritime VHF Radiotelephone Equipment Operating in High Level Electromagnetic Environments,* Version 1.0, Radio Technical Commission for Maritime Services (1999).

[44] *Radio Regulations*, Article 3 (2001).

[45] Recommendation ITU-R M.489-2, *Technical Characteristics of VHF Radiotelephone Equipment Operating in the Maritime Mobile Service in Channels Spaced by 25 kHz*, at Section 8.4.1 (1995).

[46] Recommendation ITU-R IS.1009-1, *Compatibility Between the Sound-Broadcasting Service in the Band of about 87-108 MHz and the Aeronautical Services in the Band 108-137 MHz* (1995).

[47] Recommendation 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).

[48] Recommendation ITU-R SM.332-4, *Selectivity of Receivers* (1978).

[49] *Convention on International Civil Aviation,* International Civil Aviation Organization, Annex 10 (1985 and other dates).

[50] *Id.* at Section 2.2.16.

[51] *Id.* at Section 2.2.18.

[52] *Id.* at Section 2.4.6.

[53] *Id.* at Section 3.1.4.

[54] *Id.* at Section 3.5.5.3.4.

[55] *Id.* at Section 3.9.1.1.

[56] ETS 300 162, *Electromagnetic compatibility and Radio spectrum Matters (ERM); Radiotelephone transmitters and receivers for the maritime mobile service operating in VHF bands: Technical characteristics and methods of measurement*, European Telecommunication Standards Institute (March 1998).

[57] ETS 300 086, *Radio Equipment and Systems; Land mobile service; Technical characteristics and test conditions for radio equipment with an internal or external RF connector intended primarily for analogue speech*, European Telecommunication Standards Institute (1997).

[58] ETS 300 133-5, *Electromagnetic compatibility and Radio spectrum Matters (ERM); Enhanced Radio Message Systems (ERMES),* European Telecommunication Standards Institute, at Part 5. (1997)

[59] ETS 300 249, *Satellite Earth Stations (SES); Television Receiver-Only (TVRO) equipment used in the Broadcasting Satellite Service (BSS),* European Telecommunication Standards Institute (1993).

[60] ETS 301 390, *Fixed Radio Systems; Point-to–Point and Point-to-Multipoint Systems; Spurious emissions and receiver immunity at equipment/antenna port of Digital Fixed Radio Systems*, European Telecommunication Standards Institute (2000).

[61] ETS 301 698-1, *Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio telephone transmitters and receivers for the maritime mobile service operating in the VHF bands used on inland waterways; Part 1: Technical characteristics and methods of measurement,* European Telecommunication Standards Institute (2000).

[62] Standard 1097-7, G*lobal maritime distress and safety system (GMDSS)-Part 7: Shipborne VHF radiotelephone transmitter and receiver-Operational and performance requirements, methods of testing and required test results*, International Electrotechnical Commission, at Sections 4.4 and 5.5.8.3 (1999).

[63] Technical Report 1000-2-3, *Electromagnetic compatibility (EMC) Part 2: Environment Section 3: Description of the environment, Radiated and non-network-frequency-related conducted phenomena,* International Electrotechnical Commission (1992).

[64] Digital Enhanced Cordless Telecommunications (DECT) is a low cost cellular telecommunications system widely used in Europe.

[65] Technical Report 1000-2-5, *Electromagnetic compatibility (EMC) Part 2: Environment Section 5: Classification of electromagnetic environments-Basic EMC publication,* International Electrotechnical Commission (1995).

[66] Standard 61000-4-3, *Electromagnetic compatibility (EMC) Part 4-3: Testing and measurement techniques – radiated, radio-frequency, electromagnetic field immunity test,* International Electrotechnical Commission (2002).

[67] Standard 61000-6-1, *Electromagnetic compatibility (EMC) Part 6: Generic standards – Section 1: Immunity for residential, commercial and light-industrial environments,* International Electrotechnical Commission (1997).

[68] Standard 61000-6-2, *Electromagnetic compatibility (EMC) Part 6-2: Generic standards - Immunity for industrial environments,* International Electrotechnical Commission (1999).

[69] Standard 60945, *Maritime navigation and radiocommunication equipment and systems – General requirements – Methods of testing and required test results,* International Electrotechnical Commission (2002).

[70] *General Requirements and Performance Standards for Shipborne Radiocommunications and Navigation Equipment*, International Maritime Organization, at Section III/1.1(a)/8, paragraph 8.3 (2002).

[71] BW_{60} and BW_3 refer to the 60 dB and 3 dB bandwidths respectively.

[72] Section 3.4 of this report.

[73] Section 3.2 of this report.

[74] U.S. Department of Commerce/Office of Telecommunications, *An Analysis of Remote Control and Security Devices in the 225-400 MHz Band*, OT Technical Memorandum 77-244 (November 1977).

[75] Section 3.2 of this report.

[76] Section 5.5 of this report.