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EMC ANALYSIS OF UNIVERSAL AUTOMATIC IDENTIFICATION AND PUBLIC CORRESPONDENCE SYSTEMS IN THE MARITIME VHF BAND

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PROJECT REPORT

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14. ABSTRACT
An electromagnetic compatibility (EMC) analysis of the potential for interference from a single automatic identification system (AIS) transmitter to a public correspondence (PC) VHF/FM receiver operating in both the voice and data modes was completed in December 2003. Subsequently, and prior to documenting the first analysis, the USCG requested an additional EMC analysis of potential interference from multiple shipborne AIS transmitters, again on a maritime PC receiver operating in the same modes. Both analyses are documented in this report. Frequency and antenna distance separations required in order to eliminate the interference were determined. To mitigate interference to the PC receiver in the data mode, the need for forward error correction code was investigated. The appropriate code values were calculated and are provided in this report.

15. SUBJECT TERMS
AIS, Achieved Performance Measure, Articulation Score, Automatic Identification System, Bit Error Rate, COSAM, Electromagnetic Compatibility, public correspondence, Ross DSC 500 Receiver, Spherical Earth Propagation Model

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EXECUTIVE SUMMARY

The United States Coast Guard requested that the Joint Spectrum Center (JSC) perform an electromagnetic compatibility analysis of the potential for interference from an Automatic Identification System (AIS) transmitter to a Public Correspondence (PC) VHF/FM receiver (in both voice and data modes).

The effect on the performance of the maritime PC receiver in the presence of the AIS transmitter(s) was analyzed using the JSC Cosite Model (COSAM Version 5.2). The results of the analysis are as follows:

With respect to the analysis of a maritime PC receiver operating in the voice mode, some interference from the single and multiple AISs was predicted, but the analysis results indicate that this interference would not adversely affect the receiver. Interference from both single and multiple AIS transmitters to the maritime PC receiver operating in the data mode was predicted.

The frequency and antenna separations required to reduce the interference to the maritime PC receiver operating in the data mode were determined and are documented in the report. Further, the use of a Reed-Solomon forward error correction code in the maritime PC receiver could also be used to eliminate the effects of the interference. The appropriate code values were calculated and are provided in this report.

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GLOSSARY

AGC	Automatic Gain Control
AIS	Automatic Identification System
AS	Articulation Score
BER	Bit Error Rate
bps	Bits per Second
COSAM	Cosite Analysis Model
dBc	Power Level Expressed in Decibels Referenced to the Carrier Power
dBm	Power Level Expressed in Decibels Referenced to the One Milliwatt
dBi	Antenna Gain in Decibels with Reference to an Isotropic Radiator
DSC	Digital Selective Calling
EPF	Equipment Parameter File
FEC	Forward Error Correction
FM	Frequency Modulation
GMSK	Gaussian-filtered Minimum Shift Keying
GPS	Global Positioning System
HDLC	High-Level Data Link Control
IF	Intermediate Frequency
JSC	Joint Spectrum Center
kbps	Kilobits per Second
kHz	Kilohertz
MHz	Megahertz
MMSI	Maritime Mobile Service Identity
ms	Milliseconds
PC	Public Correspondence
P_{ino}	Mean Effective On-tune Undesired Power
PRF	Pulse Repetition Frequency
RAS1	Receiver Adjacent Signal 1
RS	Reed-Solomon
SEM	Spherical Earth Model
SINAD	Signal + Noise + Distortion to Noise + Distortion Ratio
TAS	Transmitter Adjacent Signal
TDMA	Time Division Multiple Access
USCG	United States Coast Guard
VHF	Very High Frequency
WRC	World Radio Conference

SECTION 1 – INTRODUCTION

BACKGROUND

The Universal Shipborne Automatic Identification System (AIS) operates on two or more very high frequency (VHF) maritime mobile radio channels using time division multiple access (TDMA). The AIS update rate is determined by the ship speed and turn rate. The faster the ship speed and turn rate, the higher the update rate; the fastest update rate is one time every two seconds. The AIS is used to ensure safe navigation by sharing ship-to-ship position, speed, course, heading, rate of turn, ship status and voyage information, and safety-related messages. The AIS also operates in ship-to-shore and shore-to-ship modes.

After the 2000 World Radio Conference (WRC), two channels were designated for AIS operation and a footnote was added to Appendix 18 (specific footnote L) of the *ITU Radio Regulations* titled "Table of Transmitting Frequencies in the VHF Maritime Mobile Band" as follows:

> These channels (AIS 1 and AIS 2) will be used for an automatic ship identification and surveillance system capable of providing worldwide operation on high seas, unless other frequencies are designated on a regional basis for this purpose.[1]

The channels allocated are the AIS 1 (161.975 MHz.) and the AIS 2 (162.025 MHz). The AIS 1 falls within the nine 25 kHz duplex channels currently utilized by the VHF maritime Public Correspondence (PC) band. These PC channels are 24, 84, 25, 85, 26, 86, 27, 87, and 28. The AIS 2 is allocated in a federal government band and the AIS 1 is PC channel 87B.

Both the AIS transmitter and the PC receiver use duplex and simplex adjacent channels in the maritime mobile VHF band that can potentially result in numerous interference scenarios for communications between systems.

The United States Coast Guard (USCG) had requested that the Joint Spectrum Center (JSC) perform an electromagnetic compatibility analysis of the effects of a single AIS transmitter on the performance of a maritime PC receiver (in both the voice and data modes). This analysis was completed in December 2003. Subsequently, the USCG requested an additional analysis of the effect of multiple AIS

[1]*ITU Radio Regulations*, Appendix 18 (WRC-2000), Table of Transmitting Frequencies in the VHF Maritime Mobile Band, Geneva: International Telecommunication Union, 2001

transmitters on a maritime PC receiver (in both the voice and data modes). Both analyses are documented in this report.

OBJECTIVE

The objective of this task was to determine if either single or multiple AIS transmitters (simplex mode) cause electromagnetic interference to a maritime PC receiver operating in either the data or the voice mode and if so, to determine the frequency and antenna separations that are required in order to eliminate the interference.

APPROACH

General

Since the requirements for the PC receiver are undefined, with the concurrence of the USCG, the analysis team selected the Ross DSC 500 and Neulink NL6000 as typical PC receivers. The Ross is a high-end VHF receiver that can operate in either the clear FM voice mode, or a digital data mode. For this analysis, the Ross receiver was selected for the analog voice mode. The Neulink NL6000 receiver was selected for the digital data mode. The Ross DSC 500 and the Neulink NL6000 receiver performance was evaluated in the presence of a Furuno Model FA-100 AIS transmitter, an IEC 61993-2 certified[2] AIS unit. Measurements were taken of the Furuno Model FA-100 AIS transmitter and the Ross DSC 500 PC receiver. Two performance measures were established for the analysis; an articulation score (AS) for voice mode and a bit error rate (BER) for data mode. The impact of the AIS emissions on the maritime PC receivers was analyzed using a computer simulation model, the JSC Cosite Analysis Model (COSAM).[3]

When interference is predicted for the data mode, factors like, forward error correction (FEC) will be investigated to mitigate the problem.

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[2]IEC Standard 61993-1 Part 2: Maritime Navigation and Radiocommunication Equipment and Systems-Automatic Identification Systems (AIS)-Part 2: Class A Shipborne Equipment of the Automatic Identification System (AIS)-Operational and Performance Requirements, Methods of Testing and Required Test Results, Geneva: 17 December 2001

[3]Laura McIntyre and Don Wheeler, *Cosite Analysis Model Version 5.2*, JSC-UM-02-098, Annapolis, MD: DoD JSC, September 2002

Measurements

The AIS emission characteristics and the PC receiver characteristics were modeled based on measurements performed in the JSC laboratory and from data gleaned from technical manuals. The measurements conducted on the Furuno Model FA-100 AIS transmitter and the Ross DSC 500 PC VHF receiver were based on MIL-STD-449D[4] procedures for conducted emissions spectrum characteristics (Non-Pulsed CE107), adjacent signal interference (CS114), and automatic gain control (AGC) (Impulse Response Measurement CS117). The measurement results were used to construct detailed equipment parameters records required for COSAM. A summary of technical characteristics for both the Furuno transmitter and the Ross DSC 500 receiver are shown in Appendix A, and the JSC measured data are shown in Appendix B.

Neulink NL6000 receiver measured characteristics were not available. The Neulink NL6000 receiver was modeled based on data from technical manuals and telephone conversations with the manufacturer. A summary of technical characteristics for the Furuno transmitter, the Ross DSC 500, and Neulink NL6000 receivers are shown in Appendix A. The JSC measured data are shown in Appendix B. For convenience in this report, the Furuno Model FA-100 AIS transmitter will be referred to as the AIS transmitter. The Ross DSC 500 and the Neulink Nl6000 PC VHF receivers will be referred to as PC analog and PC digital, respectively.

Modeling

COSAM is a statistical model used to account for uncertainties in equipment characteristics and coupling losses in the calculation of signal power levels. The statistical distributions of the background noise power levels and the desired power levels are calculated at a PC receiver input. Samples from these distributions are selected randomly during a computer simulation to generate receiver performance distributions of the AS for analog voice or of the BER for digital receivers. The AS and BER values used in the analysis are the 95 percentile point in the predicted AS and BER distribution.

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[4] *Military Standard, Radio Frequency Spectrum Characteristics, Measurements of*, MIL-STD-449D, Washington DC: US Department of Defense; 22 February 1973 (with Notice 1, 18 May 1976)

Articulation Score

An AS, used as a measure of performance for analog voice receivers, is derived from the percent of monosyllabic spoken words correctly understood by a human listener panel. An AS prediction model is incorporated in COSAM to simulate a trained listener panel.[5,6] The AS output derived from COSAM can be interpreted as a probability that a given word is not received in error.

A human-error correction process occurs when a person listens to an analog voice signal. Each spoken word is a string of phonemes. A monosyllabic word typically contains three phonemes. The listener must correctly identify each of those phonemes to correctly identify the word. Each phoneme can be regarded as a string of 10-ms phoneme fragments, referred to as elements. Related studies indicate that the listener can correctly identify a word (or phoneme) even when many elements within the word are unrecognizable due to interference. Normal connected speech can be understood even if some of the syllables are unintelligible because the listener can deduce the meaning from the context of the sentence. Even under near perfect conditions, due to unavoidable errors, the maximum AS normally attainable is about 95 percent. Based on a previous analysis of similar receivers, an AS of 95 percent was determined to be an acceptable baseline performance threshold for the PC receiver.[7] An AS of 80 percent enables the listener to understand every sentence without significant effort. When the AS degrades to near 70 percent, the listener must concentrate to understand what is said and below 60 percent, the intelligibility is quite poor.[8]

Bit Error Rate

The BER is the ratio of the number of bits of a digital message incorrectly received due to interference, receiver noise, or ambient noise to the number of bits in the message transmitted. A BER of $1X10^{-6}$ was determined to be an acceptable baseline performance threshold for the PC receiver.

This threshold is based on a benign environment where there is no Rayleigh fading, no multipath, no external interference, and without any FEC.

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[5]T. Reilly, L. McIntyre, and M. Maiuzzo, "Models of Speech Intelligibility for Channels Subject to Intermittent Interference," IEEE Military Communications Conference, Washington, DC: 19-22 October 1987

[6]Miller, George, and Licklider, "The Intelligibility of Interrupted Speech," Psycho-Acoustic Laboratory, Harvard University, Cambridge MA: October 22, 1949

[7]Kenneth Roberts and Howard McDonald, Analysis of the UHF Surrogate Satellite Relay (USSR), ECAC-CR-93-020, DoD ECAC (now JSC), Annapolis, MD: October 1976

[8]Dr. Andrew Marsh, "Speech Intelligibility," Architectural Science Laboratory, University of Western Australia: 1999

Analysis Procedures

As a first step to identifying possible interference caused by a single shipborne AIS transmitter to a PC receiver operating in the VHF/FM voice mode, an AS threshold was determined in the presence of receiver and ambient noise, with the AIS transmitter disabled. The receiver and ambient noise level was used to determine the minimum acceptable desired signal. The sum of Galactic and background environmental noise under quiet conditions was assumed to be ambient noise.

The USCG identified four shipborne AIS transmitter environments that represent typical vessel traffic environments, with varying update rates, off the coast of Ft. Lauderdale, Florida.[9] For the analysis of the effect of multiple AIS transmitters on a maritime PC receiver, the densest environment was selected. The update rates of the AIS transmissions were determined by the speed of the ships but did not include any change in the update rate that would be caused by ship course changes since course change data were not available.

The project team repeated the analysis with the AIS transmitters in this environment turned on, and compared the PC receiver performance with the baseline case.

A breakdown of the procedures is provided below:

The baseline AS and BER values resulting from these conditions represent ideal receiver performance expected in a quiet environment with no interference present and minimum desired signal. In actual operation, the PC receiver would typically operate with higher noise levels due to man-made noise from ship systems, etc., resulting in higher desired signal levels.

Next, the AIS transmitter was enabled and tuned to channel AIS 1 (161.975 MHz). The PC receiver AS and BER performance was determined at frequencies that were off tuned by increments of 25, 50, and 75 kHz from the AIS transmitter, with horizontal antenna separations of 10, 1,000, and 10,000 feet. The AS was also determined for frequency separations of 25 and 75 kHz for a co-ship environment with a

[9]David Pietraszewski, USCG R&D Center, email to JSC/J8, Subject: *Screens of AIS traffic off coast of Ft. Lauderdale, FL*, Washington, DC: 11 December 2003

vertical separation of 60 feet. The effect of AIS interference to the PC receiver performance was determined by comparing the AS and BER baselines to the AS and BER performance with the AIS transmitter operating. In addition, with the PC receiver tuned to the edge of its tuning band (156.025 MHz), the project team determined the horizontal antenna separation required to achieve the original baseline AS and BER.

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SECTION 2 – ANALYSIS

MODELING

The AIS transmitter was turned off to establish a baseline receiver performance threshold in the presence of receiver and ambient noise. Based on a previous analysis of similar receivers, a baseline AS of 95 percent and BER of $1X10^{-6}$ were determined to be appropriate baseline performance thresholds. The desired signal was adjusted to a level that yielded a signal-to-noise ratio that ensured acceptable receiver performance for the PC receiver in the analog voice mode. The desired signal level of the PC receiver operating in the data mode was adjusted to a level of -98 dBm based on FCC Standards[10] and based on previous JSC analyses.

Next, the AIS transmitter was activated. The mean effective on-tune undesired power (P_{ino}) at the PC receiver input was calculated using the AIS peak transmit power, antenna gains, system losses, the frequency-dependent rejection factor associated with the interference mechanism being evaluated, and a propagation loss based on antenna separation. The mean P_{ino} power levels and the above associated parameters are shown in Appendixes D and E. The effect of intermodulation interference on the PC receiver performance was not considered due to the low duty cycle of the AIS transmitter. Two interference mechanisms were evaluated; transmitter broadband noise and adjacent-signal interference. The AIS TDMA emission appears as undesired pulses to the PC receiver. Depending on the pulse power and duration, pulse-stretching effects from the undesired AIS transmissions may remain for some time after the pulse has disappeared. Pulse stretching effects are generally the result of ringing in the PC receiver filters or AGC capture. In addition to pulse-stretching effects, high-power effects such as desensitization were considered. Based on the measurements taken, the noise-power levels emitted between pulses (information bursts) by the AIS power amplifier were determined to be insignificant and therefore were not considered in this analysis.

Once the desired-to-undesired power ratio was computed at the PC receiver input, COSAM was used to determine the PC receiver performance, using the appropriate degradation curve. If the AS was less than the specified receiver performance threshold, the frequency separation and/or antenna separation was increased until the required receiver output response was achieved. PC receiver performance degradation caused by the worst-case AIS transmission duty cycle of one pulse every two seconds was analyzed with the antennas separated horizontally and then vertically. The worst-case pulse repetition frequency (PRF) was used for vessels exceeding 23 knots or 14 knots and turning. A typical antenna

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[10] 47 CFR, Chapter 1-Federal Communications Commission, Part 80 – Stations in the Maritime Services, Section 80.753-Signal Strength Requirements at the Service Area Contour, Washington, DC: October 1, 1997

designed for a maritime environment is a CELWAVE coaxial antenna. A VHF antenna with characteristics similar to the CELWAVE antenna was used in the analysis.

The AIS transmitter was tuned to the AIS 1 (161.975 MHz) channel. The performance of a PC receiver operating in both the voice and data modes was determined at frequencies that were off tuned from the AIS transmitter by increments of 25, 50, and 75 kHz, with horizontal antenna separations of 10, 1,000, and 10,000 feet for each increment. The AS was also determined for frequency separations of 25 and 75 kHz, with a vertical antenna separation of 60 feet (Note: There were no significant differences noted between the 50 and 75 kHz separations). The BER was also determined for frequency separations of 25, 50, and 75 kHz, with vertical separations of 60 feet for the antennas to model the co-ship environment. In addition, for the data mode, a 150 feet antenna separation was investigated to determine if additional antenna spacing would eliminate interference for coastal stations.

For multiple AIS transmitter effects, a worst-case vessel traffic pattern was selected from four "screen grabs" of vessel traffic off the coast of Florida, provided by the USCG (Reference 9). The worst-case traffic pattern consisted of 18 vessels, of which 11 were stationary and 7 were in motion off the coast of Fort Lauderdale, Florida. The performance of the PC receiver was analyzed at frequencies off tuned from the AIS transmitter tuned frequency by increments of 25, 50, and 75 kHz.

Single AIS Transmitter – Interference to the PC Receiver

VHF/FM Voice Mode

With the AIS transmitter disabled and the PC receiver in the voice mode, the minimum desired signal level was increased to a sensitivity level that produced an AS close to the targeted 95 percent. An AS of 95.3 percent was predicted based on a desired signal of -115 dBm. The receiver and ambient noise levels were determined to be -130.2 and -132.9 dBm, respectively.

When the AIS transmitter was enabled, the PC receiver AS was minimally degraded. Table 2-1 shows the AS for frequency increments of 25, 50, and 75 kHz, with horizontal antenna separations of 10, 1,000, and 10,000 feet for each increment.

The effects of the AIS transmission on the PC voice receiver can be completely eliminated by off-tuning the receiver to 25 kHz and separating the antennas by 10,000 feet (1.9 miles) or by off-tuning the receiver to 75 kHz and separating the antennas by 1.4 miles. This is apparently due to the AIS fundamental being received by receiver skirts.

Table 2-1. AS for Selected Frequency and Horizontal Antenna Separations

Frequency Separation (kHz)	Horizontal Antenna Separation (feet)	AS without AIS (percent)	AS with AIS (percent)
25	10	95.3	93.1
25	1,000	95.3	93.2
25	10,000	95.3	95.1
50	10	95.3	93.1
50	1,000	95.3	93.4
50	10,000	95.3	95.1
75	10	95.3	93.1
75	1,000	95.3	93.5
75	10,000	95.3	95.1

Degradation to the PC receiver from the AIS transmissions may be mitigated by off-tuning the PC receiver to the edge of its tuning band (156.025 MHz) and separating the antennas horizontally by 500 feet (0.095 miles) to obtain an AS of 95.3 percent.

With the PC receiver and AIS antennas separated vertically by 60 feet and with a desired received signal level of -115 dBm, the resulting AS was predicted to be 95.3 percent, without the AIS emissions. When the AIS transmitter is operating, degradation of the performance of the PC receiver is minimal as shown in Table 2-2. For this case, with an antenna separation of 60 feet and 25 kHz frequency separation, the AIS undesired signal power produced a mean effective on-tune AIS peak power level at the PC receiver input of -87.6 dBm with an antenna to antenna coupling loss of 70.6 dB. The antenna gains used were 2.1 dBi with 1 dB combined system losses and 61.2 dB of frequency dependent rejection.

Table 2-2. AS for Selected Frequency and Vertical Antenna Separations

Frequency Separation (kHz)	Vertical Antenna Separation (feet)	AS without AIS	AS with AIS
25	60	95.3	93.3
75	60	95.3	93.8

Data Mode

With the AIS transmitter disabled and the PC receiver in the data mode, the desired signal level of -98 dBm resulted in a BER less than, or equal to, the threshold $1X10^{-6}$.

Table 2-3 shows the results for frequency increments of 25, 50, and 75 kHz, with antenna separations of 10, 1,000, and 10,000 feet for each increment.

Table 2-3. BER for Selected Frequency and Horizontal Antenna Separations

Frequency Separation (kHz)	Horizontal Antenna Separation (feet)	BER without AIS	BER with AIS
25	10	<1X10^{-6}	3.1X10^{-2}
25	1,000	<1X10^{-6}	2.8X10^{-2}
25	10,000	<1X10^{-6}	7.4X10^{-5}
50	10	<1X10^{-6}	3.1X10^{-2}
50	1,000	<1X10^{-6}	1.4X10^{-2}
50	10,000	<1X10^{-6}	<1.0X10^{-6}
75	10	<1X10^{-6}	3.1X10^{-2}
75	1,000	<1X10^{-6}	1.2X10^{-2}
75	10,000	<1X10^{-6}	<1.0X10^{-6}

The effects of AIS pulsed transmissions on the PC digital receiver can be mitigated (producing a BER of 1X10^{-6}) by off-tuning the PC receiver to

- 25 kHz and separating the antennas horizontally by 2.6 miles
- 50 kHz and separating the antennas horizontally by 1.14 miles
- 75 kHz and separating the antennas horizontally by 1.04 miles
- 156.025 MHz, the edge of its tuning band, and separating the antennas by 2,000 feet (0.37 miles).

If a BER of 1X10^{-4} was acceptable, the effects of the AIS pulsed transmissions on the PC digital receiver can be mitigated by off-tuning the PC receiver to

- 25 kHz and separating the antennas horizontally by 1.8 miles
- 50 kHz and separating the antennas horizontally by 0.81 miles
- 75 kHz and separating the antennas horizontally by 0.76 miles
- 156.025 MHz, the edge of its tuning band, and separating the antennas by 900 feet (0.17 miles).

The PC receiver BER operating without the AIS emissions, was predicted to be less than 1X10^{-6}. With the AIS transmitter operating and the AIS antennas separated vertically by 60 and 150 feet, the performance of the PC receiver was degraded as shown in Table 2-4. For this case, with an antenna separation of 60 feet and 25 kHz frequency separation, the AIS undesired signal power produced a mean effective on-tune AIS peak power level at the PC receiver input of -97.5 dBm with an antenna to antenna coupling loss of 71.7 dB. The antenna gains used were 2.1 dBi with 1 dB combined system losses and 70 dB of frequency dependent rejection.

Table 2-4. BER for Selected Frequency and Vertical Antenna Separations

Frequency Separation (kHz)	Vertical Antenna Separation (feet)	BER without AIS	BER with AIS
25	60	$<1X10^{-6}$	$2X10^{-2}$
50	60	$<1X10^{-6}$	$5.6X10^{-3}$
75	60	$<1X10^{-6}$	$4.2X10^{-3}$
25	150	$<1X10^{-6}$	$2.7X10^{-3}$
50	150	$<1X10^{-6}$	$7.3X10^{-5}$
75	150	$<1X10^{-6}$	$3.8X10^{-5}$

Multiple AIS Transmitters – Interference to the PC Receiver

Voice Mode

The effect of multiple maritime AIS transmitters on the performance of the PC receiver operating in voice mode was investigated. The USCG (Reference 9) provided four “screen grabs” that depict vessel traffic off the coast of Fort Lauderdale, Florida. Figure 2-1 depicts the scenario with the most congested vessel traffic and highest AIS update rates. This scenario was selected as the worst-case. Note, this analysis assumed that there is not an AIS on the victim ship.

The locations of selected vessels within a 10 mile radius of an origin located at the approximate center of the selected vessels were determined using Figure 2-1. The selected vessels are designated by the small solid circles. The location of each vessel was entered in COSAM to compute the separation distance between the AIS transmitter antennas and the PC receiver antenna located at the center of the coordinate system. The vessel number, name, x and y locations relative to the center of the coordinate system, and the AIS transmitter update rates are shown in Table 2-5. The update rate indicates how often the AIS pulse is transmitted.

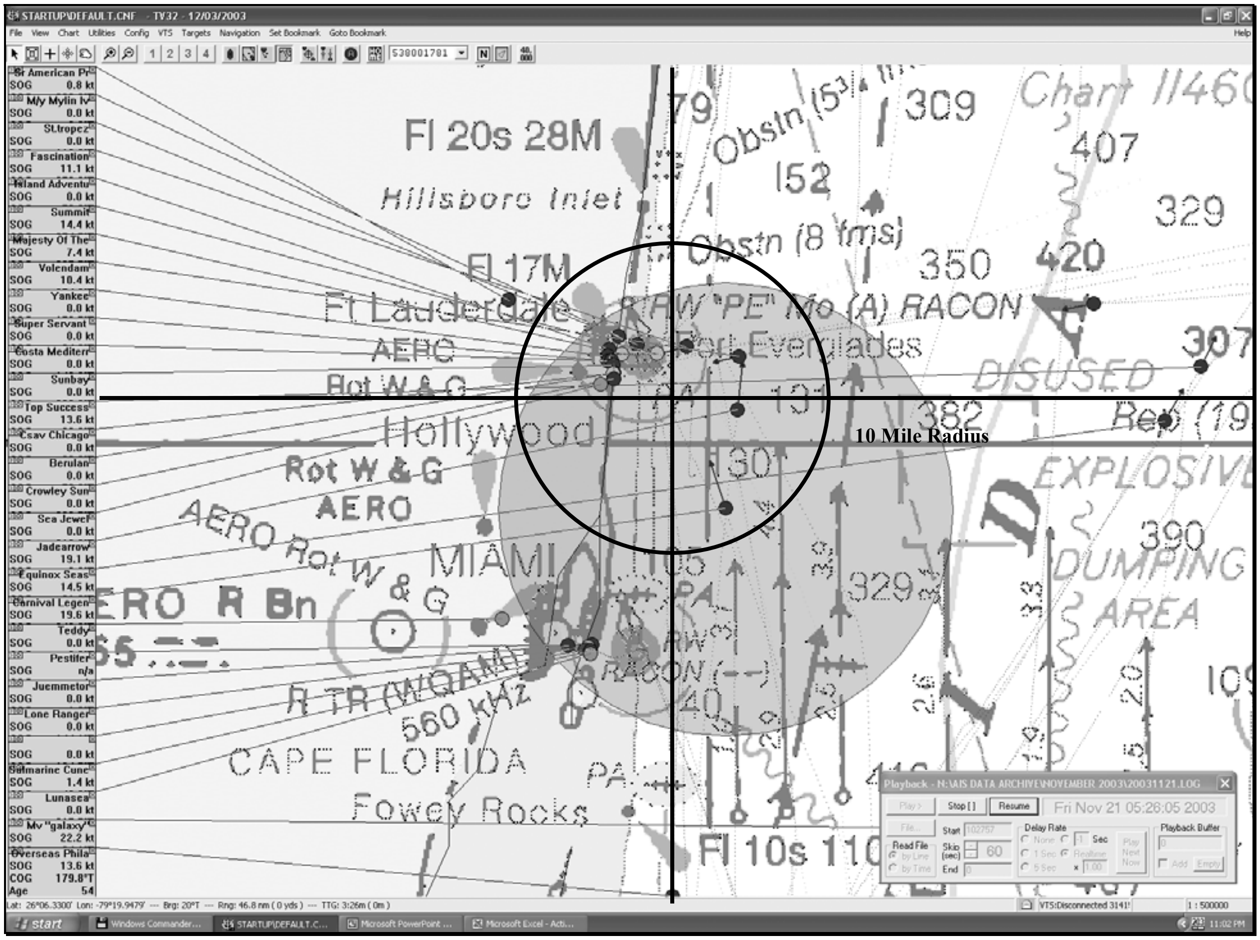

Figure 2-1. Fort Lauderdale, Florida - Worst-Case AIS Traffic Scenario

Table 2-5. Multiple AIS Transmitter Evironment

Vessel Number	Vessel Name	X-Axis (miles)	Y-Axis (miles)	Update Rate (seconds)
1	Jade Arrow	4.14	0.52	6
2	Volendam	4.14	3.10	10
3	Fascination	0.52	3.62	10
4	Carnival Legend	3.62	-7.24	6
5	Sea Jewel	-5.00	.78	10
6	Crowley Sun	-4.14	1.29	10
7	Berulan	-4.14	1.81	10
8	Summit	-1.29	3.10	3.33
9	Saint Tropez	-2.59	3.62	10
10	M/y Mylin IV	-3.88	4.14	10
11	Island Adventurer	-3.62	3.10	10
12	Majesty of the Sea	-4.40	3.36	10
13	Yankee	-4.91	3.10	10
14	Super Servant	-4.91	2.59	10
15	Costa Mediterr	-4.66	2.59	10
16	Sunbay	-4.40	2.33	10
17	Top Success	4.91	0.52	10
18	Csav Chicago	-4.14	1.55	10

The results of multiple AIS transmitter emissions on the performance of the PC receiver in the voice mode are shown in Table 2-6. The degradation to the PC receiver is minimal.

Table 2-6. AS for Multiple AIS Transmitter Emissions

Frequency Separation (kHz)	AS without AIS	AS with AIS
25	95.4	94.0
50	95.4	94.9
75	95.4	95.2

Data Mode

Using the same scenario as above, the effect of multiple AIS transmitters on the performance of the PC receiver in the data mode was investigated. The AIS transmitter environment and update rates are provided in Table 2-5. BER degradation is predicted for only the 25-kHz case for the PC data mode analysis shown in Table 2-7. This degradation is based on no Rayleigh fading or multipath of the desired signal, and in the absence of FEC and external interference other than the AIS emissions.

Table 2-7. BER for Worst-Case AIS Transmitter Emissions

Frequency Separation (kHz)	BER without AIS	BER with AIS
25	$<1X10^{-6}$	$1.2X10^{-5}$
50	$<1X10^{-6}$	$<1X10^{-6}$
75	$<1X10^{-6}$	$<1X10^{-6}$

FORWARD ERROR CORRECTION

Systems can facilitate digital communications on channels that would otherwise be unusable through the use of FEC. FEC can be designed to combat fading, multipath, and noise-like pulsed interference. FEC is available on new systems and as a retrofit to older systems. Since the AIS transmitter transmits TDMA pulses, an FEC scheme conducive to correcting the effect of pulsed interference on the PC receiver performance could be applied. Reed-Solomon (RS) code with an interleaver is an effective FEC scheme to mitigate the effect of pulsed interference.

The COSAM analysis was repeated with FEC applied. This analysis showed that the PC digital receiver desired BER performance of $1X10^{-6}$ could be achieved in the presence of a single AIS transmitter by implementing a (31, 19) RS FEC code, interleave depth of 16 with a minimal antenna separation of 10 feet and a frequency separation of 25 kHz.

Applying the same RS code and parameters to the PC receiver in the multiple AIS transmitter environment shown in Figure 2-1 mitigates the effects of AIS pulses on the PC receiver performance with a delay time of 0.112 seconds. This code works with the PC receiver information data rate of 13,515 bits per second (bps). By implementing this FEC code, the data rate must be increased to 22,050 bps (13515*[31/19]). This FEC technique is one possible way to mitigate the effect of multiple AISs and other FEC techniques may work as well.

SECTION 3 – RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

RESULTS

Single and Multiple AIS Transmitter - Interference to PC Receivers

Voice Mode

The analysis of the PC voice receiver, with single and multiple AIS transmitters resulted in the AS ranging from 93 to 95 percent. This would result in some minor interference being detected by the user.

Data Mode

Degradation to the performance of a PC digital receiver was predicted with both single and multiple AIS transmitters in the environment. A BER of $<1X10^{-6}$ was achieved by the PC digital receiver in the absence of AIS transmissions.

With a single AIS enabled, the PC digital receiver performance ranged from a BER of $3.1X10^{-2}$ to $<1X10^{-6}$, depending on frequency and distance separations as shown in Table 2-3.

To obtain the BER threshold of $1X10^{-6}$ with a single AIS transmitter enabled and with the PC digital receiver operating at the desired signal level of -98 dBm, the required separation between the AIS and the PC receiver antennas would be 2.6 miles for a frequency separation of 25 kHz, 1.14 miles for a frequency separation of 50 kHz, and 1.04 miles for a frequency separation of 75 kHz.

If the BER threshold were increased to $1X10^{-4}$ with a single AIS transmitter enabled and with the PC digital receiver operating at the desired signal level of -98 dBm, the required separation between the AIS and the PC receiver antennas would be 1.8 miles for a frequency separation of 25 kHz, 0.81 miles for a frequency separation of 50 kHz, and 0.76 miles for a frequency separation of 75 kHz.

With multiple AIS transmitters enabled and the PC receiver operating at the desired signal level of -98 dBm, with a frequency separation of 25 kHz, the PC digital receiver was degraded to a BER $1.2X10^{-5}$. When the PC digital receiver was off tuned to 50 and 75 kHz from the AISs, the BER was $<1X10^{-6}$. This assumes an AIS transmitter is not on the same ship as the PC receiver.

When FEC codes were applied to the PC digital receiver, the interference was eliminated for both the single and multiple AIS transmitter environments.

CONCLUSIONS

The predicted PC voice receiver performance degradation for both the single and multiple AIS transmitter cases will be minimal and would not prevent normal usage of the PC receiver.

The predicted PC digital receiver performance degradation is sufficient to impact the PC receiver in both the single and multiple AIS transmitter case when FEC is not employed. The use of FEC codes and block interleaving in the receiver should allow it operate normally in the presence of AIS transmissions.

RECOMMENDATIONS

Based on the results of this analysis, recommend the following further studies should be accomplished to determine appropriate mitigation techniques to resolve potential interference. These studies should examine:

- PC receiver design incorporating FEC
- effects of Rayleigh fading, multipath and existing radio systems, such as pager systems and National Oceanographic Atmospheric Administration weather transmissions, on the PC receiver.

APPENDIX A – EQUIPMENT DESCRIPTION

FURUNO MODEL FA-100 AIS TRANSMITTER

The AIS is a data system in which multiple stations operate on one or more maritime VHF channels, using TDMA. AIS systems are either mobile or base stations installed on vessels or land, respectively. Repeater stations may be used to extend coverage. The AIS consists of one VHF transmitter, two VHF TDMA receivers, one VHF digital selective calling (DSC) receiver, and a maritime electronic communications link to shipboard display and sensor systems. The vessel position and timing information transmitted by the AIS is obtained from a global positioning system (GPS) receiver.

The AIS transmitter can operate in three modes: automatic, assigned, and polled. In the automatic mode the AIS continuously transmits data at 9,600 bps over Gaussian-filtered minimum-shift keying (GMSK) FM 25 kHz or 12.5 kHz channels, using high-level data link control (HDLC) packet protocols. In the assigned mode, data transmission is remotely controlled by a traffic monitoring service. In polled mode, data transmission is in response to interrogation from a ship or base station.

The technical characteristics of the Furuno Model FA-100 AIS transmitter[11] are shown in Table A-1.

Table A-1. Furuno Model FA-100 AIS Transmitter Technical Characteristics

Transmitter Characteristics	
Transmitter Power (W)	12.5
Transmitter Tuning Range (MHz)	156.025-162.025
Modulation	GMSK
Data Rate (kbps)	9.6
Emission Bandwidth (kHz) -3 dB -83 dB -84 dB -86 dB -91 dB	 4.8 50 100 200 350
Harmonic Attenuation (dB)	60
Data compiled from JSC laboratory measurements and technical manuals	

[11]Catalogue N-848a, Class-A Universal Automatic Identification System Model FA-100, Furuno Electric Co., LTD., Nishinomiya City, Japan: undated

PC ROSS DSC 500 AND NEULINK NL6000 RECEIVERS

The technical characteristics of the PC receivers are shown in Tables A-2. Both the Ross and the Neulink receivers operate in the US VHF FM maritime band in voice and data modes, respectively.

Table A-2. PC Voice and Data Technical Characteristics

	Ross Voice	Neulink Digital
Tuning Range (MHz)	156.025-163.275	148-174
Modulation	F3E	F1D
Sensitivity (dBm)	-122.2	-118
Sensitivity Criterion	10 dB (S+N/N)	5 percent packet error rate
Combined RF & IF Selectivity (kHz) -3 dB -58 dB -101 dB -112 dB -150 dB	 12.8 40.0 800.0 20000 140000	
Combined RF & IF Selectivity (kHz) -3 dB -70 dB -90 dB -101 dB -112 dB		 18 50 100 800 20000
Receiver Noise Figure (dB)	2.7	2.7
Spurious Rejection (dB)	70	70
AGC Attack Time (ms)	4.4	4.4
AGC Release Time (ms)	22	20
Data Rate (bps)		13515
Data compiled from JSC lab measurements and technical manuals		

APPENDIX B – JSC MEASURED DATA

USCG AIS EMISSION SPECTRUM MEASUREMENTS

Objective

- Characterize the Furuno Universal AIS FA-100 transponder spectral emissions
- Examine the Ross DSC 500 audio output as the FA-100 transmits

Methodology

- Measure the emission during and between pulses
- Measure in-band, out-of-band, close-up, and broadband emissions
- Measure the DSC 500 audio output in the presence of FA-100 signals

Procedure Summary

- Design interfacing circuits between the transmitter/receiver and the measurement equipment – see block diagrams in Figures B-1 and B-2
- Mount the Furuno GPS antenna on the roof and connect it to the FA-100 GPS antenna port
- Initialize the FA-100 with proper maritime mobile service identity (MMSI) and ship static parameters
- Synchronize the FA-100 transmission bursts to the measurement equipment
- Set the FA-100, DSC 500, and measurement equipment operating parameters – see Table B-1
- Measure/record broadband and close-in emission spectrum on Furuno Channels 2087 and 2088 (with an emphasis on a 10-kHz bandwidth)
- Measure/record audio levels with the DSC 500 on channel 87
- Measure interfacing circuit gain/loss for calibration
- Provide analyses results

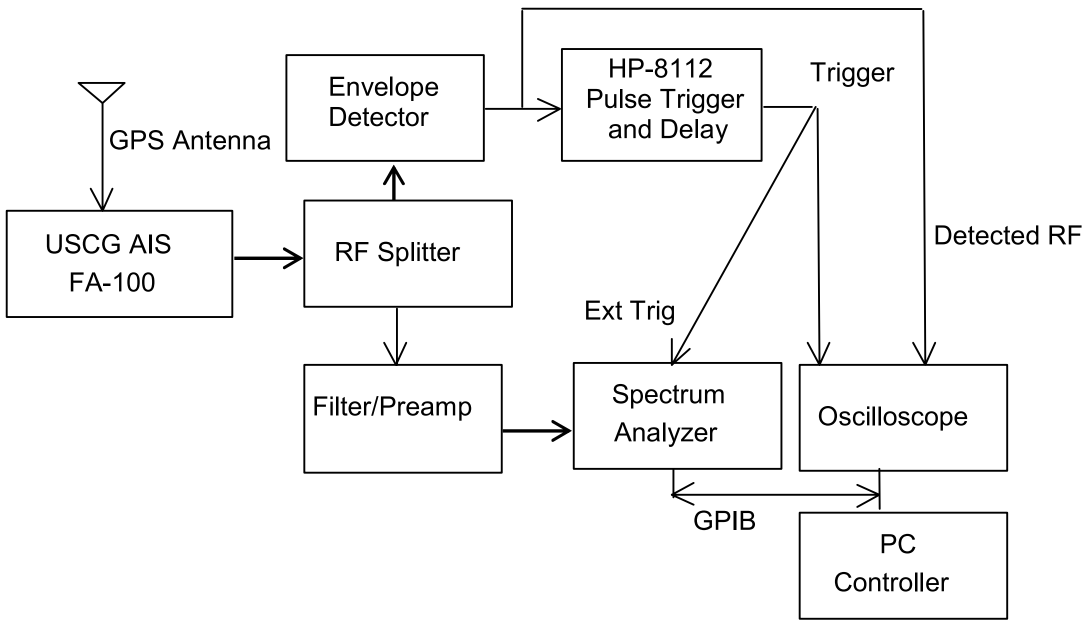

Figure B-1. FA-100 Emission Spectrum Block Diagram

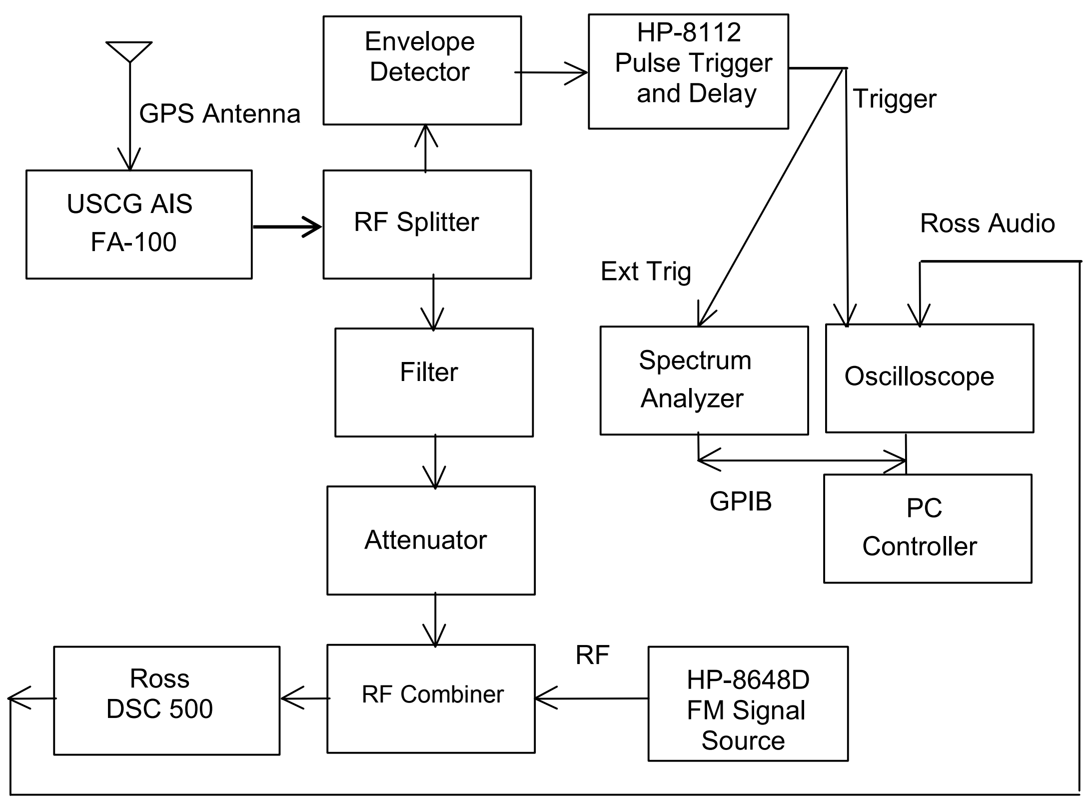

Figure B-2. FA-100 to DSC 500 Audio Sample - Block Diagram

Table B-1. Measurement Parameters - Summary and Commentary

Figure	Start Freq (MHz)	Stop Freq (MHz)	RBW	SWP (MS)	REF (dBm)	Attn (dB)	Comment
3	161.950	162.000	1.5 kHz	27	-20	10	Transition Spur at 162 MHz
4	161.975	162.125	3 kHz	65	-20	10	Out-of-band emission spectrum
5	162	162.316	10 kHz	32	-40	0	Average trace level drops 17 dB during an on-to-off transition
6	161.778	162.278	10 kHz	30	0	10	Dual channel mode measurements
7	150	2000	3 MHz	56	0	10	Spurious at 414 MHz, Harmonics out to 5th
8	1575.17	1575.67	10 kHz	50	-20	10	Noise level at -112 dBm
9	161.725	162.225	10 kHz	30	0	20	Spurious emissions resulting from variable transmission times, times varied from 6.8 to 10 seconds
RBW – Receiver Bandwidth SWP – Sweep Time REF – Reference Level ATTN – Attenuation							

Measurement Results

The results of measuring the FA-100 emission spectrum and the DSC 500 audio response in the presence of pulsed signals from the FA-100 are presented in the following set of figures.

The FA-100 emission spectrum was measured with the spectrum analyzer in both the continuous and the triggered sweep modes. If the spectrum of this signal was accumulated for a longer period of time during the continuous test mode, the line spectrum components would have fully filled-in the spectrum. Emission spectra shown in Figures B-3 through B-8 were measured with the spectrum analyzer externally triggered from the detected pulse of the FA-100.

Figure B-3 shows the FA-100 transmitter peak and average spectrum integrated over five sweeps in a 1.5-kHz bandwidth. The spectrum shows a signal at 162 MHz that is down 35 dB down from carrier.

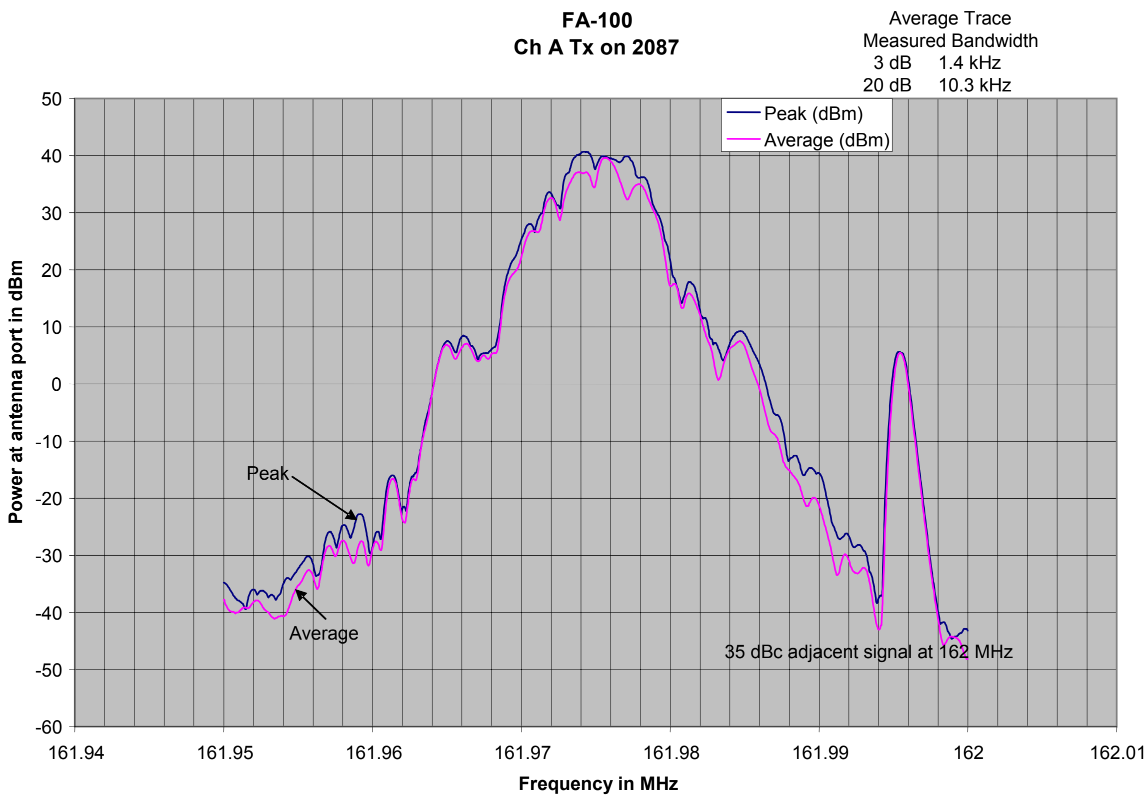

Figure B-3. In-Band Single Channel Peak and Average Emission

Figure B-4 shows the FA-100 transmitter peak and average spectrum integrated over five sweeps in a 3-kHz bandwidth.

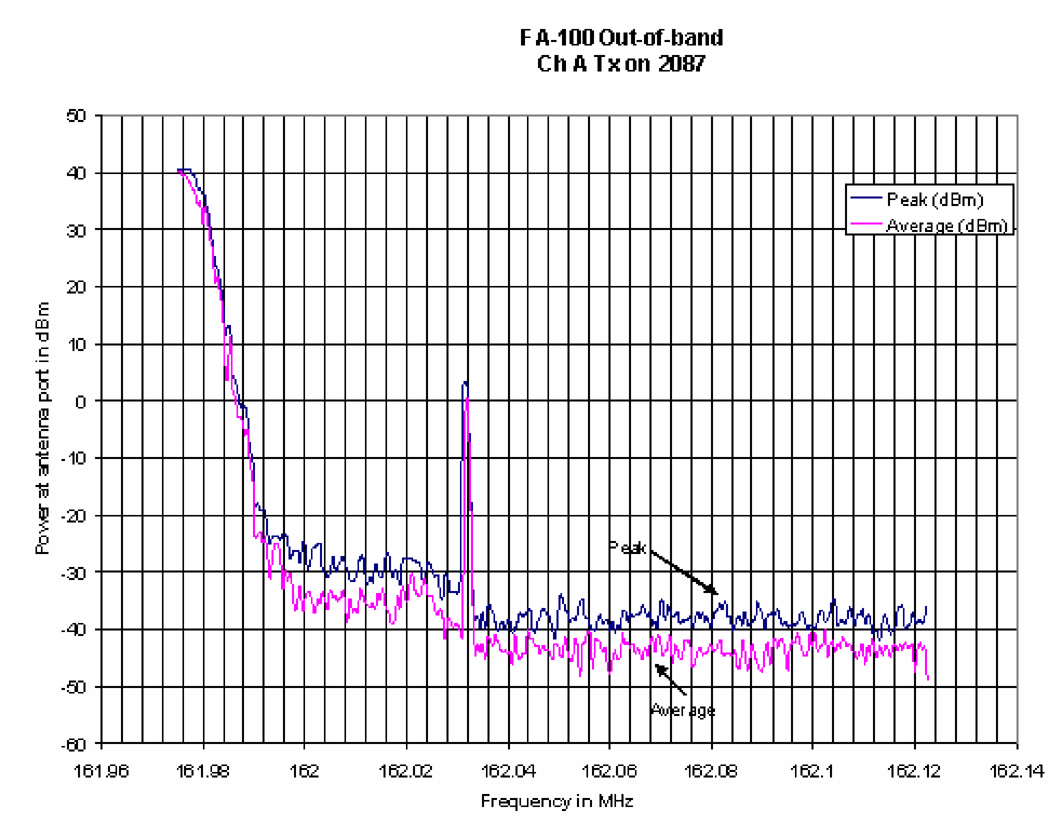

Figure B-4. Out-of-Band Emission

Figure B-5 shows a close-up of the spectrum on-to-off transition taking a 17-dB drop between 162.2 MHz and 162.25 MHz.

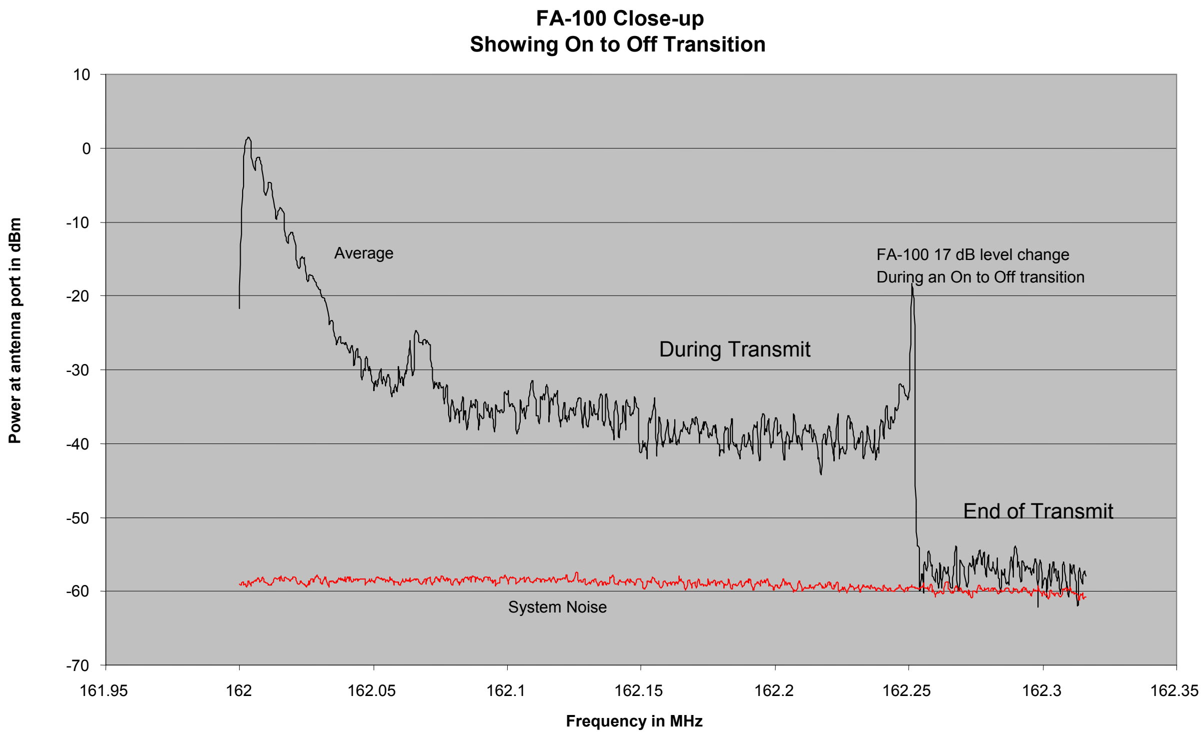

Figure B-5. Close-Up Emission View of FA-100 Transition from On-to-Off State

Figure B-6 shows the peak spectrum of two channels with equal power level, with one channel at a frequency 161.976 MHz and the second channel at 162.028 MHz. The average spectrum shows a 30-dB drop in signal level from the peak level, indicating that the channels do not transmit at the same time.

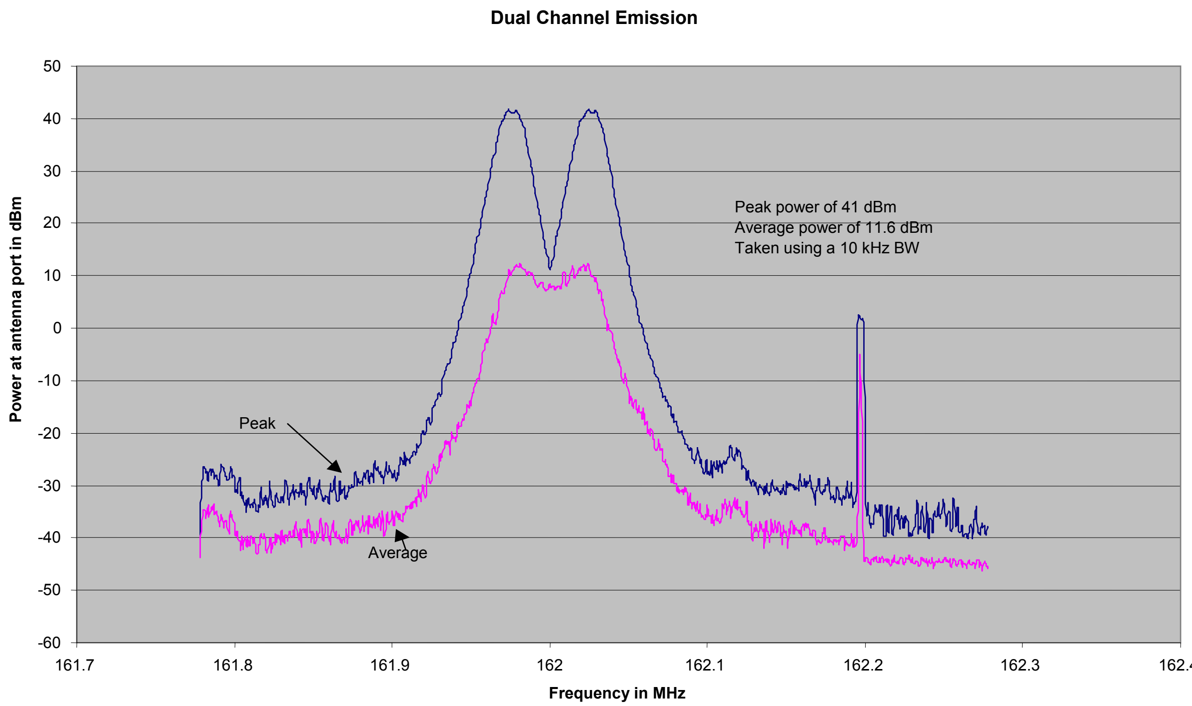

Figure B-6. In-Band Dual Channel Peak and Average Emission

Figure B-7 shows the harmonic and spurious spectrum of the FA-100 transmitter out to a frequency of 2000 MHz. The harmonic and spurious attenuations are at least 60 dB down from the carrier level.

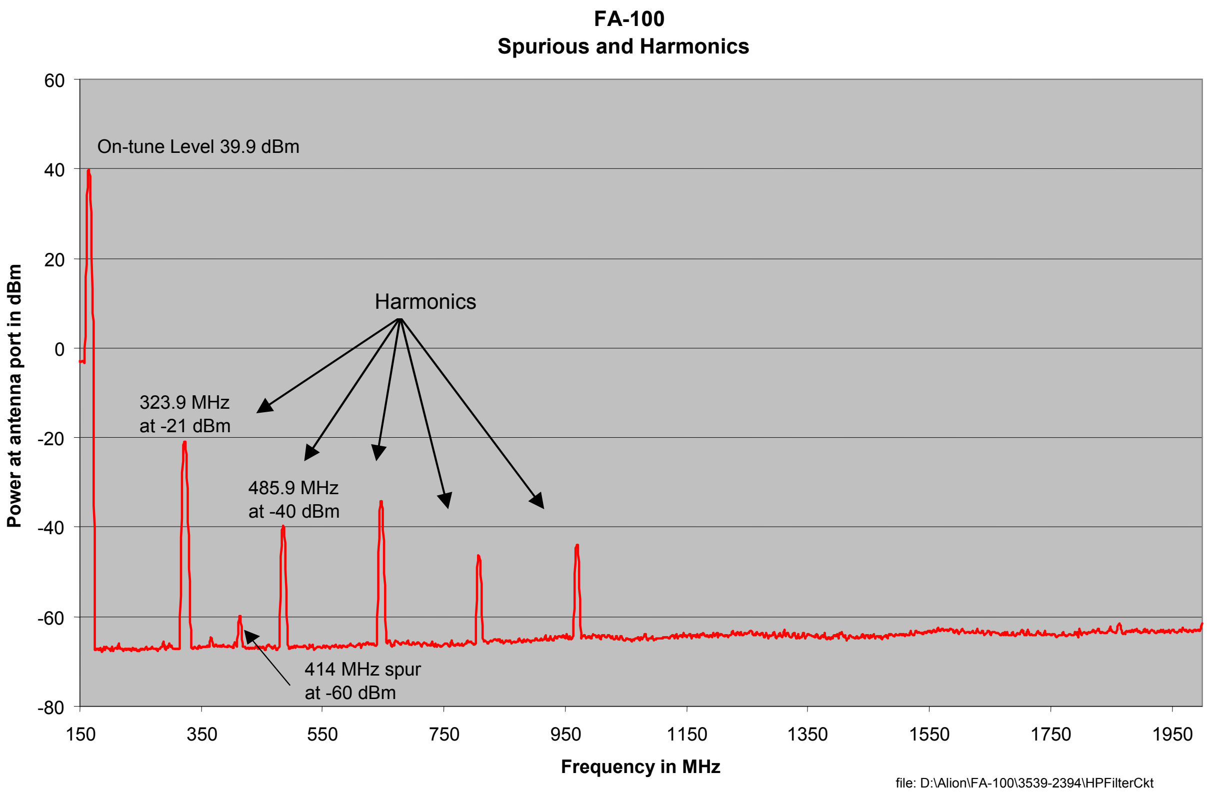

Figure B-7. Broadband Harmonic and Spurious Emissions

Figure B-8 shows the GPS-L1 frequency (out-of-band) noise level during FA-100 pulse transmission. The FA-100 noise fell below the measurement sensitivity of -112 dBm in a 10-kHz bandwidth.

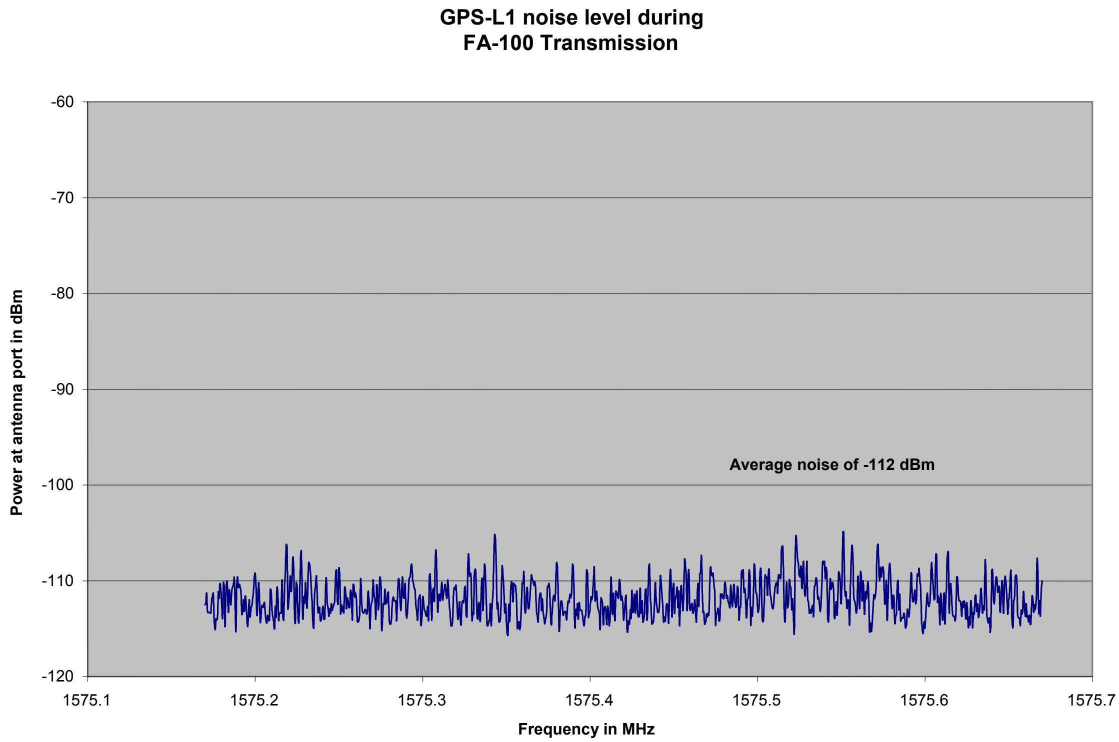

Figure B-8. Out-of-Band Emission Noise in the GPS-L1 Frequency

Figure B-9 shows the continuous sweep mode spectrum of the pulsed signal from the FA-100.

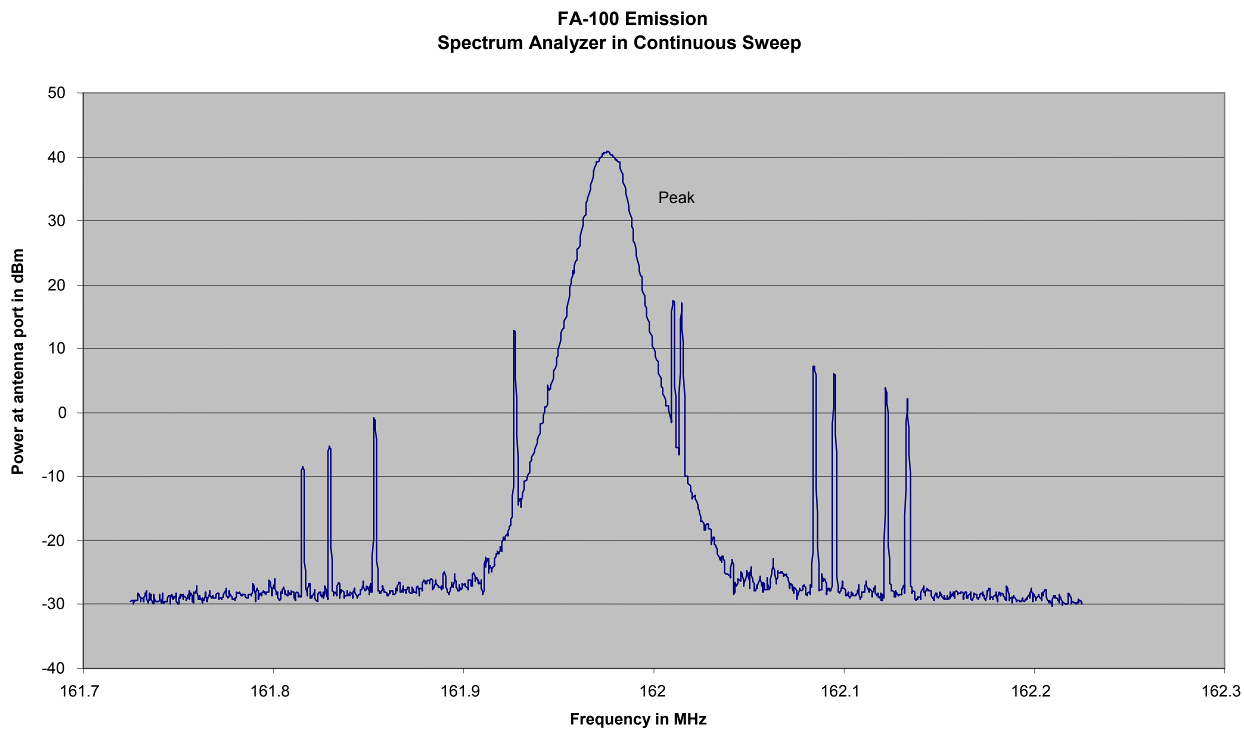

Figure B-9. Continuous Sweep (Non-Triggered) Emission Spectrum

Figures B-10 through B-18 show time-domain plots taken with an oscilloscope. These plots capture the audio response of the DSC 500 VHF transceiver both on-tune and off-tune. Measurements were taken using the interference levels shown in Table B-2. The top trace shows FA-100 pulse on-and-off conditions. The bottom trace tracks the audio output of the DSC 500 during and between interfering pulses.

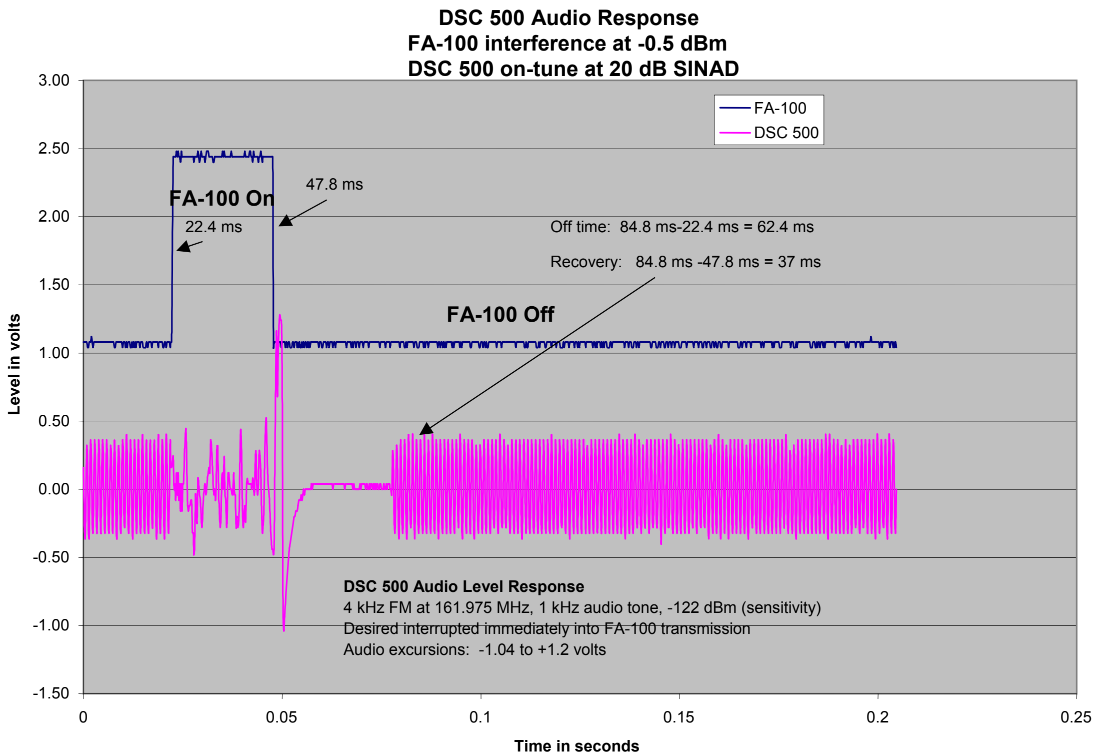

Figure B-10. DSC 500 Audio Response, FA-100 Interference at -0.5 dBm

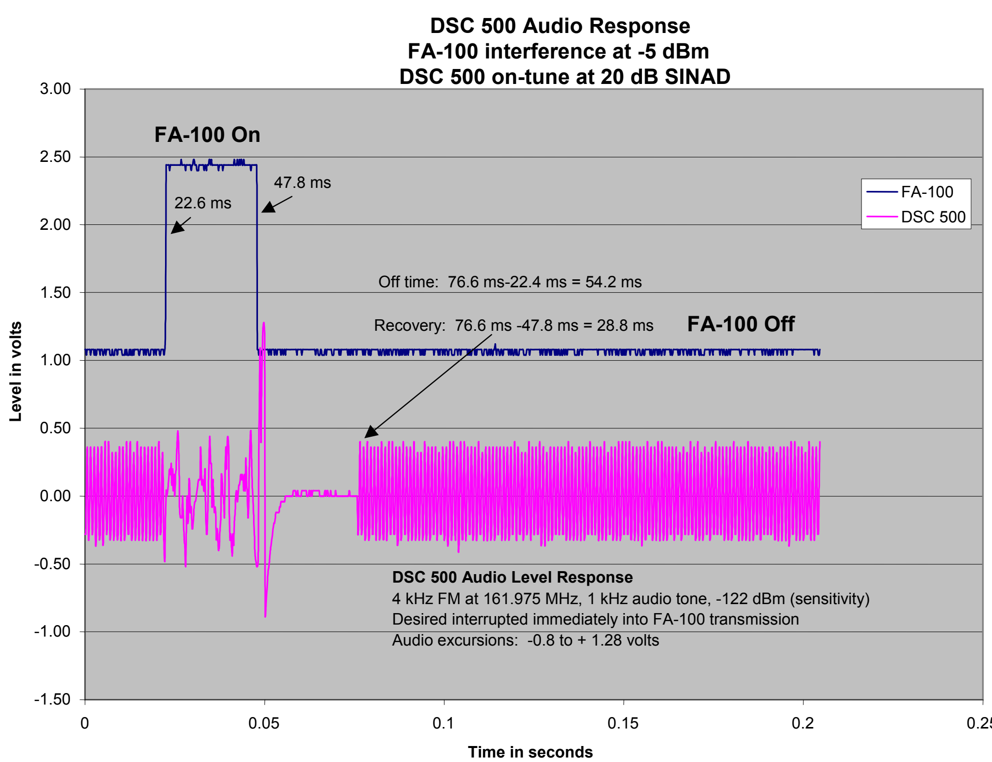

Figure B-11. DSC 500 Audio Response, FA-100 Interference at -5 dBm

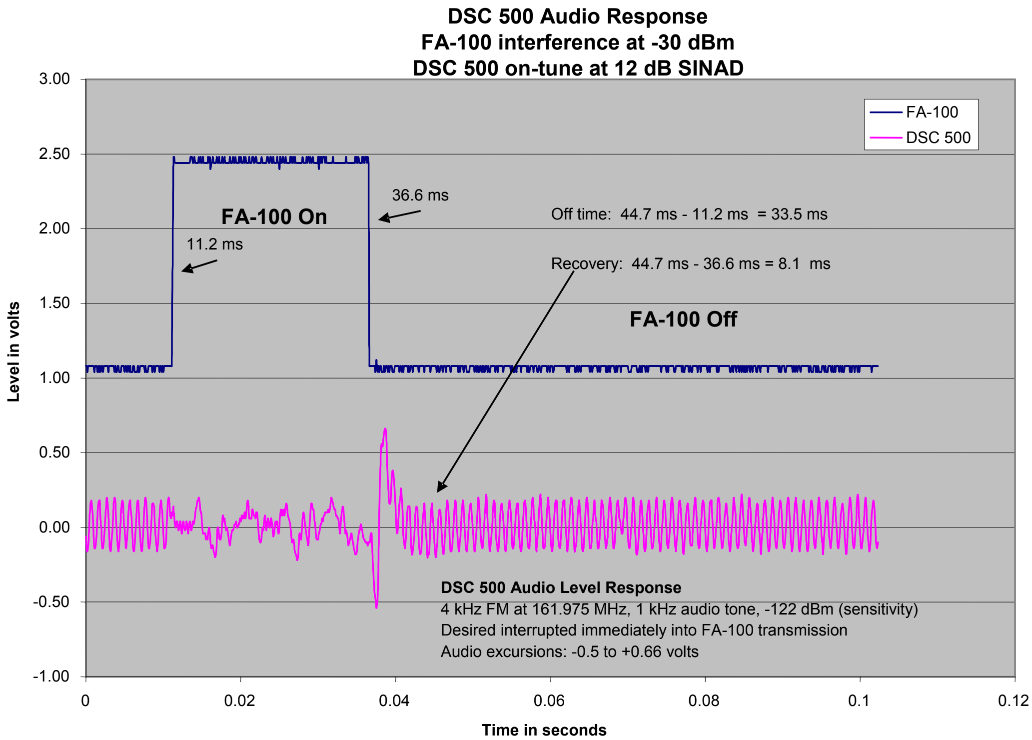

Figure B-12. DSC 500 Audio Response, FA-100 Interference at -30 dBm

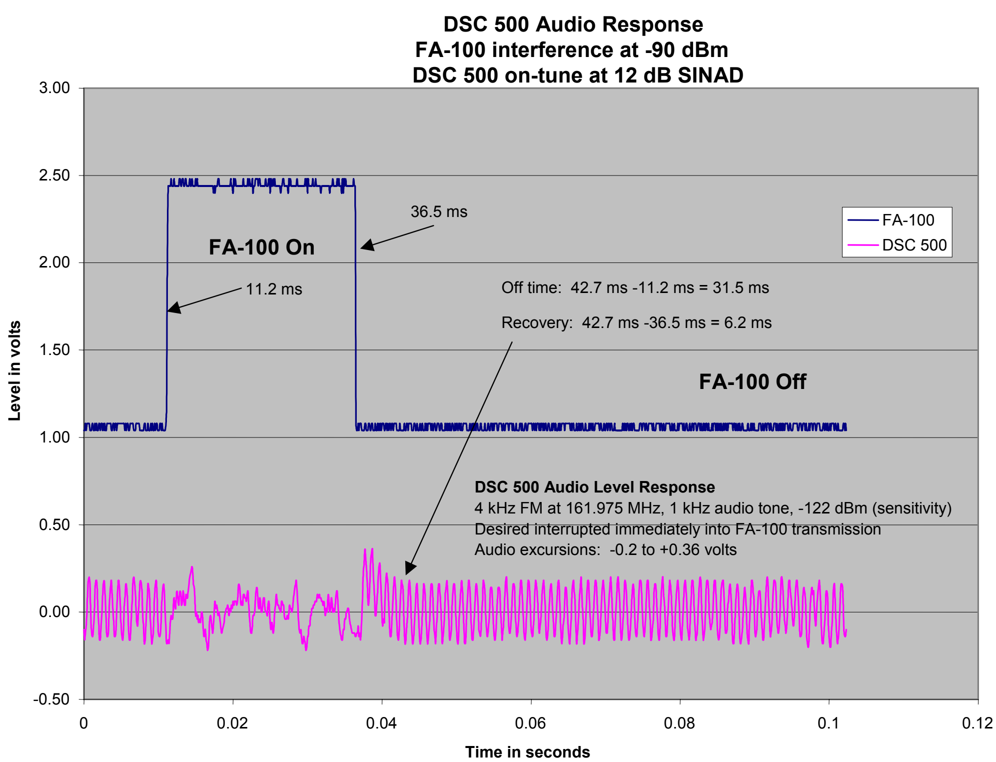

Figure B-13. DSC 500 Audio Response, FA-100 Interference at -90 dBm

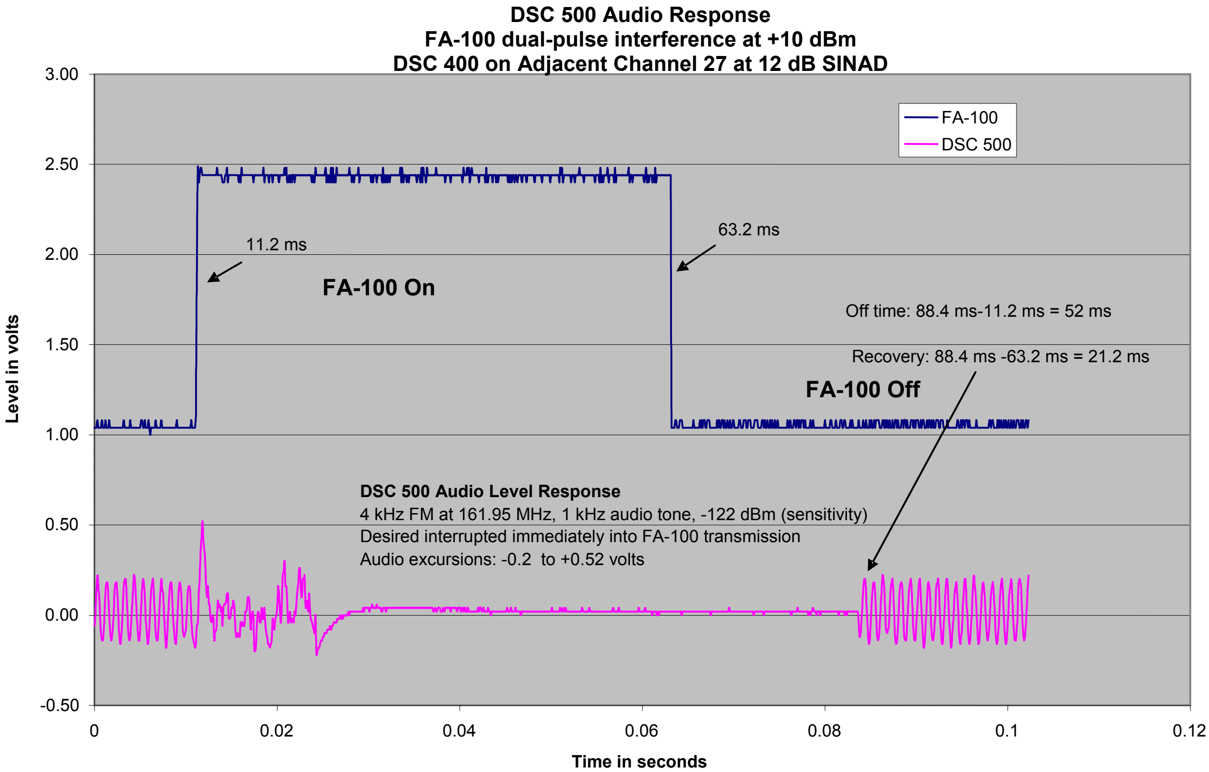

Figure B-14. DSC 500 63.2 ms Audio Response, FA-100 Interference at +10 dBm

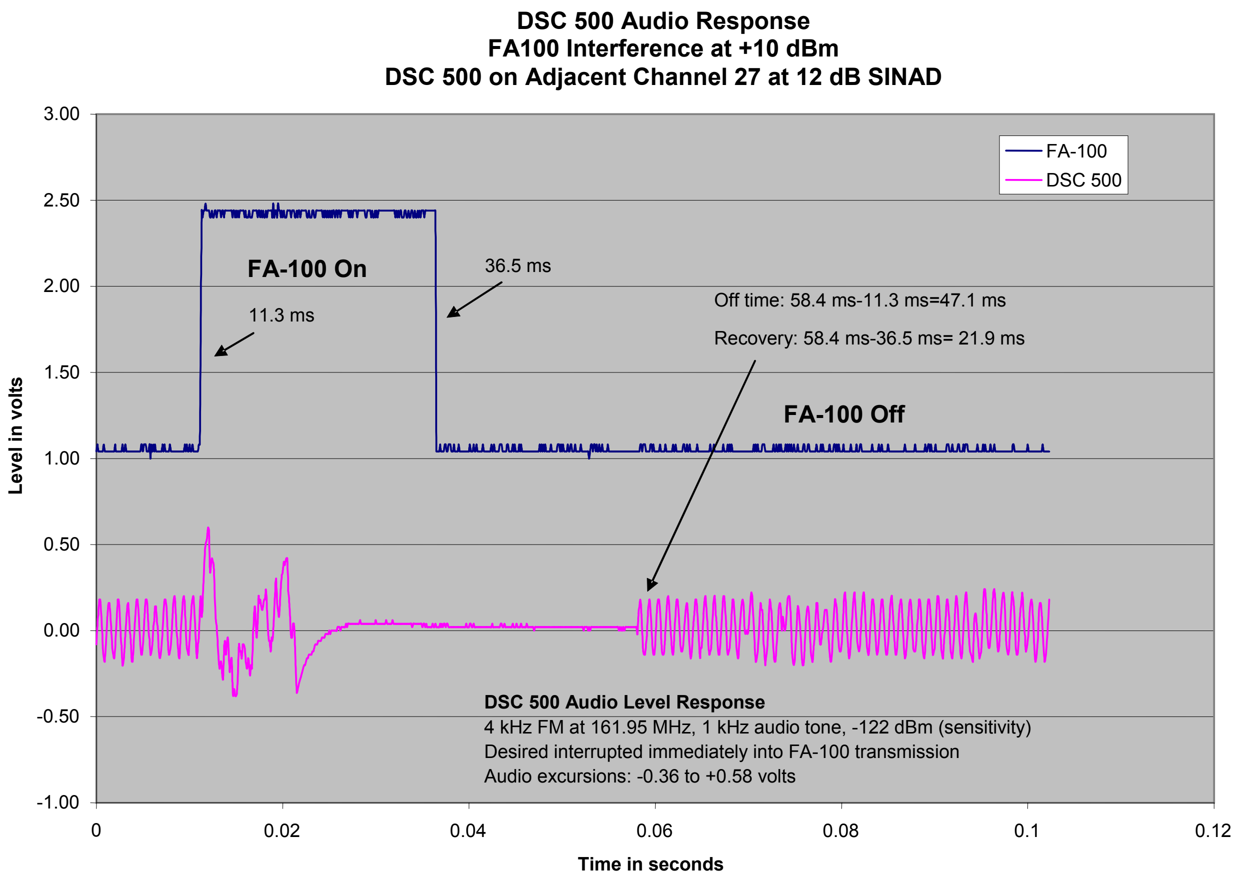

Figure B-15. DSC 500 36.5 ms Audio Response, FA-100 Interference at +10 dBm

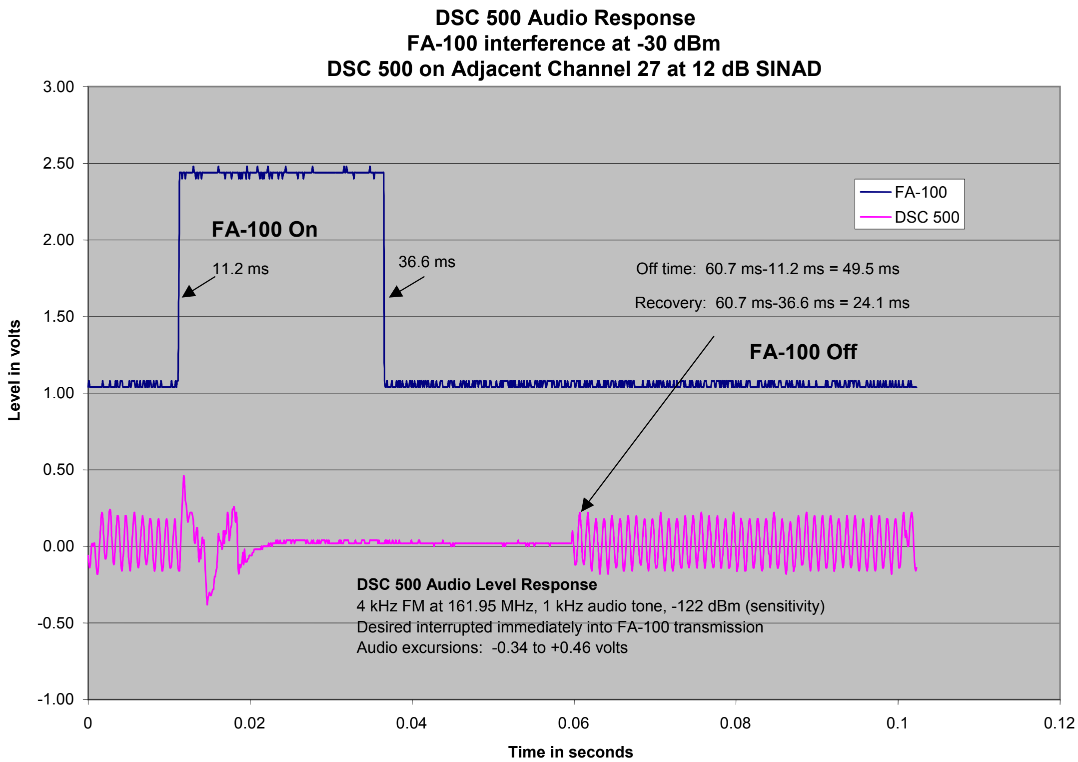

Figure B-16. DSC 500 Audio Response, FA-100 Interference at -30 dBm

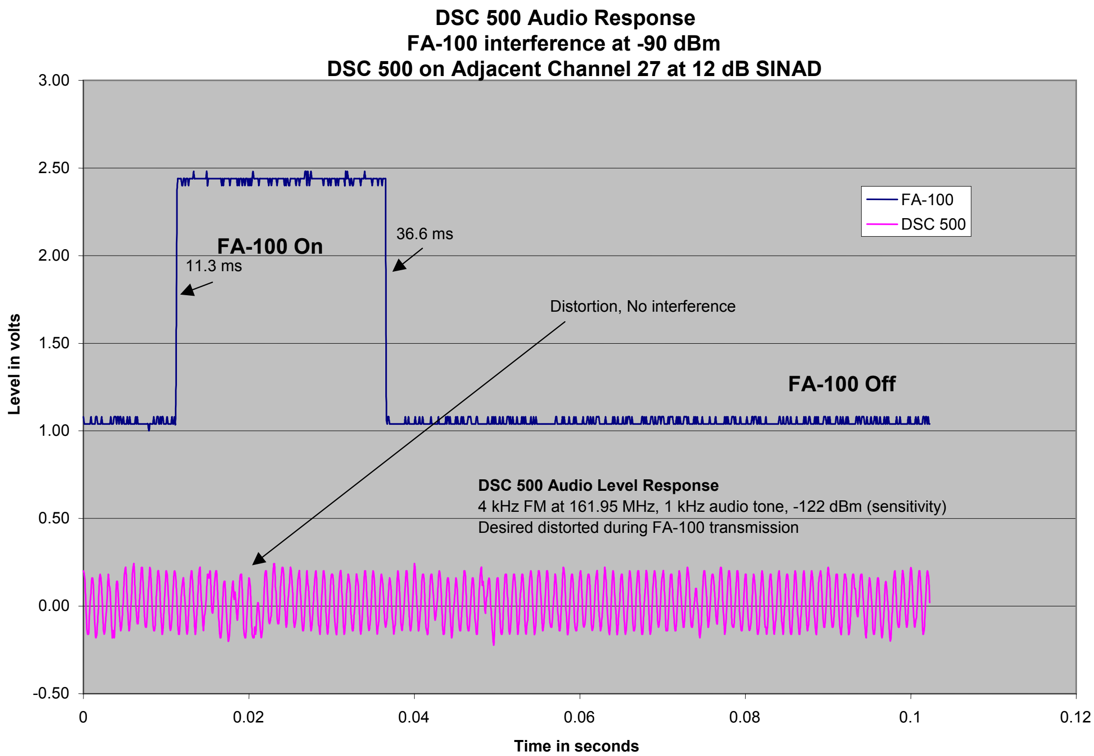

Figure B- 17. DSC 500 Audio Response, FA-100 Interference at -90 dBm

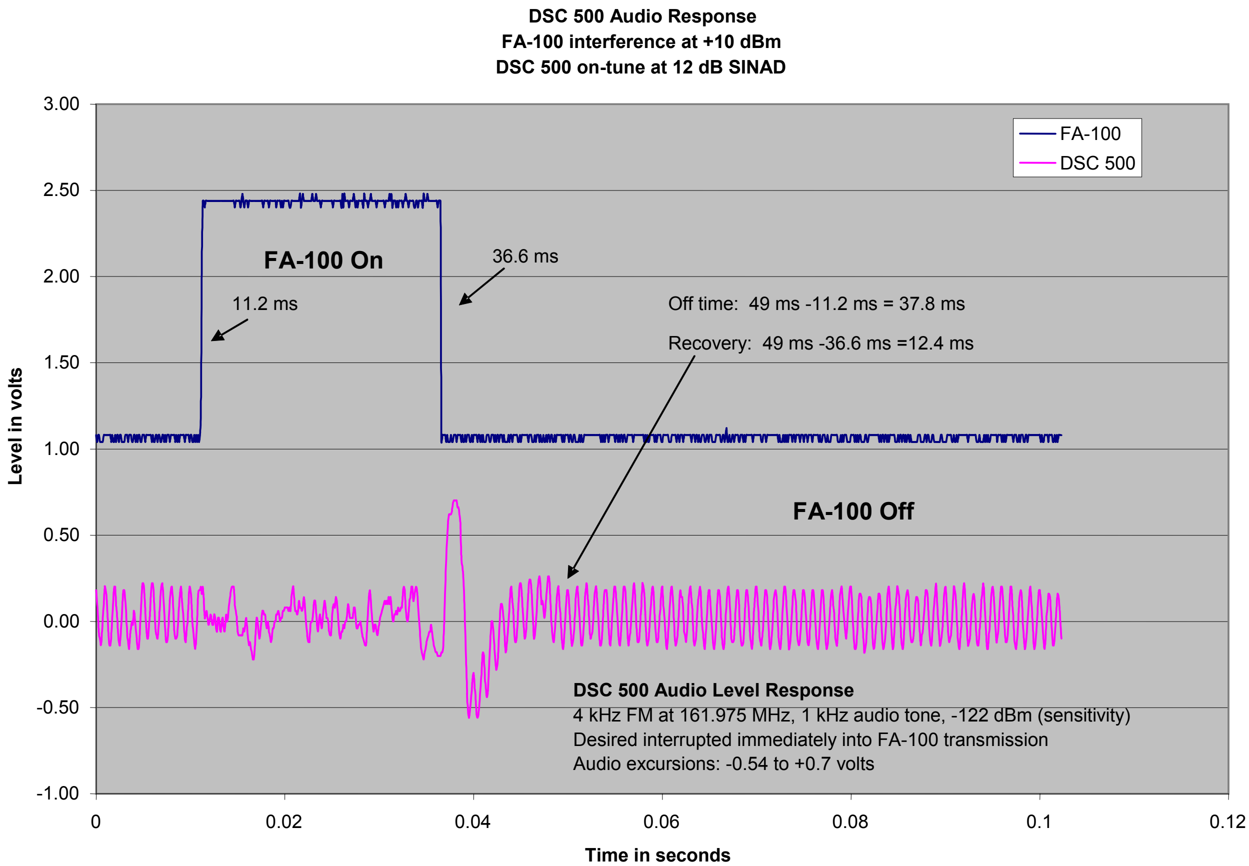

Figure B-18. DSC 500 Audio Response, FA-100 Interference at +10 dBm

Table B-2. Furuno FA-100/Ross DSC 500 Measurement Parameters

Figure	Furuno FA-100			Ross DSC 500			
	Interference Level (dBm)	Mode	Pulsewidth (ms)	SINAD (dB)	Audio Off Time (ms)	Recovery Time (ms)	Channel
10	-0.5	Single Pulse	25.4	20	62.4	37	87 on-tune
11	-5	Single Pulse	25.2	20	54.0	28.8	87 on-tune
12	-30	Single Pulse	25.4	12	33.5	8.1	87 on-tune
13	-90	Single Pulse	25.3	12	31.5	6.2	87 on-tune
14	10	Dual Pulse	52.0	12	52.0	21.2	27 (adj ch)
15	10	Single Pulse	25.2	12	47.1	21.9	27 (adj ch)
16	-30	Single Pulse	25.4	12	49.5	24.1	27 (adj ch)
17	-90	Single Pulse	25.3	12	000.0	No interference - some distortion	27 (adj ch)
18	10	Single Pulse	25.4	12	37.8	12.4	87 on-tune

MEASUREMENT SUMMARY

Peak Power Levels for the Furuno FA-100

The peak power levels shown in Figure B-6 for the Furuno FA-100 transmitter are summarized in Table B-3.

Table B-3. FA-100 Peak Power Levels

	Single Channel		Dual Channel	
	dBm	watts	dBm	watts
Peak	40.7	11.7	41.0	12.6

Furuno FA-100 Harmonics

The frequency and power level of the Furuno FA-100 transmitter are shown in Table B-4.

Table B-4. Harmonic Frequency and Power

	Frequency (MHz)	Power (dBm)	Power (dBc)
Second	323.9	-21.0	61.0
Third	485.9	-40.0	80.0
Fourth	647.6	-34.0	74.0
Fifth	810.4	-47.5	87.5
Sixth	971.4	-44.0	84.0

Out-of-Band Noise Measurement

The FA-100 out-of-band noise at the GPS-L1 frequency, fell below measurement sensitivity of -112 dBm in a 10-kHz bandwidth.

DSC 500 Interference Due to FA-100 Pulses

The DSC 500 audio recovery response time and off-time varied as a function of the FA-100 pulse power; desired signal, signal + noise + distortion to noise + distortion (SINAD) ratio level; and channel separation. The recovery time varied from zero milliseconds (ms) with no interference up to 37 ms with interference.

APPENDIX C – INTERNATIONAL VHF MARITIME RADIO CHANNELS AND FREQUENCIES

Table C-1 is adapted from the *International Telecommunication Union Radio Regulations* Appendix 18, including changes adopted by the 2000 World Radio Conference (WRC). Transmission on frequencies or channels shown in **bold** are not allowed within US territorial waters, but are allowed on the high seas and in most other countries. Note that a maritime radio operating in the international mode on a channel in which the ship station frequency is shown in ***bold italics*** and where the coastal station frequency is shown in **bold** would not be able to communicate with a US coastal station. The large number of **bolded** channels and frequencies indicates the shortage of VHF maritime spectrum in the US compared to most other maritime countries. Finally, note also that changes made by WRC 97 shown in *italics* have not yet been approved.

Table C-1. Table of Transmitting Frequencies in the VHF Maritime Mobile

Channel Number	Note	Transmitting Frequencies (MHz)		Channel Use			
		Ship Stations	Coastal Stations	Intership	Port Operations and Ship Movement		Public Correspondence
					Single Frequency	Two Frequency	
60		**156.025**	**160.625**			x	x
01		156.050	**160.650**			x	x
61	m, o	**156.075**	**160.675**			x	x
02	m, o	**156.100**	**160.700**			x	x
62	m, o	**156.125**	**160.725**			x	x
03	m, o	**156.150**	**160.750**			x	x
63	m, o	156.175	**160.775**			x	x
04	m, o	**156.200**	**160.800**			x	x
64	m, o	**156.225**	**160.825**			x	x
05	m, o	156.250	**160.850**			x	x
65	m, o	156.275	**160.875**			x	x
06	f	156.300		x			
66		156.325	**160.925**			x	x
07		156.350	**160.950**			x	x
67	h	156.375	156.375	x	x		
08		156.400		x			
68		156.425	156.425		x		

Table C-1. Table of Transmitting Frequencies in the VHF Maritime Mobile

Channel Number	Note	Transmitting Frequencies (MHz) Ship Stations	Transmitting Frequencies (MHz) Coastal Stations	Channel Use: Intership	Port Operations and Ship Movement: Single Frequency	Port Operations and Ship Movement: Two Frequency	Public Correspondence
09	i	156.450	156.450	x	x		
69		156.475	156.475	x	x		
10	h	156.500	156.500	x	x		
70	j	156.525	156.525	Digital selective calling for distress, safety, and calling			
11		156.550	156.550		x		
71		156.575	156.575		x		
12		156.600	156.600		x		
72	i	156.625		x			
13	k	156.650	156.650	x	x		
73	h, i	156.675	156.675	x	x		
14		156.700	156.700		x		
74		156.725	156.725		x		
15	g	**156.750**	156.750	x	x		
75	n	***156.775***			x		
16		156.800	156.800	distress, safety, and calling			
76	n	***156.825***			x		
17	g	156.850	156.850	x	x		
77		156.875		x			
18	m	156.900	**161.500**		x	x	x
78		156.925	**161.525**			x	x
19		156.950	**161.550**			x	x
79		156.975	**161.575**			x	x
20		157.000	**161.600**			x	x
80		157.025	**161.625**			x	x
21		157.050	**161.650**			x	x
81		157.075	**161.675**			x	x
22	m	157.100	**161.700**			x	x
82	m, o	157.125	**161.725**		x	x	x
23	m, o	157.150	**161.750**			x	x
83	m, o	157.175	**161.775**		x	x	x
24	m, o	157.200	161.800			x	x
84	m, o	157.225	161.825		x	x	x
25	m, o	157.250	161.850			x	x

Table C-1. Table of Transmitting Frequencies in the VHF Maritime Mobile

Channel Number	Note	Transmitting Frequencies (MHz)		Channel Use			
		Ship Stations	Coastal Stations	Intership	Port Operations and Ship Movement		Public Correspondence
					Single Frequency	Two Frequency	
85	m, o	157.275	161.875		x	x	x
26	m, o	157.300	161.900			x	x
86	m, o	157.325	161.925		x	x	x
27		157.350	161.950			x	x
87		**157.375**			x		
28		157.400	162.000			x	x
88		157.425			x		
AIS 1	l	161.975	161.975				
AIS 2	l	162.025	162.025				

General Notes for Table C-1

a. Administrations may designate frequencies in the intership, port operations, and ship movement services for use by light aircraft and helicopters to communicate with ships or participating coast stations in predominantly maritime support operations under the conditions specified in Nos. **S51.69, S51.73, S51.74, S51.75, S51.76, S51.77** and **S51.78**. However, the use of the channels that are shared with PC shall be subject to prior agreement between administrations that are interested and affected administrations.

b. The channels of the present Appendix [APP 18] with the exception of channels 06, 13, 15, 16, 17, 70, 75 and 76, may also be used for high-speed data and facsimile transmissions, subject to special arrangement between interested and affected administrations.

c. The channels of the present Appendix [APP 18) but preferably channel 28 and with exception of channels 06, 13, 15, 16, 17, 70, 75 and 76, may be used for direct-printing telegraphy and data transmission, subject to special arrangement between interested and affected administrations.

d. The frequencies in this table may also be used for radio communications on inland waterways in accordance with the conditions specified in No. **S5.226**.

e. Administrations having an urgent need to reduce local congestion may apply 12.5 kHz channel interleaving on a noninterference basis to 25-kHz channels, provided the following conditions are met:

   1) Recommendation ITU-R M.1084-2 shall be taken into account when changing to 12.5 kHz channels;
   2) This application shall not affect the 25-kHz channels, listed in Appendix **S18,** for maritime mobile distress and safety frequencies, especially the channels 06, 13, 15, 16, 17, and 70, nor the technical characteristics mentioned in Recommendation ITU-R M.489-2 for these channels;
   3) Implementation of 12.5 kHz channel interleaving and consequential national requirements shall be subject to prior agreement between the administrations implementing these changes and administrations whose ship station or services may be affected.

Specific Notes for Table C-1

f. The frequency 156.300 MHz (channel 06) (see Appendix **S13**, Appendix **S15** and Appendix **S51.79**) may also be used for communication between ship stations and aircraft stations engaged in coordinated search and rescue operations. Ship stations shall avoid harmful interference to such communications on channel 06 as well as communications between aircraft stations, ice-breakers, and assisted ships during ice seasons.

g. Channels 15 and 17 may also be used for onboard communications, provided the effective radiated power does not exceed 1 W, and subject to the national regulations of the administration concerned when these channels are used in its territorial waters.

h. Within the European Maritime Area and in Canada, these frequencies (channels 10, 67, 73) may also be used, if required by the individual administrations concerned, for communication between ship stations, aircraft stations, and participating land stations engaged in coordinated search and rescue and anti-pollution operations in local areas, under the conditions specified in Nos. **S51.69, S51.73, S51.74, S51.75, S51.76, S51.77,** and **S51.78**.

i. The preferred first three frequencies for the purpose indicated in note *a.* are 156.450 MHz (channel 09), 156.625 MHz (channel 72) and 156.675 MHz (channel 73).

j. This channel (70) is to be used exclusively for digital selective calling for distress, safety, and calling.

k. Channel 13 is designated for use on a worldwide basis as a navigation safety communication channel, primarily for intership navigation safety communications. It may also be used for the ship movement and port operations service subject to the national regulations of the administrations concerned.

l. These channels will be used for an automatic ship identification and surveillance system capable of providing worldwide operation on high seas, unless other frequencies are designated on a regional basis for this purpose.

m. These channels may be operated as a single frequency channel, subject to special arrangement between interested or affected administrations. (WRC-2000)

n. The use of these channels should be restricted to navigation-related communications only, and all precautions should be taken to avoid harmful interference to channel 16, e.g., by limiting the output power to 1 W or by geographical separation.

o. These channels may be used to provide bands for initial testing and possibly, in the future, for introducing new technologies, subject to special arrangement between interested or affected administrations. Stations using these channels or bands for testing or introducing new technologies shall neither cause harmful interference to, nor claim protection from, other stations operating in accordance with Article 5.

APPENDIX D – INTERFERENCE POWER LEVELS AT THE PC RECEIVER INPUT (VOICE MODE)

The equations used for calculating the P_{ino} distributions for the various interaction modes are presented in this appendix. Many of the parameters in these equations are stored in the COSAM Equipment Parameter File (EPF).

Transmitter Adjacent Signal (TAS)

The power spectral density S_p is obtained from the transmitter power spectral density curve found in the EPF transmitter record. The curve is symmetric about delta f = 0. The TAS calculation should be skipped if the frequencies are cochannel. The mean P_{ino} for the transmitter adjacent-signal interaction is given by:

$$P_{ino} = S_p(\text{Delta f}) + 10\,\text{Log}(BW_r) + G_t + G_r - L_s - L_p \quad \text{(D-1)}$$

where

P_{ino}	=	mean equivalent on-tune interference power level, in dBm
S_p	=	mean power spectral density, in dBm/MHz
Delta f	=	F_r - F_t, in MHz
F_r	=	tuned frequency of receiver, in MHz
F_t	=	tuned frequency of transmitter, in MHz
BW_r	=	receiver RF bandwidth, in MHz
G_t	=	transmitter antenna gain, in dBi
G_r	=	receiver antenna gain, in dBi
L_s	=	system losses, in dB
L_p	=	mean coupling loss from AIS transmitter antenna to PC receiver antenna, in dB

In these equations, the variable Lp represents the antenna-to-antenna coupling loss.

The TAS P_{ino} power levels in the PC receiver 3-dB bandwidth are shown in Table D-1.

Table D-1. TAS AIS Interference Power Levels at the PC Receiver Input-Voice and Data Modes

S_p (dBm/MHz)	10 Log (BW_r) (dB)	G_t (dBi)	G_r (dBi)	L_s (dB)	L_p (dB)	Horizontal Antenna Separation (feet)	Delta f (kHz)	P_{ino} (dBm)
-19.81	-18.9	2.1	2.1	1	26.3	10	25	-61.8
-20.81	-18.9	2.1	2.1	1	26.3	10	50	-62.8
-21.81	-18.9	2.1	2.1	1	26.3	10	75	-63.8
-19.81	-18.9	2.1	2.1	1	66.4	1,000	25	-101.9
-20.81	-18.9	2.1	2.1	1	66.4	1,000	50	-102.9
-21.81	-18.9	2.1	2.1	1	66.4	1,000	75	-103.9
-19.81	-18.9	2.1	2.1	1	97.4	10,000	25	-132.9
-20.81	-18.9	2.1	2.1	1	97.4	10,000	50	-133.9
-21.81	-18.9	2.1	2.1	1	97.4	10,000	75	-134.9

Receiver Adjacent Signal 1 (RAS1)

The mean receiver rejection (Beff) is obtained from the receiver rejection curve found in the EPF receiver record. The curve is symmetric about delta f = 0. The mean P_{ino} for the receiver adjacent-signal interaction is given by:

$$P_{ino} = P_t + G_t + G_r - L_S - L_p - \text{Beff (Delta f)} \tag{D-2}$$

where

P_{ino} = mean equivalent on-tune interference power level, in dBm
P_t = mean peak output power of AIS transmitter, in dBm
Beff (Delta f) = mean rejection of undesired power by PC receiver, in dB

and other terms are as defined previously.

The RAS1 P_{ino} power levels at the PC receiver front end are shown in Table D-2.

Table D-2. AIS RAS1 Interference Power Levels at the PC Receiver Input-Voice Mode

P_t (dBm)	G_t (dBi)	G_r (dBi)	L_s (dB)	L_p (dB)	Voice Mode Beff (dB)	Horizontal Antenna Separation (feet)	Delta f (kHz)	P_{ino} (dBm)
41	2.1	2.1	1	26.3	62	10	25	-44.1
41	2.1	2.1	1	26.3	72	10	50	-54.1
41	2.1	2.1	1	26.3	77	10	75	-59.1
41	2.1	2.1	1	66.4	62	1,000	25	-84.2
41	2.1	2.1	1	66.4	72	1,000	50	-94.2
41	2.1	2.1	1	66.4	77	1,000	75	-99.2
41	2.1	2.1	1	97.4	62	10,000	25	-115.2
41	2.1	2.1	1	97.4	72	10,000	50	-125.2
41	2.1	2.1	1	97.4	77	10,000	75	-130.2

APPENDIX E – INTERFERENCE POWER LEVELS AT THE PC RECEIVER INPUT (DATA MODE)

The equations used for calculating the P_{ino} distributions for the various interaction modes are presented in this appendix. Many of the parameters in these equations are stored in the EPF.

Transmitter Adjacent Signal

The mean P_{ino} interference power level received in the PC receiver 3-dB bandwidth in the voice mode is the same P_{ino} interference power levels received in the data mode. For the TAS P_{ino} interference power levels at the PC receiver input, refer to Table D-1.

Receiver Adjacent Signal 1

Beff is obtained from the receiver rejection curve found in the EPF receiver record. The curve is symmetric about delta f = 0. The mean P_{ino} for the receiver adjacent-signal interaction with nonlinear effects is given by Equation D-2.

The RAS1 P_{ino} power levels at the PC receiver front end are shown in Table E-1.

Table E-1. AIS RAS Interference Power Levels at the PC Receiver Input-Data Mode

P_{ino} (dBm)	P_t (dBm)	G_t (dBi)	G_r (dBi)	L_s (dB)	L_p (dB)	Data Mode Beff (dB)	Horizontal Antenna Separation (feet)	Delta f (kHz)
-52.1	41	2.1	2.1	1	26.3	70	10	25
-72.1	41	2.1	2.1	1	26.3	90	10	50
-74.3	41	2.1	2.1	1	26.3	92.2	10	75
-92.2	41	2.1	2.1	1	66.4	70	1,000	25
-112.2	41	2.1	2.1	1	66.4	90	1,000	50
-114.4	41	2.1	2.1	1	66.4	92.2	1,000	75
-123.2	41	2.1	2.1	1	97.4	70	10,000	25
-143.2	41	2.1	2.1	1	97.4	90	10,000	50
-145.4	41	2.1	2.1	1	97.4	92.2	10,000	75

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