

Electromagnetic Compatibility Between Marine Automatic Identification and Public Correspondence Systems in the Maritime Mobile VHF Band



technical report

Electromagnetic Compatibility Between Marine Automatic Identification and Public Correspondence Systems in the Maritime Mobile VHF Band

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Executive Summary

The Coast Guard funded the National Telecommunications and Information Administration (NTIA) to perform electromagnetic compatibility (EMC) tests between an ITU-R M. 825-3 (*Characteristics Of a Transponder System Using Digital Selective Calling Techniques for Use with Vessel Traffic Services and Ship-to-Ship Identification*) based Automatic Identification System (AIS) operating on 12.5 kHz channels and Public Correspondence (PC) Systems operating on 25 kHz channels. The tests were performed between January 17-28, 2000 in and around an AIS base station communications tower located at Point Ala Hache, La. by NTIA, SETA Corporation, and Coast Guard personnel.

AIS is a shipborne transponder-based navigation safety system that serves as the foundation for the Vessel Traffic Service (VTS) being established in New Orleans and elsewhere by the Coast Guard under the Ports And Waterway Safety System (PAWSS) project. AIS is based on technical standards established by the International Telecommunication Union (ITU). The current implementation in New Orleans is based on ITU-R Recommendation M.825-3. This will be updated in the future to the standard for Universal Shipborne AIS, ITU-R M. 1371 (*Technical Characteristics for a Universal Shipborne Identification System Using Time Division Multiple Access In the VHF Maritime Mobile Band*). Transponders that are fully compliant with ITU-R M. 1371 are not currently available. AIS facilitates the efficient exchange of data between ships and between shore stations and ships. AIS responds to the mariners' need for timely, relevant and accurate information (including data on ships position, speed, etc) delivered in an unobtrusive manner. AIS requires dedicated frequencies in order to operate safely and reliably.

AIS requires duplex channels for ship-to-shore and shore-to-ship digital data transmissions and simplex channels for ship-to-ship operations. Frequencies selected for AIS must come from Appendix 18 of the International Radio Regulations (between 156.025-157.425 MHz and 160.625-162.025 MHz).

Of the 35 duplex channels listed in Appendix 18 of the ITU Radio Regulations, only nine remain for consideration for potential AIS operations in the United States due to past U.S. regulatory decisions. These nine 25 kHz duplex channels are currently utilized within the VHF marine Public Correspondence (PC) Band, and designated as channels 24, 84, 25, 85, 26, 86, 27, 87, and 28. To obtain additional AIS frequencies, the U.S. must utilize techniques outlined in ITU-R M. 1084-3 (*Interim Solutions for Improved Efficiency In The Use of the Band 156-174 MHz by Stations In the Maritime Mobile Service*) regarding the use of 12.5 kHz interstitial channels that are interleaved between existing 25 kHz wideband channels.

AIS and Public Correspondence systems both use duplex channels in the maritime mobile VHF band for communications between a mobile unit and a base station, which results in five interference scenarios occurring between the two systems. The four interference scenarios tested were: 1) an AIS base station causing interference to a PC mobile radio receiver; 2) a PC base station causing interference in a AIS transponder receiver; 3) an AIS transponder causing interference in a PC base station receiver; and 4) a PC mobile radio causing interference to an AIS base station receiver. At a minimum, 12.5 kHz of frequency separation was used in all tests scenarios between the interfering transmitter and victim receiver. In addition, 25 kHz, 37.5 kHz, 50

kHz and 62.5 kHz frequency separations were also tested. Tests at 25 kHz and 50 kHz frequency separations are not applicable since they would require that wideband Public Correspondence to operate on interstitial channels. These tests were performed to obtain additional results to establish data trends. A fifth test scenario would be required to determine compatibility between ship-to-ship AIS and PC operations, and this was not tested due to the unavailability of suitable equipment. This fifth scenario represents a co-site concern with both AIS and PC systems operating on the same ship. The inability to test the fifth scenario does not alter the conclusions or recommendations given in this report.

Analyses of the results of the four test scenarios offer general guidelines for determining compatibility between AIS operations on interstitial 12.5 kHz channels and Public Correspondence operations on wideband 25 kHz channels.

Analyses of the test results show that, since AIS and PC systems both offer service to mariners on ships and would employ base stations with transmission towers located in the same geographic environment, operating these systems is not practical with 12.5 kHz of frequency separation (i.e., geographical separation distances on the order of 15 to 25 miles are required). Operating the systems in the same geographic environment with a frequency separation of 25 kHz may be possible if the PC system (base stations and mobile radios) were designed for 12.5 kHz channel operations. This would require testing of suitable equipment to verify this specific case. There are no current plans to modify the PC system for 12.5 kHz operation. The PC and AIS systems should be able to operate within the same geographic environment provided that a minimum of 37.5 kHz of frequency separation is provided between the two systems.

NTIA recommends that the Coast Guard consider: 1) Developing an AIS frequency coordination plan for the lower Mississippi River for the PC and AIS systems that will ensure mutually compatible and satisfactory operations. 2) Performing additional EMC testing between ship-to-ship AIS and PC operations. 3) Performing EMC tests between PC systems and ITU-R. M 1371 compliant AIS equipment when such equipment becomes available, 4) Pursuing necessary regulatory changes to improve AIS and PC operations in the same geographical area (e.g., including a 12.5 kHz channelization plan for both AIS and PC operations and developing appropriate receiver standards).

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SECTION 1

INTRODUCTION

1.1 Background

The Coast Guard plans to operate an Automatic Identification System (AIS) Digital Selective Calling (DSC) based transponder system as part of the Ports and Waterways Safety System (PAWSS) in the lower Mississippi River. The PAWSS utilizes a combination of voice and AIS working channels in the VHF maritime mobile band to provide communications in a defined Vessel Traffic Service Area (VTSA). The current AIS operates utilizing protocols established by the International Telecommunication Union (ITU) in Recommendation ITU-R M.825-3 (*Characteristics Of a Transponder System Using Digital Selective Calling Techniques for Use with Vessel Traffic Services and Ship-to Ship Identification*). In the future the system will transition to ITU-R Recommendation M.1371 (*Technical Characteristics for a Universal Shipborne Identification System Using Time Division Multiple Access In the VHF Maritime Mobile Band*) protocol when equipment utilizing this new standard is available. This recommendation is also known as the Universal AIS standard, which provides safety and efficiency enhancements over the previously approved ITU-R M.825.3.

Frequencies selected for AIS operations must come from Appendix 18 of the International Radio Regulations (between 156.025-157.425 MHz and 160.625-162.025 MHz). The AIS system requires two or more full duplex channels for ship-to-shore and shore-to-ship digital data transmissions. AIS also utilizes simplex channels(s) for ship-to-ship communications. A more detailed explanation of AIS operations is contained in Appendix A. Of the 35 duplex channels listed in Appendix 18 of the ITU Radio Regulations, only nine remain available for consideration for potential AIS operations in the United States due to past U.S. regulatory decisions. These nine 25 KHz duplex channels are currently utilized for the maritime Public Correspondence (PC) Service, and designated as channels 24, 84, 25, 85, 26, 86, 27, 87, and 28. To obtain additional spectrum for AIS, the U.S. is considering utilizing the techniques outlined in ITU-R M. 1084-3 (*Interim Solutions for Improved Efficiency in the Use of the Band 156 –174 MHz by Stations In the Maritime Mobile Service*) to interleave 12.5 KHz channels between existing 25 kHz wideband channels. The necessary channel numbering is provided in ITU-R M. 1084-3.

The current AIS duplex working channels, self-designated as 90 and 94, are not listed as duplex pairs in Appendix 18 of the ITU Radio Regulations. The ship-to-shore side of these working channels is shared with other authorized users. Interference generated by these users reduces the data throughput on the ship-to-shore link of the AIS. Therefore, to reduce interference to the AIS and operate the system on channels listed in Appendix 18, the Coast Guard is investigating selecting interstitial channels listed in Appendix 18. The frequencies of the channels are shown in Table 1-1.

Table 1-1
Duplex Channel Frequencies

Channel Designation	Transponder Transmit Frequency (MHz) A Side	Base Station Transmit Frequency (MHz) B Side
283	157.1875	161.7875
24	157.2000	161.8000
224	157.2125	161.8125
84	157.2250	161.8250
284	157.2375	161.8375
25	157.2500	161.8500
225	157.2625	161.8625
85	157.2750	161.8750
285	157.2875	161.8875
26	157.3000	161.9000
226	157.3125	161.9125
86	157.3250	161.9250
286	157.3375	161.9375
27	157.3500	161.9500
227	157.3625	161.9625
87	157.3750	161.9750
287	157.3875	161.9875
28	157.4000	162.0000
228	157.4125	162.0125

AIS channel selections and operations on them must consider existing local PC license holders to preclude mutual interference from occurring between the two systems. Channels selected for these tests were 87, 287, 27, and 227. The choice of these frequencies was arbitrary. Any channel selected from Table 1-1 for the tests would be sufficient, since all adjacent 12.5 kHz and 25 kHz channels have the same characteristics with respect to each other. Channels identified in Table 1-1 by 3 digits are known as narrowband (or interstitial) 12.5 kHz channels and channels that are identified by 2 digits are known as wideband 25 kHz channels. This labeling is in accordance with ITU-R M.1084-3. For these tests, AIS operations were on 12.5 kHz channels and Public Correspondence operations on 25 kHz channels.

The Coast Guard funded NTIA to perform electromagnetic compatibility tests on the AIS and PC systems and to determine separation distances necessary to preclude mutual interference from occurring between the two systems. The tests were performed January 17-28, 2000 in and around the PAWSS tower two site located at Point Ala Hache, Louisiana by NTIA, SETA, and Coast Guard personnel. The tower is located at N29-34-50/W89-49-40. The AIS antennas were mounted 111 meters above ground level. The results of these tests are given in the following sections.

A spectrum snapshot of the emitters that were active during the testing within the VHF maritime mobile band was taken with the a spectrum analyzer connected to the tower two receive antenna. The plots are shown in Appendix B. It should be noted that the snapshot is not representative of all emitters that could be active in the area.

1.2 Test Objectives

The objectives were to investigate the four interference scenarios outlined below and determine separation distances between base and mobile units of the PC and AIS systems to minimize mutual interference from occurring between the two systems. Both closed loop and radiated tests were performed.

Scenario 1: AIS base station transmitter causing interference in a mobile Public Correspondence users radio receiver.

Scenario 2: Public Correspondence base station transmitter causing interference in an AIS transponder receiver.

Scenario 3: AIS transponder transmitter causing interference in a Public Correspondence base station receiver.

Scenario 4: Public Correspondence mobile transmitter causing interference in an AIS base station receiver.

SECTION 2 TEST PROCEDURES

2. Performance Objectives

The performance of the PC base station and mobile radios was based on SINAD measurements that were performed with a communications test set and the aural quality of the received signal which was judged by a listener. A SINAD measurement, in dB, is the ratio of the desired signal to the desired signal added to interference, noise and distortion. A SINAD measurement of 12 dB and above is usually considered adequate for communications. A SINAD degradation to 14 dB from adjacent channel AIS interference was the performance objective for the receivers in the PC base station and mobile radios for these tests. This level is consistent with the specifications of the International Electrotechnical Commission (IEC) document 1097-7 and the Radio Technical Commission for Maritime Services (RTCM) document 87-99¹ for allowable degradation to an analog FM marine radio receiver. For aural measurements, the criteria was that the audible AIS data bursts could be no louder or discernable than the normal background noise in the receiver. This test was subjective and depended on the hearing capabilities of the listener.

The performance of the AIS base station and transponder was based on a received report count. A received report count is the number of AIS reports that a AIS receiver could demodulate and decode in a fixed amount of time, versus the expected number of received reports. For these tests the minimum rate was 90 percent. For example, in a two minute period with a 6 second reporting rate the expected received report count is 20 reports. The allowable degradation would be 2 reports. The 90 percent rate was chosen to ensure a high data throughput and still allow some degradation to the receiver performance from adjacent channel interference. Reporting rates from 1 to 6 seconds were used during the tests.

2.1 Test Procedures

The procedures for the closed loop and radiated tests for each of the four scenarios are given in the following sections of this document.

2.2 Scenario 1

2.2.1 Scenario 1 Closed Loop Test Procedures

Two mobile Public Correspondence (PC) radio receivers were tested for susceptibility to interference from AIS base station transmitter emissions using the following procedures. Commercial and recreational grade VHF radios were tested. Radio A is a commercial grade radio that is Global Maritime Distress and Safety System (GMDSS) and RTCM SC-117 certified. Radio B is representative of the type used by recreational boaters. A diagram of the test set-up is shown below in Figure 2-1.

¹“RTCM Recommended Standards For Installed Maritime VHF Radiotelephone Equipment Operating In High Level Electromagnetic Environments”, Radio Technical Commission for Maritime Services (Alexandria Va., 1999).

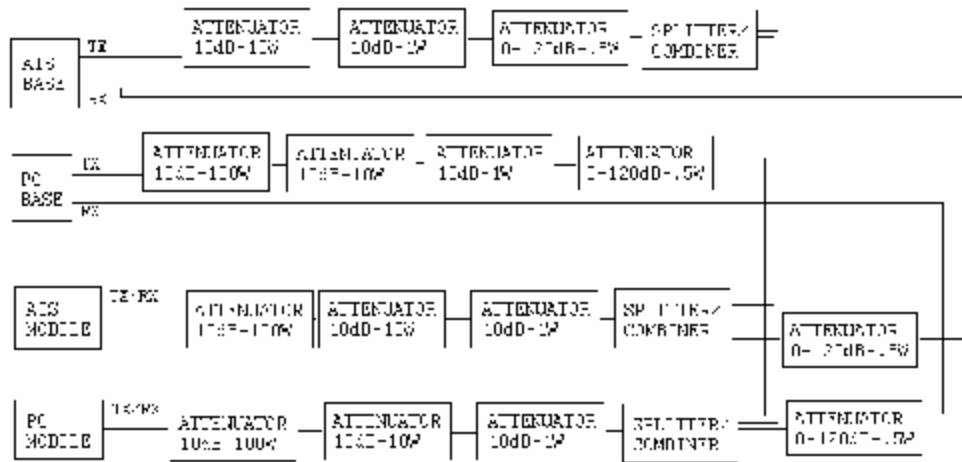


Figure 2-1
Scenario 1 Closed Loop Test Set-up

The following steps were taken to perform the tests.

1. The PC mobile radio and AIS transponder were placed inside a van and connected to the PC and AIS base stations using RF cables coming out of a small access hole in the back of the communications hut. The transponder supplied position reports to the AIS base station, which were then re-transmitted on the channel adjacent to the PC base station.
2. The attenuator on the PC base station was used to vary its RF output power so that the received desired signal, S , at the PC mobile could be changed. The desired signal at the RF input of the radio was set to -60, -95, -101, -107, -110, and -113 dBm. SINAD measurements were taken at each power level. The PC base station was modulated by a 1 kHz tone adjusted in amplitude to produce a 3 kHz deviation.
3. The attenuator on the AIS base station was used to vary its RF output power so that the received interference power, I , at the PC mobile radio could be changed. The VTC operator set the transponder report rate to one second.
4. The desired signal power at the RF input of the radio was set to each value and the power of I was adjusted so that the SINAD was 14 dB. The power of I was recorded into the test log.
5. Step four was repeated for frequency separations of 12.5, 25, 37.5, 50, and 62.5 kHz between

the AIS base station transmitter and the PC mobile receiver.

2.2.2 Scenario 1 Radiated Test Procedures

The following procedures were used in the Scenario 1 radiated tests. A diagram of the test set-up is shown below in Figure 2-2.

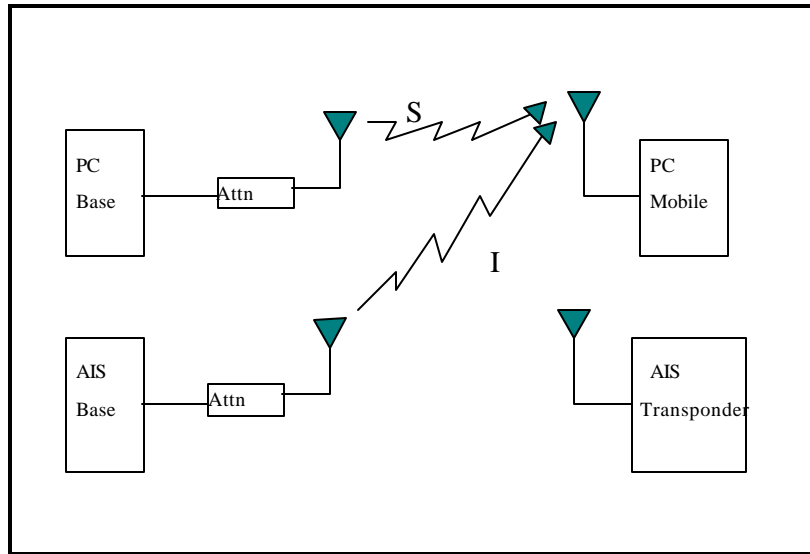


Figure 2-2
Scenario 1 Radiated Test Set-up

1. Two PC mobile radios were placed in a van located 1 mile from the PC and the AIS base station. An AIS transponder was placed outside the communication hut. The PC mobile radio were connected to a 6 dBi gain whip antenna mounted on top of the van.
2. The desired signal power of the PC base station at the mobile receiver was adjusted using the attenuators in the base station to set the mobile receiver SINAD to 14 dB without the AIS base station interference being present. The power level of the PC base station was measured at the PC mobile RF input and recorded into the test log.
3. The power of the AIS base station was then adjusted to make the SINAD fall below 14 dB. The power level of the AIS base station was measured at the PC mobile RF input and recorded into the test log. The frequency separation was 12.5 kHz.
4. The aural quality of the mobile radio receiver was judged by modulating the PC base station with phonetically balanced phrases (adjusted in amplitude to match a 1 kHz tone for a 3 kHz deviation) and listening for bursts of interference from the AIS base station.

2.3 Scenario 2

2.3.1 Scenario 2 Closed Loop Test Procedures

An AIS transponder receiver was tested for susceptibility to interference from a Public Correspondence base station transmitter's emissions using the following procedures. A test set-up diagram is shown below in Figure 2-3.

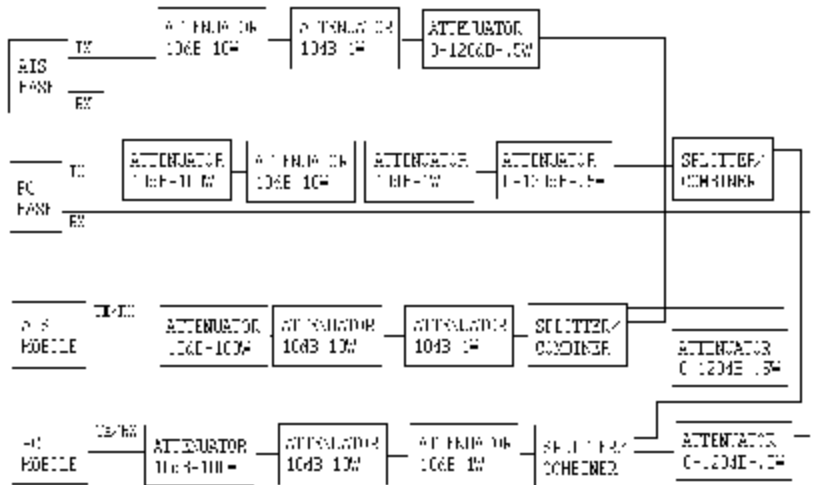


Figure 2-3
Scenario 2 Closed Loop Test Set-up

The following steps were taken to perform the tests.

1. The PC mobile radio and AIS transponder were placed inside a van and connected to the PC and AIS base stations using RF cables.
2. The VTS operator instructed the transponder to report at five second intervals. A second transponder was placed near the tower being tested. This second transponder was used to supply the AIS base station with position reports. The transponder in the van was tested by monitoring the position reports of the second transponder as they were re-broadcast by the AIS base station.
3. The attenuator on the AIS base station was used to vary its RF output power so that the received desired signal, S, at the transponder could be changed. The desired signal at the RF input of the transponder was set to -60, -95, -101, -107, and -110 dBm. At each power level, baseline received report counts were measured and recorded.

4. The attenuator on the PC base station was used to vary its RF output power so that the received interference power, I , at the transponder could be changed. The PC base station transmitter was modulated by voice shaped noise (VSN) adjusted in amplitude to match a 1 kHz tone for a 2.5 kHz deviation.

5. The transponder operator selected the icon of the second transponder on his display and monitored its report rates for a fixed amount of time. The desired signal power at the RF input of the transponder was set to each value and the power of I was adjusted so that the received report count was 90 %. The power of I was recorded into the test log.

6. Step five was repeated for frequency separations of 12.5, and 37.5 kHz between the PC base station transmitter and the AIS transponder receiver. The PC base station was then modulated by a 400 Hz tone adjusted in amplitude to produce a 3 kHz deviation (this was an IEC test requirement) and the tests were repeated.

2.3.2 Scenario 2 Radiated Test Procedures

The following procedures were used in the Scenario 2 radiated tests. A diagram of the test set-up is shown below in Figure 2-4.

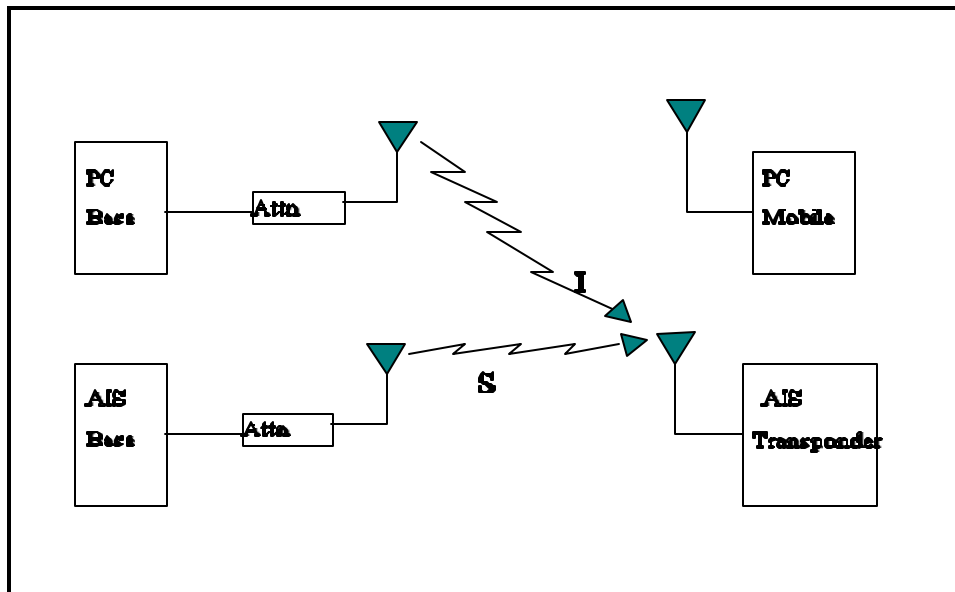


Figure 2-4
Scenario 2 Radiated Test Set-up

1. The van transponder was placed 1 mile from the PC base station and the AIS base station. Another AIS transponder was placed outside the communication hut and logged into the system on

the working channel.

2. The operator of the transponder clicked on the displayed icon of the transponder located at the communications hut and verified that they could receive its position reports which were re-broadcast by the AIS base station.

3. The desired signal power of the AIS base station was adjusted using the attenuators to obtain at least a 90 percent received report count at the transponder without the PC base station interference being present. The power level of the AIS base station was measured at the van and recorded into the test log.

4. The PC base station was then modulated by VSN adjusted in amplitude to match a 1 kHz tone for a 3 kHz deviation. The power of the PC base station was adjusted using attenuators till the received report count at the transponder fell below the baseline measurement.

5. Step four was performed for 12.5 and 37.5 kHz of frequency separation between the PC base station transmitter and the AIS transponder.

2.4 Scenario 3

2.4.1 Scenario 3 Closed loop Test Procedures

A Public Correspondence base station receiver was tested for susceptibility to interference fromn AIS transponder's emissions using the following procedures. A diagram of the test set-up is shown below in Figure 2-5.

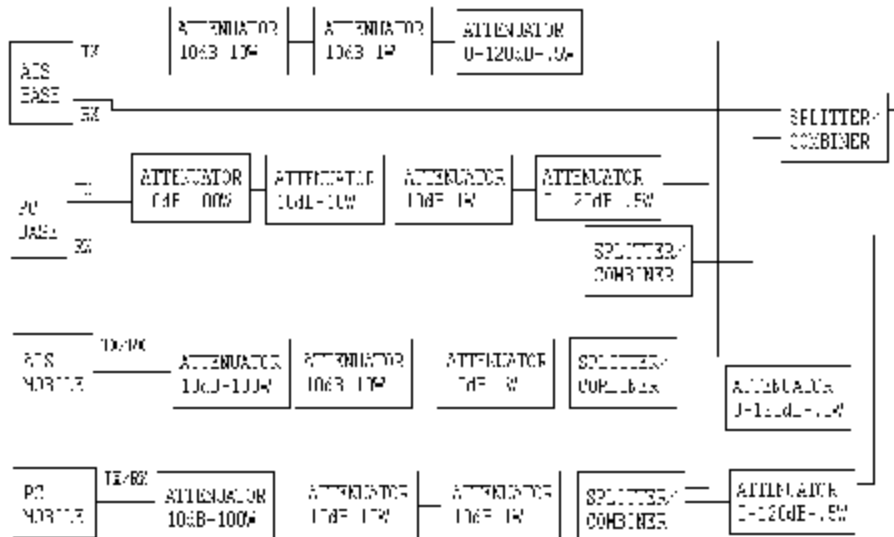


Figure 2-5
Scenario 3 Closed Loop Test Set-up

The following steps were taken to perform the tests.

1. The PC mobile radio and AIS transponder were placed inside a van and connected to the PC and AIS base stations using RF cables.
2. The VTS operator instructed the transponder to report at 2 second intervals.
3. The attenuator on the PC mobile transmitter was used to vary its RF output power so that the received desired signal power, S , at the PC base station could be changed. The PC mobile radio was modulated by a 1 kHz tone adjusted in amplitude for a 3 kHz deviation. The desired signal power at the RF input of the PC base station receiver was set to -60, -95, -101, -107, -110, and -113 dBm. Baseline SINAD measurements of the PC base station receiver were taken at each desired signal power level before the interference was introduced into the receiver.
4. The attenuator on the transponder was used to vary its RF output power so that the received interference signal, I , at the PC base station receiver could be changed.
5. The desired signal power level was set to each value and the power of I was adjusted so that the SINAD of the PC base station receiver was 14 dB. The power of I was recorded into the test log. The tests were performed with and without the bandpass crystal filter installed on the PC base station receiver. The 3 dB bandwidth of the filter is 25 kHz.
6. Step five was repeated for frequency separations of 12.5, 25, and 37.5 kHz between the PC base station receiver and the AIS transponder.

2.4.2 Scenario 3 Radiated Test Procedures

The procedures that were used in the Scenario 3 radiated tests are described below. A diagram of the test set-up is shown below in Figure 2-6.

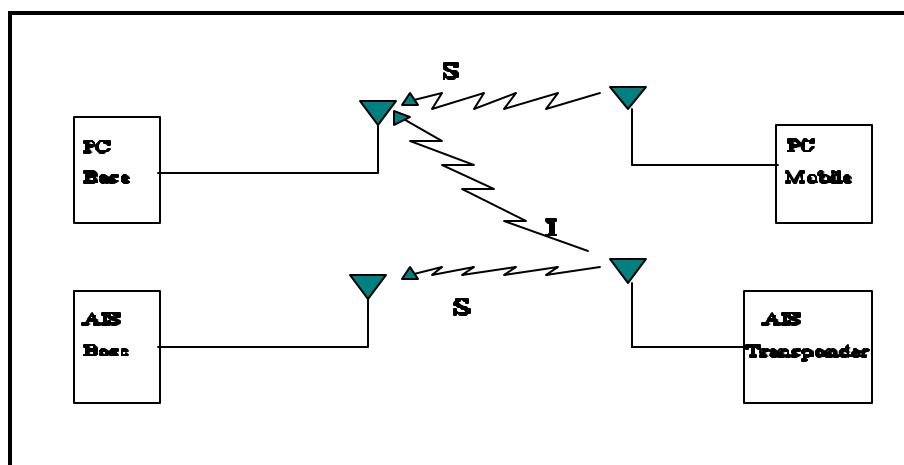


Figure 2-6
Scenario 3 Radiated Test Set-up

1. The PC mobile radio was transmitting with 1 watt output power from a van located 20 miles from the PC base station using an antenna with a 6dBi gain located on the roof. The PC mobile radio was modulated by a 1 kHz tone adjusted in amplitude for a 3 kHz deviation.

2 Personnel at the communications hut set the transponder report rate to two seconds and logged all transponders out of the system except for one located in a car. At the initial starting point, the car was located 1 mile from the PC base station. The transponder was a transportable type and transmitted with 1 watt of output power into a small telescoping whip antenna.

3. Personnel at the communications hut listened to the PC base station receiver for audible interference caused by the transponder's data bursts on adjacent channels.

4. The car containing the AIS transponder was driven away from the PC base station and stopped at distances of 10, 12, 20, 22 and 26 miles and step three was repeated.

This test was performed for frequency separations of 12.5, 25, and 37.5 kHz between the PC base station receiver and the AIS transponder.

2.5 Scenario 4

2.5.1 Scenario 4 Closed Loop Test Procedures

An AIS base station receiver was tested for susceptibility to interference from a Public Correspondence mobile transmitter's emissions using the following procedures. A test set-up diagram is shown below in Figure 2-7.

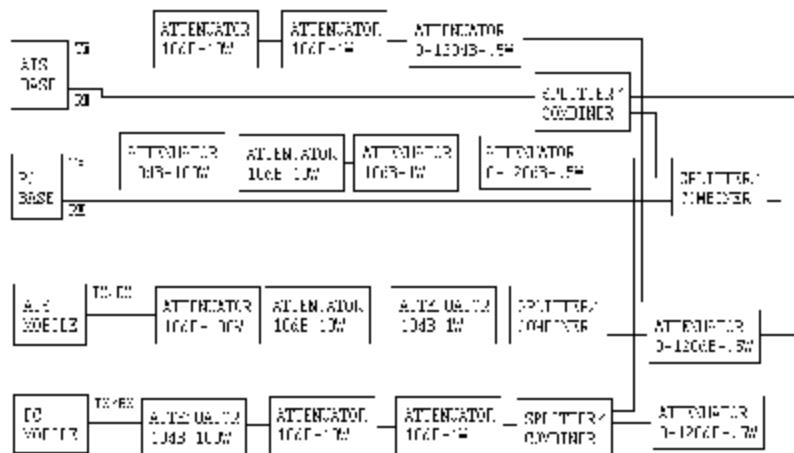


Figure 2-7
Scenario 4 Closed Loop Test Set-up

The following steps were taken to perform the tests.

1. The PC mobile radio and AIS transponder were placed inside a van and connected to the PC and AIS base stations using RF cables.
2. The VTS operator instructed the transponder to report at five second intervals on the working channel.
3. The attenuator on the transponder was used to vary its RF output power so that the received desired signal, S , at the AIS base station receiver could be changed. The desired signal at the RF input to the AIS base station receiver was set to -60, -95, -101, -107, and -110 dBm. Baseline received report counts were taken for the AIS base station receiver at each power level.
4. The attenuator on the PC mobile radio was used to vary its RF output power so that the received interference power, I , at the AIS base station could be changed. The PC mobile radio was modulated by voice shaped noise (VSN) adjusted in amplitude to match a 1 kHz tone for a 2.5 kHz deviation.
5. The VTC operator selected the icon for the transponder with the attenuator on their display and monitored its report rates for a fixed amount of time. The desired signal power at the RF input to the AIS receiver was set to each value and the power of I was adjusted so that the received report count was 90 %. The power of I was recorded into the test log.
6. Step five was repeated for frequency separations of 12.5, 25, and 37.5 kHz between the AIS base station receiver and the PC mobile transmitter. The PC mobile radio was then modulated by a 400 Hz tone adjusted in amplitude to produce a 3 kHz deviation and the tests were repeated.

2.5.2 Scenario 4 Radiated Test Procedures

The procedures that were used in the Scenario 4 radiated tests are described below. A diagram of the test set-up is shown below in Figure 2-8.

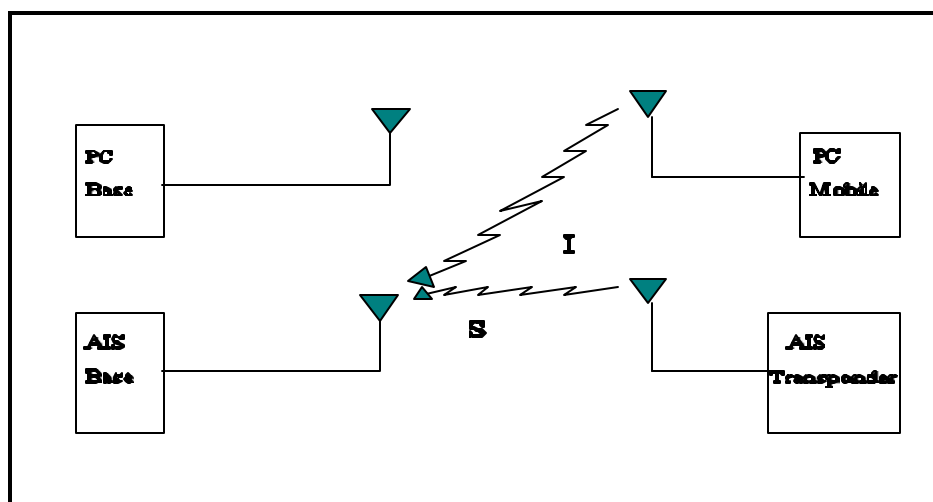


Figure 2-8
Scenario 4 Radiated Test Set-up

1. The AIS transponder was transmitting on the working channel with 1 watt output power at a location 22.4 miles from the AIS base station. Personnel at the communications hut monitored its position reports on the VTC workstation for regular updates via the AIS base station receiver. The report interval was set at five seconds.
2. The van containing a PC mobile transmitter was placed 18, 10, 4.7, 2.5, 1.1, and .5 miles away from the AIS base station. At each location, the PC mobile radio was modulated by VSN adjusted in amplitude to match a 1 kHz tone for a 2.5 kHz deviation and position reports sent from the transponder located 22.4 miles away were observed and counted on the AIS workstation display.
3. Step two was repeated with frequency separations of 12.5, 25, and 37.5 kHz between the AIS base station receiver and the PC mobile transmitter. The power levels at each location were noted and recorded into the test log.

SECTION 3 TEST RESULTS

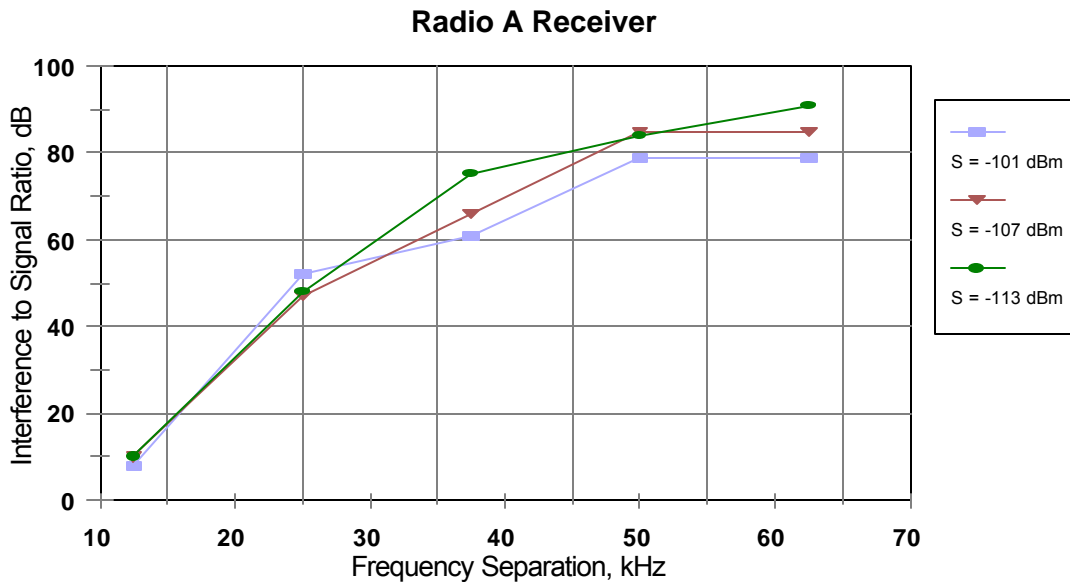
3. Test Results

The tests are based on the assumption that, for the time being, the AIS will only operate on interstitial channels. The test results made with 25 and 50 kHz of frequency separation between the AIS and PC systems do not reflect an existing interference situation because PC systems are not permitted to operate on interstitial channels at this time. The data points for those frequency separations were taken to add resolution to the graphs.

3.1 Scenario 1

3.1.1 Closed Loop

The susceptibility of PC mobile A's receiver to interference from an AIS base station transmitting on adjacent channels for frequency separations of 12.5 to 62.5 kHz can be determined by reviewing Graph 3-1. The graph shows interference-to-signal (I/S) ratios in dB versus frequency separation for desired signal powers of -101, -107, and -113 dBm for a receiver SINAD of 14 dB. These power levels represent a PC mobile radio operating at the edge of RF coverage for a PC base station tower. For these desired signal power levels and no external interference, the measured SINAD levels were 33, 32, and 28 dB, respectively. They are known as baseline measurements. The Scenario 1 measured data for radio A is contained in Table C-1 of Appendix C.

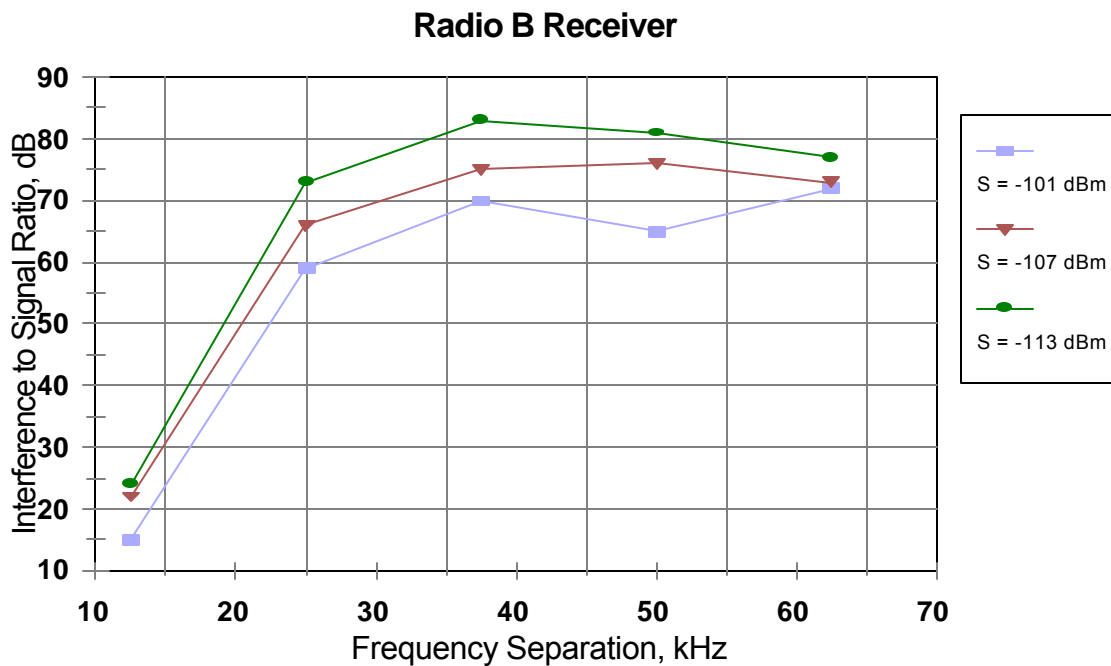


Graph 3-1
PC Mobile Radio A Receiver

Graph 3-1 shows that the I/S ratio increases as the frequency separation between the AIS

base station transmitter and the PC mobile receiver increases. A higher I/S ratio means that for a constant desired signal power, more interference power was required to lower the receiver's SINAD to 14 dB as the frequency separation increased. For example, with a desired signal power of -107 dBm the I/S ratio for 12.5 kHz of frequency separation was 10 dB. At 25, 37.5, 50 and 62.5 kHz the I/S ratios are 47, 66, 85 and 85 dB, respectively. Graph 3-1 also shows that beyond 50 kHz of frequency separation the interference rejection capability of receiver A is leveling off.

The susceptibility of PC mobile B's radio receiver to interference from an AIS base station transmitting on adjacent channels for frequency separations of 12.5 to 62.5 kHz can be determined by reviewing Graph 3-2. The graph shows interference-to-signal (I/S) ratios in dB versus frequency separation for desired signal powers of -101, -107, and -113 dBm for a receiver SINAD of 14 dB. The baseline SINAD measurements for these desired signal power levels was 34, 33, and 29 dB, respectively. The Scenario 1 measured data for radio B is contained in Table C-2 of Appendix C.



Graph 3-2
PC Mobile Radio B Receiver

Graph 3-2 shows that the I/S ratio increases as the frequency separation between the AIS base station transmitter and the PC mobile receiver increases. A higher I/S ratio means that for a constant desired signal power, more interference power was required to lower the receiver's SINAD to 14 dB as the frequency separation increased. For example, with a desired signal power of -107 dBm the I/S ratio for 12.5 kHz of frequency separation was 22 dB. At 25, 37.5, 50 and 62.5 kHz the I/S ratios are 66, 75, 76 and 73 dB, respectively. Graph 3-2 also shows that beyond 37.5 kHz of frequency separation the interference rejection capability of receiver B is leveling off.

In comparing Graphs 3-1 and 3-2, it can be seen that the receiver of radio B is more resistant to adjacent channel AIS interference at frequency separations of 12.5 to 37.5 kHz than receiver A. However, past 37.5 kHz of frequency separation, the receiver of radio A is more resistant to adjacent channel AIS interference by about 10 dB.

3.1.2 Radiated

For the Scenario 1 radiated tests, the van containing the PC mobile radios was driven approximately 1 mile north from the base station and stopped at that location. The PC radios were connected to a roof mounted VHF whip antenna when they were tested. The received desired signal power from the PC base station transmitter and the interference signal power from the AIS base station at the van were controlled by using attenuators at the base station. The frequency separation was 12.5 kHz.

For radio A to achieve a SINAD of 14 dB without the AIS interference present, the desired signal power at the RF input of the radio was -119 dBm. The interference signal power to reduce the SINAD below 14 dB was -98 dBm. This results in a I/S ratio of 21 dB. This is within 6 dB of the I/S ratio for the closed loop tests for a desired signal power of -113 dBm, which was approximately 15 dB. At that level the interference from the AIS base station was barely audible in the radio receiver speaker. To eliminate the audible interference, the AIS power needed to be reduced to -112 dBm at the radio RF input for an I/S of 7 dB. The difference between the audible interference I/S and the I/S for a SINAD of 14 dB is 8 dB.

For radio B to achieve a SINAD of 14 dB without the AIS interference present, the desired signal power at the RF input of the radio was -108 dBm. The interference signal power to reduce the SINAD below 14 dB was -101 dBm. This results in a I/S ratio of 7 dB. At that level the interference from the AIS base station was not audible in the radio receiver speaker. The interference power had to be increased to -92 dBm to make the interference audible in the radio receiver speaker. This results in a I/S ratio of 16 dB. This is within 6 dB of the I/S ratio for the closed loop tests for a desired signal power of -107 dBm which was approximately 22 dB.

3.1.3 Separation Distances

Composite I/S ratios for frequency separations of 12.5, 25, 37.5, and 50 kHz can be developed for a typical VHF radio receiver based on the results of the closed loop tests on radios A and B. The I/S ratios are 15, 60, 75, and 80 dB, respectively. However the tests showed that when the SINAD was 14 dB the interference power had to be lowered by an additional 3 to 14 dB to eliminate the audible interference in the radio receiver. Therefore, the I/S ratios are reduced by 5 dB to accommodate the difference between the audible interference and a SINAD measurement of 14 dB. The I/S ratios are then 10, 55, 70, and 75 dB. For frequency separations beyond 50 kHz the level will stay at 75 dB. These I/S ratios are based on a desired signal power of -107 dBm which is equal to 1 FV into a load of 50 ohms.

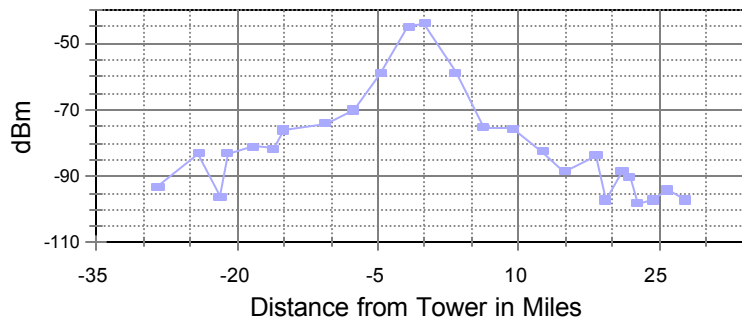
The maximum AIS base station interference power at the RF input to the PC radio receiver for each frequency separation can then be calculated by adding the I/S ratio to the desired signal power. The results are shown below in Table 3-1.

Table 3-1
Allowable AIS Base Station Interference Power in PC Radio Receiver

Frequency Separation (KHz)	I/S (dB)	PC Base Station Power S, (dBm)	AIS Base Station Power I, (dBm)
12.5	10	-107	-97
25	55	-107	-52
37.5	70	-107	-37
50	75	-107	-32
62.5	75	-107	-32

The distances that correspond to these interference power levels can be determined from previous measurements that were made of the Tower 2 signal strengths. NTIA Report 00-347, “*Lower Mississippi River Ports and Waterways Safety System (PAWSS) RF Coverage Test Results*”, contains the measured signal strength for each communications tower referenced in river miles for the AIS and PC base station transmitters. The Tower 2 signal strength graph shown below in Graph 3-3 is referenced in a straight line radial distance. The graph shows that the maximum measured power was -44 dBm. The negative miles are south of the tower and the positive values are north of the tower.

**Tower 2
Signal Strength**



Graph 3-3
Tower 2 Signal Strength

Separation distances for the AIS base station transmitter and the PC mobile radio receiver can be determined from the composite PC mobile radio I/S ratios and Graph 3-3. The PC mobile radio I/S ratios for 12.5, 25, and 37.5 kHz of frequency separation are 10, 55, and 70 dB, respectively. With a desired signal power of -107 dBm the maximum interference powers are then -97, -52, and -37 dBm, respectively. The -97 and -52 dBm power levels correspond to distances of

20 and 2.5 miles. A power level of -37 dBm is under 1 mile.

3.2 Scenario 2

3.2.1 Closed Loop

The I/S ratios for the transponder were calculated using the data collected for Scenario 2 closed loop tests. The results are shown below in Table 3-2.

Table 3-2
Scenario 2 Transponder I/S Ratios for a 90 Percent Received Report Count

Desired Signal Power (dBm)	Interference-to-Signal ratios, dB			
	VSN Modulation		400 Hz Tone Modulation	
	^a F = 12.5 KHz	^a F = 37.5 KHz	^a F = 12.5 KHz	^a F = 37.5 KHz
-60	18	35*	13	35*
-95	19	70	16	70*
-101	20	76	17	76*
-107	24	79	19	80
-110	25	81	20	81

*The interference power level was at its maximum value and was not sufficient to bring the received report count below 90 percent.

The results show that the difference between the transponder I/S ratios for the interfering PC base station using VSN modulation versus a 400 Hz tone results were only 2-5 dB.

The results show that the transponder has very good rejection of adjacent channel PC interference for 37.5 kHz of frequency separation. For example, with a desired signal power of -107 dBm the I/S ratio for 12.5 kHz of frequency separation was 24 dB with VSN modulation and 19 dB with tone modulation. For 37.5 kHz of frequency separation the I/S value for VSN was 79 dB and for tone modulation it was 80 dB. This is an improvement of 55 and 61 dB, respectively.

3.2.2 Radiated

In the Scenario 2 radiated tests, the van containing the transponder was driven approximately 1 mile north from the base station and stopped at that location. The transponder was placed on top of the van's roof. The received desired signal power at the van from the AIS base station transmitter and the interference signal power from the PC base station transmitter were controlled by using attenuators at the base station. The test was performed for frequency separations of 12.5 kHz and 37.5 kHz.

The AIS desired signal power was adjusted at the base station to obtain an approximate 90 percent received report count at the transponder without the PC base station interference present. The level was -102 dBm. The PC base station was then modulated with VSN and the received report count was monitored with the interference being on channels 12.5 and 25 kHz adjacent to the working channel.

For 12.5 kHz of frequency separation, the interference power to lower the transponder received report count below 90 percent was -80 dBm. The I/S ratios was approximately 22 dB for the radiated tests with 12.5 khz of frequency separation.

The closed loop tests I/S ratio for 12.5 kHz of separation and a desired signal power of -101 dBm was 20 dB. This is within 2 dB of the radiated test I/S ratio of 22 dB.

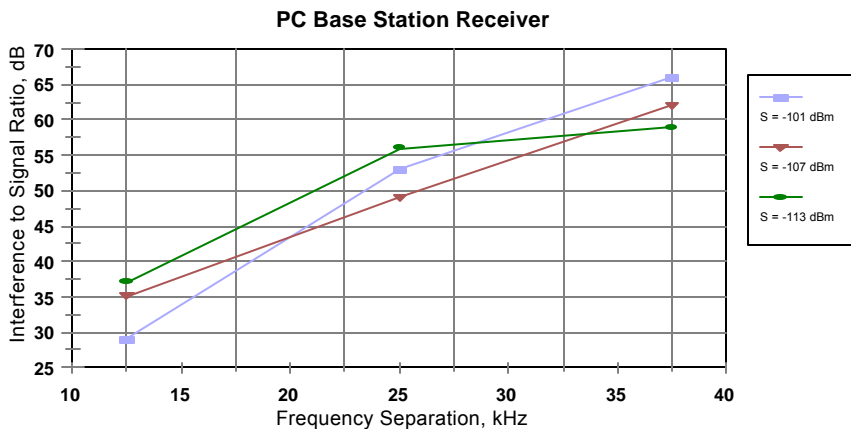
3.2.3 Separation Distances

Separation distances for the AIS transponder and the PC base station transmitter can be determined from the transponder I/S ratios and Graph 3-3. The transponder I/S ratios for 12.5, 25, and 37.5 kHz of frequency separation are 22, 50, and 80 dB, respectively. With a desired signal power of -107 dBm the maximum interference powers are then -85, -57, and -27 dBm, respectively. The -85 and -57 dBm power levels correspond to distances of 12 and 3 miles. A power level of -27 dBm is greater than the maximum level that was measured for tower 2 PC base station transmitter and for the other four tower's PC base stations as well.

3.3 Scenario 3

3.3.1 Closed Loop

The susceptibility of the PC base station receiver to interference from an AIS transponder transmitting on adjacent channels for frequency separations of 12.5, 37.5, and 50 kHz can be determined by reviewing Graph 3-4. The graph shows interference-to-signal (I/S) ratios in dB versus frequency separation for desired signal powers of -101, -107, and -113 dBm for a receiver SINAD of 14 dB. The baseline SINAD measurements for these desired signal power levels was a minimum of 30 dB. The measured data for this scenario is contained in Table C-4 of Appendix C.



Graph 3-4
PC Base Station Receiver

Graph 3-4 shows that the I/S ratio increases as the frequency separation between an AIS transponder transmitter and the PC base station receiver increases. A higher I/S ratio means that for a constant desired signal power, more interference power was required to lower the receiver's SINAD to 14 dB as the frequency separation increased. For example, with a desired signal power of -107 dBm, the I/S ratio for 12.5 kHz of frequency separation was 35 dB. At 25 and 37.5 kHz of separation, the I/S ratios are 48 and 64 dB, respectively.

3.3.2 Radiated

In the Scenario 3 radiated tests, a PC mobile radio was transmitting from a fixed location 20 miles from the base station. The PC mobile radio was modulated by a 1 kHz tone and was transmitting with 1 watt of power into a 6 dBi gain antenna. Another vehicle containing an AIS transponder was driven away from the base station. Personnel at the communications hut listened for audible interference in the PC base station receiver as the transponder transmitted on channels 12.5, 25, and 37.5 kHz removed from the PC channel.

The results are shown below in Table 3-3. For each frequency separation and distance, the table indicates if the interference was audible in the PC base station receiver speaker.

Table 3-3
Scenario 3 Radiated Tests for Audible Interference in Base Station Receiver

Distance (miles) Transponder to PC base station	af		
	12.5 kHz	25 kHz	37.5 kHz
10	yes	yes	no
12	yes	yes	no

20	yes	no	no
22	yes	no	no
26	no	no	no

Table 3-3 shows that, with 12.5 kHz of frequency separation, when the transponder was located 26 miles away from the PC base station the audible interference in its receiver was eliminated. At a distance of 22 miles the interference was audible. Therefore, somewhere between 22 and 26 miles is the point where the audible interference would begin to be heard for 12.5 kHz of frequency separation.

For 25 kHz of frequency separation the interference was audible at 12 miles but not at 20 miles. Therefore, somewhere between 12 and 20 miles is the point where the audible interference would begin to be heard for 25 kHz of frequency separation.

For 37.5 kHz of frequency separation, the interference was not audible at a distance of ten miles. Therefore, somewhere closer than 10 miles is the point where the audible interference would begin to be heard for 37.5 kHz of frequency separation. In all cases the PC mobile radio was stationary at a distance of 20 miles from the base station. These results verify the closed loop test data that additional frequency separation offers additional protection for the PC base station receiver.

3.3.3 Separation Distances

The closed loop performance goal was a SINAD of 14 dB while the radiated test performance goal was no audible interference in the PC base station receiver. The radiated tests performance goal was more stringent than the closed loop tests performance goal. In comparing the two, the audible interference was still perceptible when the SINAD was 14 dB. However, the 1 kHz modulation tone could still be heard at all times even during the bursts of interference. The tests revealed that, for an interference power level to lower the SINAD to 14 dB, the same level had to be lowered an additional 6 to 12 dB to eliminate the audible interference.

To further define the distances in Table 3-3 for 12.5 and 25 kHz of frequency separation, a distance corresponding to 12 dB of additional isolation can be added to the last distance at which the interference was heard. This will give an estimate for the separation distances for no audible transponder interference in the PC base station receiver. Graph 3-3 shows that 12 dB of isolation is equivalent to about 3 miles. The geographical separation distance for 12.5 kHz of frequency separation is estimated to be 25 miles and the distance for 25 kHz of frequency separation is estimated to be 15 miles.

The location where the transponder interference could be heard in the PC base station receiver was not found for 37.5 kHz of frequency separation in the radiated tests. However, Graph 3-4 can be used to estimate the geographical separation distance for a frequency separation of 37.5 kHz. Graph 3-4 shows that, for a desired signal power of -101 dBm, the PC base station receiver has 16 dB more protection from transponder interference with a frequency separation of 37.5 kHz than a frequency separation of 25 kHz. Graph 3-3 shows that 16 dB of isolation is equivalent to about 13 miles. Subtracting 13 miles from the 25 kHz separation distance results in 2 miles. Therefore, the geographical separation distance for a PC base station receiver and an AIS transponder for 37.5

kHz of frequency separation is estimated to be about 2 miles. The geographical separation distances would decrease if the desired signal power were increased.

These tests were conducted with and without the bandpass crystal filter inserted in the RF path leading to the PC base station receiver input. The test results showed that, for this interference scenario, the crystal filter had a negligible effect on the receivers ability to reject adjacent channel AIS interference. The crystal filter is designed for 25 kHz channel operations and it only shows 5 dB of insertion loss at 12.5 kHz off-tuned from its center frequency. At 25 kHz off-tuned from its center frequency the filter had about 29 dB of rejection in addition to its 5 dB of insertion loss.

These separation distances are based on the technical characteristics of the PC base station receiver that was tested and its antenna configuration. Other PC base stations may require slightly different separation distances to account for differences in antenna configuration/installation and RF circuitry/amplifiers. An important factor is the IF bandwidth of the receiver. If the receiver were optimized for 12.5 kHz channelized operation its IF bandwidth would be about 9 to 10 kHz. The current IF bandwidth for operation with 25 kHz channelization is set at about 15 kHz. A narrower IF bandwidth would make the receiver less susceptible to adjacent channel interference and thus lower the separation distances.

3.4 Scenario 4

3.4.1 Closed Loop

The susceptibility of the AIS base station receiver to interference from a PC mobile radio transmitting on adjacent channels for frequency separations of 12.5, 25, and 37.5 kHz can be determined by reviewing Graph 3-5. The graph shows interference-to-signal (I/S) ratios in dB versus frequency separation for desired signal powers of -101, -107, and -110 dBm for a received report count of 90 percent. The baseline received report count for these desired signal power levels was near 100 percent. The measured data for this scenario is contained in Table C-5 of Appendix C.



Graph 3-5
AIS Base Station Receiver

Graph 3-5 shows that the I/S ratio increases as the frequency separation between a PC mobile transmitter and the AIS base station receiver increases. A higher I/S ratio means that for a constant desired signal power, more interference power was required to lower the received report count to 90 percent as the frequency separation increased. For example, with a desired signal power of -107 dBm the I/S ratio for 12.5 kHz of frequency separation was 28 dB. At 25 and 37.5 kHz of separation the I/S ratios are 67 and 71 dB respectively.

Graph 3-5 also shows that beyond 25 kHz of frequency separation, the I/S ratios do not significantly increase for the AIS base station receiver. For desired signal powers of -101 and -107 dBm the difference between the I/S ratios for 25 and 37.5 kHz of frequency separation is only 5 dB. Graph 3-5 also shows that beyond 25 kHz of frequency separation the interference rejection capability of the AIS base station receiver is leveling off.

3.4.2 Radiated

The results of the radiated tests for Scenario 4 are summarized in Table 3-4. For this test a transportable AIS transponder was located 22.4 miles from the AIS base station and transmitting on low power (1 watt) on the working channel with a small telescoping antenna. At a distance of 22.4 miles, the power of the AIS transponder was calculated to be -107 dBm at the RF input to the AIS base station receiver. The transponder remained fixed at that location for the duration of this test and the van containing a PC mobile radio transmitter was stopped at different distances from the base station. At each location, the PC mobile radio was modulated with VSN on a channel adjacent to the transponder working channel. The effects of the PC mobile radio interference on the AIS base stations received report count for the stationary transponder were observed on the VTC workstation display. Without the PC mobile interference present, the received report count for the stationary transponder was at least 95 percent at all times. Table 3-4 shows the percent of the received report count for frequency separations of 12.5, 25, and 37.5 kHz.

Table 3-4
Scenario 4 Radiated Test Results

Distance (miles) PC mobile to AIS base station	af		
	12.5 kHz	25 kHz	37.5 kHz
.5	Below 10 %	\$85%	\$95%
1.1	Below 10 %	\$85%	\$95%
2.5	Below 10 %	\$87%	\$95%
4.7	Below 10 %	\$87%	\$95%
10	\$95%	\$95%	\$95%
18	\$95%	\$95%	\$95%

For this test, the AIS base station was connected to tower transmit and receive antennas in addition to the RF amplifiers inside the RF cabinet. The PC mobile radio was transmitting with 1 watt

of output power into a 6dBi gain whip antenna mounted on the roof of the van.

The data in Table 3-4 shows that the PC mobile transmitter did not have an effect on the received report count for 12.5 kHz of separation until it was 4.7 miles from the base station. At that location with 12.5 kHz of frequency separation the received report count was below 10 percent. With 10 miles of geographical separation and 12.5 kHz of frequency separation the received report count was above 95 percent. Therefore, somewhere between 4.7 and 10 miles is the point where the received report would be reduced to 90 percent for 12.5 kHz of frequency separation.

For 25 kHz of frequency separation and 4.7 miles of geographical separation, the PC mobile radio had some effect on the received report count, but it never went below 85 percent as the geographical separation decreased. For 37.5 kHz of frequency separation, the PC mobile did not have any effect on the AIS base station received report count at the closest distance of .5 miles.

The results of the radiated tests confirm the results of the closed loop tests which show that, for frequency separations of 37.5, the AIS base station receiver is very resistant to adjacent channel PC interference.

3.4.3 Separation Distances

The results of the radiated and closed loop tests for Scenario 4 show that the AIS base station receiver will not be affected by a PC mobile radio operating 12.5 kHz away from the working channel as long as the PC mobile radio was at a minimum 10 miles from the AIS base station. For a frequency separation of 25 kHz, the PC mobile radio would have a small effect on the AIS base station receiver at distances up to .5 miles. For a frequency separation of 37.5 kHz, the PC mobile radio would not have any effect on the AIS base station receiver at distances up to .5 miles.

These distances are based on a PC mobile radio transmitter power of 1 watt. The PC mobile radios are allowed to transmit with a maximum power of 25 watts. The geographical separation distance that was calculated for 12.5 kHz of frequency separation must be adjusted by 14 dB to take into account the difference between high power and low power PC mobile radio operations. Graph 3-3 shows that 14 dB of isolation is equivalent to about 5 miles. Therefore, for a frequency separation of 12.5 kHz and the PC mobile radio transmitting on high power, the separation distance between the AIS base station receiver and the PC mobile radio is 15 miles. This assumes a transponder received desired signal power of -107 dBm.

Graph 3-5 shows that the I/S ratio for 25 kHz of frequency separation is about 67 dB, which is 39 dB greater than the 12.5 kHz frequency separation I/S ratio of 28 dB. Graph 3-3 shows that 39 dB of isolation is equivalent to 11 miles. Therefore, for a frequency separation of 25 kHz and the PC mobile radio transmitting on high power, the separation distance between the AIS base station receiver and the PC mobile radio is 4 miles. This assumes a transponder received desired signal power of -107 dBm.

Graph 3-5 shows that the I/S ratio for 37.5 kHz of frequency separation is about 71 dB, which is 43 dB greater than the 12.5 kHz frequency separation I/S ratio of 28 dB. Graph 3-3 shows that 43 dB of isolation is equivalent to 14 miles. Therefore, for a frequency separation of 37.5 kHz and the PC mobile radio transmitting on high power, the separation distance between the AIS base station receiver and the PC mobile radio is 1 mile. This assumes a transponder received desired signal power of -107 dBm.

These separation distances are based on the technical characteristics of the AIS base station

receiver that was tested and its antenna configuration. Other AIS base stations may require slightly different separation distances to account for differences in antenna configuration/installation and RF circuitry/amplifiers.

SECTION 4 SEPARATION DISTANCES

4. Separation Distances

Separation distances were calculated for each of the four test scenarios described in Section 1 of the report. The tests are based on the assumption that the AIS (based on ITU Recommendation M. 825-3) will operate on 12.5 kHz interstitial channels and the Public Correspondence will operate on 25 kHz channels. The results are shown below. However, it should be noted that tests made with 25 kHz of frequency separation between the AIS and PC systems do not reflect an existing interference situation because PC systems are not permitted to operate on interstitial channels at this time. These tests were conducted for data trends purposes and are not directly applicable as such operations would require a regulatory change in existing wideband Public Correspondence operations.

The test results show that, considering all four receivers, the PC base station receiver is the most susceptible to adjacent channel interference and requires the largest geographic separation distance for protection. For 12.5 kHz of frequency separation, the PC base station receiver requires 25 miles of geographic separation from an AIS transponder. Since PC and AIS systems would employ base stations to serve mobile units on vessels in the same geographic area, operations of these systems in the same geographic area may not be practical with 12.5 kHz of frequency separation. A detailed summary of the separation distances is given in the following paragraphs.

4.1 Base Station Receiver vs Mobile Interferer

The separation distances for the PC base station receiver and an AIS transponder (Scenario 3) are shown below in Table 4-1 for frequency separations of 12.5, 25, and 37.5 kHz. To protect the PC base station receiver from transponder interference, the AIS transponder should not operate within the area that is defined by a circle which has a radius equal to the separation distance that is shown in Table 4-1 for each frequency separation. These distances are based on a received desired signal power of -98 dBm at the RF input of the PC base station receiver. This power level corresponds to a fixed mount radio transmitting from distance of twenty miles from a PC base station, which was considered a nominal distance for PC communications. The separation distances would be reduced if the desired signal power is increased.

Table 4-1
Scenario 3
PC Base Station Receiver and AIS Transponder Separation Distances

Frequency Separation (kHz)	Distance (miles)
12.5	25
25	15
37.5	2

The separation distances for the AIS base station receiver and an PC mobile radio (Scenario 4) are shown below in Table 4-2 for frequency separations of 12.5, 25, and 37.5 kHz. To protect the AIS base station receiver from PC mobile radio interference, the PC mobile radio should not operate within the area that is defined by a circle which has a radius equal to the separation distance that is shown in Table 4-2 for each frequency separation. These distances are based on a received desired signal power of -107 dBm at the RF input of the AIS base station receiver. The distances would be reduced if the desired signal power is increased.

Table 4-2
Scenario 4

AIS Base Station Receiver and PC Radio Separation Distances

Frequency Separation (kHz)	Distance (miles)
12.5	15
25	4
37.5	1

4.2 Mobile Receiver vs. Base Station Interferer

The separation distances for the PC mobile receiver and an AIS base station transmitter (Scenario 1) are shown below in Table 4-3 for frequency separations of 12.5, 25, and 37.5 kHz. To protect the PC mobile radio from AIS base station interference, the PC mobile radio should not come any closer to the AIS base station than the distances that are shown in Table 4-3 for each frequency separation. These distances are based on a received desired signal power of -107 dBm at the RF input of the PC mobile radio receiver. The distances would be reduced if the desired signal power is increased.

Table 4-3
Scenario 1

PC Mobile Radio Receiver and AIS Base Station Separation Distances

Frequency Separation (kHz)	Distance (miles)
12.5	20
25	2.5
37.5	1

The separation distances for the AIS transponder and a PC base station transmitter (Scenario 2) are shown below in Table 4-4 for frequency separations of 12.5, 25, and 37.5 kHz. To protect the transponder receiver from PC base station interference, the transponder should not come any closer to the PC base station than the distances that are shown in Table 4-4 for each frequency separation. These distances are based on a received desired signal power of -107 dBm at the RF input of the AIS transponder. The distances would be reduced if the desired signal power is increased.

Table 4-4
Scenario 2

AIS Transponder Receiver and PC Base Station Separation Distances

Frequency Separation (kHz)	Distance (miles)
12.5	12
25	3
37.5	.5

4.2 Considerations for ITU-RM1371 Standard

The new AIS standard, recommendation ITU-R M.1371, has a higher data rate and a different modulation scheme than the ITU-R M.825-3 standard, which is the current AIS protocol being used by the Coast Guard. The new standard's higher data rate and different modulation scheme will require that the transponder and AIS base stations need slightly larger separation distances from the PC systems for the same level of protection.

SECTION 5

CONCLUSIONS and RECOMMENDATIONS

5.1 General Conclusions

Tests scenarios were designed to determine compatibility between AIS operating on interstitial channels (12.5kHz) and PC operating on 25 kHz channels operating within the VHF Maritime Mobile Band using duplex channels. AIS operations conformed to ITU Recommendation ITU-R M. 825-3.

A minimum 12.5 kHz of frequency separation was used between the interfering transmitter and victim receiver in all test scenarios. In addition, dependent on the test scenario being used, 25 kHz, 37.5 kHz, 50 kHz and 62.5 kHz frequency separations were also tested. Tests using 25 kHz and 50 kHz frequency separations were conducted for data trends purposes and are not directly applicable as they would require regulatory changes applicable to PC operations.

The four scenarios tested were: 1) An AIS base station causing interference to a PC mobile radio receiver, 2) a PC base station causing interference in a AIS transponder receiver, 3) an AIS transponder causing interference in a PC base station receiver, and 4) a PC mobile radio causing interference to an AIS base station receiver. A fifth test scenario required to determine compatibility between ship-to-ship AIS operations and PC operations was not tested due to the unavailability of suitable equipment. This fifth scenario represents a co-site concern with both AIS and PC systems operating on the same ship. The inability to test this fifth scenario does not alter the conclusions or recommendations given in this report.

Analyses of results obtained for the four test scenarios offer general guidelines for determining compatibility between AIS operations on interstitial 12.5 kHz channels and Public Correspondence operations on wideband 25 kHz channels. Test results are specific to the New Orleans area and are generally applicable to other areas as well.

5.2 Specific Conclusions

Based on the previously established criteria and analyses of the test results, the following is concluded:

- 1) Since AIS and PC systems both offer service to mariners on ships and would employ base stations with transmission towers located in the same geographic environment, operating these systems in the same area may not be practical with 12.5 kHz of frequency separation (i.e., geographical separation distance on the order of 20 miles is required).
- 2) The PC and AIS systems should be able to operate within the same geographic environment provided that a minimum of 37.5 kHz of frequency separation between the two systems is maintained.

5.3 Recommendations

NTIA recommends that the Coast Guard consider:

1. Developing an AIS frequency coordination plan for the lower Mississippi River for the PC and AIS systems that will ensure mutually compatible and satisfactory operations.
2. Performing additional EMC tests between ship-to-ship AIS and PC operations.
3. Performing EMC tests between PC systems and ITU-R. M 1371 compliant AIS equipment when such equipment becomes available.
4. Pursuing necessary regulatory changes to improve AIS and PC operations in the same geographical area (e.g., including a 12.5 kHz channelization for both AIS and PC operations and developing appropriate receiver standards).

Appendix A

AIS Operations

BACKGROUND

AIS is a shipborne transponder-based navigation safety system that serves as the foundation for the Vessel Traffic Service (VTS) being established in New Orleans by the Coast Guard under the Ports And Waterway Safety System (PAWSS) project. AIS implementation is based on technical standards established by the ITU (International Telecommunication Union). The current implementation in New Orleans is based on AIS standard Recommendation ITU-R M.825-3 (DSC-based), which will be updated in the future to the new standard for Universal Shipborne AIS, Recommendation ITU-R M.1371. The Coast Guard and many port authorities are anxious to implement AIS in other ports and waterways in the United States, and it is envisioned that all will one day take advantage of this technology. AIS facilitates the efficient exchange of data between ships and between shore stations and ships that have been fitted with appropriate equipment. AIS responds to the mariners' need for timely, relevant and accurate information delivered in an unobtrusive manner. It is an autonomous, automatic, continuous system that operates in broadcast and interrogation modes. The AIS requires dedicated frequencies in order to operate safely and reliably.

In selecting frequencies to meet AIS requirements, authorities may only use those frequencies within Appendix S18 of the International Radio Regulations (from the S18 Table of Frequency Channels between 156.025-157.425 MHz and 160.625-162.025 MHz). Authorities should utilize techniques established by Recommendation ITU-R M.1084-3 for deriving any new frequencies from within Appendix S18 of the Radio Regulations. The 1997 World Radio Conference (WRC-97) designated two channels for AIS operations and allowed narrowbanding via a footnote.

AIS OPERATING MODES AND FREQUENCY REQUIREMENTS

AIS normally operates autonomously in a self-organized "ship-to-ship" mode, unless a shore station (such as a VTS area) designates a wide area "ship-to-shore" network for all ships and shore users in certain areas. The UAIS standard, Recommendation ITU-R M.1371, specifies two operating frequency channels, AIS1 and AIS2, and these channels are required to operate simultaneously and in parallel. On the high seas, for "ship-to-ship" use, these channels are channels 87B and 88B, as designated by the WRC-97. The WRC-97 also provided for regional AIS channels to be designated where required, such as within VTS areas and/or within national boundaries.

In VTS areas, "ship-to-ship" and "ship-to-shore" modes operate independently and in parallel. Separate dedicated frequencies are required to support each of the two operating modes; "ship-to-ship" needs two dedicated simplex frequency channels, and "ship-to-shore" typically needs two dedicated duplex frequency channels.

A VTS needs duplex channels in order to perform the required services and functions. For any VTS that encompasses large geographic areas served by multiple communications sites, typically two duplex channels will be required (although three channels may actually be required in some special cases, such as Puget Sound) in order to avoid radio frequency interference between adjacent tower sites. In areas with more than two tower sites, towers can alternate their use of the two frequency channels along the waterway to maximize spectrum efficiency.

AIS must be able to operate in “ship-to-ship” mode everywhere and at all times. Thus, the shipborne AIS is required to simultaneously support both “ship-to-shore” and “ship-to-ship” modes on two separate channels in a VTS area. To meet this requirement and mitigate the effects of radio frequency interference (since one channel may be jammed due to interference), shipborne AIS transponders are designed to operate on two frequency channels simultaneously. The Universal AIS standard provides for automatic channel switching (channel management, using DSC and frequency-agile AIS transponders) and for duplex as well as simplex channels.

FREQUENCY TYPES AND THE NUMBER OF FREQUENCIES

In response to a request from the International Maritime Organization (IMO), the WRC-97 (the 1997 World Radio Conference) designated the use of two frequency channels within Radio Regulations (RR) Appendix S18 (the VHF maritime band) for AIS use on the high seas. These channels, 87B and 88B, were derived from the duplex channels 87 and 88, which were previously designated for VHF marine public correspondence. Two channels were selected to increase capacity and mitigate RF interference.

The “upper legs” (B-side) of these duplex (paired frequency) ship/coast (A/B) channels (channels 87 and 88) were chosen for this service because these “upper legs” are the “coast frequencies” utilized by shore stations (ships’ radios do not normally transmit on these frequencies), thus avoiding harmful interference to the ships’ AIS transponders. The WRC-97 also provided for administrations to designate “regional frequency channels for AIS” where channels 87B and 88B are unavailable and, if necessary, to derive new Appendix S18 channels using Recommendation ITU-R M.1084-3 (simplex use of duplex channels and/or 12.5 KHz narrowband channels). The WRC-97 further stated that “these regions should be as large as possible” for navigation safety purposes. Within a VTS/AIS designated area, AIS channel switching is accomplished when the shore stations switch ships’ transponders to VTS/AIS designated working frequencies. Switching of any frequencies can be done via several methods which include: automatic switching by the shore base stations, manual switching by the AIS operator on the ship, or automatic switching by the use of imbedded data base within the AIS transponder or an interconnected terminal (AIS display system or electronic chart display system) onboard the ship. Any switching of channels should be minimized to ensure stability of the system. Since the “ship-to-ship” mode must run concurrently with “ship-to-shore” mode on separate regionally/nationally-dedicated channel(s) that are not dependent on shore-based channel switching, navigation safety cannot be impaired by shore-based system problems. In the United States waters, the WRC-designated AIS channels 87B and 88B for high seas operation. These channels are unavailable in the U.S waters due to pre-existing conflicting assignments. Therefore, two alternative national “ship-to-ship” AIS frequencies must be designated for use in US waters. Channels 87B and 88B will likely be used in the “high seas” areas, but the AIS transponders will be switched upon entering the designated waters. For regions within the United States, two duplex AIS channels should be designated for each region (with a provision to designate a third channel only where needed) for “ship-to-shore” use within VTS designated areas, and the channel switching can

be implemented according to the standard AIS ship-to-shore automatic channel management protocol.

AIS STANDARDS AND FREQUENCY USE

AIS frequency requirements must consider the two applicable AIS standards, the current standard for AIS, Recommendation ITU-R M.825-3 (DSC-based), and the new standard for the Universal Shipborne AIS, Recommendation ITU-R M.1371. All AIS transponders at some future date are expected to be in accordance with the new Universal AIS standard

DESIGNATING FREQUENCIES FOR AIS IN THE UNITED STATES

Considerations for dedicated frequencies to meet AIS requirements (two simplex frequency channels and two duplex channels) in the U.S. should include the need to use frequencies within Appendix S18 of the International Radio Regulations (from the S18 Table of Frequency Channels between 156.025-157.425 MHz and 160.625-162.025 MHz) and the need to utilize techniques established by Recommendation ITU-R M.1084-3 and the WRC-97 guidelines set forth in Appendix S18 footnotes. By following these standards and guidelines, the United States will be able to provide frequencies that will support the proposed international mandatory shipborne AIS transponders.

Appendix S18 supports VHF maritime communications worldwide. These channels support a variety of communication functions, including public correspondence, intership and ship-to-coast, coast-to-ship, port operations, calling and various safety functions. Safety functions include distress, search and rescue, ship movement, navigation (bridge-to-bridge) communications, and maritime safety information broadcasts.

Recommendation ITU-R M.1084-3 provides methods for administrations to derive new frequency channels, where needed, that could be designated for AIS operation. One method implements the simplex use of duplex channels. This method has already been used by the Federal Communications Commission (FCC) in the U.S. to split the duplex marine channels and to re-designate the “upper legs” (B-sides) for non-maritime use. Another method proposes the interleaving of 12.5 KHz narrowband channels. This method was evaluated by NTIA and the USCG in the PAWSS environment in New Orleans for narrowband AIS transponders. The test results indicate that AIS operations on the 12.5 KHz interstitial duplex channels is interoperable with voice operations on the adjacent 25 KHz duplex public correspondence channels provided that some geographic separation is provided between shore stations and mobile units or different channel spacing is used.

Within the U.S., both the Federal Communications Commission (FCC) and the National Telecommunications and Information Administration (NTIA) are the federal agencies that regulate the use of the Appendix 18 VHF maritime spectrum. This is made up of 25 KHz channels with Government and non-Government assignments. Two groups of Appendix S18 channels have been assigned to the federal government, one on each side of the marine VHF Public Correspondence (VPC) band. The 25 KHz federal government channels below VHF marine public correspondence are channels 21A, 81A, 22A, 82A, 23A, and 83A, and the channel above the VPC band is channel 88B. These channels are shared by various federal

government organizations. Note that these channels (A-channels) are derived from simplex use of duplex (A/B) Appendix S18 channels. Since the paired frequencies (B-channels, or “upper legs” which are needed for AIS) to these channels have already been assigned to other non-maritime services by the FCC, these 25 KHz federal government channels, as well as the other (non-government) 25 KHz simplex channels, are unsuitable for AIS implementation.

Since navigation safety depends primarily on ship-to-ship operations, which are not subject to frequency switching by shore stations, dedicated nationwide frequencies should be assigned for these ship-to-ship AIS operations within US waters. Frequency assignments for ship stations (for ship-ship AIS operations) should also consider non-public correspondence frequencies since ship stations are currently authorized to use VHF duplex marine public correspondence channels only in conjunction with a licensed coast station.

For shore stations (to support the required ship-shore VTS operations), duplex channels (A/B paired frequencies) are required in order to provide for a wide area information network service exchange in VTS areas. Of the 35 duplex channels listed in Appendix S18 of the ITU Radio Regulations, only nine remain available for maritime service in the United States due to past government regulatory actions. All the channels from 01-23 and 60-83, both government and non-government, as well as channel 88, have been made simplex by the FCC’s past rulemaking actions, with the A-sides retained for maritime use and the B-sides re-assigned for non-maritime use. The remaining nine 25 KHz duplex channels are contained within the VHF marine public correspondence service, which are Channels 24, 84, 25, 85, 26, 86, 27, 87, and 28. It should be noted that the VHF marine public correspondence service providers typically have a license for only one or two channels per service area.

Since existing wideband 25 KHz channels have already been designated within the VHF maritime band, it has become necessary for the US to consider 12.5 KHz interstitial channels in accordance with ITU-R M.1084-2 for AIS operations. Since AIS implementation requires duplex channels (either B-side “upper legs” or duplex pairs), these potential new interstitial channels must be implemented within the VHF maritime band. As such, potential candidate frequencies could be selected from within the Public Correspondence Band (the only remaining duplex channels in the US) and would comprise the channels numbered 224, 225, 226, 227, 284, 285, 286, and 287. This method was investigated by the USCG and the National Telecommunications and Information Administration (NTIA), in cooperation with the Radio Technical Commission for Maritime Services (RTCM) Special Committee SC117. The result of the investigation showed that 25 KHz voice radios and 12.5 KHz voice radios can be made to be interoperable with conditions.¹ However, the introduction of new 12.5 KHz voice radios into the existing 25 KHz environment must be done slowly and carefully in order to ensure that no interference occurs to users of existing 25 KHz channelized maritime radios.

The FCC addressed the need for obtaining frequencies for AIS, in its “Third Report and Order and Memorandum Opinion and Order,” FCC 98-151, released: July 9, 1998. The R&O

¹ Sole, R., Sanders, F. and Bedford, B., Assessment of Compatibility Between 25 and 12.5 KHz Channelized marine Radios, NTIA-TR 97-343, U.S. Department of Commerce, August 1997.

noted the following: 1) that duplex 12.5 KHz interstitial channels from within the VHF marine public correspondence band should be used for AIS, 2) that two interstitial (interleaved 12.5 KHz narrowband) duplex channels would be needed (in each maritime region) for “ship-to-shore” use, and 3) that channel 228B (162.0125 MHz) should be designated for AIS on a nationwide basis for “ship-to-ship” use.

Furthermore, the FCC auctioned on December 3, 1998 (in accordance with the provisions announced earlier in its R&O of July 9, 1998) the VHF duplex marine public correspondence channels. The new auction winners received licenses for all the channels in the band with provisions for interference protection for the stations operated by incumbents (who retain their current licenses). This auction was conducted on a regional basis (both maritime regions and non-maritime regions) with each of the maritime regions coinciding with the USCG districts. The FCC’s R&O requires the USCG to “negotiate” with the regional auction winner for selecting two interstitial channels for AIS operations. The potential use of interstitial channels within the Public Correspondence band allows a unique opportunity for channels to be dedicated exclusively to AIS operation since they have never been assigned. As a result modifications to the FCC rules under 47CFR80 for equipment that operates on 12.5 KHz channels will, of course, be needed. The auction winner for all maritime regions is WJG MariTEL Corporation (MARITEL). Since there is only one auction winner for all maritime regions, the USCG is negotiating with MARITEL for two interstitial frequency channels to be dedicated exclusively for AIS operations on a nationwide basis. Note that the R&O provided that the maritime VHF Public Coast licensees can use the interstitial channels for their own purposes if they have the wideband 25 KHz channels on either side of the interstitial channels. Thus, there is a need for two AIS channels to be dedicated exclusively for AIS in order to provide protection against harmful interference from other uses of these frequencies and also to insure availability of frequencies for AIS where needed in the future. If the USCG is unable to obtain nationwide exclusive dedication of two duplex interstitial channels, then two such channels could be exclusively dedicated for AIS on a region-by-region basis. The two interstitial frequency channels should be selected such that the two channels have a maximum frequency separation in order to provide maximum protection against interference. The channels used in the previous example (channels 224 and 287) would be best suited for designation for AIS because they have the maximum available frequency separation.

The FCC’s R&O recognized the needs for a nationwide AIS ship-to-ship frequency (although one more is needed to support the new Universal AIS). The 12.5 KHz narrowband channel 228B was designated for three very important reasons: 1.) this channel is currently located between the highest marine VHF public correspondence 25 KHz channel (channel 28) and the lowest non-maritime federal government 25 KHz channel (channel 88B), 2.) this channel is a new 12.5 KHz channel, and thus it would pose a minimum of conflicts to its assignment to AIS nationwide, 3.) this channel is from a duplex “upper leg”, and as such is not subject to interference from ships’ VHF marine radios. A second nationwide ship-ship AIS channel (in addition to the one channel 228B provided by the R&O) is needed to support the new Universal AIS standard. Channel 283B could be likewise designated for AIS nationwide, since this channel is also a potential new 12.5 KHz channel that is situated between the

highest frequency used in the landmobile service and the lowest VHF marine public correspondence 25 KHz channel (channel 24).

Appendix B

Spectrum Snapshots

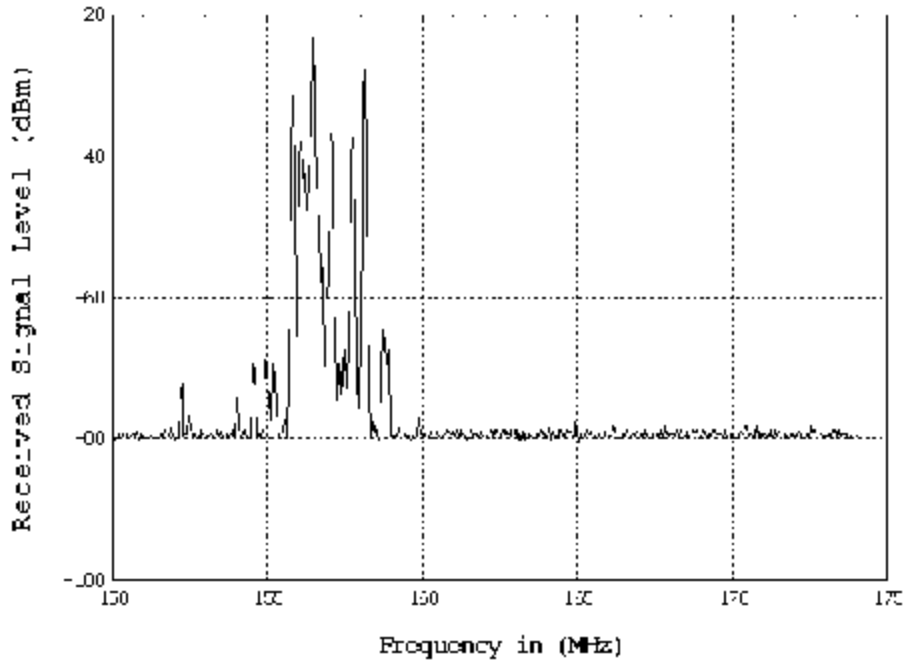


Figure B-1
Point Ala Hache Electromagnetic Environment (without 158.1 MHz) Filter

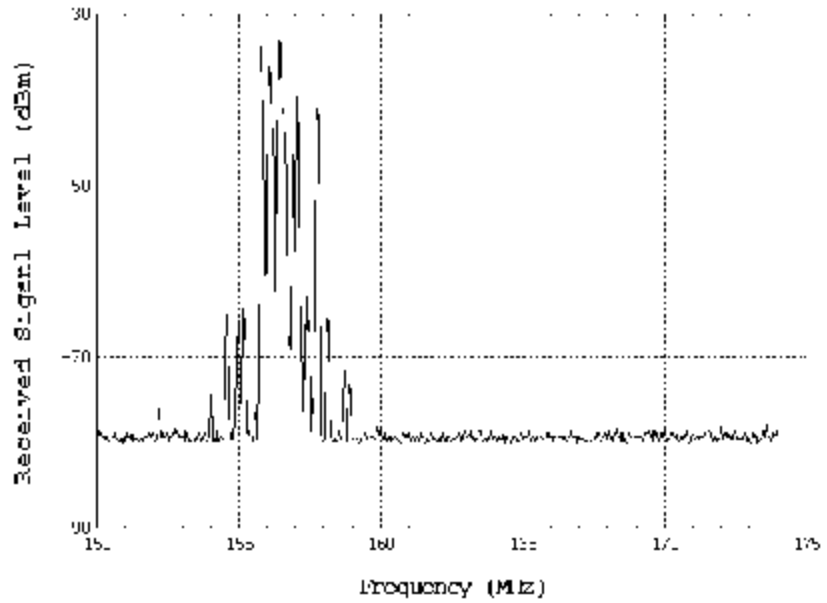


Figure B-2
Point Ala Hache Electromagnetic Environment (with 158.1 MHz Filter)

Appendix C
Measured Data

Table C-1
Scenario 1 Radio A Closed Loop Tests Data

Desired Signal Power dBm	Interference Power, dBm				
	^a F = 12.5 kHz	^a F = 25	^a F = 37.5	^a F = 50	^a F = 62.5
-60	-41	-22*	-22*	-22*	-22*
-95	-84	-35	-32	-22*	-22*
-101	-93	-49	-40	-22*	-22*
-107	-97	-60	-41	-22*	-23
-110	-100	-62	-39	-26	-23
-113	-103	-65	-38	-29	-23

Table C-2
Scenario 1 Radio B Closed Loop Tests Data

Desired Signal Power dBm	Interference Power, dBm				
	^a F = 12.5	^a F = 25	^a F = 37.5	^a F = 50	^a F = 62.5
-60	-50	-22*	-22*	-22*	-22*
-95	-80	-42	-28	-28	-27
-101	-86	-42	-31	-36	-29
-107	-85	-41	-32	-31	-34
-110	-82	-41	-29	-32	-33
-113	-89	-40	-30	-32	-36

* The interference power level was at its maximum value and was not sufficient to lower the SINAD to 14 dB.

Table C-3
Scenario 2 Transponder Closed Loop Tests Data

Desired Signal Power dBm	Interference Power, dBm			
	VSN Modulation		400 Hz Tone Modulation	
	^a F = 12.5	^a F = 37.5	^a F = 12.5	^a F = 37.5
-60	-42	-25*	-47	-25*
-95	-76	-25	-79	-25*
-101	-81	-25	-84	-25*
-107	-83	-28	-88	-27
-110	-85	-29	-90	-29

*The interference power level was at its maximum value and was not sufficient to bring the received report count below 90 percent.

Table C-4
Scenario 3 PC Base Station Receiver Closed Loop Tests Data

Desired Signal Power dBm	Interference Power, dBm		
	^a F = 12.5 kHz	^a F = 25	^a F = 37.5
-60	-39	-29	-29*
-95	-75	-47	-34
-101	-72	-48	-53
-107	-72	-58	-45
-110	-73	-61	-46
-113	-76	-57	-54

* The interference power level was at its maximum value and was not sufficient to lower the SINAD to 14 dB.

Table C-5
Scenario 4 AIS Base Station Receiver Closed Loop Tests Data

Desired Signal Power dBm	Interference Power, dBm					
	VSN Modulation			400 Hz Tone Modulation		
	^a F = 12.5 kHz	^a F = 25 kHz	^a F = 37.5 kHz	^a F = 12.5 kHz	^a F = 25 kHz	^a F = 37.5 kHz
-60	-63	-16*	-16*	-63	-16*	-16*
-95	-73	-28	-24	-72	-30	-24
-101	-77	-35	-31	-76	-36	-28
-107	-79	-40	-36	-81	-42	-34
-110	-87	-49	-39	-88	-51	-40

*The interference power level was at its maximum value and was not sufficient to bring the received report count below 90 percent.