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

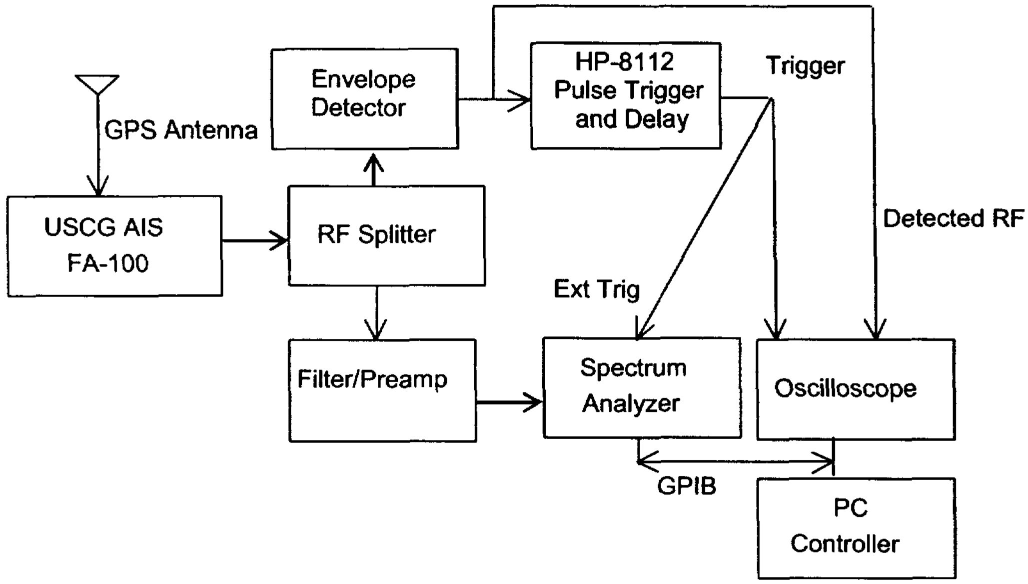

Figure B-1. FA-100 Emission Spectrum Block Diagram

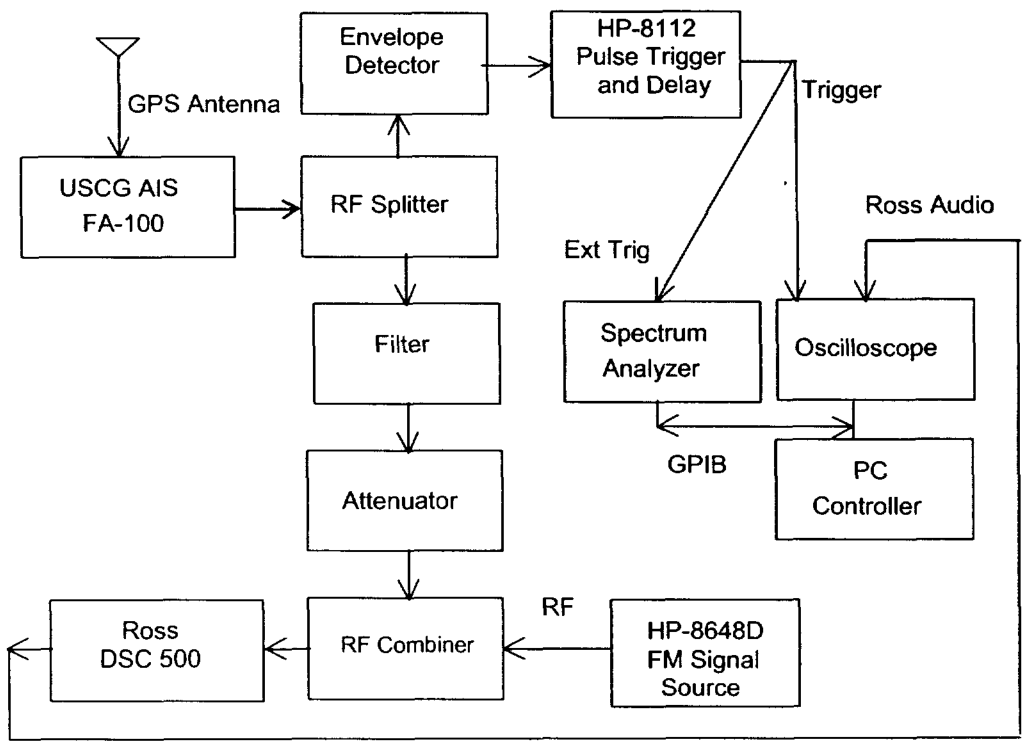

Figure B-2. FA-100 to DSC 500 Audio Sample - Block Diagram

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.

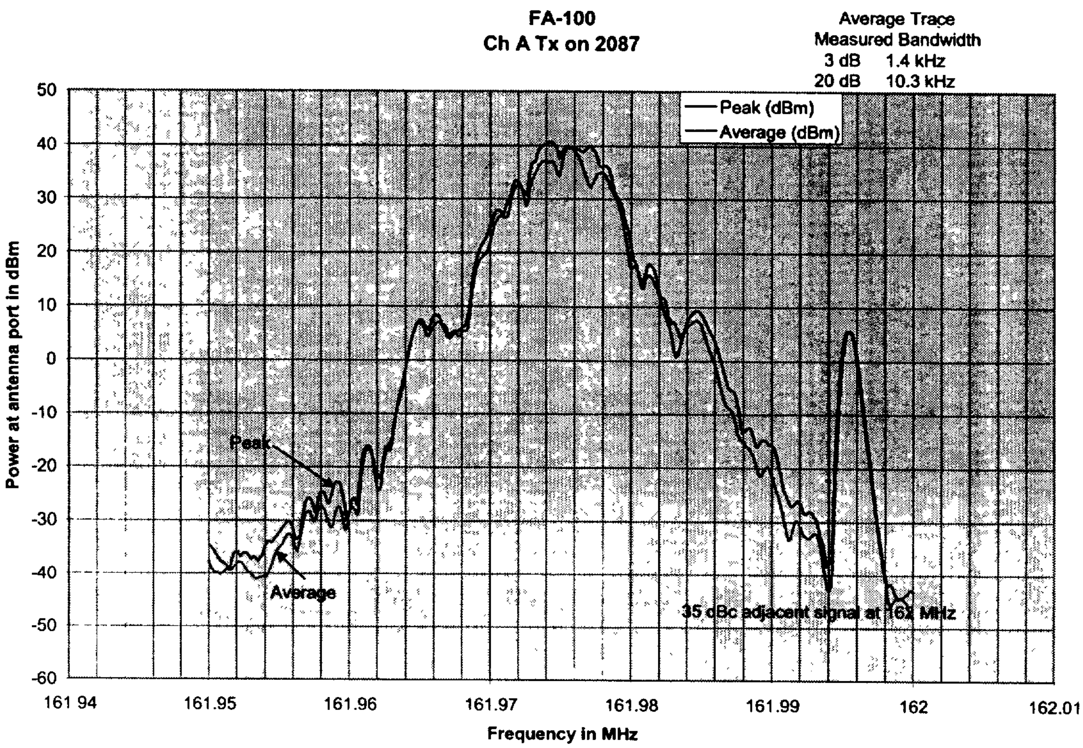

Figure B-3. In-Band Single Channel Peak and Average Emission

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

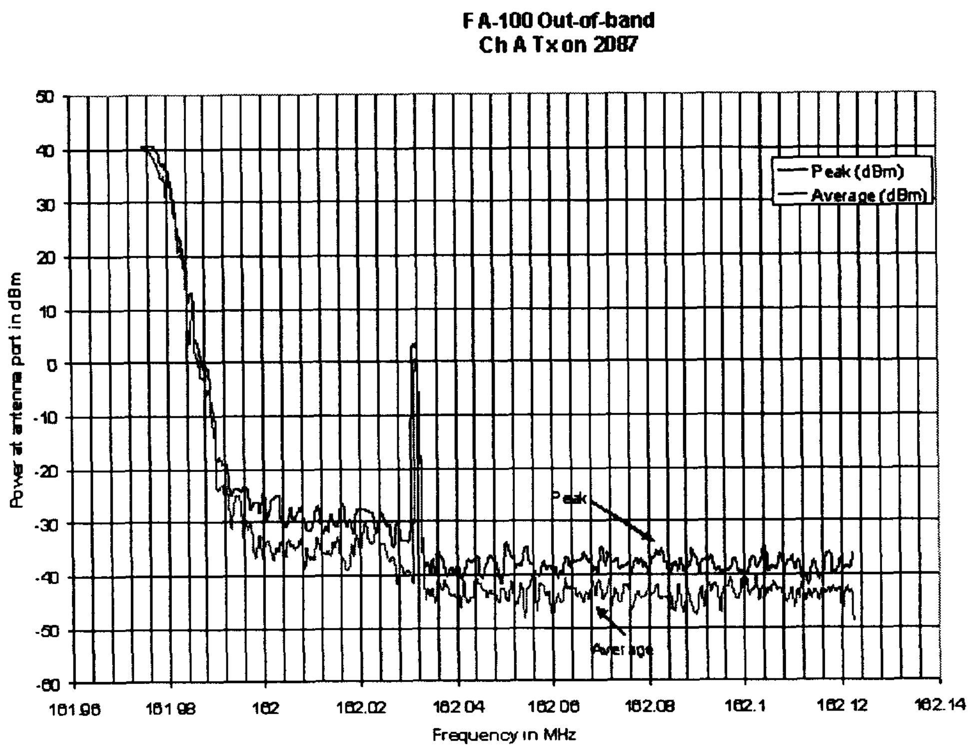

Figure B-4. Out-of-Band Emission

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.

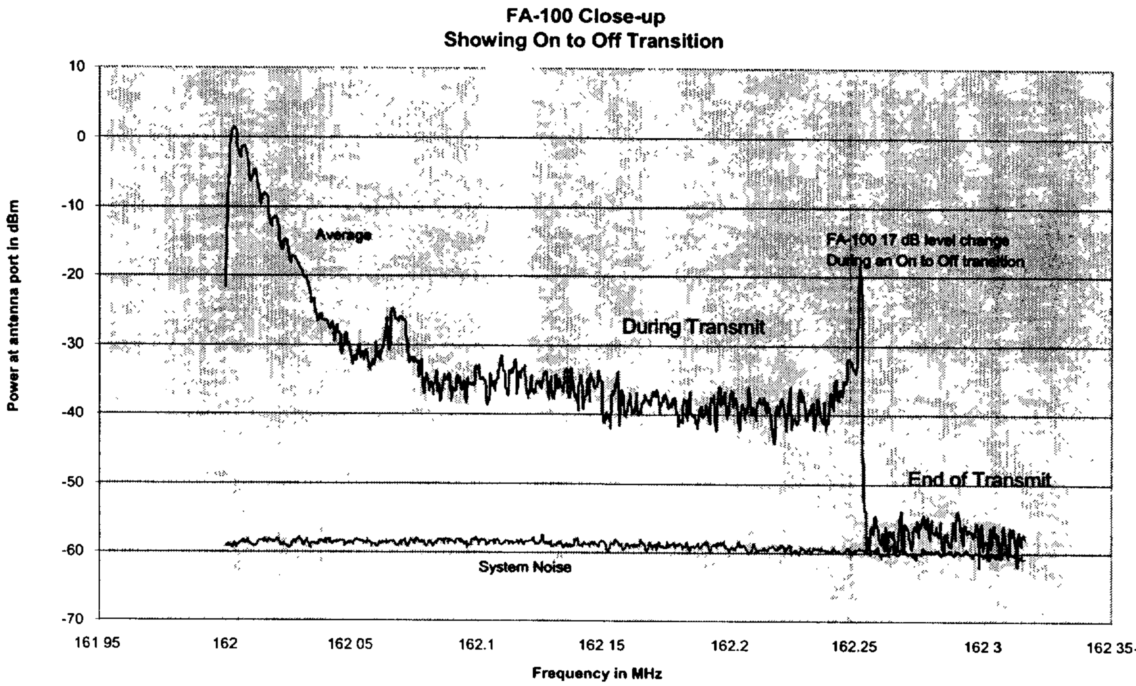

Figure B-5. Close-Up Emission View of FA-100 Transition from On-to-Off State

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.

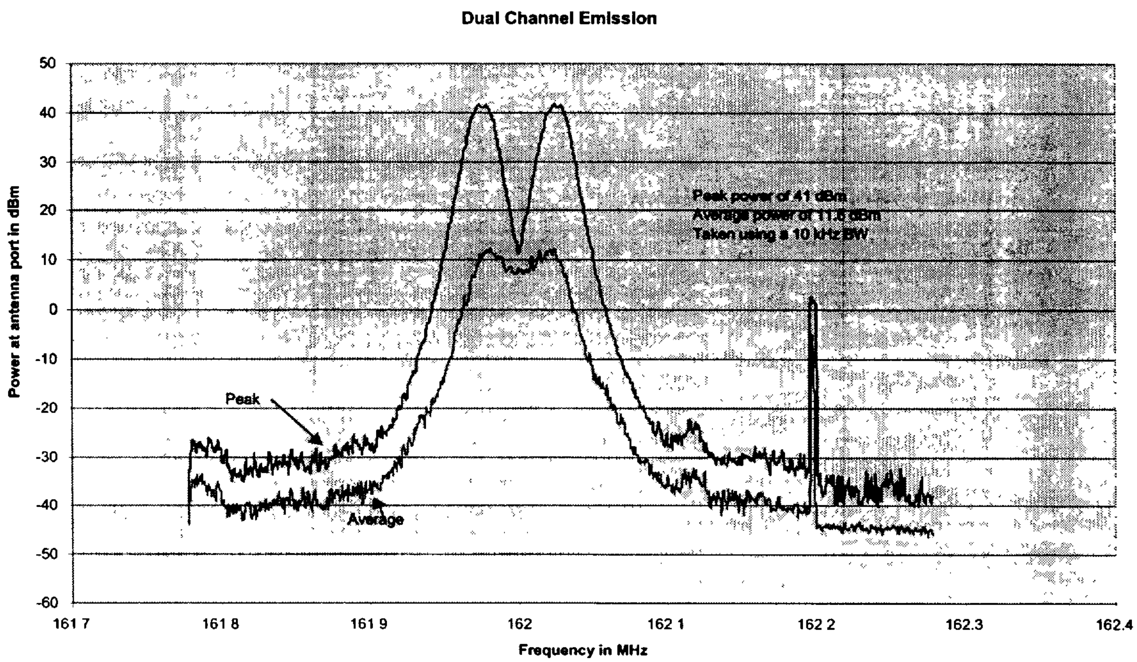

Figure B-6. In-Band Dual Channel Peak and Average Emission

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.

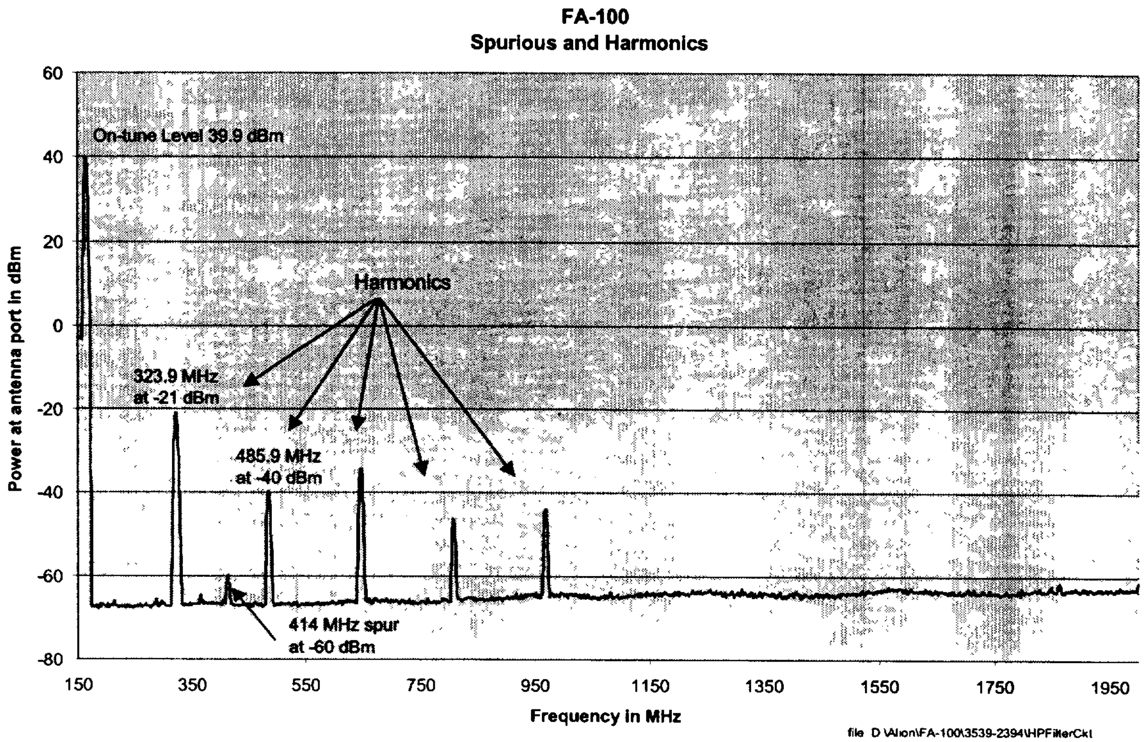

Figure B-7. Broadband Harmonic and Spurious Emissions

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.

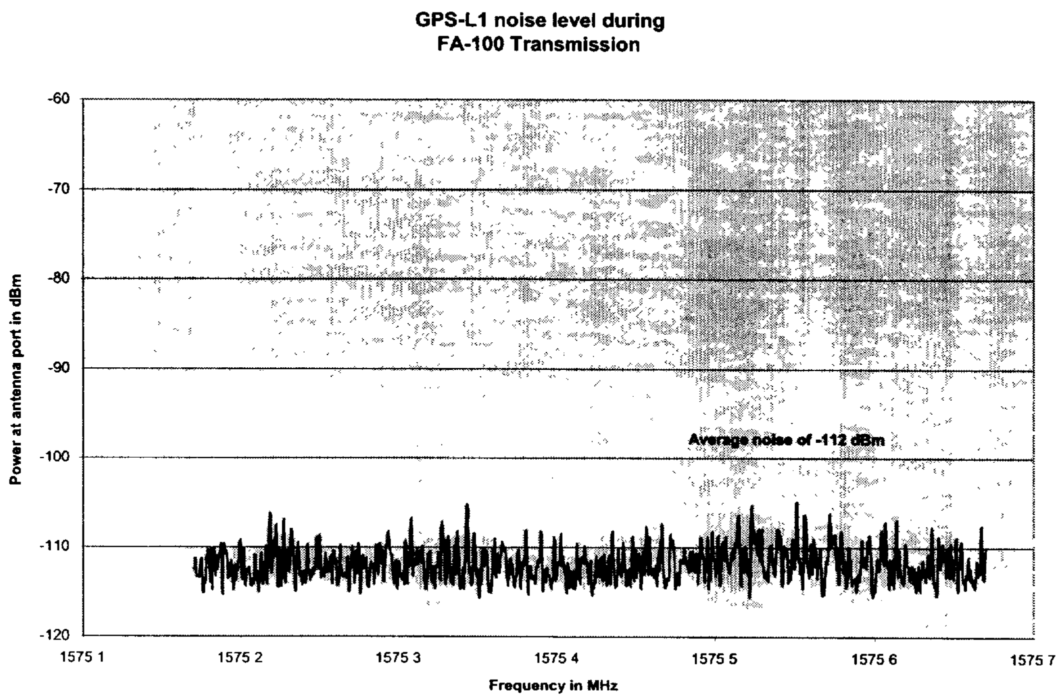

Figure B-8. Out-of-Band Emission Noise in the GPS-L1 Frequency

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

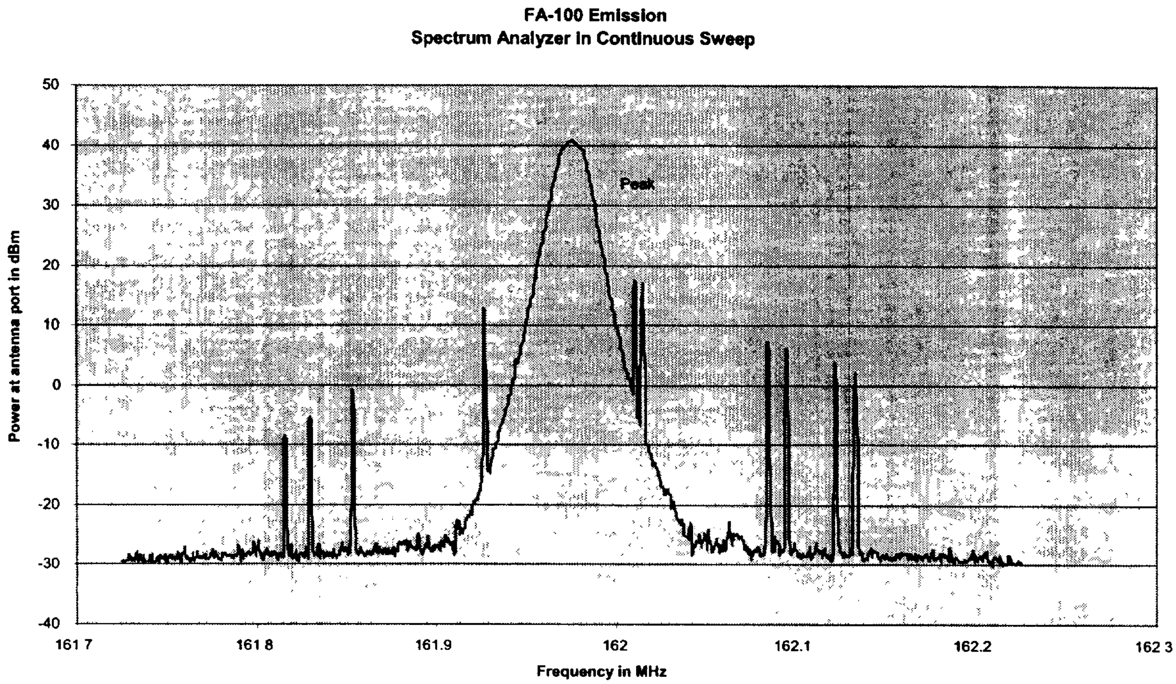

Figure B-9. Continuous Sweep (Non-Triggered) Emission Spectrum

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.

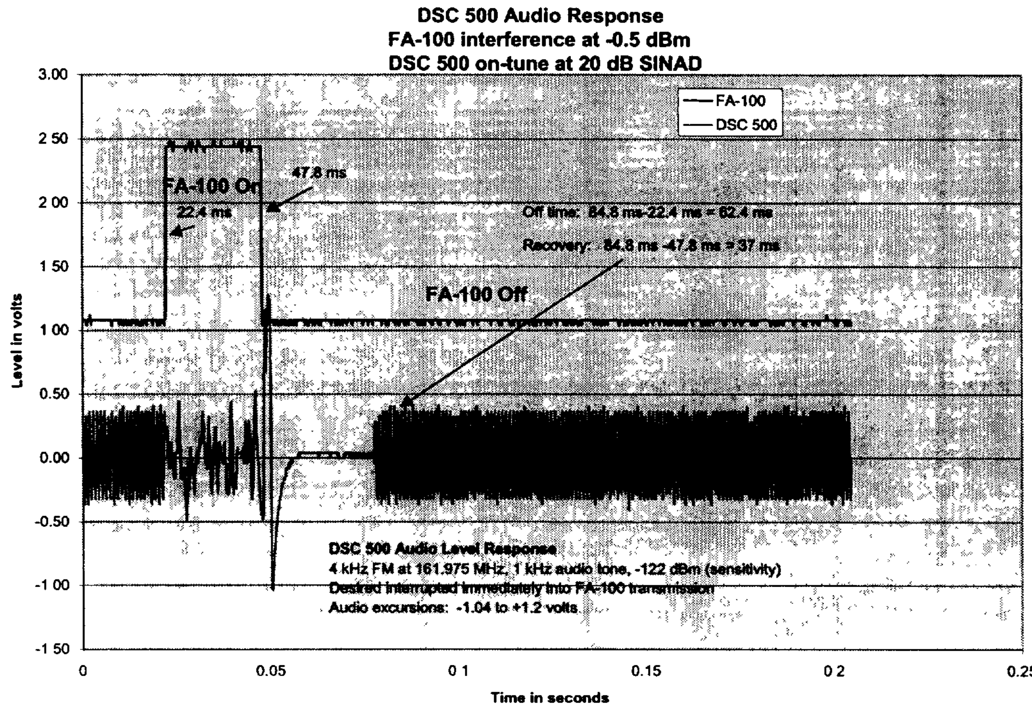

Figure B-10. DSC 500 Audio Response, FA-100 Interference at -0.5 dBm

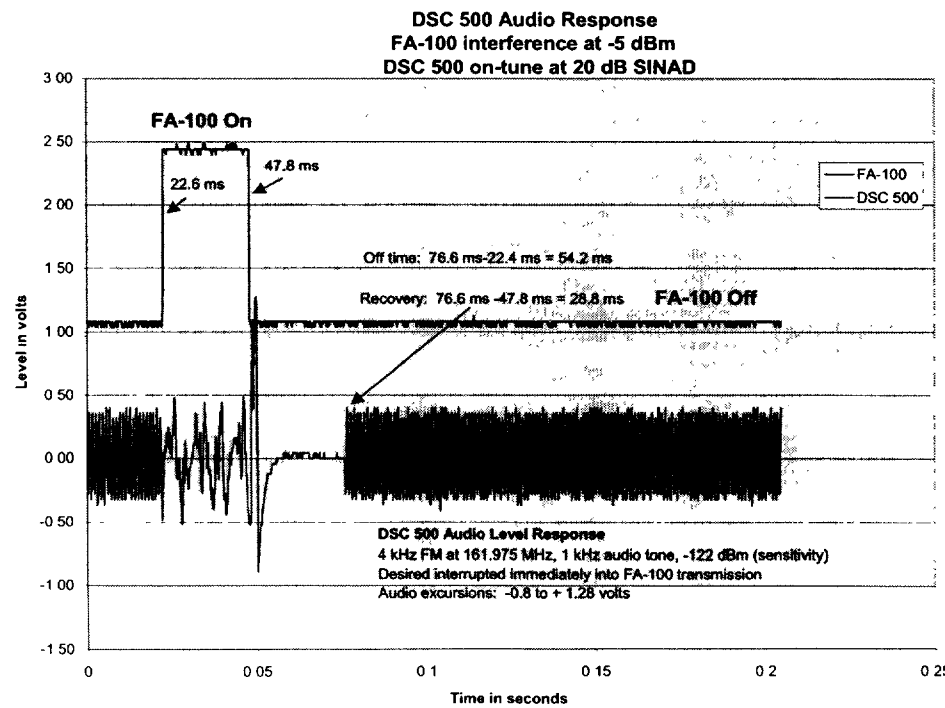

Figure B-11. DSC 500 Audio Response, FA-100 Interference at -5 dBm

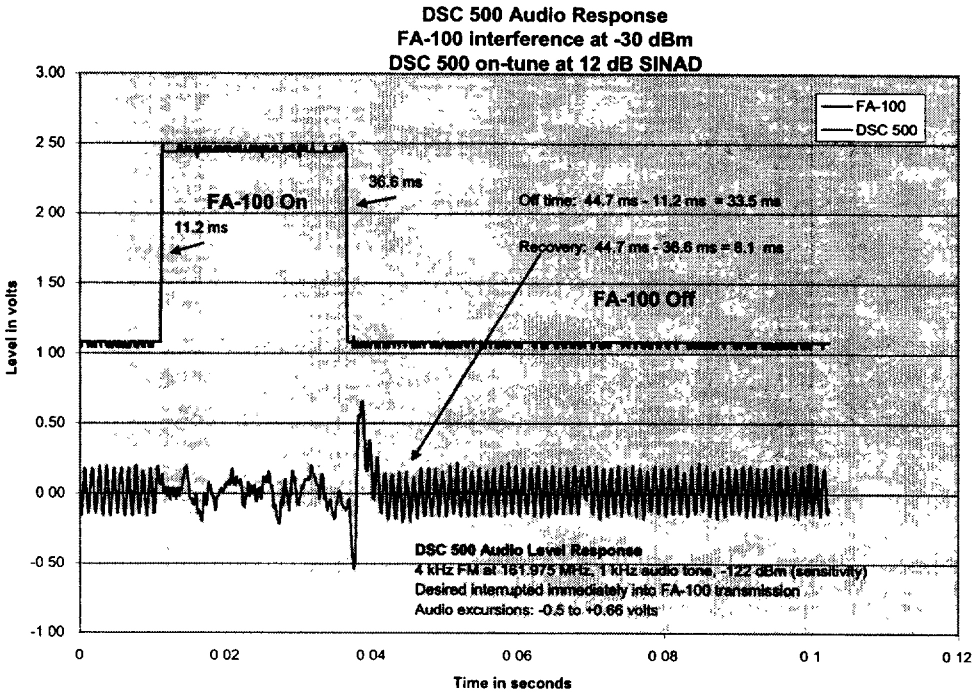

Figure B-12. DSC 500 Audio Response, FA-100 Interference at -30 dBm

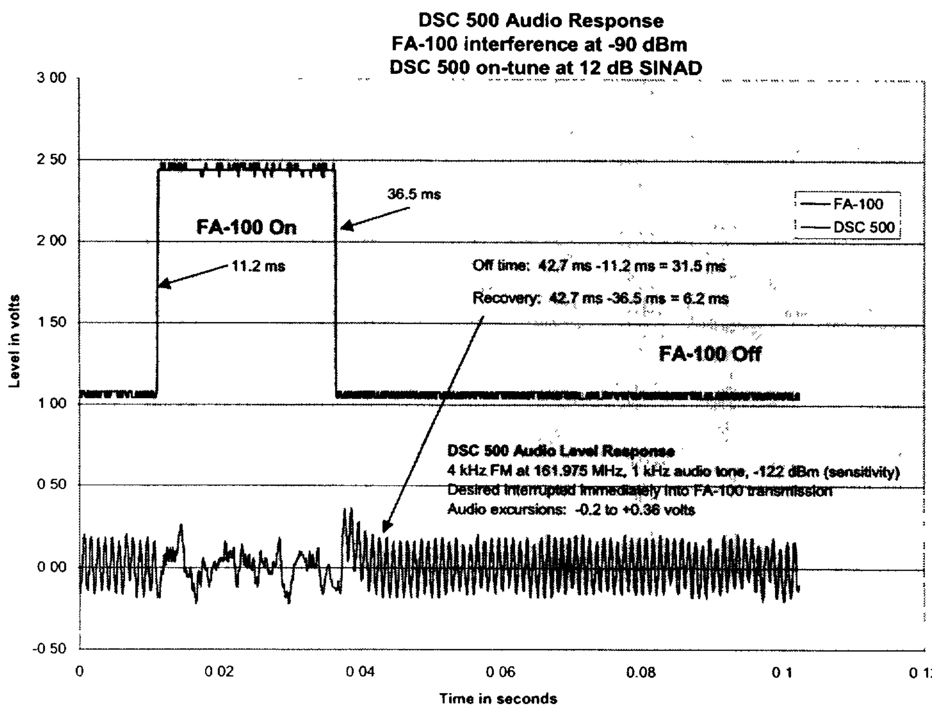

Figure B-13. DSC 500 Audio Response, FA-100 Interference at -90 dBm

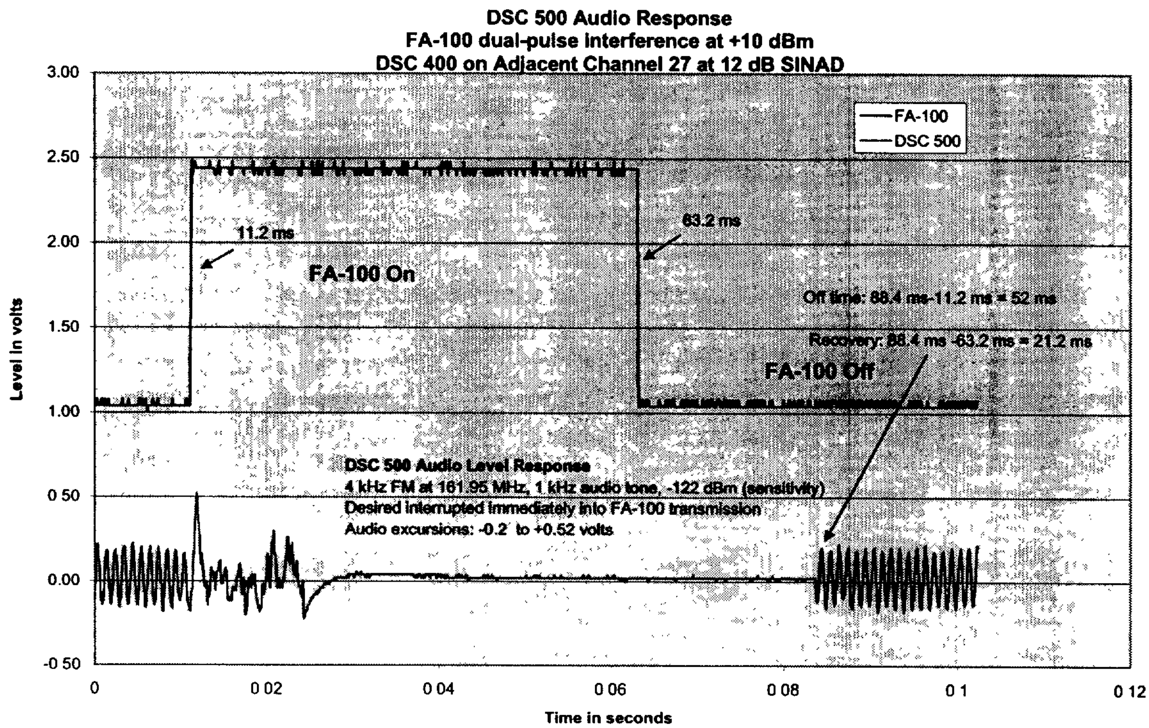

Figure B-14. DSC 500 63.2 ms Audio Response, FA-100 Interference at +10 dBm

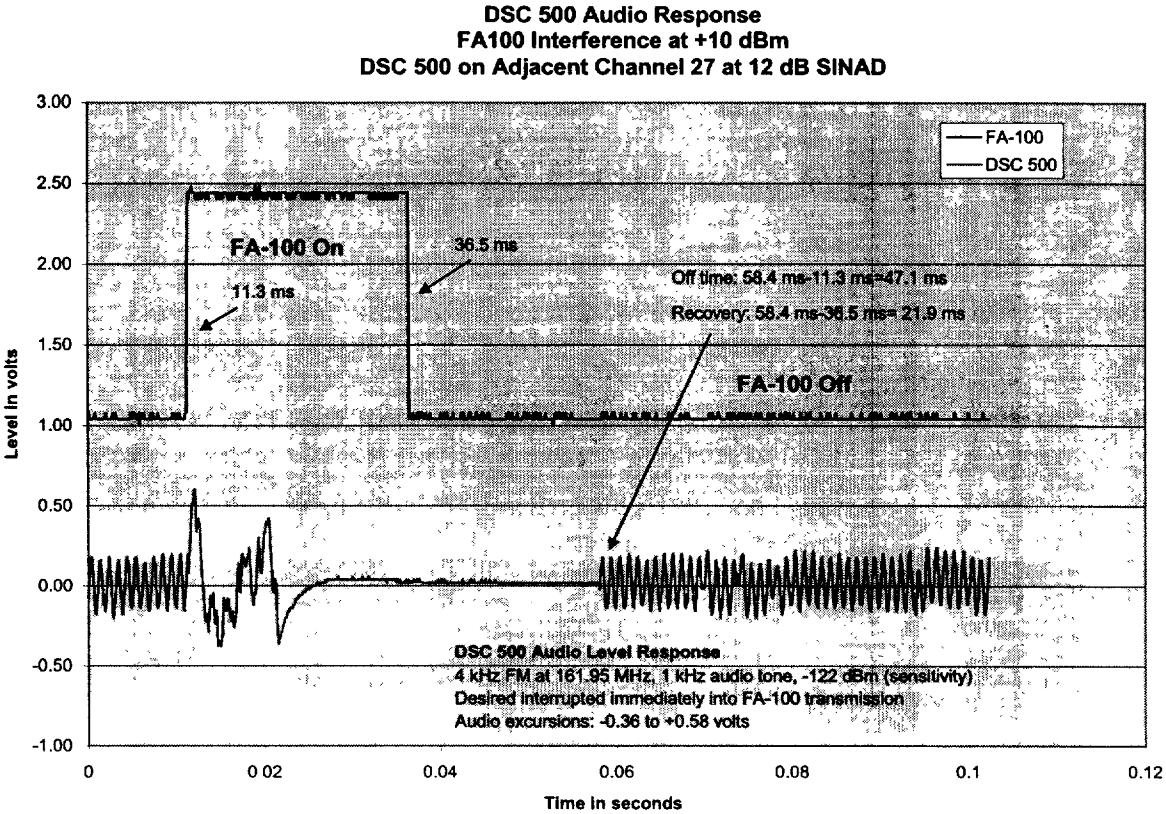

Figure B-15. DSC 500 36.5 ms Audio Response, FA-100 Interference at +10 dBm

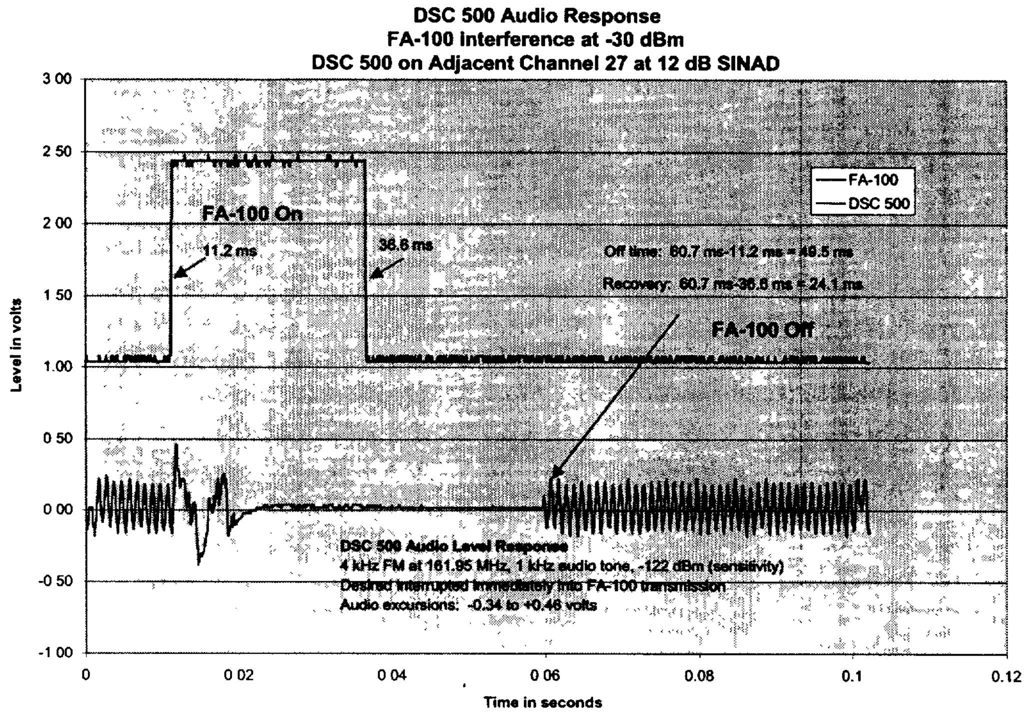

Figure B-16. DSC 500 Audio Response, FA-100 Interference at -30 dBm

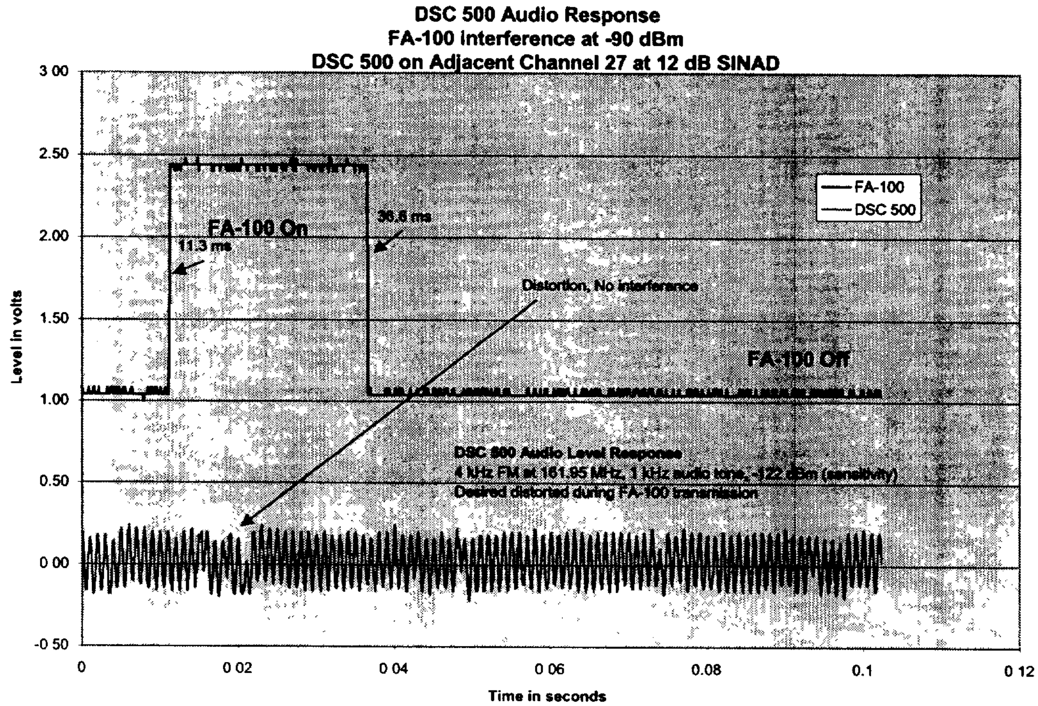

Figure B- 17. DSC 500 Audio Response, FA-100 Interference at -90 dBm

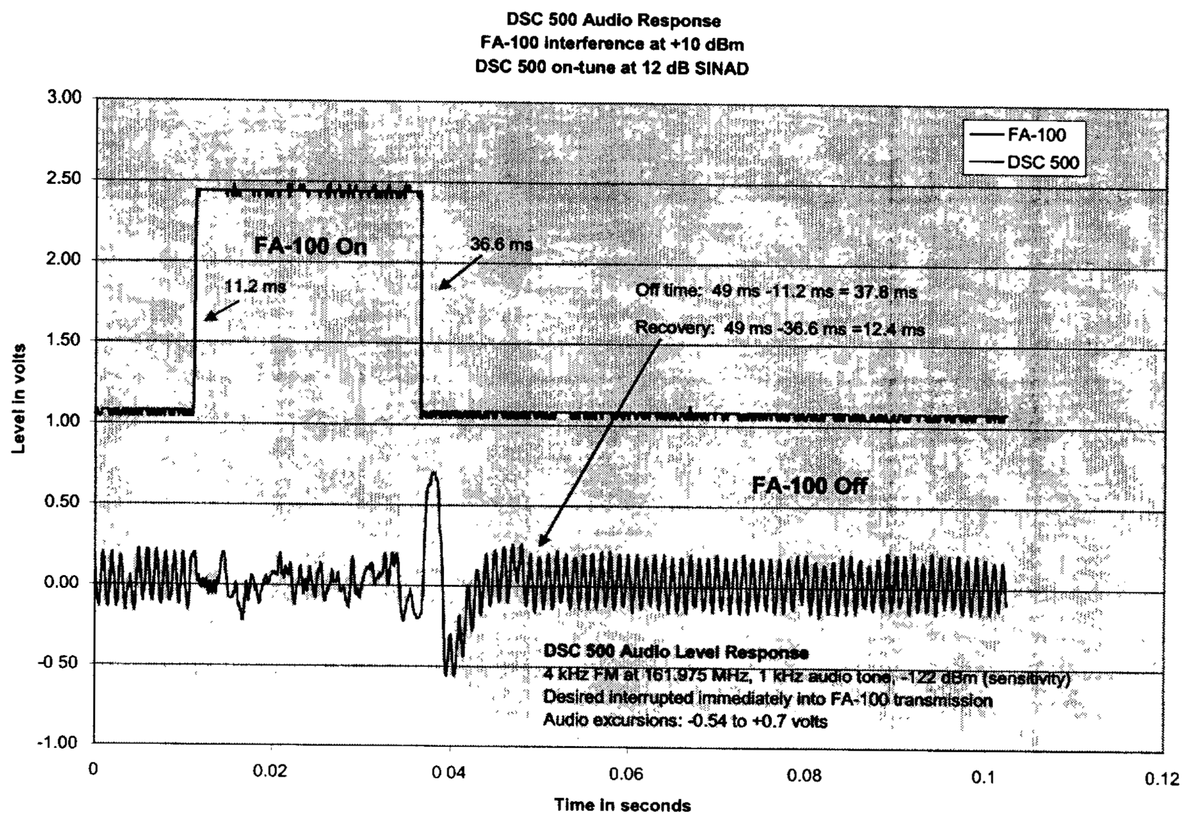

Figure B-18. DSC 500 Audio Response, FA-100 Interference at +10 dBm

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

	Furuno FA-100			Ross DSC 500			
Figure	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)		Channel Use			
		Ship Stations	Coastal Stations	Intership	Port Operations and Ship Movement		Public Correspondence
					Single Frequency	Two Frequency	
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