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Evaluation of Inter-Mountain Labs Infrasound Sensors July 2007

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Evaluation of Inter-Mountain Labs Infrasound Sensors July 2007

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Abstract

Sandia National Laboratories has tested and evaluated three Inter Mountain Labs infrasound sensors. The test results included in this report were in response to static and tonal-dynamic input signals. Most test methodologies used were based on IEEE Standards 1057 for Digitizing Waveform Recorders and 1241 for Analog to Digital Converters; others were designed by Sandia specifically for infrasound application evaluation and for supplementary criteria not addressed in the IEEE standards.

Table of Contents

1 Executive Summary

Objective:
The objective of this work was to evaluate the overall technical performance of the Inter Mountain Labs (IML) infrasound sensor model SS. The results of this evaluation were only compared to relevant noise models; due to a lack of manufactures documentation notes on the sensors under test prior to testing.

The tests selected for this system were chosen to demonstrate different performance aspects of the components under test.

Description:
The IML infrasound sensors were developed for the primary purpose of measuring avalanche generated infrasound. The design specifications were developed and optimized for avalanche monitoring. Two outputs are available, the first is the preamplifier signal and the other is a balanced differential signal. The preamplifier signal provides the user with the unaltered and broader frequency content signal for analysis. The balanced differential output signal is altered to enhance the desired frequency band of 2-12 Hz. The IML sensors were of a specific design for Southern Methodist University, which consisted of a matched filter response of 0.1 to 10 Hz. No data sheets were provided with sensors, therefore sensor specific sensitivity values were not known prior to testing. Bandwidth for analysis covered 0.1 to 10 Hz for all relevant tests. Testing was performed in the FACT site seismic vault for temperature stability. Infrasound sensor testing primarily focused on sensor response characterization and subsequent testing focused on sensor performance.

1.1 Infrasound - Sensor Evaluation Summary:

Response Model determination:
The Frequency/Amplitude Response Verification test indicated that the sensor sensitivities for the filtered output were as follows for 1 Hz; IML-605488 = 0.175 V/Pa, IML-605408 = 0.207 V/Pa and IML-605368 = 0.146 V/Pa. At 5 Hz the sensors had slightly higher sensitivities' IML-605488 = 0.361, IML-605408 = 0.389 and IML-605368 = 0.357 V/Pa. The unfiltered output sensitivities were lower than the filtered output by approximately 25% at 1Hz and 45% at 5 Hz. At 1 Hz the unfiltered output sensitivities were IML-605488 = 0.124 V/Pa, IML-605408 = 0.149 V/Pa and IML-605368 = 0.103 V/Pa. At 5 Hz the unfiltered output had sensitivities of IML-605488 = 0.198, IML-605408 = 0.216 and IML-605368 = 0.193 V/Pa.

Amplitude response versus frequency plots are shown in Figures 1.1.1 and 1.1.2 for the filtered and unfiltered, respectively.

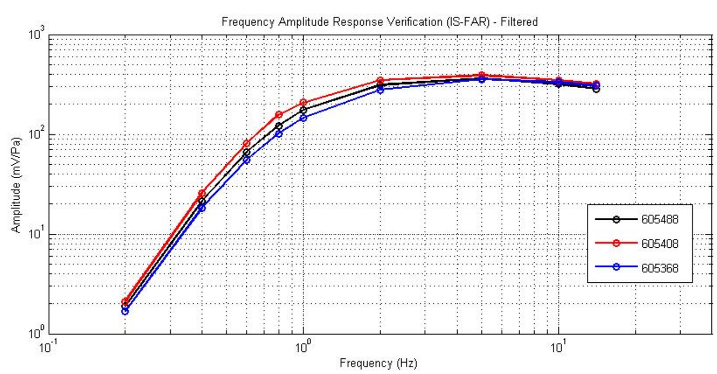

Figure 1.1.1 Amplitude Response versus Frequency plot for the filtered sensor output.

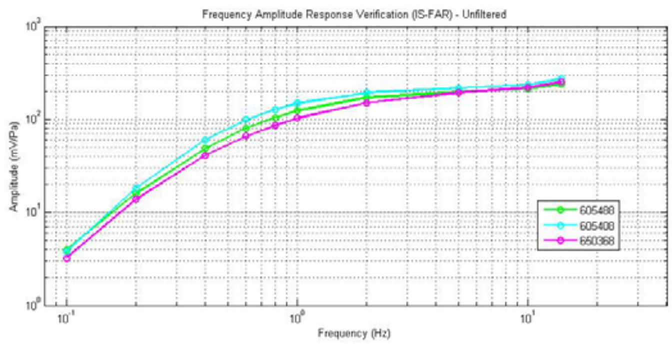

Figure 1.1.2 Amplitude Response versus Frequency for the unfiltered sensor output.

The Frequency/Amplitude/Phase Response Verification test indicated that for both the filtered and unfiltered output's the individual sensors amplitude responses were consistent in shape, varied in sensitivity and low-frequency corner frequency. The phase responses for the three sensors, for both filtered and unfiltered output's, was within 18 degrees between 0.1 and 10 Hz.

Infrasound Sensor Performance:

The Piston-phone Linearity Verification test indicated that all sensors within 3.6% of the mean sensitivity for input sinusoid amplitudes 0.05, 0.1, 0.2, 0.5, 1.0, 2.0 and 5 volts at 1 Hz. The filtered output's were linear to 1% between 0.007 and 7.3 Pa and 8% between 0.007 and 11 Pa. The Unfiltered output's were linear to 2.5% between 0.007 and 7.3 Pa and 7.9% between 0.007 and 11 Pa.

The sensor Self-Noise test indicated the sensors filtered output's self-noise at 1Hz were between -74.2 and -77.5 dB. The three sensors tested have self-noise at or below the Acoustic Low Noise Model between 0.2 and 7 Hz. The Self-Noise for the filtered sensor output is shown in Figure 1.1.3.

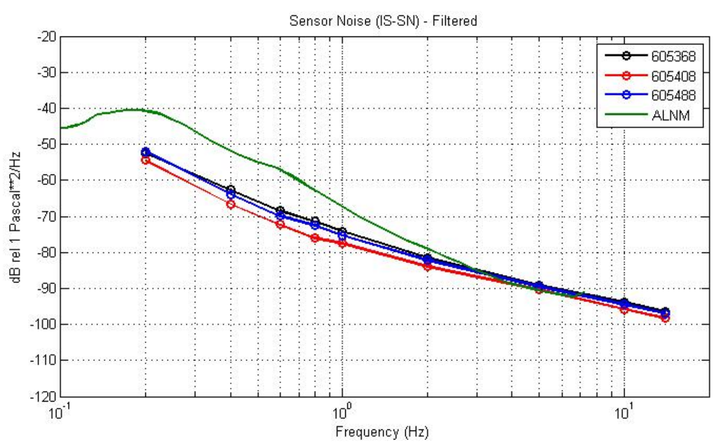

Figure 1.1.3 Sensor Self-Noise for the filtered sensor output.

The sensor Self-Noise test indicated the sensors unfiltered output's self-noise at 1Hz were between -77.3 and -80.4 dB. The three sensors tested have self-noise below the Acoustic Low Noise Model between 0.3 and 7 Hz. The Self-Noise for the unfiltered sensor output is shown in Figure 1.1.4.

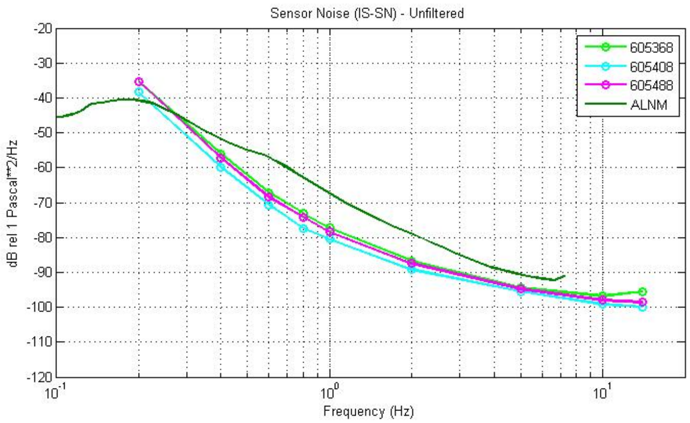

Figure 1.1.4 Sensor Self-Noise for the unfiltered sensor output.

2 Introduction

2.1 Scope

This Evaluation Report defines the activities that were performed as part of the evaluation of the Inter Mountain Labs (IML) infrasound sensor.

2.2 Objectives

The objective of this work was to evaluate the overall technical performance of the IML infrasound sensor as recorded by a Smart24 digitizer.

3 Infrasound Sensor Test and Evaluation Program

3.1 Test and Evaluation Background

Sandia National Laboratories (SNL) Ground-based Monitoring R&E Department has the capability of evaluating the performance of infrasound sensors for geophysical applications.

3.2 Infrasound Sensor Tests

The following set of tests has been developed or is under development to evaluate infrasound sensor performance.

3.3 Test/Evaluation Process

3.3.1 Testing

Testing of the IML infrasound sensors was performed during July 2007, at the Sandia National Laboratories Facility for Acceptance, Calibration and Testing (FACT Site), Albuquerque, NM.

3.3.2 General Infrasound Sensor Tests

The following tests were conducted on the IML sensors as described in the test plan: *Test Definition and Test Procedures for the Evaluation of Infrasound Sensors* [Reference 3].

The tests selected provide a high level of characterization for System Test Evaluation and Monitoring Project for evaluating the seismic application.

Infrasound Sensor Characterization
- Response Model Determination - Alternative Frequency/Amplitude Response
  - Infrasound Sensor Frequency/Amplitude Response Verification (IS-FAR)
- Response Model Determination - Alternative Frequency/Amplitude/Phase Response
  - Infrasound Sensor Frequency/Amplitude/Phase Response Verification (IS-FAPR)

Infrasound Sensor Performance Tests
- Infrasound Sensor Piston-phone Linearity Verification (IS-PLV)
- Infrasound Sensor Self-Noise (IS-SN)
- Infrasound Sensor Calibration Response (IS-CR)

3.4 Test Configuration and System Specifications

3.4.1 Infrasound Test Description and Test Configuration

The IML infrasound sensors were developed for the primary purpose of measuring avalanche generated infrasound. The design specifications were developed and optimized for avalanche monitoring. The IML sensors were of a specific design for Southern Methodist University, which consisted of a matched filter response of 0.1 to 10 Hz. Actual sensitivity values for the sensors are unavailable, or not documented. Bandwidth for analysis covered 0.1 to 10 Hz for all relevant tests. Infrasound sensor testing primarily focused on sensor response characterization and subsequent testing focused on sensor performance.

Test data was acquired through Geotech Smart24™ data acquisition system. The Smart24D digital waveform recorder serial number s1036 was used to acquire the filtered data along with two reference sensors, MB2000 SN:1380 and Chaparral Physics 2.2c SN 051694. The Smart24D digital waveform recorder serial number s1043 was used to acquire the unfiltered data along with one reference sensor, MB2000 SN:1380and s1043) and Smart acquisition software system was used to record and archive test data for the IML sensors. The Samrt24D data loggers were configured to acquire data at 40 samples per second. Typical arrangement of sensors within test chamber (Figure 3.4.1) and test equipment (Figure 3.4.2).

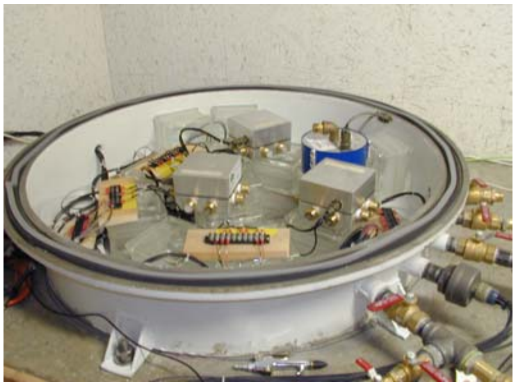

Figure 3.4.1 Infrasound sensor configuration for sensor testing in FACT site acoustic chamber.

Figure 3.4.2 Sensor testing chamber, acoustic piston-phone and acoustic reference sensor (MB2000 – SN1380).

3.4.2 Infrasound Application Parameters and Response

The IML sensor has two output types single-ended unfiltered and 1-10 Hz filtered differential outputs. The filtered output sensitivity is approximately 200 mV/Pa at 1 Hz. The sensor connector pinouts is given in Table 3.4.1. The IML sensor uses a connector PT02E-10-6P, use mating connector PT06E-10-6S.

+12 Vdc	+ Filtered Output	- Filtered Output	12 Vdc COM	+ Unfiltered Output	- Unfiltered Output
A	B	C	D	E	F

Table 3.4.1. IML infrasound sensor connector pinouts.

4 Inter Mountain Labs Infrasound Sensor Tests

4.1 Infrasound Sensor characterization

The infrasound sensor will be independently characterized due to a lack of manufacturer data sheets to determine sensor gain, sensor bandwidth, self-noise and output impedance. Ability to calibrate is explored using a impulse response technique. At the time of testing no mathematical response model or calibration transfer response existed.

If the manufacturer has not provided adequate sensor information, the actual response can be determined through various tests.

4.1.1 Infrasound Sensor Frequency/Amplitude Response Verification (IS-FAV)

Purpose: The purpose of the infrasound sensor frequency/amplitude response verification test is to determine or verify the infrasound sensor amplitude response at multiple frequencies using a variable amplitude, variable frequency piston-phone acoustic signal generator.

Configuration: Infrasound sensors, (1) a characterized reference infrasound sensor and (2) the infrasound sensors under test, are installed side-by-side in a specially designed infrasonic test chamber. The chamber is sealed and isolated from external acoustic signals. Sensor output(s) are connected to a data acquisition system. A multiple sine-waves of 1 volt amplitude and frequencies (0.1, 0.2, 0.4, 0.6, 0.8, 1, 2, 5, 10 and 14 Hz) are programmed into a variable amplitude, variable frequency piston-phone acoustic signal generator. A co-located, characterized infrasound sensor is used as a reference.

Evaluation: The sensor amplitude response is determined from the recorded data. A mathematical fit of the sine data determines the amplitude response of the sensor(s) at the multiple test frequencies. A plot of frequency vs. amplitude indicates overall frequency/amplitude response.

Test Results:
Filtered Output:
Sensor Serial Number: 605368 IS-FAV Test Data Sheet, Appendix I, Section 6.1.
Sensor Serial Number: 605408 IS-FAV Test Data Sheet, Appendix I, Section 6.1.
Sensor Serial Number: 605488 IS-FAV Test Data Sheet, Appendix I, Section 6.1.
Unfiltered Output:
Sensor Serial Number: 605368 IS-FAV Test Data Sheet, Appendix I, Section 6.2.
Sensor Serial Number: 605408 IS-FAV Test Data Sheet, Appendix I, Section 6.2.
Sensor Serial Number: 605488 IS-FAV Test Data Sheet, Appendix I, Section 6.2.

4.1.2 Infrasound Sensor Frequency/Amplitude/Phase Response Verification (IS-FAPR)

Purpose: The purpose of the infrasound sensor frequency/amplitude/phase response verification test is to determine or verify the infrasound sensor frequency/amplitude/phase response at all frequencies using a variable amplitude, variable frequency piston-phone acoustic signal generator and a characterized reference infrasound sensor.

Configuration: Infrasound sensors, (1) a characterized reference infrasound sensor and (2) the infrasound sensors under test, are installed side-by-side in a specially designed infrasonic test chamber. The chamber is sealed and isolated from external acoustic signals. Sensor output(s) are connected to a data acquisition system. A bandwidth-limited white noise function is programmed into a variable amplitude, variable frequency piston-phone acoustic signal generator. A co-located, characterized infrasound sensor is used as a reference.

Evaluation: The sensor frequency/amplitude/phase response is determined from the recorded data. Coherence analysis indicates the relative gain and phase for the infrasound sensors under test with respect to the reference infrasound sensor. The frequency, amplitude and phase response of the sensor under test can be determined by mathematically correcting for the response of the characterized reference infrasound sensor.

Test Results
Filtered Output:
Sensor Serial Number: 605368 IS-FAPV Test Data Sheet, Appendix I, Section 6.3.
Sensor Serial Number: 605408 IS-FAPV Test Data Sheet, Appendix I, Section 6.3.
Sensor Serial Number: 605488 IS-FAPV Test Data Sheet, Appendix I, Section 6.3.
Unfiltered Output:
Sensor Serial Number: 605368 IS-FAPV Test Data Sheet, Appendix I, Section 6.4.
Sensor Serial Number: 605408 IS-FAPV Test Data Sheet, Appendix I, Section 6.4.
Sensor Serial Number: 605488 IS-FAPV Test Data Sheet, Appendix I, Section 6.4.

4.2 Infrasound Sensor Performance Tests

Piston-phone generated signals are used as test stimuli to measure sensor performance.

4.2.1 Infrasound Sensor Piston-phone Linearity Verification (IS-PLV)

Purpose: The purpose of the infrasound sensor piston-phone linearity verification test is to determine or verify the infrasound sensor linearity at one frequency using a variable amplitude, variable frequency piston-phone acoustic signal generator.

Configuration: Infrasound sensors, (1) a characterized reference infrasound sensor and (2) the infrasound sensors under test, are installed side-by-side in a specially designed infrasonic test chamber. The chamber is sealed and isolated from external acoustic signals. Sensor output(s) are connected to a data acquisition system. A sine-wave of different amplitudes (0.005, 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 1, 2, 3, 4, 5 volts) at a known frequency (1Hz) are programmed into a variable amplitude, variable frequency piston-phone acoustic signal generator. A co-located, characterized infrasound sensor is used as a reference.

Evaluation: The sensor amplitudes are determined from the recorded data. A mathematical fit of the amplitude data determines the linearity of the sensor(s) at the test frequency.

Test Results:
Filtered Output:
Sensor Serial Number: 605368 IS-PLV Test Data Sheet, Appendix I, Section 6.5.
Sensor Serial Number: 605408 IS-PLV Test Data Sheet, Appendix I, Section 6.5.
Sensor Serial Number: 605488 IS-PLV Test Data Sheet, Appendix I, Section 6.5.
Unfiltered Output:
Sensor Serial Number: 605368 IS-PLV Test Data Sheet, Appendix I, Section 6.6.
Sensor Serial Number: 605408 IS-PLV Test Data Sheet, Appendix I, Section 6.6.
Sensor Serial Number: 605488 IS-PLV Test Data Sheet, Appendix I, Section 6.6.

4.2.2 Infrasound Sensor Self-Noise (IS-SN)

Purpose: The purpose of the infrasound sensor self-noise test is to determine the infrasound sensor self-noise in the absence of infrasound background signals.

Configuration: The infrasound sensors are installed in a specially designed infrasonic test chamber. The chamber is sealed and isolated from external acoustic signals. Sensor outputs are connected to a data acquisition system that samples the data synchronously.

Evaluation: The sensor self-noise is determined from the recorded data. Convert the data from each infrasound sensor to pressure units using the sensor response mathematical model for each sensor.

Coherence analysis should indicate that there is no coherence between the sensors. If some coherence is present from conditions such as local barometric pressure changes over the test period, the coherence noise-power computation provides the noise-floor of the infrasound sensor with the coherent signal removed.

Test Results
Filtered Output:
Sensor Serial Number: 605368 IS-SN Test Data Sheet, Appendix I, Section 6.7.
Sensor Serial Number: 605408 IS-SN Test Data Sheet, Appendix I, Section 6.7.
Sensor Serial Number: 605488 IS-SN Test Data Sheet, Appendix I, Section 6.7.
Unfiltered Output:
Sensor Serial Number: 605368 IS-SN Test Data Sheet, Appendix I, Section 6.8.
Sensor Serial Number: 605408 IS-SN Test Data Sheet, Appendix I, Section 6.8.
Sensor Serial Number: 605488 IS-SN Test Data Sheet, Appendix I, Section 6.8.

5 Summary

Objective:
The objective of this work was to evaluate the overall technical performance of the Inter Mountain Labs (IML) infrasound sensor model SS. The results of this evaluation were compared to relevant noise models due to a lack of manufactures documentation notes on the sensors under test.

The tests selected for this system were chosen to demonstrate different performance aspects of the components under test.

Description:
The IML infrasound sensors were developed for the primary purpose of measuring avalanche generated infrasound. The design specifications were developed and optimized for avalanche monitoring. Two outputs are available, the first is the preamplifier signal and the other is a balanced differential signal. The preamplifier signal provides the user with the unaltered and broader frequency content signal for analysis. The balanced differential output signal is altered to enhance the desired frequency band of 2-12 Hz. The IML sensors were of a specific design for Southern Methodist University, which consisted of a matched filter response of 0.1 to 10 Hz. No data sheets were provided with sensors, therefore sensor specific sensitivity values were not known prior to testing. Bandwidth for analysis covered 0.1 to 10 Hz for all relevant tests. Testing was performed in the FACT site seismic vault for temperature stability. Infrasound sensor testing primarily focused on sensor response characterization and subsequent testing focused on sensor performance.

5.1 Infrasound - Sensor Evaluation Summary:
Response Model determination:
The Frequency/Amplitude Response Verification test indicated that the sensor sensitivities for the filtered output were as follows for 1 Hz; IML-605488 = 0.175 V/Pa, IML-605408 = 0.207 V/Pa and IML-605368 = 0.146 V/Pa. At 5 Hz the sensors had slightly higher sensitivities' IML-605488 = 0.361, IML-605408 = 0.389 and IML-605368 = 0.357 V/Pa. The unfiltered output sensitivities were lower than the filtered output by approximately 25% at 1Hz and 45% at 5 Hz. At 1 Hz the unfiltered output sensitivities were IML-605488 = 0.124 V/Pa, IML-605408 = 0.149 V/Pa and IML-605368 = 0.103 V/Pa. At 5 Hz the unfiltered output had sensitivities of IML-605488 = 0.198, IML-605408 = 0.216 and IML-605368 = 0.193 V/Pa.

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Infrasound Sensor Performance:

The Piston-phone Linearity Verification test indicated that all sensors within 3.6% of the mean sensitivity for input sinusoid amplitudes 0.05, 0.1, 0.2, 0.5, 1.0, 2.0 and 5 volts at 1 Hz. The filtered output's were linear to 1% between 0.007 and 7.3 Pa and 8% between 0.007 and 11 Pa. The Unfiltered output's were linear to 2.5% between 0.007 and 7.3 Pa and 7.9% between 0.007 and 11 Pa.

The sensor Self-Noise test indicated the sensors filtered output's self-noise at 1Hz were between -74.2 and -77.5 dB. The three sensors tested have self-noise at or below the Acoustic Low Noise Model between 0.2 and 7 Hz. The sensor Self-Noise test indicated the sensors unfiltered output's self-noise at 1Hz were between -77.3 and -80.4 dB. The three sensors tested have self-noise below the Acoustic Low Noise Model between 0.3 and 7 Hz.

References:

1. IEEE Standard for Digitizing Waveform Recorders, IEEE Std. 1057-1994.

2. IEEE Standard for Analog to Digital Converters, IEEE Std. 1241-2001.

3. Kromer, Richard P. and Hart, Darren M. and J. Mark Harris (2007), 'Test Definition for the Evaluation of Infrasound Sensors', SAND2007-5038.

6 Appendix I: Infrasound Sensor Test Data Sheets

6.1 Infrasound Sensor Frequency/Amplitude Response Verification (IS-FAR)

IML Test Sensor SN: 605368, 605408, and 605488
Output Type: Filtered
MB2000 Reference Sensor SN: 1380
Smart24 (SN 1036) Sample Rate: 40 sps
****

Test Description: Determine the infrasound sensor amplitude response for a fixed set of frequencies.

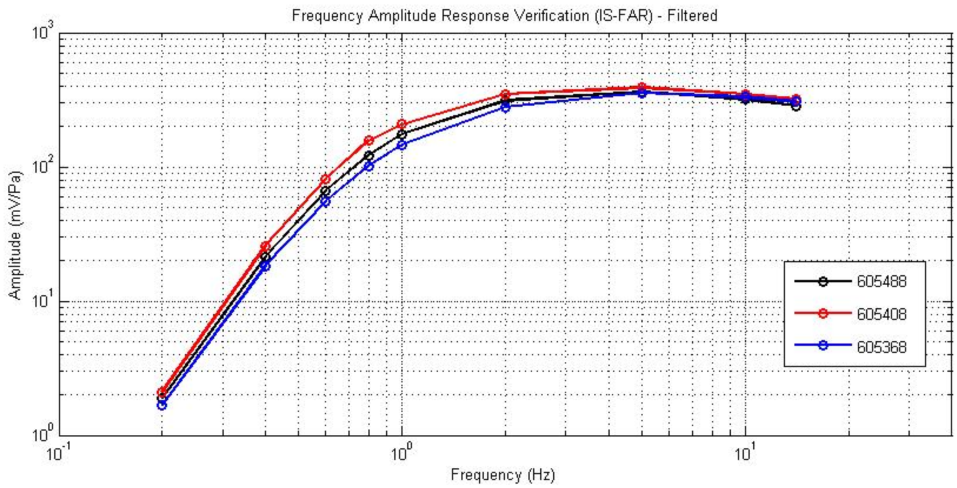

Figure 6.1.1 Frequency Amplitude Response Verification results. Frequencies tested were 0.2, 0.4, 0.6, 0.8, 1.0, 2.0, 5.0, 10.0 and 14.0 Hz.

Test Input Sine Frequency (Hz)	IML-605488 (mv/Pa)	IML-605408 (mv/Pa)	IML-605368 (mv/Pa)
0.1	-	-	-
0.2	1.9	2.1	1.7
0.4	21.2	25.8	18.2
0.6	66.1	81.1	55.4
0.8	122.3	157.0	101.8
1.0	174.6	207.0	145.8
2.0	312.7	348.4	277.6
5.0	361.7	389.0	356.6
10.0	319.1	347.6	330.7
14.0	283.4	319.0	304.6

Table 6.1.1 tabulated results for the Frequency Amplitude Response Verification.

Test Results: Figure 6.1.1 and Table 6.1.1 indicate that the estimated sensitivities at 1Hz varies from 3.5% to 27% of the expected values of 0.2 mV/Pa @ 1Hz for the three sensors tested.

6.2 Infrasound Sensor Frequency/Amplitude Response Verification (IS-FAR)

IML Test Sensor SN: 605368, 605408, and 605488
Output Type: Unfiltered
MB2000 Reference Sensor SN: 1380
Smart24 (SN 1036) Sample Rate: 40 sps
****

Test Description: Determine the infrasound sensor amplitude response for a fixed set of frequencies.

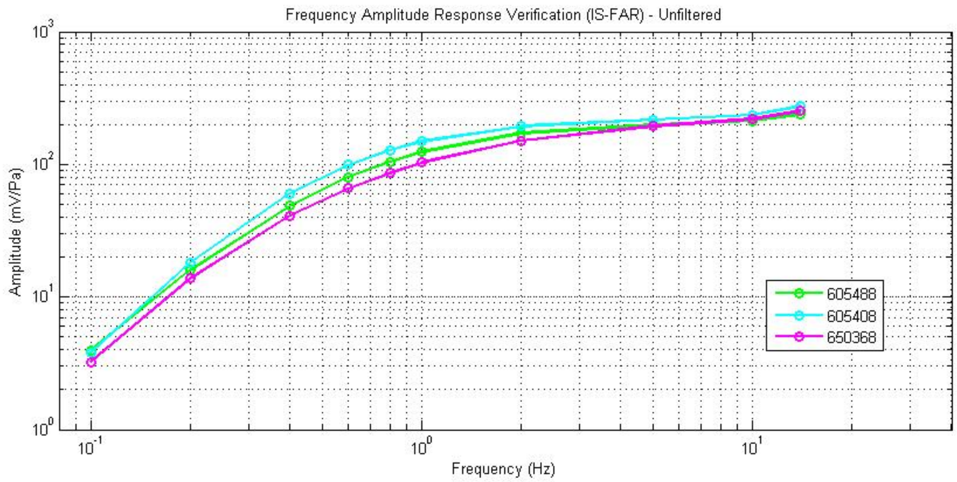

Figure 6.2.1 Frequency Amplitude Response Verification results. Frequencies tested were 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 2.0, 5.0, 10.0 and 14.0 Hz.

Test Input Sine Frequency (Hz)	IML-605488 (mv/Pa)	IML-605408 (mv/Pa)	IML-605368 (mv/Pa)
0.1	4.0	3.8	3.2
0.2	16.0	18.1	13.8
0.4	48.6	60.3	41.1
0.6	79.8	99.1	66.1
0.8	104.6	128.0	86.4
1.0	124.0	148.9	102.8
2.0	171.3	192.9	150.7
5.0	198.1	215.8	193.4
10.0	212.8	236.1	218.7
14.0	236.5	272.7	252.7

Table 6.2.1 tabulated results for the Frequency Amplitude Response Verification.

Test Results: Figure 6.2.1 and Table 6.2.1 indicate that the estimated sensitivities at 1Hz varies from 1.0% to 19% of the average value of 0.125 mV/Pa @ 1Hz for the three sensors tested.

6.3 Infrasound Sensor Frequency/Amplitude/Phase Response Verification (IS-FAPV)

IML Test Sensor SN: 605368, 605408, and 605488
Output Type: Filtered
MB2000 Reference Sensor SN: 1380
Smart24 (SN 1036) Sample Rate: 40 sps
****

Test Description: Determine the infrasound sensor frequency/amplitude/phase response at all frequencies using a variable amplitude and frequency piston-phone acoustic signal generator and a characterized reference infrasound sensor.

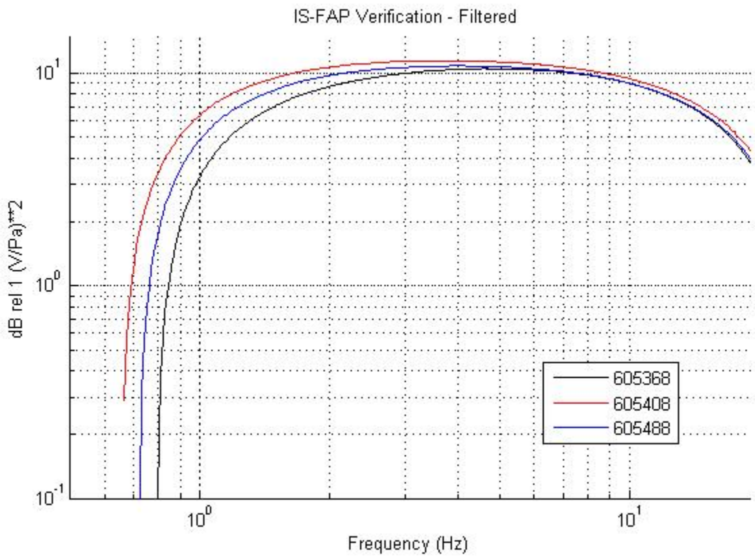

Figure 6.3.1 Amplitude results for Frequency Amplitude Phase Response Verification results.

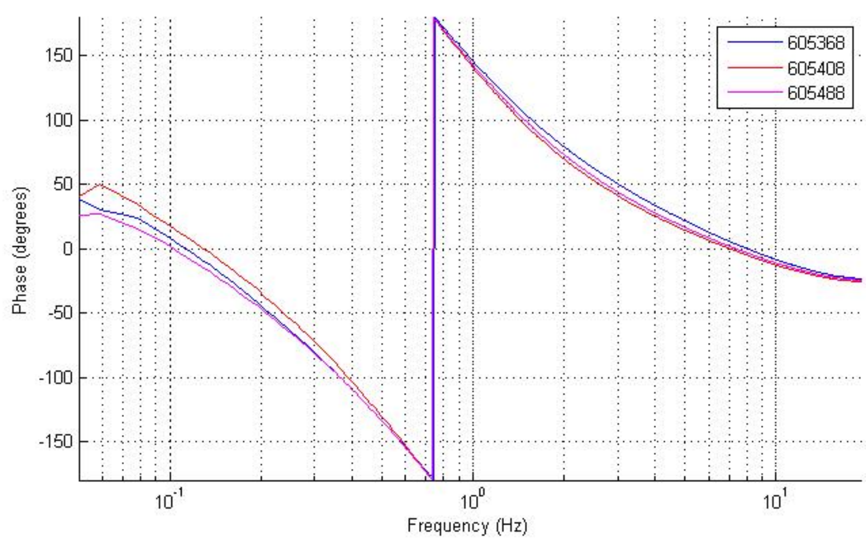

Figure 6.3.2 Phase results for Frequency Amplitude Phase Response Verification test.

Test Results: Figure 6.3.1 indicates the amplitude responses among the three sensors tested have a consistent shape, but vary in sensitivity as observed in bias among amplitude spectra; with sensors 605368 and 605488 having a similar amplitude response above 4Hz. The low-frequency roll-off also varies between sensors. The flat portion of the sensor's pass band is considered to be 2 to 8 Hz. Figure 6.3.2 indicates the phase responses among the three sensors tested have a consistent shape, and are within 20 degrees between 0.1 and 10 Hz.

6.4 Infrasound Sensor Frequency/Amplitude/Phase Response Verification (IS-FAPV)

IML Test Sensor SN: 605368, 605408, and 605488
Output Type: Unfiltered
MB2000 Reference Sensor SN: 1380
Smart24 (SN 1036) Sample Rate: 40 sps
****

Test Description: Determine the infrasound sensor frequency/amplitude/phase response at all frequencies using a variable amplitude and frequency piston-phone acoustic signal generator and a characterized reference infrasound sensor.

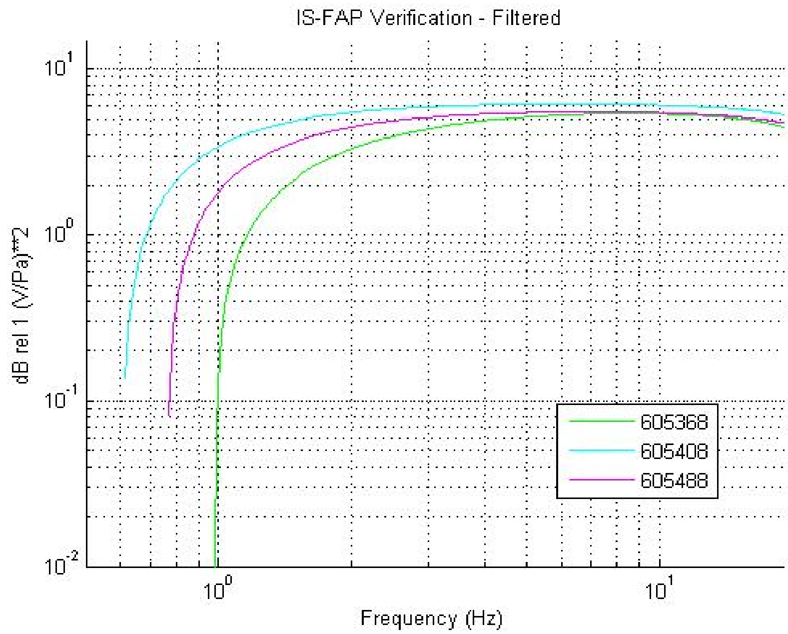

Figure 6.4.1 Frequency Amplitude Phase Response Verification results.

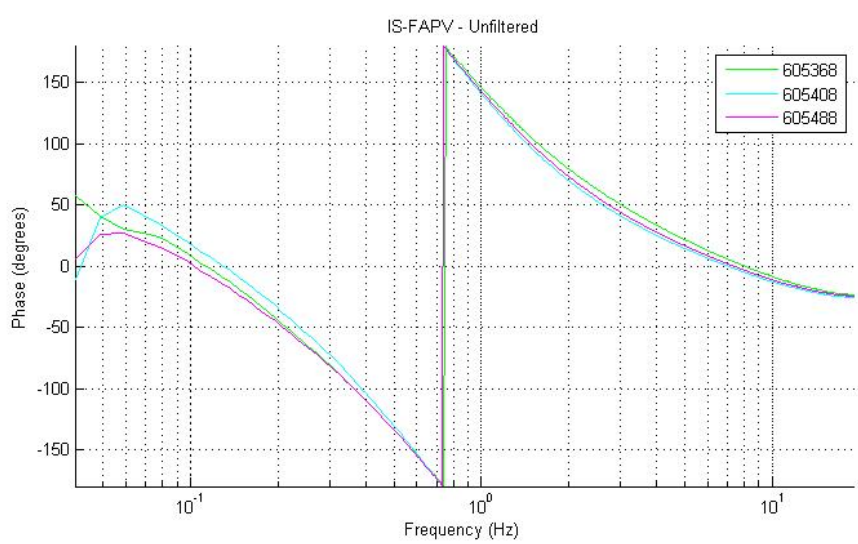

Figure 6.4.2 Phase results for Frequency Amplitude Phase Response Verification test.

Test Results: Figure 6.4.1 indicates the amplitude responses among the three sensors tested have a consistent shape, but vary in sensitivity as observed in bias among amplitude spectra. The low-frequency roll-off also varies between sensors. The flat portion of the sensor's pass band is considered to be 2.5 to 16 Hz. Figure 6.4.2 indicates the phase responses among the three sensors tested have a consistent shape, and are within 20 degrees between 0.1 and 10 Hz.

6.5 Infrasound Sensor Piston-phone Linearity Test (IS-PLV)

IML Test Sensor SN: 605368, 605408, and 605488
Output Type: Filtered
MB2000 Reference Sensor SN: 1380
Smart24 (SN 1036) Sample Rate: 40 sps
****

Test Description: Determine the infrasound sensor response at one frequency.

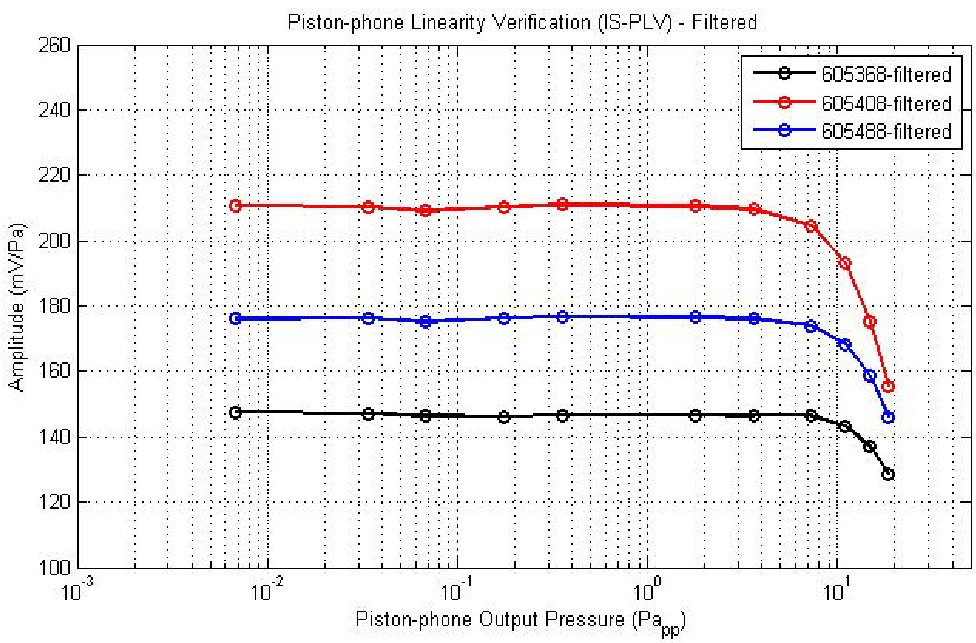

Figure 6.5.1 Piston-phone Linearity Verification results. Piston-phone input amplitudes tested were 0.005 to 5 volts peak, which translated to pressures ranging from 0.007 Pa to 170 Pa.

Piston-phone Output (Pa_{pp})	IML-605368 (mV/Pa)	Linearity % Deviation from mean = 146 mV/Pa	IML-605408 (mV/Pa)	Linearity % Deviation from mean = 209 mV/Pa	IML-605488 (mV/Pa)	Linearity % Deviation from mean = 175 mV/Pa
0.0068	147.50	0.61	176.18	0.61	210.88	0.16
0.0336	147.16	0.38	176.35	0.37	210.38	0.25
0.0681	146.48	-0.08	175.23	-0.16	209.26	-0.38
0.1760	146.04	-0.38	176.24	0.39	210.41	0.19
0.3542	146.54	-0.04	176.73	0.64	210.95	0.47
1.784	146.52	-0.05	176.61	0.49	210.64	0.41
3.593	146.35	-0.17	176.10	-0.03	209.54	0.11
7.265	146.35	-0.17	174.07	-2.32	204.74	-1.04
10.981	143.29	-2.26	168.42	-7.90	193.04	-4.25
14.748	136.99	-6.55	158.66	-16.43	175.17	-9.80
18.560	128.64	-12.25	146.21	-25.82	155.47	-16.88

Table 6.5.1 tabulated results for Piston-phone Linearity Verification.

Test Results: Figures 6.5.1 and Table 6.5.1 indicate that the sensor linear to within 1.0% out to 7.3 Pa, and are linear to within 8.0% at 11 Pa.

6.6 Infrasound Sensor Piston-phone Linearity Test (IS-PLV)

IML Test Sensor SN: 605368, 605408, and 605488
Output Type: Unfiltered
MB2000 Reference Sensor SN: 1380
Smart24 (SN 1036) Sample Rate: 40 sps
****

Test Description: Determine the infrasound sensor response at one frequency.

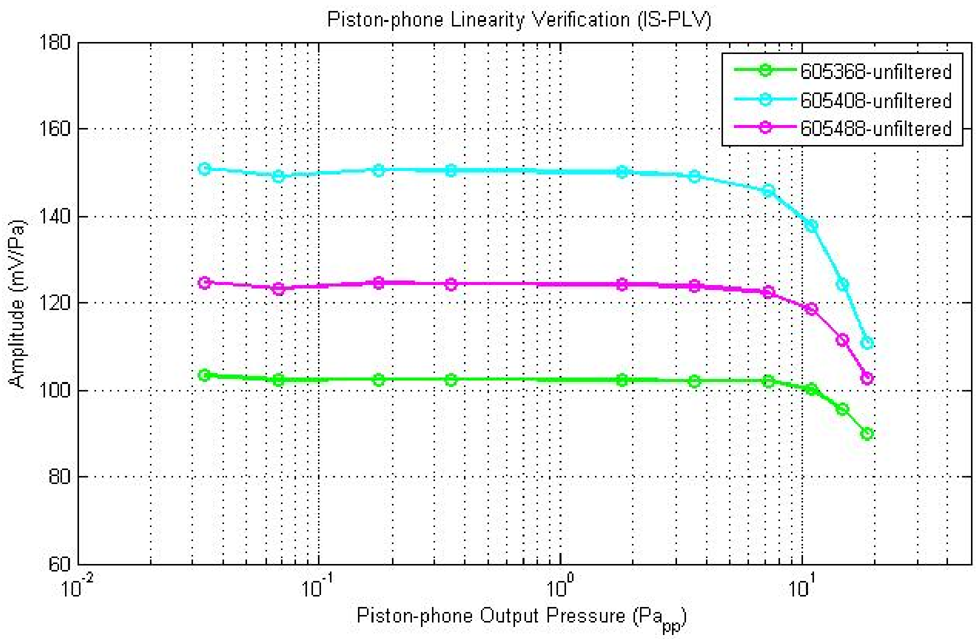

Figure 6.6.1 Piston-phone Linearity Verification results. Piston-phone input amplitudes tested were 0.01 to 5 volts peak, which translated to pressures ranging from 0.03 Pa to 170 Pa.

Piston-phone Output (Pa$_{pp}$)	IML-605368 (mV/Pa)	Linearity % Deviation from mean = 146 mV/Pa	IML-605408 (mV/Pa)	Linearity % Deviation from mean = 209 mV/Pa	IML-605488 (mV/Pa)	Linearity % Deviation from mean = 175 mV/Pa
0.0336	103.30	0.62	150.80	0.94	124.72	0.66
0.0681	102.29	-0.08	149.20	-0.14	123.3	-0.50
0.1760	102.36	-0.03	150.50	0.73	124.43	0.42
0.3542	102.31	-0.06	150.30	0.60	124.37	0.38
1.784	102.21	-0.13	149.94	0.36	124.17	0.22
3.593	102.05	-0.24	149.08	-0.22	123.76	-0.11
7.265	102.06	-0.23	145.67	-2.50	122.35	-1.25
10.981	100.06	-1.60	137.66	-7.86	118.55	-4.32
14.748	95.42	-4.76	124.37	-16.76	111.35	-10.13
18.560	89.77	-8.62	110.69	-25.91	102.82	-17.01

Table 6.6.1 tabulated results for Piston-phone Linearity Verification.

Test Results: Figures 6.6.1 and Table 6.6.1 indicate that the sensor linear to within 2.5% out to 7.3 Pa, and are linear to within 7.9% at 11 Pa.

6.7 Infrasound Sensor Self-Noise Test (IS-SN)

IML Test Sensor SN: 605368, 605408 and 605488
MB2000 Reference Sensor SN: 1380
Output Type: Filtered
Smart24 (SN 1036) Sample Rate: 40 sps
****

Test Description: Determine the infrasound sensor's self-noise. Sensor's self-noise was performed by placing caps on all eight inlets.

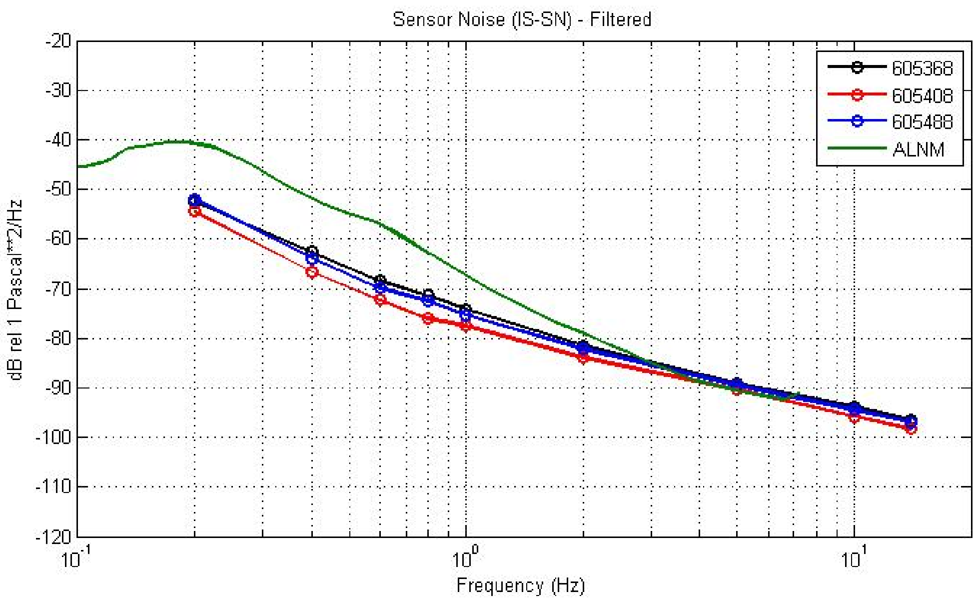

Figure 6.7.1 Self-Noise test results.

Test Sensor Serial Number	Self-Noise dB @ 1 Hz
605368	-74.2
605408	-77.5
605488	-75.4

Table 6.7.1 tabulated results for IS-SN.

Test Results: Figures 6.7.1 and Table 6.7.1 indicate that the IML sensors has self-noise better than -74.2 dB rel 1 Pa^2/Hz at 1Hz. The three sensors tested have self-noise at or below the Acoustic Low Noise Model between 0.2 and 7 Hz.

6.8 Infrasound Sensor Self-Noise Test (IS-SN)

IML Test Sensor SN: 605368, 605408 and 605488
MB2000 Reference Sensor SN: 1380
Output Type: Unfiltered
Smart24 (SN 1036) Sample Rate: 40 sps
****

Test Description: Determine the infrasound sensor's self-noise. Sensor's self-noise was performed by placing caps on all eight inlets.

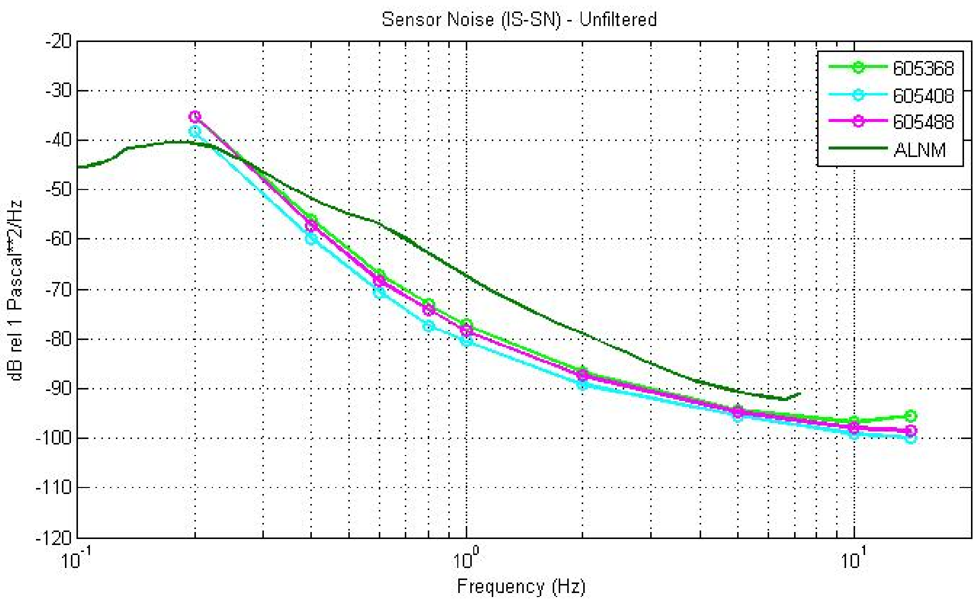

Figure 6.8.1 Self-Noise test results.

Test Sensor Serial Number	Self-Noise dB @ 1 Hz
605368	-77.3
605408	-80.4
605488	-78.4

Table 6.8.1 tabulated results for IS-SN.

Test Results: Figures 6.8.1 and Table 6.8.1 indicate that the IML sensors has self-noise better than -77.3 dB rel 1 Pa^2/Hz at 1Hz. The three sensors tested have self-noise below the Acoustic Low Noise Model between 0.3 and 7 Hz.

7 Manufacture Data Sheets

The following table was obtained from the manufacture in a newly published datasheet for the IML Model SS infrasound sensor.

OBSERVED SPECIFICATIONS

Parameter	Nominal Value Comments
Width	17.5 cm Includes hose adaptors
Length	17.5 cm Includes hose adaptors
Height	9 cm
Weight	1.4 kg
Operating Temperature Range	-40 to 85 °C Design criteria
Power Supply Voltage	12 Volts 11 Volts min, 18 Volts max
Current Consumption	14 mA @ 12 Volts
Analog Signal Reference**	4.1 Volts ± 10% Virtual analog ground
Low Pass Acoustic Filtering*	30 Hz corner
Preamplifier Signal Frequency Band*	2 – 30 Hz
Preamplifier Signal Sensitivity*	† 0.018 Volts/μbar Relative to analog signal reference @ 5 Hz
Preamplifier Signal Self Noise***	< -85 dBV/√Hz @ 2 Hz
Balanced Signal Frequency Band*	2 – 12 Hz Emphasized band
Balanced Differential Signal Sensitivity*	†,‡ 0.032 Volts/μbar Standard Setting @ 5 Hz
Balanced Differential Signal Self Noise***	< -80 dBV/√Hz @ 2 Hz

* Custom options available.
** Variation due to power supply range.
*** Decreases as frequency increases. IML measurement environment does not allow for better determination.
† Varies with frequency and exhibits tolerance as shown in charts.
‡ Setting used in snow avalanche monitoring exhibits additional 1.67 gain providing nominal 0.054 volts/μbar @ 5 Hz.

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